the ceramic process

a manual and source of inspiration
for ceramic art and design

european ceramic work centre



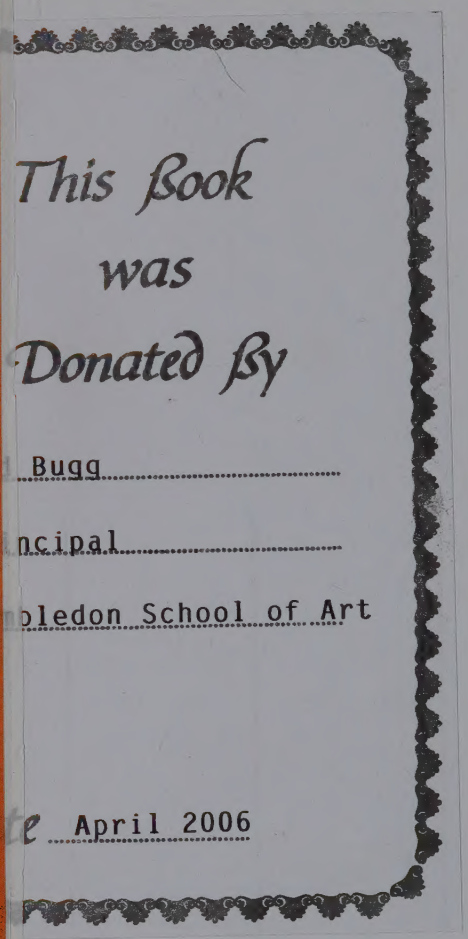
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THE CERAMIC PROCESS

A Manual and Source of Inspiration for Ceramic Art and Design
European Ceramic Work Centre

THE CERAMIC PROCESS is a comprehensive manual on ceramics that has grown out of the experience and practices developed at the European Ceramic Work Centre (**EKWC**) in the Netherlands. Over the years in their vast studios, they have played host to a wide variety of artists and designers, many of whom had never worked with clay before, helping them to learn about ceramics and develop new work with the benefit of the Centre's extensive staff of specialist technicians and tutors, equipment and support. The staff have also encouraged experiments to find new ways of presenting ceramics. Among the artists who have worked at the Centre are: Tony Cragg, Ewen Henderson, Jun Kaneko, Anish Kapoor, and Marcel Wanders. The result is that the people at the Centre have a vast knowledge of the ceramic process and in this volume they share that knowledge with all those who work with clay.

The book is based on the series of worksheets that the Centre's chief technician Anton Reijnders wrote to help the participants who were new to clay. Here they have been developed into a complete A-Z on the whole ceramic process, discussing everything from types of clay and equipment through to practical techniques such as wedging clay and packing huge trolley kilns. The reader is taken carefully through all the stages of making and firing ceramics, covering all the basics for beginners as well as including chemistry and theory for the more advanced ceramicist. There are diagrams throughout the book to help illustrate the more complex aspects of the subject. The book is also filled with images of the spectacular work of many of the artists and designers who have worked at the Centre. The result is a volume that is not only an informative manual but also an inspirational and stimulating look at the world of ceramics. This is a landmark title that should be a must on the bookshelves of everyone who works with clay.



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THE CERAMIC PROCESS



THE CERAMIC PROCESS

A Manual and Source of Inspiration for Ceramic Art and Design

European Ceramic Work Centre

Anton Reijnders

A & C BLACK • LONDON

UNIVERSITY OF PENNSYLVANIA PRESS • PHILADELPHIA

First published in Great Britain 2005
A&C Black Publishers Limited
Alderman House
37 Soho Square
London W1D 3QZ
www.acblack.com

ISBN 10: 0-7136-6768-0
ISBN 13: 978-0-7136-6768-4

Published simultaneously in the USA by
University of Pennsylvania Press,
3905 Spruce Street
Philadelphia, Pennsylvania 19104-4112

ISBN: 0-8122-3932-6

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CIP catalogue records for this book are available from the British Library
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Book design by Jo Tapper.
Edited by Alison Stace and Jan Mitchell.

Printed and bound in Singapore by TWP.

Cover: front and back
Ilia Utkin and Alexander Brodsky (Russia), *Portal* (details), 1992. Ceramics and steel. Ht: 16 m (52½ ft). Coiled and press-moulded ceramic elements and steel construction. Commissioned by the EKWC and located at the front gate. (Photo: Peer van der Kruis)

Frontispiece
Antoine Berghs (The Netherlands), *All about Change*, 1998. Various sizes. Ceramics, house paint and overhead projector. An amorphous ceramic form placed on an overhead projector. The projection creates the silhouette of a head on a screen. (Photo: Peer van der Kruis)

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Wienerberger supports the EKWC and enables the centre to interest architects and designers in the application of ceramics in architecture through various activities. Wienerberger produces facing bricks, paving bricks and windowsills (Terca), ceramic inner wall bricks (Porotherm) and roof tiles (Koramic), and is the main sponsor of the EKWC.

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Foreword

by Joel Fisher

Making the link: persuasion and permanence

At this very moment, somewhere in the world, wet clay is being shaped, and this has been true without end since before history was recorded.

Of all the materials that have been in continuous use by human beings, only ceramic survives from all time periods. Despite its passivity and fragility, clay is a substance with strong survival skills. After it has been fired, clay becomes so permanent that it has been used to date archeological digs. In other ways too, this substance has helped to preserve information which would otherwise have been lost. Already, in ancient times, clay was used to make images and imitations of things which originally had been made in other materials: the only evidence we have of some objects long since rotted away (wooden chalices, for instance) is that they had been duplicated in clay. Through clay, the replica becomes more persistent than the original. In a similar way surviving fossils discovered in hardened natural clay stones preserve the shapes of extinct creatures that predate human beings. Clay has had an association with image making for a long time.

In the hands of artists, clay is a medium that can bridge one human mind with another, manifesting thoughts as gentle as a kiss, as lofty as mountains or as cosmic as stars. Clay has habitually been transformed into containers for daily use, but it also becomes a container in more metaphoric ways. It holds and transfers. In cases when clay is made into tools, it makes further making possible. Clay has been instrumental in processing and preserving everything from food to ideas.

What is this substance? The Pueblo potters of the ancient Zuni Tribe used to make annual ritualised trips to the top of a local mountain to bring back the clay they needed for the following year's work. In Melanesia, the aboriginal people of the Amphlett islands were not able to find enough of the right clay nearby even though they had become dependent on the ceramics they made for trade. They would make excursions every six months to Ferguson Island, an entire day's journey by boat, where they would dig, dry, and fill their canoes with tons of clay for the journey home. Clay must be a precious substance to be valued so highly; we are prepared to think that it is very rare. Not so. The basic material of clay – largely feldspars, and quartz – covers three quarters of the surface of the earth. Clay's physical origins are in ancient mountains – mountains which have decomposed into the substance we know so well. Clay is mud, the most humble of materials. It is the exact substance of the earth. It is the soft stuff that squishes between our toes.

Ceramics has a long history, which can be made even longer (in a material sense) if we trace its raw materials back to the original decomposed stone. Etymologically, the word ceramic comes from Keramos, a man who in Greek myth was the grandchild of Zeus and Semele. According to the myth, Ariadne, after being abandoned by Theseus, sought solace in the arms of Dionysus. From the union of Ariadne and Dionysus, Keramos was born.

How can it be that Ariadne, so well known for her life-saving thread, is credited with giving birth to ceramics rather than, for instance, storytelling or weaving or mapmaking? How can Dionysus with his first-hand knowledge of the intoxicating power of grapes be the father? Considering clay's purely physical ancestry, can we speculate if any

of the original majestic spirit we feel in mountains remains after the crust of rock is degraded into clay? Clay seems to be such a peaceful substance, yet viewed through either myth or as material history, it has a rather wild ancestry.

Try for a moment to think of the world as a library of substances, each with qualities of weight, texture, hardness, permanence. Few of the substances in this library can be shaped by the hand unaided, and of these few, clay is the most important. Only gentle pressure is needed to shape clay. In contrast to other materials, the act of shaping is persuasive rather than coercive.

Enormous energy, however, is required for the firing. The quantity of fuel consumed is immense, often exceeding that of the clay fired by many times. All this expenditure is largely invisible in the finished product. The firing process transforms the nature of clay from a material that can be endlessly recycled to one that is inert. A fired vessel can carry water without absorbing it and consequently collapsing. It takes on a different, more melodious, sound. It will now survive burial.

One curious aspect of clay is such an essential part of its contribution to human culture that we may overlook it. The simplest clay form – and the first vessel we make as children – is the pinch-pot. The principle hidden in its making is that it is necessary to rotate the lump of clay as the cup is being made. Many other methods of shaping clay – rolling sausage shapes, for instance – are also based on rotation. When we build up a clay structure with coils we again circle the work. (And ultimately the same rotary motion will be necessary to view it.) Circularity keeps reappearing. Even before the advent of the wheel, the majority of pots were round. Although there may be some advantage in the firing, nothing in the nature of the material itself predetermines circularity: that quality is introduced solely by the making. When the potter's wheel eventually came into use it simply incorporated what was already established. The invention of the wheel itself was presaged, perhaps predetermined, by centuries of ceramic work. The ancient Greeks may have missed an opportunity by not proposing that Keramos – grandson of Zeus – was the father of the wheel.

Anton Reijnders, the actual author of this book is an artist of considerable accomplishment. The way he uses clay in his own work is almost an encyclopaedic inventory of techniques. Anton has thought carefully not only about the source and application of his methods, but also about deeper meanings embedded in them. He takes process as metaphor and infuses each technique with extended resonance. His tendencies as an artist carry over into other things he does. This book is one of them.

Many of the chapters in this book grew out of the handouts that Anton developed for participants at the European Ceramic Work Centre (EKWC). As a descendant of those first technical handouts, the book you have in your hand has had its own wild ancestry; the material in it has been tested and twisted by both experts and novices. These early technical summaries – introducing approaches, materials and techniques of using clay – were offered to everyone who came to the centre. Sometimes experienced ceramic artists discovered to their surprise that what they always 'knew' as right, was wrong. More often the papers found their way into the hands of artists who had little experience in ceramics and as a result of their wild stumblings, misinterpretations, or wilful disobedience, a deeper understanding grew, and increased clarity entered the texts.

The original handouts were dynamic little treasures, wonderful additions to the literature of practical ceramics. Because of their unusually clear nature, these sheets were treasured by the participants. What made them more valuable was that much of the information included in these notes was based on unpublished research. It is good that they can now reach a wider audience.

The EKWC, for those who are not already familiar with it, is a research centre located in 's-Hertogenbosch, in the Netherlands. In addition to being Hieronymus Bosch's home town, Den Bosch, as it is colloquially known, is increasingly famed as the home of the EKWC. Within the workshops of the EKWC a wide range of ceramic ambitions are brought together under one roof by those privileged to work there. These ideas are considered collectively by a knowledgeable staff and innovative solutions are frequently discovered.

Something that occurred to me while thinking about the EKWC is that advances in education don't necessarily happen in schools. Certain kinds of information can inhibit learning. Traditional 'education' occasionally limits real progress, especially when it involves accumulating a sequence of disembodied techniques or rules, passed from person to person unexamined. The question, in disciplines such as ceramics which embody a well-established tradition, is whether anything can still be learned, and to what extent knowledge can actually be advanced rather than simply repeated. It often happens that an artist arrives at the centre 'educated' in the ceramic lore which passes off as knowledge. A tradition established at the EKWC (and modelled for the participants by the staff) is to examine what is really there, not what one thinks or has been told is there. One of the liberating messages of the EKWC is to disregard the blockage that happens when we are told that something cannot be done. 'It is not possible', is a phrase seldom articulated at the EKWC. Here is a place that is reluctant to accept the possibility of the impossible. Many impossible things have been done there over the years. When one observes what is there, then growth is possible. Looking at what is really there is the key to a living tradition.

People who work in clay are sometimes accused of being unduly interested in technique. 'Temperature and recipe', Anton once said to me, 'is not true technique.' As a result of this attitude the form of this book takes a particular shape. It is not a book of recipes to be followed. A genuine concern with technique has deep implications; and is as rare in ceramics as it is in any other art. Recipes are meant to standardise expectation, and eliminate risk. Education in any of the arts can be thought of as how one deals with expectations. A recipe's illusion is that it eliminates risk. With real technique, risks are not eliminated, but trivial repeatable mistakes are minimised so that more challenging puzzles appear. This sometimes results in an artist's willingness to risk more. There is always an unknown, but confrontation with what cannot be known can be made more powerful.

All this becomes part of the EKWC's concept of learning. From the earliest years when the centre was finding its identity this spirit infused the EKWC with an approach which put understanding and relevance into the heart of each process. Every skill was considered not as an end in itself, but as a link. Learning as link is an important idea.

Nearly everyone who has passed through the EKWC has been educated in a profound way, without feeling that they were in school, and often without realising it was happening. At EKWC, research is so much a part of the regular routine that it becomes completely natural. While there, one is exposed to a pattern of thinking, and a pattern of making, either of which can lead one in new directions.

These patterns were incorporated into the EKWC early on, and have now crossed over to become part of this book. The patterns are a combination of principles and exceptions, always related to making. The heart of this book springs from, and is anchored by, making. In your hands, it is a link.

Joel Fisher
Paris, March 2004

Introduction

by Koos de Jong

This important publication from the European Ceramic Work Centre (EKWC), the first on a global scale, creates a wonderful opportunity to explain how this centre, based in 's-Hertogenbosch in the south of the Netherlands, operates.

The EKWC's function can be summarised as follows: the centre is a workshop for ceramicists, visual artists, designers and architects, referred to from now on as 'participants'. Assisted by the staff, they explore the artistic and technical possibilities of ceramics as a medium. Other experiments by the participants and the staff focus on new ways of presenting ceramics. The knowledge and experience thus gained is circulated as widely as possible. The overall objective is to promote the development of ceramic art, design and architecture. For its core tasks, the work centre is subsidised by the Dutch Ministry of Education, Culture and Sciences.

How it began

The EKWC originated as the Keramisch Werkcentrum (KWC) which was formerly established in Heusden near 's-Hertogenbosch. Primarily Dutch ceramicists were able to work there for long or short periods of time. Toward the end of the 1980s, the government proved willing to assume the costs of professionalising the centre, on two conditions: the centre had to open its doors to visual artists, and it had to operate on an international level. The latter stipulation meant that approximately half of the participants had to be from other countries. In order to satisfy these and other more practical requirements, the centre moved to a former factory complex in 's-Hertogenbosch in the south of the Netherlands, which had to be completely rebuilt. Following a trial period of six months, the centre was officially opened on 18 January 1992. The general director Adriaan van Spanje was the driving force behind this operation.

Since then the centre has been functioning in two ways: as an artist-in-residence centre and as a centre of excellence in the field of ceramics. The EKWC also works on a project basis with art education, the ceramics industry, scientific research institutions, museums and galleries.

The EKWC as artist-in-residence centre

Every year the centre provides 44 participants with working space and housing as well as a team of assistants, so that they can work for an uninterrupted period of three months or in phases. Each year the participants are recruited in three ways: 20 via an open worldwide application, 4 via a competition for recent graduates and 20 by invitation. From its start in 1991 up to and including 2003 an impressive number of [470] artists and designers have worked in the EKWC. The total number of [635] workperiods is even bigger, because some participants have either had the opportunity to work for a second time in the EKWC or were involved in projects.

The breakthrough to the visual arts

What makes the EKWC so unique is that, aside from the twelve living and working spaces and the specialised workshops and equipment, it has an extensive staff of eight expert assistants, most of whom were trained as artists. They work with and advise the

participants, helping them to develop their own ideas. This interactive process, in which participants and assistants constantly learn from one another, draws in participants who have no knowledge of or experience with ceramics. Over the past thirteen years the success of this approach in developing ceramics has become apparent.

This breakthrough from traditional ceramics to ceramic visual arts must be credited to the Spaniard Xavier Toubes. From the time he took office in 1992 until 1999, he made a deep impression on the EKWC's artistic policy both as an artistic director and as a ceramicist. The fact that Xavier himself is a visual artist, working for and with the artists – he made his ceramic sculptures at the centre – was pivotal for his approach. This policy allowed chiefly visual artists from home and abroad to discover and further develop the artistic possibilities of ceramics as a medium via the centre.

The introduction of ceramic design

In 1997, the state granted the EKWC the opportunity of carrying out a pilot ceramic design project from 1998 to 2000. The project aimed to give design a more distinct place in the centre. Expanding the technical facilities (for example, CAD/CAM), appointing trained personnel, encouraging an active approach on the part of designers and, last but not least, strengthening the bonds with industry, science and education, ensured the project's success. In 2001 this led to the decision to allocate a permanent place for ceramic design at the centre. Since then the number of applications each year from designers who primarily work independently has increased gradually from two to fifteen.

The introduction of architecture

In 2004 the centre took the decision to expand its sphere of work once again and to strengthen the relation between ceramics and architecture. As for its approach to ceramic design, the centre started a project in 2005 to explore this new field in order to learn what is possible, before setting up activities on a more structured basis.

Renewed interest in the work of ceramicists

Because of all the attention focused on the ceramic visual arts and ceramic design and more recently on architecture, the work of ceramicists has become somewhat overlooked. This development, however, is not isolated. It is a fact, at least in the Netherlands, that ceramicists are losing ground. Art critics tend to ignore ceramicists, and the number of students at the art academies electing to explore this field is dwindling. Consequently, ceramics departments are being discontinued and museum collections are disappearing into storage.

So the EKWC thinks it is high time to impress upon the 'real' ceramicists that their approach to ceramics as a medium is still crucial. Not only because of the ongoing artistic development within this field, but also because, through them, the necessary knowledge and experience can be passed on to following generations. Hence, the EKWC encourages ceramicists to apply for a residency.

Greater openness

The departure of the general director Adriaan van Spanje in 1998 and of the artistic director Xavier Toubes the following year was seized upon to radically alter policy in a number of areas. It was decided to further professionalise the organisation by combining the two directorships and breaking open the centre's somewhat closed character. The first steps in this direction were taken by interim director Joop van Wingaarden. He was responsible for managing the centre until I took over in October 1999.



Xavier Toubes (Spain/USA), *Polvo*, 2002. Ht: 217 cm (85 in.). Built hollow by squeezing wads of clay of a fairly wet consistency into each other. Porcelain as well as a stoneware sculpture body was used. High biscuit, low glaze firing. Different types of coloured lustres painted on top of a satin gloss glaze and fired for a third time. Finally the lustre was partly removed by using an etching agent.
(Photo: Peer van der Kruis)

The intended openness is expressed in a series of changes and new activities that have since taken place. This began with listening to and taking into account the wishes of the participants. Thus, since then, the EKWC has been offering participants the opportunity of phasing their residencies or of working on a part-time basis. Another outcome is a different approach to the presentations at the end of the participants' residencies. Nowadays these final presentations have the more closed character of a workshop visit. Participants wishing to mount a 'real' exhibition of their work, are encouraged and helped to do so in a gallery, museum or other appropriate setting. This practice has demonstrated the increasing opportunities for doing this, in which the EKWC plays a mediating role.

The centre is doing this because it wants to strengthen its bonds with art education, museums and galleries and with the ceramics industry. For, in the long run, a wide social basis is essential for such a high-quality institute as the EKWC. This will not be achieved all at once, but steadily and systematically, for example by consulting with these institutions and businesses on a regular basis and being open to any input they might have. A great advantage of this kind of 'openness' is that the centre profits from the knowledge and experience of others.

Our regularly updated interactive website, which contains a great deal of information about our purpose and our activities, and current and future participants and their work, is instrumental in promoting the centre worldwide.

Another way we promote the centre is by organising congresses on an annual basis, publishing monographs dedicated to individual participants and, more recently, by organising master classes. And last but not least, 2005 has brought the opening of a gallery for ceramics by the EKWC – together with the Museum of Modern Art and Design; the Academy for Visual Arts and Design; and Cor Unum, a factory which produces ceramic art and design, all based in 's-Hertogenbosch.

Experiments with the presentation and acceptance of ceramics

More openness also means that the EKWC wants to expand its laboratory functions and move into the area of presentation and the acceptance of ceramics. Accordingly, the centre interacts with all those who are interested, professionally or otherwise, in ceramics: ceramicists, visual artists, designers, architects, teachers and students, the ceramics industry, the scientific realm, museums, the art trade, the press and the media. To prevent any of this from becoming too unstructured, the EKWC provides a framework as a source of inspiration and focus. A thematic approach has been chosen in which the relationship of ceramics to one of the five senses is pivotal. During the last few years experiments were devoted to sight and taste, while from 2005 onward new experiments will focus on hearing, touch and smell.

These experiments involve more than just finding practical solutions for presenting ceramics. The EKWC is convinced that the investigation into novel forms of presentation will inevitably lead to fresh insights into the artistic and technical aspects of making ceramics. The purpose of this less-conventional approach is to present new and inspiring aspects of ceramic art that will foster the interest of the makers, distributors and users.

The EKWC as a centre of excellence: research and the transfer of knowledge

Performing artistic and technical research is one of the core tasks, while research into the presentation and acceptance of ceramics is a consequence of the new policy that

focuses on reaching out to a wider public.

The participants perform artistic research in close cooperation with the supervisors. That is why we employ people who have also been educated at an art academy. That artistic research is the rule rather than the exception is because the participants are selected for that purpose and are encouraged to undertake this during their work period.

The usual result of all this is that participants engage in technical research. After all, trying out new ideas and continually expanding the boundaries of technical possibility provides a wealth of new information. In contrast to artistic research, where our influence is deliberately restricted to entering into dialogue with the participants, the supervisors play a more active role in instigating and undertaking technical research because of their knowledge and experience. While the participant usually applies the results of artistic and technical research directly in his or her work, it is the supervisor's job to record the experience gained as extensively as possible so that others can benefit from it too. Technical information is recorded both by hand and by means of the computer.

The centre regularly undertakes research on its own initiative too. This can be because a need arises in-house for a solution to a regularly occurring problem, for a particular technical improvement or as a result of an interesting question that comes from analysing stored data. Technical research is also undertaken for companies and educational institutions.

Transfer of knowledge

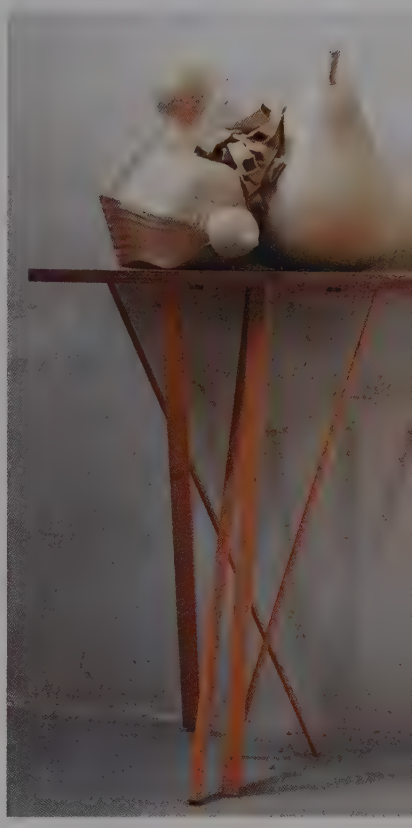
The participants transfer the results of their artistic research by means of the work itself and through exhibitions, publications and reviews devoted to them. In addition to this the EKWC publishes these results in the form of its own publications or by contributing text and/or funding to publications by third parties. In the main, the director takes care of these artistic publications. In 2004, the number of publications, including those devoted to the experiments, rose to an average of five per year.

The centre also contributes in an indirect way to making the artistic results public, by encouraging renowned museums and galleries to exhibit work produced here.

In 1998 extra financial support was provided by the Dutch Ministry of Education, Culture and Science for the Expertise Development Project that, over the years, has resulted in the publication of 15 Technical Papers in Dutch and 12 in English. The distribution of these sheets, which we published ourselves, took place in a limited circle primarily consisting of former participants and lecturers at the academies. Anton Reijnders, Head of the Workshop and Studios, was the driving force behind this operation.

The publication of technical information sheets as a book

The centre wants to use this English edition of technical information to reach a worldwide audience. The publication is aimed at an international circle of professional visual artists who want to find out more about the medium of ceramics in visual art or who want to become more skilled in using the medium and to do so want to study both the artistic content and the practical aspects in depth. It is an adaptation and a supplement to the technical information sheets published by the EKWC in the last few years. These technical information sheets incorporated not only the practical experience recorded by our employees, but also the results of dozens of specific technical studies undertaken in the centre as part of its centre-of-excellence function. Anton Reijnders was released from his duties as head of the workshop and studios in the middle of 2003, and has worked at adapting the technical information sheets and, where necessary, completing them on the basis of his own further research and that of his former colleagues. The dedication and meticulousness with which Anton Reijnders has performed this task deserves our greatest respect.



Anton Reijnders (The Netherlands), *Status* 7, 2003. Ceramics and wood. Ht: 220 cm (86¼ in.). Two press-moulded pieces and extruded elements. A fine-grained sculpture body was used. The middle part was extruded. A fully-matured shiny HTR-clay terra sigillata was applied on the surface and fired to the mid temperature range. A transparent shiny finish was achieved resembling the quality of a still wet piece.
(Photo: Anton Reijnders)

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The result is an extensive manual explaining the entire artistic and technical process from design of the concept as regards content through to its execution. The book highlights the production of ceramic sculptures, functional work and other objects by means of various construction and reproduction techniques, explaining in detail how complex and large-scale works come about. This is done using text, instructional drawings and pictures and by means of technical information about materials, tools and techniques. To show where this wealth of technical possibilities could lead, pictures of works of art, most of which were made in the centre, are used throughout the book. In his foreword the American visual artist and author, Joel Fisher, a former participant explains in his inimitable way the significance of the centre and this book. The EKWC also owes him much respect and gratitude.

The centre is grateful to all the people who in one way or another helped with the realisation of this ambitious book. First of all, the people who advised or assisted Anton: Ad Swinkels, Patricia Rieger, Xavier Toubes, and Auke van den Berg who has translated a large part of the text in to English. Many colleagues or former colleagues helped where they could: Andrea Wach and Matthias Keller, also Marlies Crooijmans, Marc Kohlen, Peter Oltheten, Marian Pijnenburg, Rob Ruimers and not forgeting Simone Immink, Joris Link and Han Sietsma who were involved in the research. Then, the people who, on behalf of the EKWC, helped with the production of the book: consulting editor Astrid Vorstermans, legal consultants Marian van Eck and Mr Jan Willem Knipscheer. I also want to name our manager Marc Graetz who did a great job!

It should be obvious that the EKWC wants the publication of this book to confirm its reputation on an international level as a centre of excellence in the ceramics field. We are delighted that such a renowned publisher as A&C Black is giving us the opportunity of fulfilling this ambition. Here I would like to thank Linda Lambert, publisher of the department of Visual Arts, and Alison Stace, who coordinated the whole project.

Last but not least, I would like to thank the complete staff of the centre who, each in their own way, have worked to make the centre a success. I am proud to be able to lead a close-knit team that day-in and day-out demonstrates that expertise and dedication is the foundation on which the EKWC is built.

Drs. Koos de Jong
Director of the European Ceramic Work Centre

About Anton Reijnders

Being active as a ceramic sculptor Anton Reijnders became head of the workshop and studios of the former Ceramic Work Centre in Heusden and later on of the European Ceramic Work Centre in 's-Hertogenbosch, The Netherlands. He was the driving force in setting up the material and process research program. As a rounding off of a successful job for 17 years the EKWC offered him the opportunity of putting his expertise and that of his former colleagues in writing.

His artistic career is marked by exhibitions throughout the world, his sculptures are part of public collections in Europe, Asia and the USA and he has contributed to many international conferences. He was curator of the European section of the Now&Now exhibition for the Second World Ceramic Biennale 2003, in South Korea, and in 2004 he was visiting professor at the New York College of Ceramics at Alfred University in the USA. Currently, he is board member of the sculpture workshop Beeldenstorm, Eindhoven, The Netherlands, and member of the Artist Advisory Board of KANEKO, Omaha, USA.

Note by Anton Reijnders

This book is meant as a guideline for artists, designers and students, with or without a background in ceramics, who want to use ceramics as a means to express their ideas. It intends to show the various stages of the ceramic process and the use of specific materials and methods and their interaction. The making of ceramic sculpture and functional objects using hand-building and reproduction techniques is the main focus. The execution of complex and large scale work, always demanding special attention and knowledge in ceramics, is extensively addressed.

The order of the chapters follows the logic of the making process; starting with choosing a method of making, the clay body, preparations prior to making, hand-building, using a mould, drying, biscuit firing, glazing up to glaze firing and treatments after firing. Recipes for clay bodies and a variety of glazes and sinter engobes are provided using a specific range of ingredients, most of them generally available. These recipes are first of all meant to serve as a guide in choosing between the numerous possible combinations of materials. In an attempt to bridge the gap between the trial and error approach commonly used in studio practice and a more research-orientated approach advanced sections are added. They address more advanced background information as well as methods to analyse the materials at hand. This information will enable the reader to gain a deeper understanding of materials and processes and allow the potential of the ceramic medium to come to the forefront.

The 155 colour images of ceramic works form an important part of this book. They are fine examples of specific ways of using materials and/or methods. Each serves to illustrate some of the subjects discussed in the text.

I hope the text and depicted works will be a valuable source of information and inspiration for those who want to take their knowledge and ideas a step further.

Acknowledgements

I am very grateful to the many friends and colleagues who have helped me in the preparation of this book, especially Ad Swinkels, Patricia Rieger and my former colleagues Andrea Wach and Matthias Keller who were my sparring partners over the last six years. I would like to thank William M. Carty of the Whiteware Research Center at the New York State College of Ceramics at Alfred University, for sharing many of his state-of-the-art insights. I owe special thanks to Marc Graetz for his commitment to this demanding project. I am very grateful to Xavier Toubes, the first Artistic Director of the EKWC, who was a great supporter of my investigations from the start and to Koos de Jong the present director of the EKWC who granted me a sabbatical. I would like to thank Netty van den Heuvel, my beautiful wife, for her help and encouragement while I wrote this book.

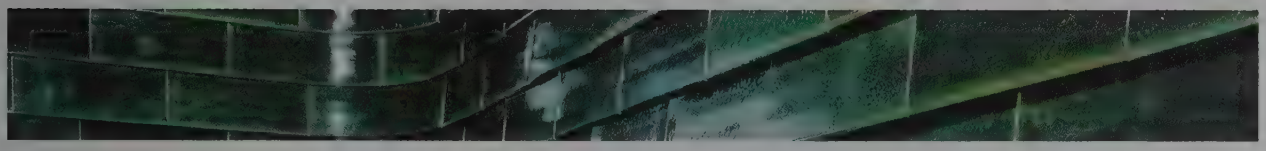
Finally, this book would not be possible without the involvement of all the participant artists and designers* who challenged the EKWC with their ideas and their willingness to take risks while realising their projects. Due to the intense exchange of experience between participants and the workshop team, as well as research initiated by the EKWC and myself, boundaries have been shifted and the possibilities of the ceramic medium have been brought to the forefront.

*(*All the participants who worked at the EKWC between 1999 and 2003 are listed in Appendix 5.)*

Anton Reijnders



1 Material, method and process



The ability to manipulate a material by hand and the process of transforming an amorphous material into any shape has fascinated craftsmen, artists and designers all over the world throughout time. The various methods of making – modelling, throwing, constructing or using a mould – each give their own character to the final piece, contributing to the potential of ceramics as a medium. The possibilities are enhanced by the broad range of qualities of the material and the varieties of textures and colours. This richness, guided by the ideas of the maker, has led to many significant works of art, craft and design.

1.1 Understanding material and processes

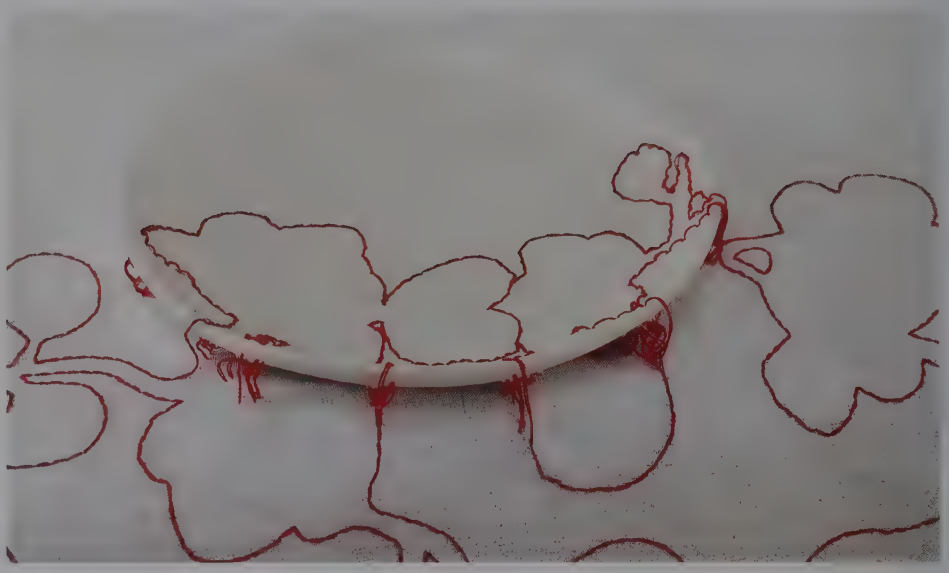
An understanding of the drastic changes in the material as they occur during the various stages of the ceramic process is crucial to working in ceramics. There are tactile and visual changes as well as material transformations. A clay body can be used in a liquid, spreadable, plastic, leatherhard or dry stage. Each stage will influence the visual quality of the final piece in a distinctive way. A liquid or spreadable clay body cannot be formed, therefore a mould is used to produce a piece. A clay body in the plastic stage can easily be shaped but at the same time it tends to sag, deform or collapse. As it dries it gains more stability but it becomes less easy to manipulate. While drying it shrinks and changes in colour. Once dry it tends to be very brittle. During firing even more shrinkage occurs and after being taken out of the kiln its visual characteristics will have changed again. In addition, a drastic change will be seen after the glaze firing as the fired glaze in no way resembles the applied glaze. Besides shifts in visual and tactile qualities, vast physical changes also occur.

The following scientific definition of ceramics is useful in shedding light on how complex and unpredictable the materials and processes can be:

> *Ceramics: made out of minerals with a varying composition and dubious purity being exposed long enough to a (non-measurable) treatment of heat in order to let unknown reactions take place, whereby heterogeneous compounds are formed*[1].

This highlights that the composition of ceramic materials varies; that the firing cannot be controlled fully; and that the end product cannot be defined accurately. Moreover it makes clear that materials from each location tend to differ and that the kind of equipment used has a noticeable effect on the end result. This implies that there is never one reason why things happen as they happen and that there is never one way to go about the process. Applying strict rules of practice or the notion of 'this is the

OPPOSITE:
Tony Cragg (England/Germany), *In Camera*, 1992. Ht: 195 cm (77 in.). A grouping of three pieces assembled from coiled-and-thrown and modelled sections. For the silhouette section on the left a template was used to obtain a continuous 3-dimensional profile. A copper-saturated glaze was brushed on the surface. Collection: Van Abbemuseum, Eindhoven, The Netherlands. (Photo: Peer van der Kruis)



Hella Jongerius (The Netherlands), *Multiple-Embroidered Tablecloth*, (detail), 2000. Dimensions: 110 x 80 cm (43 x 31½ in.). Linen, cotton and porcelain. A cast porcelain plate and embroidery. The plate was perforated at the plastic leatherhard stage. A transparent shiny glaze was applied on top.
Collection: Textiel Museum, Tilburg and Museum voor Hedendaagsekunst 's-Hertogenbosch, The Netherlands.
(Photo: Peer van der Kruis)

way we always work so we had better stick to it', diminishes the richness and potential of the medium. Being well-prepared and open to what occurs is an important and creative challenge. But some guidelines can be followed in order to find a way through the large number of variables. One method that could be applied is to balance the dynamics linking form, weight, shrinkage, time and temperature. This guideline, developed from the daily practice at the EKWC, will be followed in this book to facilitate synergy between ideas, materials and methods.

Table 1.1
Shape of a piece

Simple	*Complex*	*Tiles and slabs*
	Rectangular shapes	
	Multiple joined pieces	
Round shapes	Abrupt differences in wall thickness	Includes all flat pieces
	Structural support inside a piece	

1.2 The consequence of form

To balance forces, each piece will demand specific attention during making, drying and firing as it could be subjected to the build-up of tension. The extent of this tension will be different according to the form and the size of a piece. Round shapes are perfectly suited as they are able to absorb tension more uniformly than rectangular forms, flat pieces and tiles. Corners, abrupt changes in the direction of a form, and sudden changes in wall thickness all negatively affect the desired distribution of tension resulting in an uneven build-up of tension within a piece. As the wall thickness and size of a piece increases, the chance of tension build-up increases. For consistency some general descriptions to distinguish certain shapes and dimensions will be used throughout this book. *Tables 1.1* and *1.2* can be used as a reference.

1.3 Choosing a method of making

Ceramic sculptures and objects are usually hollow, especially when the work is large. In addition to reducing the weight considerably, there are several reasons for this.

Table 1.2

Dimensions of a piece

	Medium	*Medium-large*	*Large*	*Extra large*
Height	30–40 cm (12–16 in.)	60–100 cm (24–40 in.)	120–160 cm (47–63 in.)	180–230 cm (71–91 in.)
Diameter/Width	25–30 cm (10–12 in.)	35–50 cm (14–20 in.)	60–80 cm (24–32 in.)	90–120 cm (35–47 in.)
Preferred wall thickness*	1–1.5 cm (⅜ – ⅝in.)	1.5–2 cm (⅝–¾ in.)	2–2.5 cm (¾–1 in.)	2.5–3.5 cm (1–1⅜ in.)
Approx. weight of required clay body	6–13 kg (13–29 lb)	26–80 kg (57–176 lb)	120–240 kg (264–525 lb)	300–740 kg (660–1625 lb)

Tiles and slabs

	Medium	*Medium-large*	*Large*	*Extra large*
Surface area	25 x 25 cm (10 x 10 in.)	50 x 50 cm (20 x 20 in.)	80 x 80 cm (32 x 32 in.)	120 x 120 cm (47 x 47 in.)
Wall thickness	< 1 cm (< ⅜ in.)	1–1.5 cm (⅜–⅝ in.)	1.5–2.5 cm (⅝–1 in.)	2.5–3.5 cm (1–1⅜ in.)
Approx. weight of required clay body	0.5–2 kg (1–5 lb)	3–10 kg (6–22 lb)	15–40 kg (33–88 lb)	50–160 kg (110–350 lb)

** A thick-walled piece is considered to have a wall of > 2.5 cm (1 in.).*

Hollow work can be dried more evenly as compared to solid work. Also heat distribution throughout the firing will be more even, increasing the chance that a piece will get through the entire process successfully. Hollow pieces can be made in three ways: the work can be built or thrown as a hollow form from the start; it can be built solid and hollowed out afterwards; or it can be made using a mould. Each method has an impact on the final piece. The desired visual character of the piece and the control over the final shape will determine the choice of the method of making. Several methods are presented in general terms in the sections below and subsequent chapters will go into more detail.

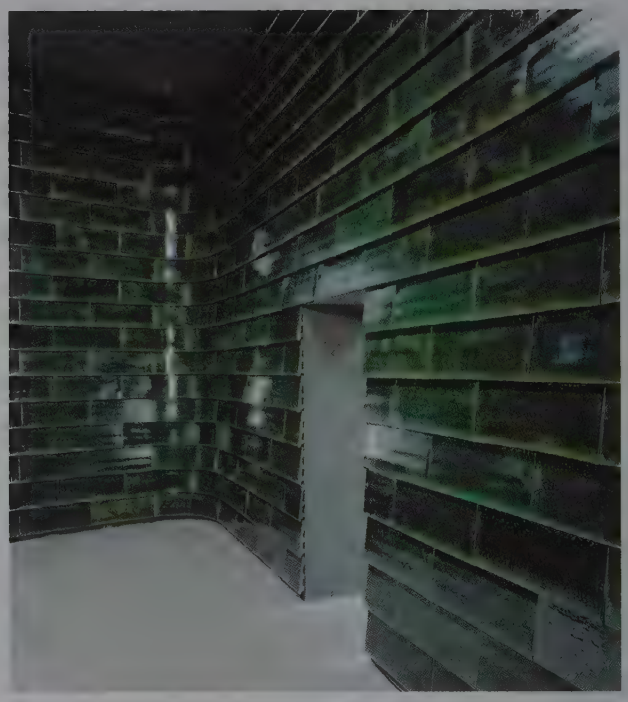


Didier Vermeiren (Belgium), *Solide plastique #23*, 2001. Ht: 143.5 cm (56 in.). Ceramics, wood, polystyrene film. Lumps of terracotta sculpture clay thrown on top of each other resulting in a solid form. This process was evident in the structure and surface of the piece. The piece was hollowed out at the leatherhard stage. A terra sigillata made from an HTR-clay was sprayed thinly on the surface to allow the colour of the terracotta clay to partially show through.
Collection: C Galeria Massimo Minni, Brescia, Italy
(Photo: Didier Vermeiren, A.D.A.G.P. Paris)

1.3.1 Building a hollow piece

Building hollow is a method often used by ceramic sculptors as it allows a large variety of forms to be made. A hollow piece is usually built gradually from the bottom up. In the process of making the piece, the lower part must gain sufficient strength to support the added weight and avoid deformation. This strength is achieved by a controlled drying of the bottom section. Drying limits the possibility for adjustments; a newly applied layer on top of a section that has been allowed to dry adheres less well. Moreover the gain in firmness, as desirable as it is, reduces the ability of the piece to withstand the pressure of pulling and pushing as building continues. From the outset a decision has to be made: either i) work without a strict plan and allow the piece to evolve; this is a more organic and intuitive way of working, accepting what happens, or ii) try to follow as meticulously as possible a scale model but still expect to be confronted with deviations during making.





ABOVE, LEFT:
Barbara Diduk (USA), untitled, 1997. Ceramics and steel. Ht: 40 cm (15¾ in.). Thrown and assembled forms treated with glazes and sinter engobes having a saturated colouring oxide content. After the glaze a lustre was sprayed on the surface at places and the pieces were fired in an unvented kiln to enhance the smokey appearance
Collection: Princessehof, Leeuwarden, The Netherlands.
(Photo: Peer van der Kruis)

ABOVE, RIGHT:
Marien Schouten (The Netherlands), *De Groene Kamer,* 2002. Ht: 450 cm (175 in.). The walls of a 34m² room consist of extruded tiles, each 26 cm (10¼ in.) high and 55 cm (22 in.) wide with a copper-saturated glaze applied. Slight differences in glaze thickness resulted in a large range of green shades.
Collection: Museum De Pont, Tilburg, The Netherlands.
(Photo: Jannes Linders)

1.3.2 Modelling a solid piece

Modelling a solid piece is a method more commonly used by sculptors. There is an advantage to modelling a solid piece: it allows for the addition and removal of clay. If enough structural stability is provided, it is possible to work on the whole piece at once. This gives a freedom and the possibility of a direct way of working that is not easily achieved otherwise. Sculptors use this method for making maquettes or as a means of producing a mould for further processing. Modelling small-scale solid pieces is a very useful method for developing ideas. If a modelled piece of a larger scale is to be fired, it should be hollowed out before firing.

1.3.3 Using a wheel

By its nature, throwing requires a lot of skill and results in rotation-symmetrical forms. It is the method often used to create functional ware but also can be used to make non-functional pieces. It is beyond the scope of this book to go deeply into this technique. Many handbooks on ceramics address this subject, see *Suggested further reading* in *Appendix 2*.

The throw-and-coil method can be also used to build up a rotation-symmetrical shape by adding coils of clay while the wheel is revolving very slowly. A template can be used as a guide or to actually shape the form. The remarks in section *1.3.1 Building a hollow piece* also apply for this method. The combination of template and revolving motion tends to lend itself well to achieving a more mechanical look.

1.3.4 Extruding

A clay body can be processed into coils, strips and pipes using an extruder. Extruding allows a more mechanical quality as uniformity in thickness and surface are obtained. Extrusion is a very useful method to create repetitive elements that can be used in architecture or to make parts to construct a piece.

1.3.5 Using a mould

A mould is used to make a series of identical pieces or a repetition of identical forms with small adjustments. Another motive for using a mould may be the desire to have more control over the final shape: a clay body in a mould follows the shape of the mould and is supported during the first part of drying until sufficient firmness has been achieved. An interest in the visual characteristics of a mould-made form, or the time-saving advantages – especially if a large series of pieces is needed – is another reason for using a mould. This book focuses on three kinds of reproduction techniques: casting, press-moulding and a technique developed at the EKWC called plemping.

In the **casting technique**, a specially-composed liquid casting slip is used. The casting slip is poured into a plaster mould and absorption of water by the plaster produces a clay wall on the inside of the mould. After a sufficiently thick wall has been formed, the remaining slip is poured out of the mould. Of all the reproduction techniques described here, the casting technique yields the most precise replica of the original model as far as its surface is concerned. The casting technique is ideal for the creation of large series of small work and is often used to make functional ware. By its nature it has its limitations as to the maximum size that can be achieved.



Netty van den Heuvel (The Netherlands), untitled, 1996. Ht: 36 cm (14¼ in.). Extruded coils (stoneware clay body) joined together in the plastic-stiff stage. The piece was built the other way round as depicted. A layer of casting porcelain was sprayed on top of the biscuit fired piece using a spray gun under a very low pressure resulting in a granular texture. (Photo: Anton Reijnders)

The **press-moulding technique** can provide a form with directness or 'roughness', as the marks related to the making can be incorporated as a characteristic into the final piece. Because a clay body with a coarser structure is used, a less-detailed surface will be produced. The press-moulding technique is very well suited for reproducing large work because it allows gradual tapering of wall thickness towards the top; more stability during drying and firing will be obtained. One advantage of this technique is that it allows the use of moulds made of materials other than plaster and existing forms. Press-moulding shallow forms using a single slab is also used for making functional ware.

The **plemping technique** (a method developed at the EKWC) entails spreading or rubbing a clay body specially composed for this purpose into a plaster mould; this clay body has a paste-like consistency. The main advantage of plemping as compared to press-moulding is that details are better preserved in the cast: a quality can be achieved comparable to the casting technique. The advantage compared to casting is that it allows the production of large to extra large work. The plemping technique is used if a smooth surface on the inside of a form is not aimed for.

1.3.6 Constructing a piece from segments

Any (open) structure can be made by joining pre-formed elements. These units can be made by several different methods. Coils or slabs made by hand or extruded, thrown parts, or segments made by using a mould, can all be used to construct a piece. Some more information about constructing a piece from segments is provided in section *4.7 Multi-segmented pieces.*

Note:

1 Gorter, H. *Energiebesparing door Reductie van de stooktemperatuur van Fijnkeramiek,* THN TPD, Eindhoven, The Netherlands, 2001.



2 Clay body and casting slip



A closer look at clay will reveal its special qualities. Its uniqueness comes not from being precious – it can be found in vast quantities all over the world – but from its special characteristics. Clay mixed with water has plasticity, it is malleable or can be cast and, above all, forms made of clay can be made permanent through firing. The fact that it is found in many places all over the world and that it is easily malleable has surely contributed to its long history of use. Clay is not just one thing, it is a material composed of many different components in varying amounts. Due to these variations the properties of clay vary a lot. Some clays can be used straight away 'as found' but often a blend of clay and non-plastic materials has to be made; this is called the 'clay body'. A clay body is formulated in order to meet specific demands related to a certain method of making, size and shape. Some materials are added to alter the visual qualities such as colour or texture.

2.1 Properties of a clay body and casting slip

Clay bodies and casting slips do have a large number of properties as listed below. These properties will influence the choice of method of making, and the composition of the clay body and its behaviour during drying and firing. Understanding these properties will allow a better insight into how to formulate a clay body recipe. Processes and ingredients that influence these properties will be mentioned briefly in this section, with more detailed discussions in later sections. See also sections *13.2 Testing a clay body*, *13.3 Testing a casting slip* and *13.4 Testing a plemp body*.

2.1.1 Workability

Workability is a property related to the modelling, throwing or press-moulding technique and refers to the ability of a clay body to be manipulated without rupture taking place. It is important that a clay body be suitable for the intended method of making. The timespan of manipulation before rupture occurs, is called the **workability range**. The workability range is determined by the ability of a clay body to retain water within a certain timespan and is largely related to plasticity.[1]

Plasticity

To obtain the necessary workability and a sufficient workability range a certain amount of plasticity is necessary. Plasticity is linked to clay minerals. There are a large number of different clay minerals, the most common and important ones present in clay are kaolinite, disordered kaolinite, illite, mixed-layer minerals and montmorillonite,

OPPOSITE:
Hartmut Wilkening (Germany), *Willy Cleas*, 1999. Ht: 160 cm (62½ in.). A coiled piece. A terracotta sculpture body containing flax fibres was used. There is no internal structural support. A terracotta slip and a terracotta slip containing manganese oxide were painted on the surface. (Photo: Peer van der Kruis)



Müller –B- (Switzerland), *Hanging onto* (work in progress 1992–) Ceramics and cement. Ht: 140 cm (55 in.). Forms made by using the coiling method. A mixture of terracotta and a sculpture clay body that fires to an off-white colour was used. Handles were made by pulling, a method used on traditional pottery. A layer of cement was poured and spread on the surface of the pieces.
(Photo: Peer van der Kruis)

(see section 13.1 *What is clay?* for more information about these minerals). Plasticity can be explained as the capacity of these minerals to retain water and slide over each other. The **capacity to retain water** is determined by three facts:

- The electric charge of the clay minerals
- The size of the clay minerals
- The capillary force (a force that keeps particles together due to the presence of water within the capillaries).

Clay minerals have an (albeit very small) electrical charge. Due to this charge they attract each other, but they do not touch because this charge also results in a thin layer of water firmly attached to the outside of these minerals: this is called **held water**. If sufficient water is added a film of water will surround the clay minerals and other non-plastic components and all pores will be filled as well. This extra water is called **water of plasticity**, it allows the clay minerals to slide over each other. The extent of the electrical charge does vary with the type of clay mineral and, as such, the amount of held water and water of plasticity in a clay will vary. In the following order the electrical charge increases: kaolinite, disordered kaolinite, illite, mixed-layer minerals, montmorillonite.

The **surface area of the clay minerals** is the other decisive aspect in relation to the amount of water that will be held. Individual clay minerals are too tiny to be seen with the naked eye, but still their size can vary a lot. Kaolinite minerals can be relatively large compared to the other clay minerals, and montmorillonite minerals are extremely small. Small minerals will hold more water due to the surface/volume relation: a smaller volume leads to a relatively larger surface area. For more information see: section *13.1.1 Clay minerals and size.*

The **capillary force** is another factor in relation to plasticity and can be explained by the following comparison. Two pieces of flat glass are placed on top of one another with a little bit of water in between. The two parts can slide around, but they can't easily be separated as a strong force, the capillary force, holds them together. The clay minerals are subjected to a similar force and thus they provide the necessary cohesion in a clay body.

To achieve the necessary workability and a sufficient workability range the clay body should contain the right amount of plasticity. A highly plastic clay body will be very sticky and difficult, or even impossible, to work with. Low plasticity results in a short workability range, such a clay body is called a 'short' clay.

Consistency and homogeneity

The **right consistency** is essential to obtain good workability. A clay body having the right plasticity but containing too little or too much water will still have a poor workability. Too much water causes the clay minerals to slide too easily past each other; during making the piece is more likely to collapse. Too little water will make the clay



Tom Claassen (The Netherlands), Exhibition overview, 1994. (Photographs on the wall by Rineke Dijkstra).
The piece at the right was coiled with a relatively thin wall (1–2 cm/¼–¾ in.) and no internal structure. A terracotta sculpture clay body with sufficient working strength was used to allow the piece to be coiled from the feet all the way up.
(Photo: Tom Claassen)

body difficult to manipulate, because it loses flexibility as the clay minerals are not able to slide along each other. The chance of cracking increases considerably. A clay body with insufficient **homogeneity** will also give poor workability.

Cohesion

As has become clear, clay minerals provide the necessary cohesion to a clay body. Cellulose fibres can be added to a clay body to increase cohesion. Research at the EKWC has shown that a relatively small addition[2] of flax and/or paper fibres can have a major effect in balancing tensions that occur during drying and the first part of firing.

Working strength

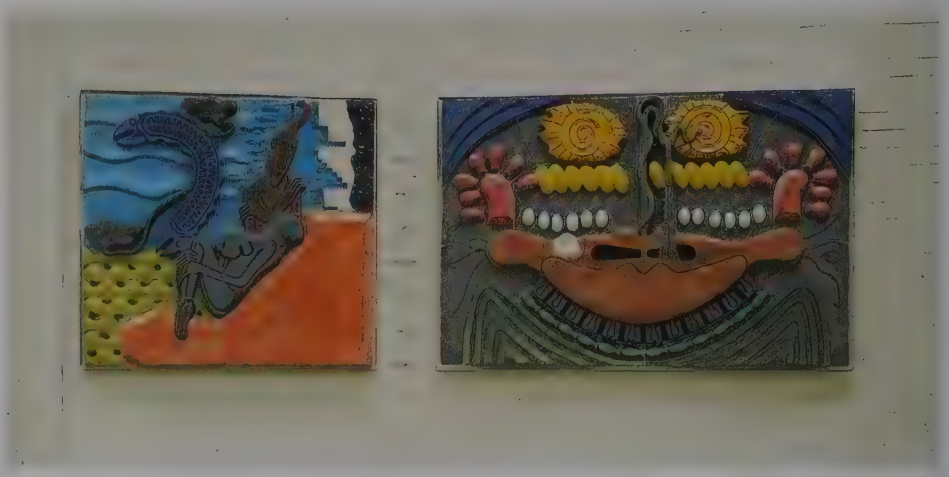
The ability of the clay body to support its own weight and retain its shape well during making is called working strength. Using a filler (coarser particles like *grog*) and cellulose fibres in a body having sufficient plasticity and the right consistency will improve its working strength. The extra friction these add, balances out the sliding tendency of the clay minerals. As a result it will have more stability during making.

2.1.2 Casting properties

In order to cast a piece successfully several points are of importance: the time it takes until a sufficient wall build-up is achieved; the ability of the slip to flow evenly during draining; and the time it takes until the cast has gained sufficient firmness and can be taken out of the mould without deformation. These concerns are linked to four vital properties of a casting slip: viscosity, thixotropy, density, and permeability. These aspects are very much determined by the degree of so-called deflocculation.

Deflocculation

Deflocculation is the action of dispersing clay particles in a slip. As has been discussed before, clay minerals have a very small electrical charge; being in suspension they tend to flock. Adding a deflocculant (sometimes also called electrolyte) will cause a change in the electric charge. As a result the clay minerals will disperse and repel each other



Bjørn Nørgard (Denmark), *J'ai froid–metamorfose* and *Beowulf*, 1991. Ht: approx. 104 cm (40½ in.). Two reliefs of a series of seven. Solid modelled pieces. A clay body with an open structure and coarse grog was used to make these extra thick reliefs. They were cut in segments at the leatherhard stage. A base glaze with various ceramic pigments was used.
(Photo: Peer van der Kruis)

(deflocculate), hence the fluidity of the slip increases in spite of the fact that no extra water is added. As previously mentioned, illite, mixed-layer minerals and especially montmorillonite have a larger electric charge, and as a result they are more difficult to deflocculate. Clay types containing mainly kaolinite or disordered kaolinite are easier to deflocculate, and thus are preferred for composing a casting slip.

Viscosity

Viscosity is about the ability of a slip to flow slowly due to internal friction. A slip with a low viscosity will flow more easily. A slip with a high viscosity will hardly flow at all. Internal frictions in a slip tend to be high due to the mutual attraction of the clay minerals. By adding a deflocculant the viscosity of a slip will be reduced considerably. Even small additions of a deflocculant will have a marked effect. The viscosity of a slip is not constant; it will reduce as soon as the slip is stirred, faster stirring will result in a further decrease of viscosity.

Thixotropy

Thixotropy is the property of a slip to change viscosity by being left undisturbed. A high thixotropy indicates a vast increase of viscosity over time. It is favourable for a slip to have some thixotropy; a reasonably fast build-up of the wall inside the mould and a cast having sufficient firmness is created. Therefore measuring the extent of thixotropy provides valuable information on the best way of attuning a slip to achieve optimal casting results.

Density of the slip

The amount of dry substance that is being suspended in water determines the density of a slip. The density of a slip is expressed by the so-called **slop weight**. A slop weight is the weight of a measured volume of a mixture of water and suspended ingredients. The weight of 1000 ml of water is 1000 g and the weight of 1000 ml of slip will increase accordingly as dry ingredients are added.

Permeability

Permeability is the ability of water to pass through the wall of clay that is being formed during casting. Only sufficient permeability will guarantee a reasonably fast wall build-up. Ultra-fine clay minerals, like illite and especially montmorillonite, will counteract



Canan Dagdelen (Turkey/Austria), untitled, 2001. W: 105 cm (41 in.). Parts of the body of the artist were painted with an engobe. After carrying out a praying ritual the imprint of the feet, knees, arms and forehead remained. A tile body was used for this large tile having an optimal packing as well as an addition of cellulose fibres. (Photo: Corné Bastiaansen)

permeability, moreover they tend to clog the pores in a plaster mould. Kaolin and/or non-plastic ingredients like quartz, fine grog or Molochite will improve permeability. In practice a delicate balance between the extent of deflocculation, density of the slip and the composition of the body has to be achieved to provide sufficient permeability.

2.1.3 Structure

A clay body can have an open, dense, or very dense structure. The structure is determined by its plasticity in combination with its grain size build-up. As the plasticity increases the clay body tends to have a more **dense structure**; only if sufficient grains between 0.425 mm (36's) and 0.125 mm (120's) are present will an **open structure** be achieved. Grains larger than 0.425 mm will open the structure. Within the range of an open to a dense structure further divisions can be made between a coarse, fine and very fine grained clay body. A clay body is considered to be **very fine grained** if no grains larger than 0.075 mm (200's) are present, **fine grained** if no or only a small number of grains larger than 0.25 mm (60's) are present. **A medium fine grained** clay body contains no grains larger than 0.425 mm. A **coarse grained** clay body contains grains larger than 0.425 mm. The structure determines the behaviour during drying and firing (especially during the first part of the firing). Therefore knowledge of the kind of structure of a clay body at hand is crucial.

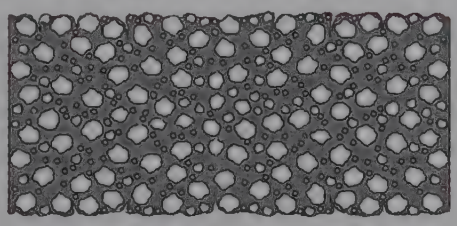


Figure 2.1 A relatively high ratio of coarse grog compared to other grains results in a far from optimal packing. A bumpy surface and surface cracks could occur. (Image: Anton Reijnders)

Packing

Packing is related to the distribution of grains and particles in a clay body. An **optimal packing density** will be achieved if all grains and particles fit together in such a way that maximum packing density is achieved. A clay body having an optimal packing will show more working strength and better drying and firing properties. For large work a near to optimal packing density will be beneficial; for complex pieces, especially large tiles or slabs, an optimal packing density is essential.

In conventional sculpture bodies, a large amount of coarse grog is used in order to open the structure, but often the packing is far from optimal. After the firing this results in a very bumpy surface, even when the surface has been smoothed during the modelling stage. Tiny surface cracks may become visible after firing if a clay body is composed of highly plastic clays and coarse grog, see *Figure 2.1*.

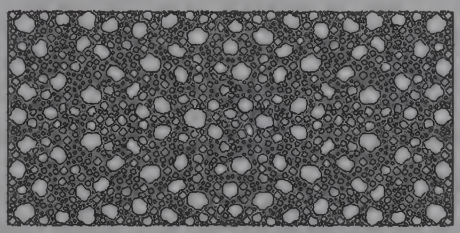


Figure 2.2 A well balanced ratio between coarse, medium and fine grains will result in a optimal packing: the surface will be less bumpy, the chance of surface cracks occurring is reduced and the total shrinkage will be less. (Image: Anton Reijnders)





ABOVE, LEFT:
Diet Wiegman (The Netherlands), *3D Drawing*, 1999. Ht: 212 cm (83 in.). A clay body with optimal packing mixed with cellulose fibres allowed this piece to be made quickly, and significantly shortened the drying time. The piece was built horizontally on a shrinkage slab directly on top of a construction of kiln shelves.
(Photo: Peer van der Kruis)

ABOVE, RIGHT:
Barbara Schmidt (Germany), *Letter Cups*, 1999. Ht: 6 cm (2½ in.). Cast porcelain, glazed inside. Due to its translucency the text becomes visible when the cup is picked up. Collection: Icheon World Ceramic Center, Icheon City, South Korea.
(Photo: Barbara Schmidt)

2.1.4 Drying properties

During drying, shrinkage occurs. The composition of a clay body determines how much shrinkage will occur; whether a piece will tend to dry evenly; whether it resists cracking during drying; as well as the strength of the piece when fully dried.

Shrinkage

The degree of plasticity determines to a great extent the drying shrinkage. A clay body containing a large amount of (ultra) fine clay minerals will shrink more; montmorillonite is notorious for its high shrinkage. Optimal packing density and/or a large amount of large grains will reduce the drying shrinkage.

Equal drying

As has been discussed before, the presence of large amounts of (ultra) fine highly plastic clay minerals in a clay body results in a strong bond of water hence a prolongation of the drying time and more unequal drying within the piece will occur. This will increase if the structure of a body becomes more dense: the transport of water from the inner part of the work towards the surface will be more difficult.

Drying crack resistance

During drying it is almost inevitable that **drying stress** will be generated to a greater or lesser extent within the work. High stress will cause a piece to crack. The ability of a clay body to withstand stress without cracking is called in the EKWC 'drying crack resistance'. The drying crack resistance of a clay body will increase if plasticity of the clay body is neither too high nor too low. It will also increase if cellulose fibres are added (for extra cohesion) and if a (near to) optimal packing density is present.

Dry strength

The ability of a completely dried piece to withstand pressure or shock is called dry strength. A piece with a high dry strength is able to withstand more stress during handling (as during transport of the work to the kiln). Highly plastic clay bodies tend to have a good dry strength. An optimal packing density but especially an addition of cellulose fibres will increase dry strength.

Readsorption

A piece that has been fully dried and is then returned to a humid atmosphere will attract water in its pores; this is called readsorption. For example, a clay body containing a fair amount of montmorillonite in combination with an open structure could attract water to such an extent that it expands slightly. Montmorillonite has a high readsorption capacity and swells during readsorption, while an open structure allows moisture to penetrate more deeply. Due to this expansion, distortion and/or cracks may occur.

2.1.5 Properties related to firing

The composition of the clay body will affect certain reactions that take place during firing; it also influences the properties of the piece after firing. These reactions will be discussed here in general terms. For more details see section *7.3 Biscuit firing*.

Pressure build-up

Occasionally, during the first part of the firing process parts of the piece or even the total piece may shatter. The reason for this is linked to build-up of water (steam) pressure within the piece. Despite a piece being fully dry it will always contain some water. This water will be released during the first part of the firing. A clay body having a dense structure (high plasticity in combination with a fine grog content) will contain more water and it will take a long time for it to evaporate. As a result more pressure build-up will take place. An open structure allows for faster evaporation, thereby reducing the risk of damaging the piece considerably.

Sintering, vitrification and porosity

During firing, so-called **sintering** (the stage before melting) takes place: the outside of individual particles and the least refractory and smallest particles start to fuse first.[3] As soon as some particles become fused, other particles close by are taken into the process faster, accelerating the sintering process: **vitrification** occurs. Vitrification will start at a lower temperature if a fair amount of illite is present; this is even more true if montmorillonite is present. The fact that these clay minerals are not refractory and have a very small particle size clearly influences vitrification. On the other hand kaolin added to a body will markedly increase the point where apparent vitrification will occur, due to the presence of a large amount of 'coarse' and more refractory kaolinite clay minerals. As soon as vitrification starts, **firing shrinkage** occurs and all particles move closer together. As the temperature rises shrinkage will increase and the body becomes more vitrified.

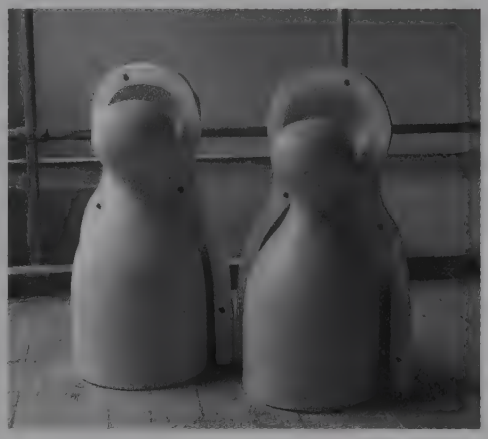


Figure 2.3
The full extent of drying and firing shrinkage becomes clearly visible if compared to the mould. The left-hand side shows a dried piece; on the right-hand side a piece fired to 1220°C (2228°F) is shown. Work in progress by Anton Reijnders.
(Photo: Anton Reijnders)

Porosity of the piece is determined by the amount of open pores that are interconnected. Due to vitrification very small pores will be filled with a **liquid melt** due to fluxing action, hence larger pores will get isolated leading to the so-called closed pores. Porosity will be reduced and ultimately the body will become waterproof if there is no inter-connection between the remaining pores. Coarse grog will make a piece less waterproof if compared to fine grog as open pores will tend to be present despite sufficient vitrification. Porosity of a fired work and **frost resistance** (the ability to withstand severe outdoor winter climates) are very much linked. For more information about frost resistance, see section *2.4.5 Clay body suited for outdoor work*. As the temperature rises, gases that are formed within the body cannot escape due to vitrification. These gases will be trapped within the remaining pores. If the temperature continues to

increase the gases will begin to expand within the closed pores. As a result, shrinkage will stop and the body will eventually expand. The temperature at which firing shrinkage stops and before expansion occurs is a useful indication for whether the **vitrification point** has been reached in stoneware and porcelain bodies. A body that needs to have a low porosity, only a moderate likelihood of **distortion** and a good fired strength is fired up to this point. As the body becomes more vitrified, and as such a large quantity of liquid melt is present, the chance of distortion will be more apparent: the form will distort under its own weight.[4] Provided a low iron and titanium oxide is present, a well-balanced body and full vitrification will lead to **translucency**, as is the case in porcelain bodies.

The **fired strength** of a body is related to porosity. Increasing the firing temperature will reduce porosity and will increase strength. This is true only up to a certain temperature. As has been pointed out before, beyond the vitrification point gases could be formed to such an extent that expansion will occur, and this will result in a decrease of strength.

The temperature span between apparent vitrification and the vitrification point of a body is called the **maturing range**. This range is determined by the composition of the clay body. A clay body with a high kaolin and quartz content will tend to have a high vitrification point and a long maturing range. Additions of nepheline syenite will reduce the point where vitrification starts but the maturing range is still fairly long; the same is true if a clay with a fairly large proportion of illite is used. The maturity range will be substantially shortened as the amount of montmorillonite and calcium oxide compounds increases. (Calcium compounds are often attached to the outside of the clay minerals, present as a natural component in some clays, or they can be added to a clay body in the form of whiting, for instance.)

Expansion rate

Most ceramic materials expand at a steady and progressive rate when heated and contract progressively during cooling. The amount of expansion and contraction, referred to as the expansion rate, varies for each material. Some components like **quartz** (SiO_2) (sometimes also referred to as **free quartz**) are subjected to a sudden increase of expansion at a specific temperature. This sudden increase of expansion or contraction could result in **firing** and **cooling tension**, especially in the case of large thick-walled and complex pieces as well as tiles. Quartz is a natural component in many clays and is added to certain types of clay bodies. **Cristobalite** is a type of silica that could be formed during firing and has an even higher expansion rate. This sudden expansion (and contraction) is known as the **quartz and cristobalite inversion**. In section *7.3 Biscuit firing* this subject will be discussed in more detail.

During the firing, starting at least at 990°C (1814°F), components begin to fuse and new components are formed having again a different expansion rate. Also quartz, and if present, cristobalite as well, will be taken into fusion. As soon as they are fused the expansion rate drops, no inversion will take place any more and cooling tension will be reduced. Fusion can take place if a sufficient amount of a fluxing agent like nepheline syenite is added to a clay body but also if a clay containing a fair amount of illite is used. It is believed that the particle size of quartz present in the body is also critical: ultra-small particles would transform more easily to cristobalite. On the other hand, if sufficient fluxes are present cristobalite will be fused more readily as compared to large particles of quartz.

Quartz and sometimes whiting, wollastonite or large amounts of talc are added to an earthenware clay body intended to be used for functional ware (also bathroom tiles)

in order to increase the expansion rate of the body intentionally. These encourage a good **glaze fit**: a balancing out of the expansion rate between glaze and body reducing the chance of crazing. **Molochite** is added to a clay body to reduce the expansion rate.

Methods to test for a clay's firing shrinkage, vitrification, porosity, frost resistance and expansion rate are discussed in section *13.2 Testing a clay body*, testing for glaze fit will be discussed in section *14.2.4 Determining tendency of crazing*.

Fired colour

The colour of a body **after the firing** can vary from white to buff, ochre, red brown, aubergine or dark brown. **Iron oxide**, always present in clay as a natural component, determines the colour to a great extent. The amount can vary from trace (e.g. kaolin) to substantial amounts (terracotta clay). The colour will vary according to the increase of vitrification and the atmosphere in the kiln: oxidation/reduction/reoxidation (see section *11.4 Reduction firing* for more information about reduction). Besides iron oxide, **titanium oxide** and **calcium oxide** (both natural components in clay as well) will also influence the coloration of the body. For a more extensive discussion see *Choosing a powdered clay* under section *2.2.1 Clay*. More information about expanding the colouring range of a body will be discussed in section *2.5 Using colouring oxides and ceramic pigments*.

NB: The colour of the clay or clay body before firing gives no clear idea about the colour after firing.



Tony Hepburn (England/USA)
The Marriage in Cana, 1995.
Ht: 70 cm (27 in.).
This piece was made with a variety of methods: slab-building, throwing and casting. A white as well as a terracotta sculpture clay body was used. The terracotta pieces were fired in separate firings: oxidation and slight reduction, resulting in different shades of brown (reduction) and orange red (oxidation). The top of the cast bottle has a thin layer of bronze-coloured sinter engobe.
Collection: Frans Hals Museum, Haarlem, The Netherlands
(Photo: Peer van der Kruis)

2.2 Ingredients

To achieve the required properties a whole range of ingredients can be used. In this section they are divided into the following types: clay ingredients; fillers; plasticisers; cellulose fibres and fluxing agents. Within these types a limited group of ingredients are discussed because they yield reliable results.

2.2.1 Clay

Clay is of course the main ingredient in a clay body. Clay as found often needs processing (like drying, milling, sieving and mixing). Nowadays good quality powdered clays are generally available at ceramic supply shops. Commercially-available casting clay powders can be used as well to compose a clay body. A pre-packed clay body can also be used as an ingredient.

Choosing a powdered clay

Powdered clays are processed materials, often they are blends of different clays to achieve a reasonably constant quality[5] within a certain period of time. It is important to realise that a certain type of clay, like for instance ball clay, from different origins may yield considerably different results, due to the presence of a variety of different clay minerals, non-plastic components and colouring oxide compounds. Therefore

Table 2.1

Ultimate analyses of ball clay

Oxides	*Average oxide range*	*Aluminous ball clay WWB 102*
SiO_2 (Silica)	47–66	53.4
Al_2O_3 (Aluminium oxide)	15–39	31.4
TiO_2 (Titanium oxide)	0.2–2.5	1.17
Fe_2O_3 (Iron oxide)	0.8–2.5	0.95
CaO (Calcium oxide)	0.1–1.2	0.20
MgO (Magnesium oxide)	0.10–0.7	0.30
Na_2O (Sodium oxide)	0.1–1.3	0.38
K_2O (Potassium oxide)	0.4–2.8	2.6
Igneous loss*	8–18	9.6

* *Percentage of organic components and/or structural water that is lost during firing.*

plasticity, vitrification temperature, and colour can diverge a lot. Using a so-called ultimate analysis[6] can be helpful as a first step to finding out if a certain clay is suitable to achieve an intended outcome. Such an analysis consists of data on the most important oxide compounds expressed in percentages of a specific blend from a certain manufacturer. These compounds are linked to a variety of clay minerals and other minerals present in a specific batch of clay. *Table 2.1* provides an average oxide percentage range of ball clay and an example of a specific kind of aluminous ball clay.[7] By comparing the different ratios of oxides an indication of the amount of free quartz can be gained and also some guide as to whether the clay will vitrify at a low or high temperature and whether it is suitable to be used in a casting body. It is also possible to get a rough indication of the kind of clay minerals present, and the maturing range and colour.

Interpretation of the ultimate analysis

The amount of quartz can be deduced from the Al_2O_3:SiO_2 ratio. Clay minerals largely consist of a structure of aluminium, silicon and oxygen atoms (for more information see section *13.1.4 The crystal structure of clay minerals*). Because no 'free aluminium oxide' exists (Al_2O_3 is in principle always linked to other minerals like clay minerals and feldspar), the amount of Al_2O_3 leads to the linked portion of SiO_2 in these minerals; the remainder can be labelled as quartz often referred to as **free quartz**. A maximum of 63% of SiO_2 and a minimum of 24% of Al_2O_3 indicates the presence of a moderate amount of quartz. Such a clay is suited as a basic ingredient to give a body with a moderate expansion rate.

Whether the **vitrification point** will occur at reasonably low or high temperatures can be deduced to a certain extent from the CaO/MgO/K_2O/Na_2O percentages. Less than 22% Al_2O_3 and a total of more than 0.4% of CaO and 1% of MgO and more than 2.5% of K_2O and Na_2O indicates a low vitrification point and a shortening of the maturing range. A high CaO content could indicate a short maturing range and an increased chance of bloating and premature distortion. Around 30% or higher of Al_2O_3 and 3% or less of CaO, MgO, K_2O and Na_2O is an indication of a high vitrification point.

The K_2O amount is often linked to the presence of **illite**. More than 2.5% of K_2O is usually an indication of a type of clay with a high illite content. This could also indicate a high content of so-called mixed-layer minerals; minerals consisting of interlocked illite and montmorillonite. In the case of less processed kaolin and in some secondary clays the potassium oxide can also be related to the non-plastic potash feldspar or mica. MgO could be linked to **disordered kaolinite**, **mixed layer minerals** and/or **montmorillonite**, or to magnesium-containing associate minerals (like dolomite or magnesite).

A low K_2O (<1.8%), CaO (<0.3%) and MgO (<0.3%) content could indicate the clay is very suitable for a casting clay body.

As pointed out, the **colour** of a fired body is very much determined by the presence of Fe_2O_3 in relation to TiO_2 and CaO. The following general indications on colour are based on a low CaO (<0.4%) and an oxidation firing (see more about coloration in

reduction under section *11.4 Reduction firing*). Clays having a low titanium oxide and iron oxide content (both <1%) are called white firing although the colour tends to be off-white especially if fired up to vitrification. A slightly higher titanium oxide and iron oxide content (up to 1.5%) could cause a shift to a buff (low vitrification) grey colour (if fired to vitrification). Ochre brown colours could appear if sufficient vitrification is combined with a sufficient amount of iron oxide (1.5%–3%) and titanium oxide (1.5%–2.2%). Beyond 4% of iron oxide often yields an orange red/brown (titanium oxide content is above 1.5%) to red/brown, more vitrification will yield a shift towards red/brown to brown. Calcium oxide will bleach the colour if present beyond 0.6% and especially beyond 1.2%. Calcium oxide could also support the forming of ochre colours. Kaolin suitable for making a white porcelain will contain a low percentage of iron oxide (max. 0.5%) and titanium oxide (max. 0.1%). Still these amounts will not yield a pure white but more of a creamy white in oxidation, and a slight bluish-white in reduction.



Stéphane Choquet (France), *Ceramic Extrusion*, 2001. Extruded profile intended to be used as an armature for a strip light. A fine-grained body containing large amounts of Molochite was used. The process of extrusion allows the pieces to be made to fit the exact length of the strip light.
(Photo: Corné Bastiaansen)

Clay type categories

For the sake of clarity the powdered clays are divided into four categories: **T-MTR-clay** (terracotta-mid-temperature-range clay), **MTR-clay** (mid-temperature-range clay), **HTR-clay** (high-temperature-range clay) and **Kaolin**. These four categories will be used throughout this book. To distinguish types of clay and to make a more informed choice *Table 2.2* can be used as a reference. Having the maximum and minimum percentages as discussed previously in mind, clays fitting within the oxide range of *Table 2.2* will yield reliable clay bodies.

T-MTR-CLAY (TERRACOTTA-MID-TEMPERATURE-RANGE-CLAY)
In this book this type of terracotta clay refers to a clay firing to an orange/brown to red/brown colour. Terracotta clays that fit within the oxide range of *Table 2.2* often tend to have high plasticity and the expansion rate can be fairly high. If used in a clay body suited for large and complex work it should preferably be mixed with one of the clay types that will be discussed next in order to limit the total free quartz content and to temper plasticity. Provided a terracotta clay fits within the oxide range it can be used to compose a reliable stoneware clay body suitable up to the mid temperature range (1220°C/2228°F). A low CaO and MgO content and a K_2O content not exceeding 2.6% (preferably up to a maximum of 1.8%) indicates that T-MTR-clay might be suitable for using in a casting clay body.

Table 2.2

Oxide ranges of basic types of clay related to the ultimate analysis

	T-MTR-clay	*MTR-clay*	*HTR-clay*	*Kaolin*
SiO_2	<62	58–63	47–58	47–50
Al_2O_3	>22	24–27	30–35	35–38
TiO_2	<2.2	<2.2	<1.0	<0.1
Fe_2O_3	>6	<2	<1.0	<0.5
CaO	<0.4	<0.4	<0.4	<0.2
MgO	<1.6	0.4–1.0	<0.8	<0.5
Na_2O	<0.3	<0.3	<0.3	<0.2
K_2O	>2.5	2.2–3.2	<2.2	<1.6
Igneous loss*			Variable	

* *Percentage of organic components and/or structural water that is lost during firing.*

MTR-CLAY (MID-TEMPERATURE-RANGE CLAY)
A mid-temperature-range clay having an oxide range as indicated in *Table 2.2* often shows high plasticity. Besides fine-grained kaolinite a



Thomas Weber (Germany), *Das Dorf*, 1992–2002. Work in progress. Average height approximately 12 cm (4¾ in.). A reddish brown coloured terracotta clay with a coarse grain size fraction was used for these pieces. The immediate way of modelling allowed an intuitive way of working. Some parts were glazed with a shiny glaze after which a gold lustre was applied. (Photo: Peer van der Kruis)

reasonable amount of illite and only a small amount of montmorillonite will be present. Some so-called **stoneware clays** will fit within this range. Used in combination with fillers, like grog or Molochite, a very suitable sculpture body can be obtained having a good firing strength at moderate firing temperatures (1180°C–1240°C/2156°F–2264°F) and a low expansion rate (a part or all of the free quartz will be fused during vitrification). Often these kinds of clay contain more iron oxide and titanium oxide, compared to HTR-clays, resulting in a buff coloured body. MTR-clays tend to be less suited as a main ingredient in a casting clay body. The ultra-fine clay minerals tend to counteract permeability.

HTR-CLAY (HIGH-TEMPERATURE-RANGE CLAY)

A high-temperature-range clay having an oxide range as indicated in *Table 2.2* is more refractory and often fairly plastic (although less plastic compared to most MTR-clays). As less iron oxide and titanium oxide are present such a clay can be used if a more white colour is aimed for. Several of the so-called **aluminous ball clays** fit within the HTR-clay range. Some of these clays show a low amount of K_2O and a MgO content up to the maximum or higher as indicated. This often indicates a low illite content and a high content of **disordered kaolinite**. Less common are clays with a low iron and titanium content and a high illite content (>2.5% K_2O) fitting within the silica/aluminium range of an HTR-clay. Provided the percentages of Fe_2O_3 and TiO_2 do not exceed the indicated maximum such a clay is very suitable to obtain an off-white firing body at a high temperature range 1260°C–1280°C (2300°F–2336°F). Generally HTR-clays, particularly those having a low K_2O, CaO and MgO content, are more suited to compose a casting clay body as compared to an MTR-clay or T-MTR-clay.

KAOLIN

If a white colour and translucency is aimed for, as in porcelain, kaolin has to be the main clay ingredient. A high quality kaolin should be used to make a porcelain clay body: the percentage of iron oxide and titanium oxide should not exceed the indicated maximum. Most kaolins have only a very low plasticity, if used in a sculpture body the workability range will be very short. Kaolin is very suited to be used in a casting clay body; it supports permeability. Some, more rare, types of kaolin can be fairly plastic though. These are kaolin's often of secondary type (see section *13.1.3 Types of clay*) and/or contain large amounts of illite[8] and small amounts of montmorillonite in addition to more fine-grained kaolinite.



Louise Schouwenberg (The Netherlands), untitled, 1998. Ht: approx. 120 cm (47 in.). Porcelain, textile and table. Installation combining partly glazed and unglazed cast porcelain forms and textile. The seams were not removed forming an intrinsic part of the piece. Collection: Frans Hals Museum, Haarlem, The Netherlands (Photo: Peer van der Kruis)

Alternatives

Some **red firing clays** tend to differ quite a lot from the terracotta clay fitting within the oxide range of *Table 2.2*: often a higher CaO, MgO content and a much higher SiO_2 is present. As a result a short maturing range, a tendency to bloat and high expansion rate occurs. These types of clay are less suited to be used as a main ingredient in a sculpture or casting clay body to be fired at the mid temperature range, but could be used in combination with an HTR-clay.

If the available **white or buff firing clay** does not fit within the indicated range of an MTR- or HTR-clay the percentage of SiO_2 should preferably not exceed 65%, Al_2O_3 not be less than 22%, and the CaO, MgO and Na_2O percentage should not exceed the indicated maximum, if to be used as the main ingredient in a sculpture body. This will reduce the chance of firing and cooling tension and ensures a sufficiently long maturing range. In the case of small-scale (functional) pieces a clay with a SiO_2 content of more than 65% is beneficial to help with glaze fit.

If the available **kaolin** shows a higher TiO_2 and Fe_2O_3 content a less white result should be expected. A decrease of the maturing range occurs if the Al_2O_3 content is lower and the CaO, MgO, Na_2O and K_2O exceeds somewhat the indicated maximum.

NB: Interpreting an ultimate analysis is only a first step. Particle sizes of the components and size of the clay minerals can have a major effect particularly on vitrification and plasticity. As a next step a sample of the clay should be used to determine its properties. For more details see section *13.2 Testing a clay body*.

Ready-to-use clay body

As nowadays more and more commercially-prepared pre-packed clay bodies are available the question arises as to whether it is worth the effort of preparing a clay body oneself. As clay tends to vary from one batch to another, properties of a studio-prepared clay body can vary every time a new batch of clay is used. Here lies one of the advantages of a ready-to-use clay body. Professionally produced, these clay bodies will be subjected to extensive testing in the manufacturer's laboratory and therefore show only small fluctuations. The disadvantage of ready-to-use clay bodies is the fact that they are formulated to achieve satisfying results for average types of work. In the case of large and complex pieces alterations will be necessary to achieve good results.

NB: An ultimate analysis of a ready-to-use clay body cannot be interpreted in the way previously described, apart from vitrification and colour interpretation. Added grog and other non-plastic additions are also recorded in such an analysis. To determine if such a body has suitable properties, methods as described in section *13.2 Testing a clay body* have to be implemented.

Ready-mixed casting clay powder

Ready-mixed casting clay powders are formulated in such a way that good casting properties will be obtained if the right amount of water and deflocculants are added. It is essential to have a reliable quality with limited fluctuations over time in the composition of a casting clay because casting properties are based on a delicate balance between all ingredients. Commercially-available ready-mixed casting clay powders with a well-balanced composition are, if professionally produced, reliable. When purchasing, information is provided concerning the amount of water and the amount and type of deflocculant to use. Ready-mixed casting clay powders can also be used to prepare a body suitable for the plemp technique. Porcelain casting powder could be used to make a sculpture and plemp body as well.

NB: Apart from vitrification and colour the ultimate analysis of ready-mixed casting clay powder cannot be interpreted in the same way as applicable for a powdered clay.

2.2.2 Deflocculants

As has been discussed deflocculants are added to a casting slip to regulate viscosity and thixotropy. **Sodium silicate** (water-glass) in combination with **sodium carbonate** (sodium ash) are commonly used. Sodium carbonates for reducing viscosity and sodium silicate for reducing viscosity and thixotropy. **Polyacrylate** type of deflocculants can be used as well, especially for regulating thixotropy when using a clay that is more difficult to deflocculate. Dolapix PC 67, Darvan 7, Darvan 811 and Dispex are some brand names. Calgon (sodium metaphosphate) is not recommended as it could inhibit the release of the cast from the mould. Sodium carbonate is considered to be useful as a deflocculant if clay containing organic components is used. If a studio-mixed casting clay powder is to be prepared the right water:deflocculant ratio has to be tested (see section *13.3 Testing a casting slip*). The recommended casting clay powder:water: deflocculant ratio of a ready-mixed casting clay powder is given by the supplier.

NB: Do not add a deflocculant to a sculpture body as it might cause a loss of shape during modelling. It could be added to a tile body provided it is used only for flat tiles or slabs.

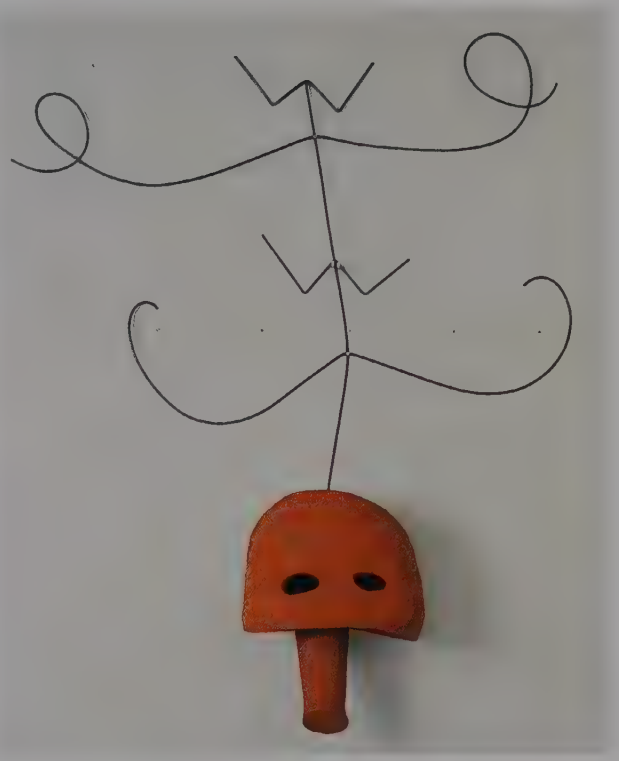
2.2.3 Fillers

A filler is a material added to a clay body to control plasticity, increase working strength, create a more open structure and reduce shrinkage.

Grog

Grog is an important component in most clay bodies and indispensable in sculpture bodies. Grog is produced by several companies all over the world resulting in various qualities and large differences in grain size build-up. Generally it is made out of refractory non-plastic clay types. A vitrified grog is preferable and is essential in a body used for outdoor pieces in order to obtain frost resistance. It is important to realise that grog with a high silica content (more than 70% in its fired analysis) could increase the expansion rate of the body. This kind of grog can be used in clay bodies suited for

medium-sized pieces or smaller and is useful in clay bodies for functional ware (it will not disturb glaze fit too much). Grog containing a high aluminium oxide content is best for a sculpture body suited for large and complex pieces. Most grog is cream or buff coloured, and is sold in various grades. It is important to note that, for instance, a '0.5 mm grog' or '30's mesh grog' refers only to the maximum size of the grains, but a (substantial) part will often have much finer grains.



Joel Fisher (USA), *Mosquito Misquoted*, 2001. Ceramics and metal wire. Ht: 160 cm (63 in.). One of the 'punctuations' of a memory drawing sequence. A terracotta sculpture clay containing buff-coloured grog was used for this piece. Due to scraping the surface at the leatherhard stage the grog has become visible. (Photo: Corné Bastiaansen)

Molochite

Molochite, a brand name, is a specific type of grog: it is made out of kaolin and fired at very high temperatures. It has a white colour and reduces firing and cooling tension due to a very **low expansion rate**. Therefore Molochite is an important ingredient in clay bodies suited for large and/or complex work, large tiles or work that requires multiple firings. It is also used when the colour of the body after firing should be fairly white, especially at temperatures from 1200°C (2192°F) onwards. Small amounts of Molochite can be added to a porcelain body suitable for making large pieces as it makes it less prone to deformation and will reduce firing shrinkage, but it will affect the typical porcelain quality: a reduction of translucency and a less white colour. Molochite can be obtained in a variety of grades. In the EKWC the most used grades are:

- 30 (0–0.5 mm)
- 80 (0–0.18 mm)
- 120 (0–0.125 mm)

A grog high in aluminium oxide like Mulcoa® 47, 35's mesh and 100's mesh could be used as an alternative if Molochite is not available (although it is not white in colour).

Quartz

Quartz is a very common filler added to a conventional clay body. It is relatively cheap compared to grog and especially to Molochite. But because of the fact that it increases the expansion rate considerably it is preferably not added to sculpture clay and should never be used in a clay body suited to making large tiles and complex pieces. As has been discussed, added to clay bodies for functional ware quartz will enhance **glaze fit**. It is an essential ingredient in porcelain clay bodies; provided it is added in the right amount it reduces the chance of warping and helps with translucency.

2.2.4 Plasticisers

Plasticisers are added in small amounts to improve plasticity of a clay body. Except for casting slip, plasticisers can be added to all types of clay bodies if an increase of plasticity and workability range is needed. Nowadays there are a whole range of plasticisers available; here only bentonite and Bentone EW will be discussed in more detail. In order to avoid a negative influence on workability (too sticky), drying (high and uneven

drying shrinkage), and firing properties (slow release of water during the first part of the firing), the additions are kept low. **NB:** Plasticiser should not be added to a casting clay body as the ultra-fine clay minerals tend to clog the pores of a plaster mould.

Bentonite

Bentonite is a highly plastic material consisting mainly of montmorillonite. To increase plasticity it is added to a clay body up to a maximum of 3%, often less is sufficient. Most bentonites contain iron oxide, which will influence the firing colour, especially if added to a white firing clay body (like porcelain). Alternative: ferro purified bentonite, more suitable in white firing bodies.

Bentone EW

Bentone EW, a brand name, is an extremely plastic material containing clay minerals of the smectite group.[9] It is very pure, meaning it contains hardly any iron oxide, therefore it is especially useful in porcelain clay bodies. Due to its very high plasticity Bentone EW is added in little amounts; often not more than 0.8% and to a maximum of 1.2% is needed to increase plasticity of a porcelain clay body. Alternatives: Veegum or Macaloid.

2.2.5 Cellulose fibres

Cellulose fibres are vegetable fibres. There are many kinds of cellulose fibres that can be used; for example cotton, hemp and flax. The fibres differ in length from a few millimetres to a couple of centimetres, depending on their source and ways of manufacturing. They are added to a clay body to improve the following properties:

- Working strength
- Cohesion
- Drying crack resistance
- Dry strength.

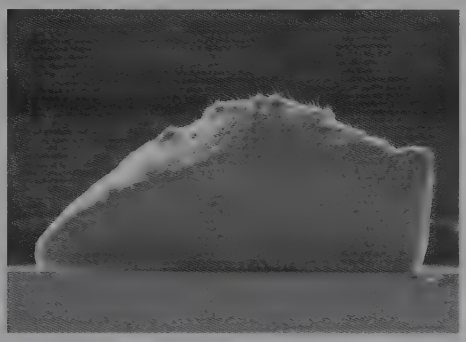
To achieve these properties relatively small additions suffice,[10] see sections *2.4.1 Sculpture bodies* and *2.4.4 Casting clay body* for more information.

In the case of a sculpture body, its workability range will also be increased indirectly, due partly to rotting of the fibres during storage, see also section *2.8 Storing*.

Flax fibres

Flax fibres come from the stem of the flax plant. After being cut, the plants are left on the field. During this time the structure of the stems breaks down: the soft parts 'rot' away. Then they are collected and mechanically manipulated to obtain **flax skeins** used in the textile (linen) industry. These skeins can have a length of up to 50–60 cm (20–24 in.) The textile industry needs a high quality skein and its whole length must be maintained. The kind suitable for use in clay bodies is of average quality and is mechanically cut. The flax skeins used in the EKWC are obtained from Belgium, cut into lengths of ±2 cm (¾ in.), see *Figure 2.4*. One of the biggest advantages of these flax skeins, unlike most other fibres, is that they can be added directly during mixing without having to be made into a pulp first, provided the right mixing tools are available. The flax skeins (from now on referred to as flax fibres) consist of countless numbers of cellulose fibres, which separate during mixing and become evenly dispersed. The fibres are approximately 0.8 mm (⅜ in.) long. Research made apparent that the length of the fibres is of importance. These long cellulose fibres (in comparison





FAR LEFT:
Figure 2.4
Flax skeins chopped to a length of approximately 2.5 cm (1 in.) (Photo: Anton Reijnders)

LEFT:
Figure 2.5
Flax skeins disperse very evenly through the clay body. The cellulose fibres will only become visible if a lump of clay is torn apart. (Photo: Anton Reijnders)

to the shorter fibres present in paper for instance) add more cohesion, working strength, and drying crack resistance if added in the same weight. If properly mixed, flax fibres will disperse very evenly through the clay body. They will only be visible if the clay body is torn and held against light, see *Figure 2.5*. **NB:** Flax fibres cannot be used in a casting slip as they will disturb the casting properties.

Paper fibres

Paper is made out of different kinds of cellulose fibres. Paper fibres can be used in all types of clay bodies including a casting slip. To obtain cellulose fibres different kinds of paper can be used. Good results have been gained using **toilet paper**: it is easy to process as it does not contain (much) glue.

2.2.6 Fluxing agents

A fluxing agent is added to alter the maturing range of a body. It reduces the vitrification point, resulting in a lower porosity and a strong body at similar temperatures. Here only nepheline syenite is discussed as its characteristics are useful for both the medium and high temperature ranges.

Nepheline syenite

Nepheline syenite belongs to the family of the feldspars. It is a compound of potassium, sodium, aluminium and silicon oxide. Two main resources of nepheline syenite are found; in Norway[11] and Canada. Due to its relatively long maturing range and low melting point (sintering starts approx. 1060°C/1940°F and melting at 1200°C–1230°C/2192°F–2246°F), it is ideal for adding to a clay body to increase vitrification if fired to at least 1060°C. Its influence becomes especially noticeable beyond 1150°C (2102°F). Compared to potassium feldspar (an ingredient more commonly used in clay bodies) nepheline syenite can be used to achieve a maturing range starting at a lower temperature, it also contains no (or very little) free quartz and, as such, it is very suitable for sculpture bodies. All feldspars (including nepheline syenite) reduce possible **firing** and **cooling tension** due to the fact that they bring quartz and cristobalite into fusion, provided the body is fired up to the middle temperature range or higher.

2.2.7 Stains

To expand the colour range, ceramic stains can be added to a clay body (see section *8.3.5 Ceramic stains* for more information). The most commonly used colorant is iron oxide; this gives different shades ranging from pink (low amounts, low titanium oxide content in the clay body and low temperatures) to aubergine brown (larger amounts and mid-temperature range). Manganese oxide is added to obtain dark brown to



Bouwdewijn Payens (The Netherlands), *The Imagination of the Action,* 1996. Ceramics, video and wood. The installation is a collection of ceramic elements made by stacking, slamming, beating and cutting the clay, and a video recording of this process. Three clay bodies were used: an off-white sculpture body partly coloured with blue stains, a 'black firing' sculpture body containing manganese oxide and a terracotta sculpture body. The pieces made from the black firing sculpture body were fired in reduction. Collection: Universiteitsbibliotheek van Amsterdam, The Netherlands. (Photo: Peer van der Kruis)

black/brown.[12] **NB:** Manganese oxide is hazardous. Ceramic pigments are added to extend the colour range. If more clear colours are aimed at, a porcelain body yields the best results. See also section *2.5 Using colouring oxides and ceramic pigments*. Altering the colour of a body could require an addition of 3%–12%, perhaps making the cost a determining factor. The amount of vitrification influences the colour saturation: a higher firing temperature (above 1120°C/2048°F) will generally result in more saturation. **NB:** Grog and Molochite of 80's (0.18 mm) and larger tend to become visible on the surface of a coloured body.

2.2.8 Other possible ingredients

As has been discussed, ingredients like talc (magnesium silicate), **whiting** (calcium carbonate) and **wollastonite** (calcium silicate) are added to earthenware clay bodies suited for functional ware to counteract crazing. These ingredients are supposed to decrease the absorption of moisture and support the formation of crystobalite during firing (therefore increasing the expansion rate) and, as such, improving glaze fit. Because they increase the expansion rate and therefore increase the chance of firing and cooling tension occurring they should only be added to a clay body intended for small to medium-sized pieces. Talc and wollastonite are sometimes added to stoneware clay bodies, because at high temperatures (higher than 1200°C/2192°F) the opposite effect occurs: the expansion rate of the body decreases. The maturing range will be shortened as well, therefore an accurate monitoring of the firing around the vitrification point is essential. Whiting should not be added to a stoneware clay body. It reduces the maturing range and increases the tendency to bloat considerably.



Madeleine Child (New Zealand), *Bossche bollen Shelf*, 1996. W: 163 cm (64¼ in.). This piece was made by reshaping a rim of approximately 2 m (6½ ft) in diameter. The rim was thrown on a wheel and reshaped by stretching and pushing the clay. A fine-grained sculpture body with sufficient plasticity, mixed with paper fibres was used to get the necessary cohesion. A high-lead glaze was used on top. Collection: Princessehof, Leeuwarden, The Netherlands (Photo: Peer van der Kruis)

2.3 Types of clay bodies

One of the most commonly-used classifications for clay bodies is related to the characteristics after firing. Porosity, colour and translucency are the three most important properties often used to classify a fired body. According to these properties, earthenware, stoneware and porcelain can be distinguished. Clay bodies specially composed to meet these requirements are named accordingly. Another classification, related to the method of making, will be discussed in section 2.4 *Formulating a clay body recipe*.

2.3.1 Earthenware

An earthenware clay body is intended to be fired at low temperatures (less than 1180°C/2156°F) and is formulated to fit well to low temperature glazes: no crazing should occur (crazing will make the piece neither waterproof nor strong). As discussed before to achieve a good glaze fit whiting and quartz are often added to earthenware clay bodies for functional pieces; talc and wollastonite are used for the same reason. Because the whiting reduces the maturing range markedly such a body is not fired up to vitrification. Either a T-MTR-clay, MTR-clay or HTR-clay can be used as a basic ingredient. Kaolin could be added in the case of a casting body, and nepheline syenite is added to achieve somewhat more vitrification.

2.3.2 Stoneware

A stoneware clay body is formulated to achieve a vitrified and strong body at a particular temperature. Fired to its vitrification point the body will have a low porosity and no glaze will be needed to make it waterproof although a stoneware body containing coarse grog will tend not to be waterproof, in spite of being fired to its vitrification point. A simple combination of an MTR-clay and grog or Molochite could result in a strong body within the mid-temperature range (1200°C–1220°C/2192°F–2228°F) and could form the basis of a sculpture body. If an HTR-clay is used, often nepheline syenite is added to achieve a more vitrified body. In the case of functional ware, quartz is added to support good glaze fit.

A stoneware casting clay suited for medium-sized pieces, a so-called **vitreous china** used in the sanitary industry, contains a mixture of HTR-clay, kaolin and some fine grog or Molochite, nepheline syenite and quartz.

2.3.3 Porcelain

Porcelain can be distinguished from the two other types of bodies by its very white and glassy appearance. It is non-porous if fired to full vitrification. Above all it can show some translucency provided the wall is sufficiently thin. There are two main types of porcelain: soft paste porcelain (1200°C–1300°C/2192°F–2372°F) and hard paste porcelain (1300°C–1460°C/2372°F–2660°F). The main ingredients are kaolin, potassium feldspar (or nepheline syenite) and quartz. To achieve a soft paste porcelain nepheline syenite is preferable.



Satyendra Pakhalé (India/The Netherlands), *Flower Offering Chair*, 2001. Ht: 85 cm (33½ in.). Thrown sections joined at the leatherhard stage. Fine-grained sculpture clay was used. The piece was placed on a shrinkage slab to allow equal shrinkage during drying and firing in order to avoid deformation or splitting. At the dry stage a terra sigillata, made from a white HTR-clay and a small amount of terracotta clay, was applied by brush to obtain a light-salmon colour. The piece was fired to the mid-temperature range. Collection: Gabrielle Ammann, Designers agency, Germany.
(Photo: Corné Bastiaansen)

2.4 Formulating a clay body recipe

The method of making, and also the size and complexity of a piece, decides the required composition of the clay body. In this section four major types of clay bodies are discussed: the sculpture body, the tile body, the plemp body and the casting clay body. Aspects specific to the formulation of a clay body suitable for outdoor work will also be discussed.

As has been addressed in section *2.2 Ingredients*, ingredients (particularly clay) do vary a lot. Therefore it is not very helpful to provide recipes with exact amounts of, let's say, ball clay, nepheline syenite and grog. In order to provide recipes that can be used as a starting point, percentage ranges of most ingredients are provided. The percentages of Molochite in the tile body recipes in *Table 2.5* will lead to a fairly optimal packing. If an alternative high aluminium oxide containing grog is used, first a grain size analysis has to be carried out to obtain an optimal packing, see section *13.2.8 Grain size analyses*. **NB:** Testing a recipe before implementing is strongly advised, because personal preferences of what is considered to be a good workable body, play a decisive role. It is important though to remember that an increase in size and complexity of the form requires a body composition that will be less subjected to drying, firing and cooling tension. Test and analysis as discussed in sections *13.2 Testing a clay body* and *13.4 Testing a plemp body* could be a help in finding out the optimal balance of ingredients in order to arrive at the desired workability range, drying and firing properties.

2.4.1 Sculpture bodies

In this section, first sculpture bodies suited for **extra large, large** and **complex work** will be discussed. Then clay bodies suited for smaller work will be covered, as their composition can be deduced from the previous ones.

A sculpture body suited for building free-standing (hollow) extra-large pieces and complex pieces should have sufficient working strength and cohesion, a more moderate drying shrinkage, a good drying crack resistance, not be likely to be subjected to pressure build-up and have a moderate expansion rate. To achieve this it should contain a low to moderate free quartz content, a high aluminium oxide containing grog (like Molochite), and an open structure. On top of that, the amount of clay has to be

Table 2.3a

Sculpture body for medium-large to extra-large pieces

		MTR/HTR (T-MTR-clay)	Molochite 30's	Molochite 80's	Molochite 120's	Grog 30's	Nepheline syenite	Flax fibres	Paper fibres
Large and extra large pieces 1060°C–1240°C (1940°F–2264°F)		50–55%	40–43%				0–10%	+ 0.25%	+ 0.4–1%
Medium-large pieces 1060°C–1240°C (1940°F–2264°F)	*1.*		30–35%		0–10%				
	2.	60–65%		30%	5–10%		5–10%	+ 0–0.25%	+ 0.4–1%
	3.					30–35%			

Table 2.3b

Sculpture body for small to medium pieces

	MTR/HTR clay	T-MTR-clay	Grog 30's	Grog 80's	Nepheline syenite	Quartz	Talc	Paper fibres
Medium and smaller pieces 1060°C–1260°C (1940°F–2300°F)	65%		0–10%	20–25%	0–15%	15–20%	0–15%	+0–0.4%
Red burning clay 1060°C–1220°C (1940°F–2228°F)	0–15%	50–55%	10–15%	15–20%	0–7%	0–15%		+ 0–0.4%

limited to what is strictly needed because a high amount of grog is needed to achieve a near to optimal packing density; therefore a compromise has to be made in relation to plasticity and workability range. The addition of clay may vary between 50% and 55%, the latter percentage is used if a less plastic clay is available (a method to achieve an indication of plasticity is provided in section *13.2.2 Determining plasticity*). An MTR-clay is very suitable as the main clay ingredient; in general it has a high plasticity and it vitrifies at a low temperature making nepheline syenite (partly) redundant and allowing a higher grog content. If an HTR-clay is used extra nepheline syenite needs to be added to attune vitrification. A combination of an HTR-clay and T-MTR-clay can be used instead if a non-white body is appropriate. If a good firing strength is aimed at, the body should be fired at least up to 1200°C (2192°F). Due to a fairly low clay content cellulose fibres are added to safeguard the necessary cohesion; the clay body will be much more forgiving as the fibres will absorb stress during making and drying. The amount and kind of fibres that can be added is determined by the kind of mixing device available (see section *2.6.1 Mixing devices*). In general, up to 0.25% **flax fibres** can be added to a sculpture body. Higher percentages result in poor workability (the clay becomes too cohesive). If flax fibres or the right equipment to mix the clay body and flax are not available **paper fibres** can be added up to 1.6%, although a maximum of 1% is preferred as higher amounts may affect the visual quality of the piece; the surface will show a more papier-mâché like quality. A combined use of paper and flax fibres will increase the dry crack resistance and drying strength considerably: a combination of 0.25% flax fibres and 0.4% paper fibres yields very good results.

A sculpture body suited for **medium-large** work puts less of a demand on the composition. An optimal or near to optimal packing density is less necessary therefore the clay content can be increased allowing a broadening of the workability range. Instead of a

high aluminium oxide containing grog an average grog can be used. An open structure is still recommended especially if the wall thickness is 3.5 cm (1½ in.) or more: in this case, the percentage of powdered clay should not exceed 60%. Cellulose fibres can be added if a very reliable and forgiving clay body is aimed for.

For **medium and small pieces**, quartz (and/or talc) can be added to support the glaze fit. Paper fibres could be added in the case of complex and/or multi-sectioned pieces.[13]

A sculpture body can be used for **press-moulding** or **modelling** a solid piece that will be hollowed out afterwards. For the latter, a clay body with an open structure is strongly recommended as there is an increased chance of air pockets forming. Adding flax fibres will mean extra care is necessary with mixing (see section *2.6.1 Mixing devices*). For **throwing** large pieces on a wheel, and especially if the **wheel/template method** is used, a sculpture body is the best choice, although the addition of cellulose fibres will demand extra attention during trimming.[14] A throwing body suited for small-scale functional work could contain up to 65% of plastic clay. Grog can partly be replaced by quartz or talc. Up to 0.4% of paper fibres can be added in the case of very demanding pieces.

Porcelain sculpture body

Most commonly-available porcelain clay bodies are less suited for building large-sized work. Workability is often very poor as well as the drying properties. Experience in daily practice at the EKWC has shown that a porcelain body can be made suitable for large-scale objects by adding cellulose fibres and Bentone EW. A combined use of flax and paper fibres will increase the dry crack resistance and dry strength considerably. If flax fibres are not available, up to 0.8% of paper fibres can be added (higher amounts tend to affect the porcelain quality). The addition of Bentone EW (or alternatives) is necessary to increase plasticity. Commercially available porcelain casting powder could be used as a base as well. **NB:** Some porcelain casting powders contain pre-mixed deflocculants and therefore they are not suitable to be used as a basic ingredient for a sculpture body as the work could easily become unstable during modelling. In a studio-made porcelain clay body, kaolin, nepheline syenite (or potassium feldspar for temperatures beyond 1280°C/2336°F) and quartz are the main ingredients. A small amount of HTR-clay will improve the workability. To maintain a porcelain quality the HTR-clay should contain a very low iron and titanium oxide content. Adding a small amount of Molochite 80's or 120's mesh improves the working strength, although additions of more than 7% influence the porcelain quality unfavourably (especially Molochite 80's). To reduce the chance of distortion, more quartz should be added (at the expense of nepheline syenite) as the firing temperature is increased.

2.4.2 Tile body

As has been pointed out, tension is spread more unevenly in a flat shape, even more if it is rectangular, like a tile. Therefore it is best to use a tile body. A tile body is a sculpture body specially attuned to withstand extra tension during drying (high drying crack resistance) and firing (low expansion rate). The ratio of clay can be less, compared to a sculpture body, as the workability range is less of an issue for flat pieces. This allows a higher addition of grog. Molochite is preferred as it will clearly reduce the firing and cooling tension. An optimal packing density is very important as well as an open structure. The lower amount of clay as indicated in *Table 2.5* is used if it has sufficient plasticity. To provide sufficient firing strength the addition of extra nepheline syenite may be necessary and the body should be fired up to at least 1200°C (2192°F).The addition of cellulose

Table 2.4

Porcelain sculpture body

	HTR-clay	*Kaolin**	*Molochite 80's*	*Molochite 120's*	*Nepheline syenite*	*Quartz*	*Bentone EW*	*Flax fibres*	*Paper fibres*
Porcelain clay body for large pieces 1220°C–1260°C (2228°F–2300°F)	0–5%	50–55%	5–7%	–	10–15%	33%	+ 0.6–1%	+ 0.25%	+ 0.4–0.8%
Porcelain clay body for medium-large pieces 1220°C–1260°C (2228°F–2300°F)	0–5%	50–55%	–	0–7%	10–15%	33%	+ 0.6–1%	+ 0–0.25%	+ 0.4–0.8%
Porcelain clay body for medium and smaller pieces 1240°C–1280°C (2264°F–2336°F)	–	55%	–	–	12–16%	29–33%	+ 0.3–0.8%	+ 0–0.25%	+ 0.4–0.8%

** Grolleg kaolin is used with very good results in these recipes. Kaolin with lower potassium content requires more nepheline syenite – replace some of the quartz with up to 5% nepheline syenite.*

Table 2.5

Tile body

1060°C–1240°C (1940°F–2264°F0	*MTR/HTR/ (T-MTR-clay)*	*Molochite 30's*	*Molochite 120's*	*Nepheline syenite*	*Bentone EW*	*Flax fibres*	*Paper fibres*
Tile body for extra large and large tiles	35–40%	50%	0–5%	10–15%	+ 0.3–0.5%	+ 0.25%	+ 0.4–1%
Tile body for medium-large tiles	40–45%	40–45%	0–5%	10–15%	+ 0.3–0.5%	+ 0.25%	+ 0.4–1%

fibres becomes very important to provide the necessary cohesion and drying crack resistance. A tile body can also be used when constructing a piece from leatherhard slabs. Medium and small tiles could be made of a sculpture body for medium-large work.

2.4.3 Plemp body

The plemping technique is a method suited to reproducing large and complex pieces with the aid of a mould and obtaining a cast quality. In terms of composition a plemp body is midway between a sculpture body and a casting slip, and has a spreadable consistency. The use of cellulose fibres is essential to a plemp body in order to achieve sufficient cohesion. However, do not add more than 0.8% paper fibres if the clay body is applied into a mould by brush; as de-moulding will be more difficult. The addition of a deflocculant makes it possible to keep the total amount of water to be added as low as possible. This will prevent excessive drying shrinkage. A casting clay body, either purchased or studio made, is used as the base ingredient. To create an open structure, extra grog or Molochite is added. A plemp body can also be used to build a free-standing sculpture. The body is built up or added layer by layer. Vibration of the wall should be limited as the presence of a deflocculant could lead to instability or even collapsing of the piece.

A **porcelain plemp body** can be of similar composition to a porcelain sculpture body, only the plasticiser is reduced by half.

Table 2.6

Plemp body[1]

	MTR/HTR (T-MTR-clay)	*Molochite 30*	*Molochite 80*	*Molochite 120*	*Nepheline syenite*	*Quartz*	*Bentone EW*	*Flax fibres*	*Paper fibres*
Plemp body for medium up to extra large pieces 1060°C–1220°C (1940°F–2228°F)	35–40%	5–15%	30%	10%	10–15%	–	0–0.25%	0–0.25%	+ 0.4 (1%)
Porcelain plemp body for large pieces 1200°C–1220°C (2192°F–2228°F)	5–10% 50%	–	5–7%	–	10–13%	20–25%	0–0.25%	0–0.25%	+ 0.4 (1%)
Porcelain plemp body for medium-large pieces 1200°C–1220°C (2192°F–2228°F)	5% 50–55%	–	0–7%	–	10–13%	20–25%	+ 0.2–0.5%	0–0.25%	0.8%

Note: [1] *See section* 13.4 Testing a plemp body *to determine the amount of deflocculant to be added.*



Anne-Marie van Sprang (The Netherlands), untitled, 1999. Ht: 10 cm (4 in.). Cast porcelain, using a two-piece mould. The pour-hole located in the area of the ear was closed with a separate cast element. The casting technique revealed all details of the original model. No glaze was used. (Photo: Peter Cox)

2.4.4 Casting clay body

A casting body is composed in such a way that optimal casting properties will be achieved. As has been pointed out before, there is a delicate balance between clay body composition, and the amount and kind of deflocculant(s) and water. The optimal balance between all ingredients has to be determined by testing if a studio-made casting slip is prepared, see section *13.3 Testing a casting slip*. If a ready-mixed casting clay powder is used, the recommended deflocculant:water ratio should be followed. For casting medium-large sized stoneware pieces a vitreous china casting clay body is recommended. **Paper fibres** (usually an addition of up to 0.3% will suffice, and no more than 0.5%) can be added to improve the strength during de-moulding and improve its joining capability considerably; especially important for multi-sectioned pieces and a porcelain casting body. As stated before, flax fibres should not be added to a casting slip, as they affect the casting properties of the slip unfavourably.

2.4.5 Clay body suited for outdoor work

If a work is to be kept outdoors in a severe winter climate, damage caused by freezing can occur. To prevent this kind of damage the clay body will need to meet specific requirements. Whether a work will be damaged in freezing conditions depends on several factors in addition to the composition of the clay body.

What determines frost resistance?

The kind of pores present in the fired body are an essential factor. A lot of open ultra-

Table 2.7

Casting clay body recipes[1]

	T-MTR-clay[2]	*HTR-clay*	*Kaolin*	*Molochite 120*	*Grog 120's*	*Nepheline syenite*	*Quartz*	*Paper fibres*
Vitreous china for medium-large and smaller pieces 1200°C–1260°C (2192°F–2300°F)	–	25%	30%	7–12%	–	10–13%	20–25%	+ 0–0.5%
Red burning casting body for medium to small pieces 1060°C–1220°C (1940°F–2228°F)	45%	–	–	–	10–18%	5–7%	25–30%	+ 0–0.5%
Porcelain casting body for medium to small pieces 1220°C–1280°C (2228°F–2336°F)	–	0–5%	50%	0–5%	–	18–15%	27–33%	+ 0–0.5%

Notes: [1] *See section* 13.3 Testing casting slip *for more information about determining the required amount of deflocculant.*
[2] *See T-MTR-clay under section* 2.21 Clay *for more information.*

fine pores will increase the water absorption, on the other hand large pores will reduce the chance of damage. Vitrification is also important as it will reduce the number of ultra-fine pores. An improper way of making, drying and firing makes a piece more vulnerable to being damaged by frost. In the end the actual weather conditions will be the deciding factor.

Pores

The pore structure (more precisely the number of open pores in the body) is a critical factor in whether or not a work will be frost resistant. The kind of pores present in the body determine the amount of water that will be absorbed and whether or not this water will have room to expand when it freezes. The transformation of water into ice generates an expansion of ±9%! **Ultra-fine pores**, especially the pores smaller than 0.7 µm (0.0007 mm) play an important role. The presence of these pores increases the absorption and retention capacity of a body considerably. Water absorbed into the body will fill these kinds of pores completely, as a result no room is left for expansion, causing an internal pressure. Vitrification reduces the amount of these kinds of pores. The presence of illite, montmorillonite and mixed-layer minerals in a clay body is especially advantageous. Even at relatively low temperatures (from 900°C/1652°F onwards) they will be strongly involved in a fluxing action and so the ultra-fine pores will be filled with a liquid melt. Clays consisting mainly of kaolinite and used as the main ingredient, will tend to yield a body having a lot of ultra-fine pores up to fairly high temperatures (at least 1200°C/2192°F). **Larger pores** play an important role in relation to frost resistance as well. They fill only partially with water allowing it room to expand when subjected to freezing. Pores larger than 1 µm (0.001 mm) are beneficial and grog or Molochite grains of 80's mesh (0.18 mm) and larger will support the formation of sufficiently large pores.



Ilia Utkin and Alexander Brodsky (Russia), *Portal*, 1992. Ceramics and steel. Ht: 16 m (52½ ft). Coiled and press-moulded ceramic elements and steel construction. A piece commissioned by the EKWC and located at the front gate. (Photo: Peer van der Kruis)

Way of making

The way of making and the shape of the piece is also of importance. A poor bond as a result of careless modelling or joining will create weak spots leading to an increased chance of damage. Cavities or open spaces in the work that allow water to be trapped should be avoided; expansion here during freezing could shatter the work in spite of the body being frost resistant. Also there should be a hole in the bottom of all hollow or open forms for outdoors, to allow water to drain.

Weather conditions

The fact that a work has been outside for a few years without showing any traces of damage does not prove that the body is frost resistant. It can sometimes take years before damage occurs simply because weather conditions vary – not every winter has conditions severe enough to cause this to happen. Rapid and frequent changes of freezing and thawing, particularly after a long period of rain, can cause damage to the work: a fully-saturated work subjected to a sudden dramatic drop in temperature will be subjected to more stress.

Sealing the surface

The application of glaze to protect a work against frost damage has only a limited effect and it can even be counteractive if the body itself is not frost resistant. Water can be absorbed into the body in unglazed areas (like the bottom part) through little cracks in the piece itself or even in areas where the glaze crackles (although this will be a very slow process). As a result parts including the glaze could chip off. Therefore it is advisable only to apply a glaze to a body with the correct composition in combination with sufficient vitrification. If a glaze is applied to the work it is best to use a well-balanced shiny or satin gloss glaze. These kinds of glazes tend to be more durable and will better withstand environmental pollution (like acid rain) as compared to matt glazes. However, sealing the surface to achieve frost resistance by adding a coating of chemical compounds onto a fired piece has been proved to be counteractive.

Ingredients and frost resistance

An MTR-clay is a very good choice to make a frostproof body: due to the presence of a fair amount of illite there will be a reduction in the number of ultra-fine pores. An HTR-clay can be used if combined with nepheline syenite; often such a body needs to be fired at higher temperatures to achieve sufficient vitrification. T-MTR-clay, or a mix with one of the previously mentioned clay types, could also be used, but adding kaolin is not recommended as it leads to an increase of ultra-fine pores. As stated before, the addition of grog or Molochite larger than 80's (0.18 mm) will result in sufficiently large pores; grains of 36's (0.43 mm) and larger are very effective. **NB:** If grog is used it should have a low porosity! The addition of flax fibres does not have a negative effect on the frost resistance. Tests indicate that there can even be a positive effect if the fibres are not mixed too extensively. To achieve a frost-resistant body the recipes provided in *Table 2.3a* could be used as a starting point.

Testing for frost resistance

As has been stated before, besides the composition of the body sufficient vitrification is essential to achieve frost resistance. There are different ways to determine the degree of frost resistance of a fired body. The most reliable, but also an expensive method, is a test executed in ceramic brick industry laboratories. Several methods are used, here is one example: a test piece is saturated with water under vacuum and high pressure, it is then frozen and defrosted many times in repeated cycles. Freezing can be done on only one side of the test piece, or on all the sides. The first is suited for testing bodies used for brick work, the latter is more suited for bodies used for sculptures.

A more indirect method to obtain an indication of whether a body will be frost resistant is provided in section *13.2.6 Vitrification, porosity and frost resistance*. It is a useful method to compare different clay bodies and to find out the best firing temperature, before the ultimate test is executed in a laboratory.



Ilia Utkin and Alexander Brodsky (Russia), detail of *Portal*, 1992. The stoneware clay used to build the pieces has a coarse grain size structure. It was fired to vitrification to achieve frost resistance. The pieces are (partly) glazed with a satin matt, mid-temperature range glaze. (Photo: Peer van der Kruis)

2.5 Using colouring oxides and ceramic pigments

Iron oxide and manganese oxide are the most common colouring oxides added to a clay body. The addition of red iron oxide (up to 5%) tends to yield an aubergine colour in oxidation and brown in reduction in a vitrified body. Manganese oxide (officially known as manganese dioxide) is added (between 5% and 10%) to a terracotta clay body in order to achieve a 'black firing clay body'. At temperatures between 1100°C and 1150°C (2012°F and 2102°F) a very dark brown, and in reduction a black colour, can be achieved. **NB:** Manganese oxide is hazardous to health and increases the chance of bloating.

Ceramic pigments can also be added to extend the colouring range (3%–12%, *Table 8.4* could be used as a guide), as can so-called **body stains** that are specially prepared to be added to a clay body and are less expensive (although the colour range is more limited). Ceramic pigments added to a porcelain clay body will yield the best results. Zirconium silicate could be added to increase whiteness. A clay body with an MTR-clay as its main ingredient will generally yield darker colours at similar firing temperatures as compared to an HTR-clay due to the occurrence of more vitrification. An addition of nepheline syenite will also produce darker colours. The presence of grog and especially Molochite 80's mesh or larger tends to become visible on the surface of a coloured body. **NB:** Additions of colouring oxides and pigments will influence vitrification of the body. Testing is recommended.

2.6 Preparing a plastic clay body or plemp body

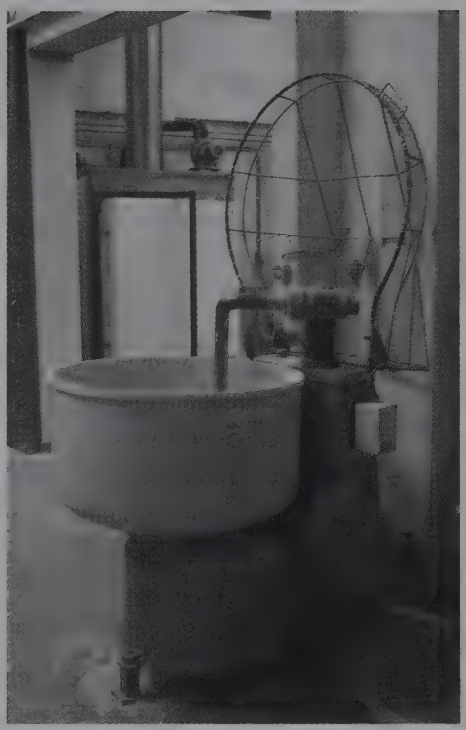
A clay body should be prepared in such a way that proper homogeneity and consistency is achieved. It is important to note that improper mixing and an improper consistency is a major source of faults during making, drying and firing; mixing should be done with utmost care. Several kinds of mixing devices can be used. The mixing device that is most appropriate depends on the amount and consistency of the clay body, and whether flax and/or paper fibres are to be mixed.

2.6.1 Mixing devices

A second-hand **dough (arm) mixer** is very useful if different coloured clay bodies are to be mixed on a regular basis. There are many different types: the one where both the

RIGHT:
Figure 2.6
A dough mixer. Very suited for mixing different types of clay body as it can be relatively easily cleaned. A cover has been installed for safety during mixing.
(Photo: Anton Reijnders)

FAR RIGHT:
Figure 2.7
A gallon mixer suitable for mixing a sculpture or plemp body provided no flax fibres are added. For mixing casting slip the gallon mixer should preferably be equipped with a speed control.
(Photo: Anton Reijnders)





arm and the tub[15] rotate (see *Figure 2.6*) would be easy to clean and also very well suited for mixing flax fibres. A dough mixer can be used to prepare a sculpture body out of dry ingredients, or for mixing dry ingredients to an already prepared clay body. It can also be used to mix a plemp body when flax fibres are added. An arm mixer specially designed for mixing clay is only suitable for mixing flax fibres provided the diameter of the revolving blade(s) or paddles is more than 2.5 cm (1 in.) in diameter and preferably with no crosswise connections: the flax fibres could become tangled in the blades. **NB:** Each type of mixer has a minimum and a maximum mixing capacity. If an amount is mixed to less than the minimum capacity, mixing will not evolve homogeneously. Neither a dough mixer nor an arm mixer is suited for mixing casting slip.

A **pug mill** is suitable for mixing a plastic clay. When mixing flax fibres the machine should be checked after each round to see whether the fibres have accumulated in the mechanism. A vacuum pug mill cannot be used if a clay body contains flax or paper, as the fibres will clog in the filter. A **gallon mixer** (see *Figure 2.7*) or a **power drill mixer** can be used to mix a clay body in a liquid state. They can serve as an alternative to an arm mixer provided no flax fibres are to be mixed. Flax fibres cannot be mixed because they will get entangled in the mixing blade. For regular mixing of larger amounts, the use of a stucco mixer or a **press-drill** is recommended; they are better suited for mixing heavy liquid and semi-liquid substances. In order to prevent overstraining the equipment, the consistency of the mixture should be of a thick slurry. High-speed mixing will result in less clustering of materials in the clay body.[16] A mixing device with a stainless steel mechanism should preferably be used for mixing a porcelain clay body. This will prevent the porcelain from being stained. If not available, the machine should be well cleaned before mixing and the clay body or slip should be removed immediately after mixing.

2.6.2 Using a dough mixer or arm mixer

To achieve a sculpture body with the right consistency and homogeneity several aspects have to be taken into account related to adding the ingredients.

Amount of water

The amount of water has to be determined first. The total amount needed depends very much on the plasticity of the clay component. An addition of 16% (high grog content) –23% (high clay content) of water calculated on the total weight of all dry ingredients could be used as a starting point. When making a plemp body from a ready-mixed casting clay powder, use the amount of water recommended by the manufacturer or determine the amount of water as described in section *13.4 Testing a plemp body*. In both cases keep back 50% of the water.

Making a paper pulp

If paper is to be added it should be shredded first and mixed, with part of the previously mentioned water that has been kept back, to make a pulp prior to mixing into the clay body. Toilet paper easily disperses in water because not much glue is added. It can be added to water in relatively large pieces as compared to most paper. Using hot water will speed up the pulping process. Using a (**hand**) **blender** will create a good pulp in a very short time. The paper:water ratio should be a 1:15 mix when using a (hand) blender and 1:30 when using an electric drill and mixing blade. For a plemp body add the deflocculant(s) to the pulp and mix thoroughly.

Order of ingredients

The type of mixer determines whether water (or pulp, when paper is to be added) or the dry ingredients have to be added first. In general it is best to add water or pulp first followed by the powdered clay. Mix thoroughly to allow water to interact with the clay minerals. Quartz, if appropriate, is added and thoroughly mixed as well. Then nepheline syenite is added, and finally grog or Molochite. Add all ingredients in small steps. Plasticisers like Bentone EW, bentonite, or Veegum T should first be dry-mixed with some of the grog or Molochite. **NB:** When adding dry ingredients a lot of dust is created. In order to prevent hazardous working conditions it is very important to ensure proper ventilation and to wear a fine dust respirator. At the time the grog or Molochite is added the mixture should not be sticky. **NB:** Do not check the consistency while the machine is running. If very dry, small amounts of water can be added a little at a time. If too wet, more dry materials are added in the proportions of the clay recipe. Mixing at this stage should be continued until a homogeneous mixture is achieved. Homogeneity can be checked by taking a lump of mixed clay body and slicing it in two halves by using a wire tool (see *Figure 4.11*). All ingredients should be dispersed evenly: no colour or structure difference should be visible.

Adding flax

Flax fibres are to be added last. They are added a little at a time and mixing is continued until they are evenly distributed (see *Figure 2.5*). Mixing flax fibres is done most efficiently if the clay body contains less water than eventually needed to obtain an optimal consistency. They are also more-easily processed if they are first loosened by blowing them apart with a high-pressure air pistol in a plastic bag. The bag should only be filled to a maximum of one third. Putting the hand with the pistol in the bag and keeping the bag closed with the other hand while pressure is released works well.

NB: If the clay body is to be used for making a solid piece that has to be hollowed out afterwards, the **flax fibres** could hamper the hollowing out process. To alleviate this problem try prolonged mixing, reducing the length of the individual flax fibres and avoiding the inclusion of larger **flax skeins**.

Adding final amount of water

Finally, water is added a little at a time until the right consistency is achieved. See section *2.6.5 Optimal consistency of a clay body*. For a plemp body the remaining 50% of water has to be added to achieve the right consistency.

Compressing

Mixing with the aid of an arm mixer makes a **sculpture body** far from compact. Compressing the clay body after mixing will increase workability and to this end, lumps of clay body are thrown vigorously on top of each other when removing the mixed body out of the arm mixer. The clay body is thrown on top of a plastic sheet. Beating the top of each layer, using flat hands, before the next layer is added will reduce the inclusion of air pockets and the clay body will get more compressed. For hand-building generally this method leads to a sufficient amount of compression, if a clay body is to be used for making a solid piece, kneading (see *Kneading* under section *2.6.4 Mixing ingredients to a plastic clay body*) or pug milling will be beneficial. In the case of a **throwing body**, kneading is necessary to obtain sufficient workability.

NB: Allow the newly mixed clay body to rest for at least 24 hours before being used.

2.6.3 Using a power drill or gallon mixer

In order to mix a clay body using a power drill or gallon mixer the consistency of the mixture should be at least as fluid as thick slurry: as has been pointed out before, this will prevent overstraining the equipment. In the case of a **sculpture body** at least 50% of water, calculated on the total weight of all dry ingredients, should be used as a starting point. If **paper** is used, a paper pulp is made first (see *Making a paper pulp* under section *2.6.2 Using a dough mixer or arm mixer*). **NB:** Do not add flax fibres because they get tangled up. **Flax fibres** can be mixed by using a pug mill or by kneading, see following section. Mixing on high speed will result in a better blending. The inclusion of extra air bubbles will be avoided by making sure the level of the mixture is high enough to completely submerge the mixing blade. To arrive at the plastic stage the surplus water can be removed by spreading the clay body out on a drying trough made out of plaster, see *Figure 2.8*. As soon as the surplus water is drained from the bottom part (the clay body does not feel sticky anymore) the clay body is flipped onto its other side. The length of time before flipping is possible varies considerably: a tile body, and especially a porcelain body, needs much less time compared to a highly plastic clay body.

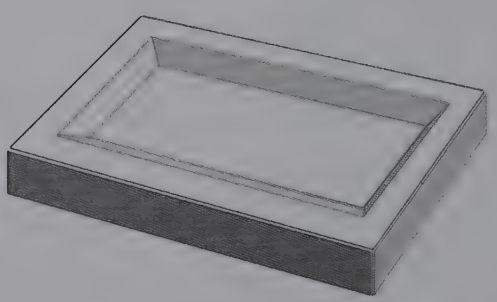


Figure 2.8
Plaster trough.
(Image: Anton Reijnders)

2.6.4 Mixing ingredients to a plastic clay body

To mix ingredients to a plastic body a **dough mixer** or **arm mixer** can be used. The pre-mixed clay body is added first. Add the additional dry ingredients with the machine running (plasticisers should first be dry-mixed with some of the dry ingredients). If paper is to be added, a pulp is made first as described previously. In order to be able to press out the excess water the pulp should be strained by putting it in a coarse sieve



Harumi Nakashima (Japan), *A Struggling Figure EP-1*, 2002. Ht: 43 cm (17 in.). This porcelain piece was made by joining pinched round shapes. Paper fibres and Molochite were added to a porcelain clay body. A transparent shiny glaze was sprayed on the bisque and fired in oxidation. The blue dots are inglaze decals fired in a third firing to a lower temperature than the glaze. Collection: EKWC (Photo: Corné Bastiaansen)

(approximate mesh size 24's/0.8 mm). The pulp in the sieve is pressed by placing one hand flat on the pulp with the other hand under the sieve. The strained paper pulp is torn in small pieces and added a little at a time while the machine is running. Mix until the fibres are evenly distributed. Next homogeneity is checked, followed by adding the flax fibres. Finally, water is added a little at a time until the right consistency is achieved, see section *2.6.5 Optimal consistency of a clay body*, and the body is compressed as described previously.

When a **pug mill** is used the clay body is divided into lumps and each lump is cut in slices of 1 cm (½ in.) by using a cutting wire (see *Figure 4.11*). Dry ingredients (a plasticiser should first be dry-mixed with some of the dry ingredients), strained paper pulp or flax fibres (see p.55) are spread evenly on top of all slices. (See section *2.6.1 Mixing devices* for matters concerning mixing flax fibres in a pugmill.)

Strained paper pulp is torn in small pieces first. Next the slices are brought together and added to the pug mill. This procedure will yield a homogeneous mixture and shorten the mixing time. Depending on the mixing mechanism, the clay body has to be put through the machine a number of times to achieve sufficient homogeneity.

Kneading

Kneading can be used to mix ingredients to a **plastic clay body** although it will be hard labour if a large amount of clay has to be mixed. To obtain a homogeneous mixture and shorten mixing time the total amount of clay is divided into lumps. Each lump is cut into slices of 1 cm (½ in.). Strained paper is torn in small pieces and spread evenly on top of the slices. Then flax fibres are spread evenly on top of all the slices as well. Next the slices are put on top of each other with strong force and pounded into a lump of clay. The lump of clay is placed on a porous base and cupped with both hands. Pressing the palms forward and downward at a 45° angle toward an imaginary point will create an 'ox head' shape in the clay. See *Figure 2.9*. This ox head, cupped loosely by the hands, is rolled back towards the body to an upright position. This process is



Figure 2.9
Kneading. A lump of clay is cupped with both hands and pressed with the palms forward and downward at a 45° angle toward an imaginary point. This will create an 'ox head' shape. (Photos: Anton Reijnders)

repeated until the desired consistency is achieved. Occasionally turning the ox head 90° on the table will accelerate the process. Pressure should not be exerted on the clay body by the arm muscles, as this would be too tiring; a working height which allows pressure to be exerted by the entire upper part of the body is preferable. These actions will decrease the water content, homogenise and compress the clay body. A highly absorbent base, plasterboard for instance, will extract a great deal of water in a short period of time. Some clay bodies lose water very quickly (particularly bodies with a high grog content). On a firm unpainted plywood board, or on moist plasterboard, this process will be more gradual. A very moist clay body requires a highly absorbent surface, such as dry plasterboard. To check if ingredients are distributed evenly and that no air pockets are present, the lump of clay is cut in half with a cutting wire (this will be more difficult if flax fibres are used as they get tangled around the wire). Regular checking is necessary to achieve the right consistency.

2.6.5 Optimal consistency of a clay body

What can be considered as the optimal consistency is determined by the method of making. The optimal consistency of a sculpture body is achieved at the point where, during the making of a piece, there is a balance between good adhesion (between successive layers) and a fair amount of stability (to carry added weight). To determine the optimum consistency of a sculpture body the following method can be used:

1. A handful of clay is rolled into a coil about 15 cm long and 4 cm in diameter (6 in. by ½ in.).
2. This coil is broken in two; the parts are put together and rolled into a coil again.
3. This is repeated three times; the third time one side of each coil is smoothed with a finger.
4. The two coils, with the smooth surfaces facing each other, are pushed together with a medium force and then pulled apart.

The following observations will indicate whether the right consistency has been reached. Traces of adhesion on the coils after they have been separated indicate whether sufficient water is added:

- If no traces of adhesion are visible on the coils after they have been separated (see *Figure 2.10a*); too little water has been added.
- Slight traces of adhesion are visible (see *Figure 2.10b*); a consistency suited for coiling, extruding and throwing.
- Clear traces of adhesion are visible (see *Figure 2.10c*); a consistency suited for model-

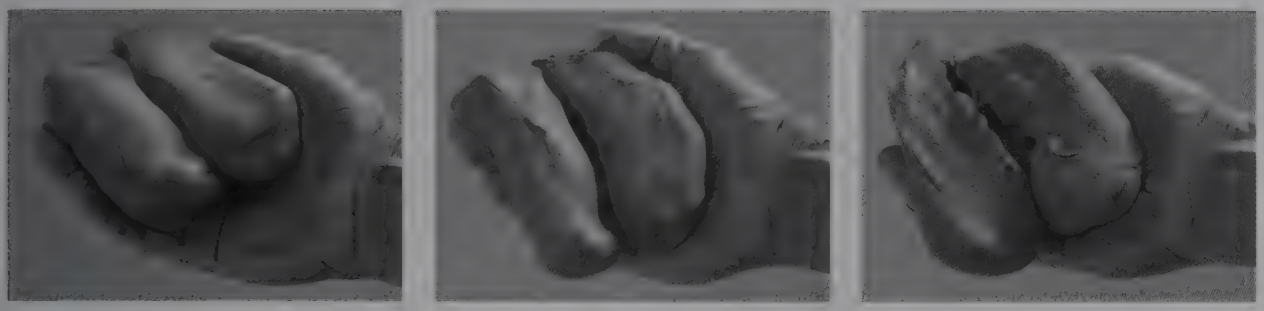


Figure 2.10
Checking consistency.
a) Shows the coils with no traces of adhesion: too little water is added.
b) Shows slight traces: consistency suited for coiling, extruding and throwing.
c) Shows clear traces of adhesion: a consistency suited for modelling solid pieces, slab-building, making tiles, extruding and throwing.
(Photos: Anton Reijnders)

ling solid pieces, slab-building, making tiles, extruding and throwing.
- The clay body sticks to the hands during the entire procedure: too much water has been added.

NB: During mixing, dry ingredients such as powdered clay, quartz, Molochite, grog and nepheline syenite create a lot of dust. Colouring oxides and ceramic pigments are hazardous and some colouring oxides are toxic (see section *8.3.5 Ceramic stains*). To prevent a hazardous working environment proper ventilation is essential and it is very important to wear a fine dust respirator. Mixing time will vary for each type of mixer.

2.7 Preparing a casting slip or plemp body

Several kinds of mixing devices can be used for mixing a casting slip. The same devices can be used for mixing a plemp body provided no flax fibres have to be added. The mixing device that is most appropriate for mixing casting slip depends on the amount and frequency of mixing, and as mixing is done at various speeds, the mixing device should be equipped with a speed control. High-speed mixing for the first part of the mixing procedure will achieve the best results. A hand-held variable-speed **electric drill** with a mixer blade is suitable for mixing up to 20 litres of casting slip. A press drill is recommended if mixing of large quantities is done regularly. A **gallon mixer** (see *Figure 2.7*) could also be used, provided it is equipped with a speed control. A stainless steel mixing blade is preferable for mixing porcelain casting slip, as this will prevent the porcelain from being stained. If not available, the blade should be immediately removed after mixing and cleaned well. **NB:** The mixing blade should be fully submerged in order to minimise the amount of air being drawn into the mix.



Andrea Wagner (Germany/The Netherlands), untitled, 2003. Dia: 23 cm (9 in.). The mould required 11 sections due to the many undercuts. A shell mould was used around the mould sections to give them stability. Bone china was splashed on the surface of the unfired piece. The piece is unglazed.
Collection: EKWC
(Photo: Corné Bastiaansen)

2.7.1 Amount of water

The clay body:water:deflocculant ratio of a casting slip or plemp body has to be finely tuned; a method to determine the right amount of water and deflocculants will be discussed in sections *13.3 Testing a casting slip* and *13.4 Testing a plemp body*. When a ready-mixed casting clay powder is used, use the amount of water recommended by the manufacturer.

2.7.2 Paper and deflocculant

If paper is to be added,[17] a pulp is made first. Follow the instructions in *Making a paper pulp* under section *2.6.2 Using a dough mixer or arm mixer*.



Victor Mira (Spain/Germany), *Heroes*, 1994. Ht: approx. 135 cm (53 in.). Solid pieces built by stacking and modelling, and then partly hollowed out. A coarse-grained terracotta and black (terracotta clay and manganese oxide) sculpture clay was used. All pieces were fired in reduction.
(Photo: Peer van der Kruis)

The required amount of deflocculants can be added while making the pulp. If no paper is to be added, dissolve the deflocculant(s) in part of the water. Heat the water to ensure the deflocculants will be well dissolved. The pulp, dissolved deflocculants and the rest of the calculated or described amount of water are put into a bucket and mixed thoroughly.

2.7.3 Mixing of ingredients

The order in which to add ingredients is described in section 2.6.2 *Using a dough mixer or arm mixer*. Add the ingredients in small steps. **NB:** When adding dry ingredients a lot of dust is created. In order to prevent hazardous working conditions it is very important to have proper ventilation and to wear a fine dust respirator. The mixer should be set to high speed for at least half an hour to achieve good homogeneity. Submerging the mixing blade deeply and making sure the level of the mixture is sufficiently high will avoid the inclusion of extra air bubbles. When mixing a casting slip, at least one and a half hours of slow mixing follows to allow air bubbles to escape. This does not apply for a plemp body. Allow the mixture to rest for 24 hours before being used.

2.8 Storing

Storing a **plastic body** for a while will increase workability considerably, because water is allowed to penetrate better between all clay particles (and penetrate the mineral structure of montmorillonite or plasticisers, if added). Other processes can also occur: the breaking down of organic matter (including part of the cellulose fibres, if added) by bacteria, producing a gel in the water between the clay particles, and the creation of a slightly acid environment which results in a more pronounced polarity of the clay minerals. Both enhance the workability range considerably.[18] These processes will develop better if more water than is strictly needed to achieve an optimal consistency has been added. An excess of water also supports the process of clay minerals being split into smaller fractions although this will happen even more readily if the clay body is also stored in a warm environment. If the clay body is to be stored over a long period of time (a few months), it is preferable to wrap it in two layers of plastic. The first layer can be a thin plastic sheet[19] sealed over the surface, after which it can be put into a plastic bag. The inside of the plastic bag should be moistened by using a plant spray. This will postpone the drying out of the clay body.

Storing a **plemp body** will also increase workability and due to the fact that more water is added, compared to a sculpture body, this will be speeded up. Storing is done in sealed plastic containers.

A **casting slip** should not be stored over a long period of time, preferably not longer than two months: the casting properties could be affected. Added paper fibres decrease the time a slip can be stored even more. Restrict the amount of prepared casting slip to what will be used within two months, and when paper is added to two weeks if repeatable results related to wall build-up and stability during demoulding are aimed for.

Notes:

1 The presence of organic components will have a positive effect on the workability range as well, see also section *2.8 Storing*.

2 Research at the EKWC focused on achieving an optimal cohesion and minimising the visual effect of adding cellulose fibres. Even 0.3% of flax fibres or a combination of flax and paper (0.3-0.5%) will have a major effect. The established and popular material known as 'paper clay' often has an addition of up to 2% (dry weight) of paper. These large amounts of cellulose fibres are added to acheive a weight reduction as well as better cohesion.

3 The sintering and fusion process always starts from the surface of a particle and moves towards the core. Ultra-fine particles have a greater surface area in comparison to their volume than large particles; hence the total area of surface contact is larger. Therefore fusion will happen faster with small particles, see more about surface area of clay minerals in section *13.1.1 Clay minerals and size*.

4 During vitrification, quartz is dissolved in the liquid melt. The ratio of quartz that can be dissolved will increase as the temperature rises. If there is a deficiency of quartz a melt is formed with a lower viscosity, hence more deformation will occur. For more on this subject see Carty, William under *Articles* in *Consulted Writings*, Appendix 2.

5 Due to varying geological circumstances even in the same clay pit there can be a large variation in quality.

6 Obtainable from the supplier. NB: Ask for an up-to-date analysis.

7 A ball clay containing more than 30% Al_2O_3.

8 These types of kaolin are found in China where the production of porcelain first began. Also the kaolin used in Meissen, Germany is of this type and contains up to 34% illite. Grolleg, a well-known and widely available kaolin, has a reasonable plasticity and can be used with good results in a sculpture body. Its relatively high potassium content (1.8%) might be an indication of a fair amount of illite.

9 A clay mineral group that also includes montmorillonite, see section *13.1 What is clay?*

10 This in contrast to the so-called paperclay where large amounts are added to achieve a weight reduction as well.

11 If available, Norwegian nepheline syenite is preferred as it introduces more potassium and less sodium compared to the Canadian type, giving a slightly longer maturing range and slightly less warping.

12 As an alterative to achieve a black result use a black-coloured terra sigillata, see section *10.6 Terra sigillata recipes*.

13 Paper fibres in the clay body will give reliable joints.

14 Trimming should be done not later than the plastic leatherhard stage.

15 A tub with a round-shaped bottom works even better.

16 Research at the Ceramic Research Center at Alfred University , NY, USA, has shown that this is the major cause of faults like, bloating, deformation and probably is also the cause of cristobalite formation.

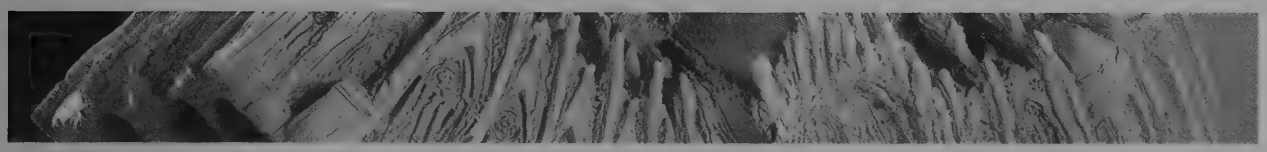
17 NB: Paper will negatively affect the casting properties of a casting slip over time, see section *2.8 Storing*.

18 Chinese potters stored their porcelain clay bodies for decades so that their descendants could benefit from the increase in workability range.

19 Thin plastic sheet (obtainable at a hardware store) works very well.



3 Preparations prior to making



Before starting a piece it is advisable to consider the consequences of a work being made in one piece or out of segments; on what kind of foundation base it is best made; and what equipment will be needed to move the piece around. All these decisions are linked to the size and weight of the eventual piece.

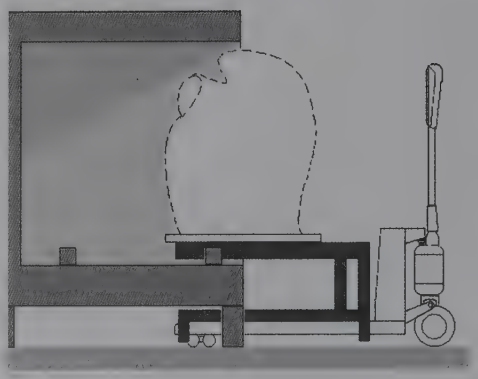
3.1 Taking size and weight into consideration

For practical reasons, large-scale and complex ceramic works are often assembled from separate segments. There may be a size limitation due to the dimensions of the kiln, or the means for moving heavy objects may be lacking (for very heavy work a forklift or even a forklift truck is needed). However, there is a challenge in creating large-scale work in one piece. As can be seen in *Table 1.2* the **weight** of a piece increases substantially as the size increases. A work of about 80 cm (31½ in.) in height, a cross-section of 50 cm (19¾ in.), and an average wall thickness of 2 cm (32 × 20 × ¾ in., see *Table 1.2*) cannot easily be lifted manually by one person as it would weigh over 50 kg (110 lb) after drying.[1]

The maximum size of a piece is obviously determined by the size of the available kiln. In order to make a piece with the largest possible dimensions there is often a tendency to use kiln shelves that are too large for the kiln or to place the piece too close to elements (electric kiln) or burners. This approach is not advisable as it may lead to great temperature differences within the kiln and within the piece and thus cause firing cracks. Taking drying shrinkage into account is essential in order to determine the maximum size of a piece. The linear dry shrinkage of the body can be used to determine the maximum dimensions of the finished wet piece. The ultimate dry shrinkage can only be roughly estimated as it is influenced by several factors like size, weight and shape (for more detailed information about determining the extent of drying shrinkage see section *6.1 Drying shrinkage*) and, in the case of modelling or handbuilding, the amount of shrinkage that will occur during making. To stay on the safe side only half of the expected linear dry shrinkage should be used to calculate the maximum possible dimensions of the finished wet piece. See section *13.2.3 Shrinkage* for determining the linear dry shrinkage of the clay body.

As size, vulnerability or complexity increases, the way the piece will be moved, the means of transport and the type of foundation base all need to be well planned.

OPPOSITE:
Nicholas Pope (England), *Yahweh and the Seraphim*, 1994. Ht: 430 cm (168 in.). Coiled pieces. The central piece was made from coarse black firing sculpture clay. The surrounding pieces were made from fine-grained white sculpture clay. The pieces were made in separately-built segments to fit in the kiln. The central piece is unglazed. An opaque glaze was used on the surfaces of the surrounding pieces. Gold lustre was added in a third firing on the 'wing forms'.
Courtesy of Bernard Jacobson Gallery, London. (Photo: Thijs Quispel)



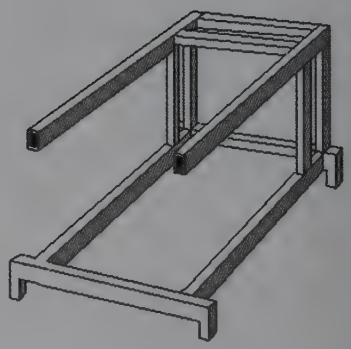


Figure 3.1
A structure combined with a pallet jack intended for loading a kiln. This solution is the cheapest, as pallet jacks in particular are inexpensive nowadays. To avoid shocks, it is important that the tyres are not made of a stiff material.
(Images: Anton Reijnders)

3.2 Means of transport

When making large-sized delicate pieces and heavy pieces, a suitable means of transport is required in order to move and ultimately load them into the kiln. This will avoid the risk of breakage and back problems. If sufficient space is available under a kiln the most affordable option is a structure under which a **pallet jack** can be manoeuvred; see *Figure 3.1*. Pallet jacks are reasonably affordable.

NB: Use a pallet jack with full-rubber wheels, to minimise shaking. The height of the structure should be slightly more than 1 cm to 2 cm (½ in. to ¾ in.) above the kiln floor plus kiln props. The entire kiln stack is built on this structure and placed into the kiln in its entirety, see *Figure 3.1*. A pallet jack has a lifting range of approximately 18 cm (7 in.), which is ample manoeuvring room for placing the stack into the kiln, provided there is free space below the kiln to drive in the undercarriage. For very heavy weights a manually-operated **forklift** could be used (see *Figure 3.2*). The most suitable forklifts must have full-rubber wheels and be provided with a throttle valve or proportional controls, to minimise shocks when lifting and lowering.



Figure 3.2
A forklift suited for lifting and transporting heavy pieces.
(Photo: Anton Reijnders)

3.3 Foundation base in general

In general the base on which the work is built should be flat and solid. Very small pieces can be built directly on a plywood board (use non-coated wood to prevent the piece from sticking; alternatively, a layer of newsprint or cloth could be used between the board and piece to prevent sticking). The foundation base will determine how the piece can be moved. In the case of very delicate and vulnerable pieces, and obviously when weight increases, handling a piece manually is not an option. In those cases the piece should be left in position on the foundation base so both can be lifted together from underneath. Large and delicate pieces should be moved as little as possible anyway. The following preparations are recommended:

- The base on which the work is built should be flat and covered with several layers of newsprint or a layer of cloth. This becomes more important as the size of the bottom area of a piece increases. Strong cloth, for instance canvas, makes it possible to slide the work onto the kiln shelf. **NB:** The kiln shelf and the surface on which the work has been built should be level with each other during sliding.
- If the weight of the work to be built exceeds approximately 20 kg (44 lb), a layer of



Fortuyn/O'Brien (The Netherlands), *Cave Canem*, 1993. Ht: 190 cm (75 in.). A coiled piece, no inner-structure construction was used. It was made and fired on a shrinkage slab. The shrinkage slab was positioned on pieces of kiln shelves and tube props to allow for shrinkage (see Figure 7.3). A low-temperature glaze was poured over the surface and once-fired.
(Photo: Marco Sweering)

± 1 mm (1/16in.) **silver sand** (pure silica sand containing hardly any iron oxide) is necessary as this helps to reduce the chance of warping. **NB:** A dust mask should be worn when sprinkling sand. Strong, stiff **cloth** (canvas or jute) in combination with silver sand makes it possible to slide heavier work onto the kiln shelf.

- Work resting on only a few points should be made, or placed, on a **shrinkage slab** (see section *3.3.1 Shrinkage slab*). This reduces the chance of deformation and/or cracks occurring during drying and firing.
- To prevent deforming during making, drying and firing, the work could be supported with clay props. As props and the piece tend to shrink in different directions during the drying or firing, it may be necessary to use these props in combination with a shrinkage slab, as it will keep the props in position.
- Position three or four blocks under the foundation base to allow it to be picked up easily (especially for heavy pieces that will be picked up with aid of a pallet jack or forklift).
- Vulnerable and heavy pieces can be built directly on the **kiln shelf**. Then the work itself need not to be handled and no transfer is needed, reducing the chance of

damaging the piece considerably. This kind of arrangement also makes a controlled fast drying possible (see section 6.7 *Controlled fast drying*). **NB:** Silver sand and/or shrinkage slab should still be used if necessary when a piece is built directly on a kiln shelf.

3.3.1 Shrinkage slab

A shrinkage slab reduces the risk of deformation and/or cracks occurring during drying and firing, because the slab moves with the shrinkage of the work. This is especially important if a piece stands on only a few points.

The dimensions of a shrinkage slab are determined by the thickness of the wall near the bottom of the final work and the dimensions of the piece. It should be about 0.5 cm (¼ in.) thicker than the bottom part of the piece and 5cm (2 in.) wider than the diameter of the base of the work. The shrinkage slab should be made from the same clay body as the work itself. Making a shrinkage slab should be done carefully. Adhering the layers of clay thoroughly during making will minimise the chances of the shrinkage slab cracking during drying and firing. One requirement is that the clay body be prepared with a sufficient amount of water (see section *2.6.5 Optimal consistency of a sculpture body*). Section *4.3 Slabs and tiles* gives a method of making that will lead to a reliable shrinkage slab. If a flat base is aimed for, the surface of the shrinkage slab should be fairly level, as the eventual piece will warp wherever there is deviation in thickness, following the shape of the slab.

NB: A shrinkage slab is always made in advance to allow it to reach the plastic-leatherhard stage (see *Table 4.2*). This will prevent it from being dented in places due to the weight of the piece. All sides, include the edges of the shrinkage slab, should be covered with thin plastic. About 2 cm to 3 cm (¾ in. to 1¼ in.) from the outer edge should be covered. The remainder of the top may dry in the air. During building, the edges of the shrinkage slab remain covered with plastic until the slab has reached the light-cold stage. Making on a strong, stiff cloth (canvas or jute) allows the slab to be slid onto a kiln shelf easily. In the case of heavy pieces, a layer of silver sand should be sprinkled under the cloth. A shrinkage slab can also be made directly on the kiln shelf, see *Figure 3.3*.

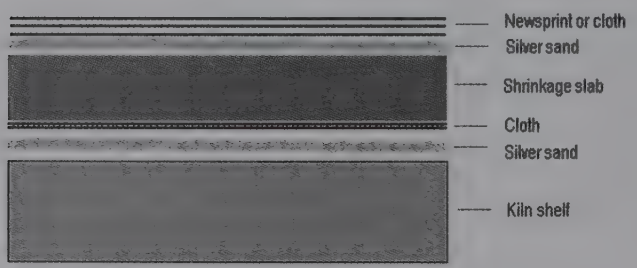


Figure 3.3
A foundation base to guide shrinkage of a large piece. (Image: Anton Reijnders)

3.4 Foundation base for large and complex pieces

Besides the general considerations and preparations as mentioned previously, large pieces need specific attention. Because of the sizes and weights involved, a foundation base on which the piece can be built and fired needs extra attention in order to allow the course of drying and firing to be successful. During drying the piece will shift towards the middle of its base caused by drying shrinkage. During the firing and cooling the piece will shift even more due to expansion, firing shrinkage and contraction (see *Expansion, contraction and firing shrinkage* under section *7.3.1 What determines the way of firing biscuit?*). This shifting could lead to tension build-up if it is obstructed. This will be the case with large heavy pieces and especially with large-scale vertical pieces. A shrinkage slab in combination with sand (about 2 mm/⅛ in.) and newsprint or cloth will help to facilitate the shifting of the piece and as such reduce the

chance of cracking. A foundation base consisting of a combination of kiln shelves has to be made if the bottom part of the piece exceeds the size of the available kiln shelves.

3.4.1 Kiln shelf construction

A piece with a bottom part larger than one shelf could be built on a combination of kiln shelves. Such a construction must keep the shelves level and prevent them from twisting during transport and placement into the kiln. There are two options: using kiln shelves that are placed on top of each other or a construction of kiln shelves and bars. For more information on moving a kiln shelf construction see section *7.2 Loading a kiln for biscuit firing*.

Shelf-on-shelf construction

In this method one kiln shelf constitutes the base. Two shelves are placed on top of it in such a way that they meet in the middle of the first shelf, creating a larger base. The whole can subsequently be lifted with a forklift, ensuring that the forks lift only the bottom shelf, see *Figure 3.4*. Kiln props or refractory bricks positioned between the shelves will lead to a more even temperature distribution, both within the kiln shelves and the piece. Wads of clay or pieces of fired clay can be placed between the shelves and props to level the shelves and stabilise the construction.[2]

A combination of kiln shelves and bars

Two kiln shelves are placed on top of two steel bars in this method. These bars are placed on four blocks (wooden blocks or refractory bricks, see *Figure 3.5*). The steel bars should be sufficiently strong so they won't bend under the weight of the work. A

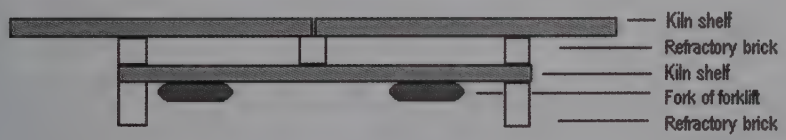


Figure 3.4
Shelf-on-shelf construction.
(Image: Anton Reijnders)

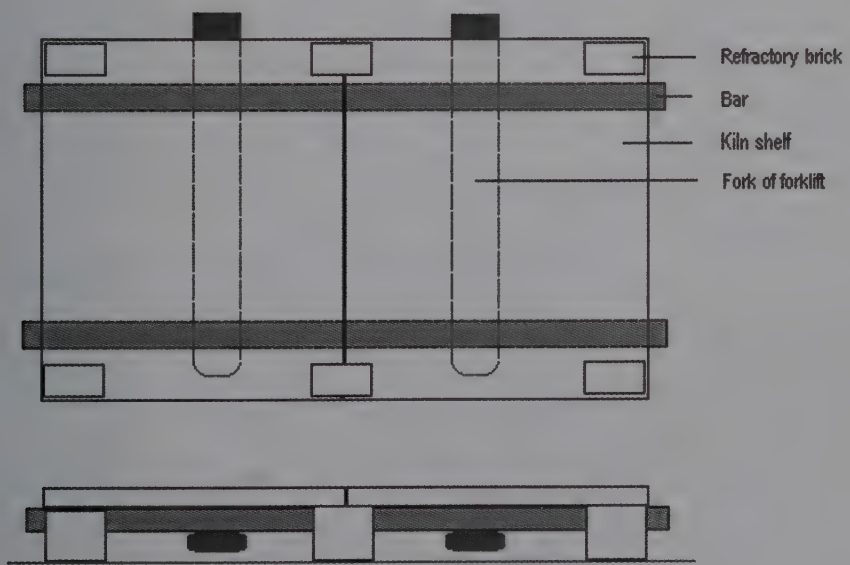


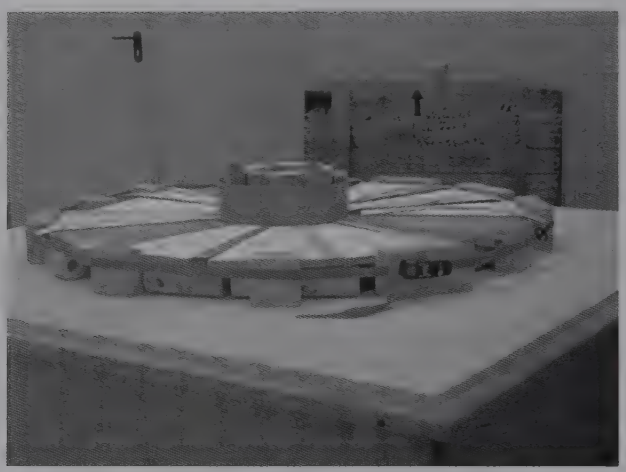
Figure 3.5
A construction of kiln shelves and bars.
(Image: Anton Reijnders)

rough indication: a span of 120 cm (48 in.) and a weight of 250 kg (550 lb) requires two metal bars measuring 5 × 5 cm (2 × 2 in.) with a wall thickness of 2 mm (⅛ in.). Alternatively, two hollow SiSiC bars (see section *7.2.1 Kiln furniture*) may be used if available (60 × 40 cm/23⅝ × 15¾ in. with a wall thickness of 7 mm/¼ in.) instead of metal bars . The bars should be levelled and placed parallel to each other. The shelves placed on top should be levelled and stabilised by using wads of clay or wedges of fired clay.

3.4.2 Foundation base for extra large vertical pieces

Very large vertical pieces need extra attention as extra pressure of weight at the bottom part of the piece will obstruct the shifting of the piece. By constructing a foundation base that can move, tension at the bottom of the piece will be considerably reduced. To achieve this, strips of kiln shelves are place on horizontally positioned tube props. Some space is left open between the strips to allow them to move closer together during drying and firing, see *Figures 3.6* and *7.3*. To create a firm construction wooden slats are placed in between the strips and an adjustable strap holds the kiln shelf and wooden slats in place. On to this place a cloth then a shrinkage slab followed by silver sand and finally a cloth or newsprint on which the work can be built, see *Figure 3.3*. If the work has a circular base, it is best to use wedge-shaped kiln shelf strips, see *Figure 3.6*.

When the work and shrinkage slab reaches the plastic-leatherhard stage, the wooden strips can be removed, allowing the whole to shrink optimally. Tightening the adjustable strap regularly will help shrinkage.



ABOVE:
Figure 3.6
Wedge-shaped kiln shelf strips in combination with tube props are used for extra large pieces with a circular base.
(Photo: Anton Reijnders)



RIGHT:
Figure 3.7
A solid modelled piece on top of a bed of bars. This allows the piece to be hollowed out, ensures an even drying and firing, and facilitates the loading of the piece into the kiln by means of a fork lift. Work in progress by Tony Cragg (England/Germany).
(Photo: Peer van der Kruis)

3.4.3 Foundation base for large solid pieces

Some extra preparations are necessary for solid pieces due to the fact that they have to be hollowed out. A flat-based work of medium or larger size can only be hollowed out in its position of making, as it becomes too heavy and/or vulnerable to be tipped over in order to be hollowed out from underneath.[3] As a consequence the foundation base has to be made fit for this action. Medium-scale work with a flat base can be built from the outset on a wooden board out of which a shape has been sawn which corresponds to the eventual hole to be hollowed out in the bottom of the work. The sawn out shape is kept in position until the hollowing out stage. The piece and the board should be positioned in such a way that enough space is available underneath for hollowing out. Modelling of large pieces should be done on a bed of metal or SiSiC bars (see *Figure 3.7)* onto which cloth and sand are added.

3.4.4 Foundation base for large tiles and slabs

As has been pointed out before, tension is divided more unevenly within slabs and tiles during drying and firing compared to other forms. Therefore large tiles (>70 × 70 cm/28 × 28 in. see *Table 1.2*) and large slabs require special attention. The tiles are made on a foundation of sand and strong cloth (canvas or jute). This will make it easier when the leatherhard-brittle stage has been reached to slide them onto a bed of, for instance, tube props. The tiles can be rolled on these tube props while new ones are added into the kiln. If a forklift is available a large tile could be made on a bed of metal bars. The advantages of this construction will be explained in sections *6.7 Controlled fast drying* and *7.2 Loading a kiln for biscuit firing.*



Pieter Kusters (The Netherlands), *No title,* (after H. Bosch), 2001. Ht: 80 cm (31 in.). An example of a form that should preferably be made on top of a shrinkage slab to avoid tension build-up during drying and firing. The piece was coiled using a coarse sculpture body. Layers of maiolica paint were applied on top of a white maiolica background to achieve different nuances in colour. (Photo: Pieter Kusters)

Notes:

1 It is worth noting that a reduction in wall thickness from, for instance, 2 cm to 1.5 cm (¾ to ⅝ in.) could reduce the weight by nearly 25% (down to 39 kg).

2 Packing conventional kiln shelves on top of each other could cause them to crack.

3 An alternative is to divide the piece into sections that are then hollowed out and rejoined, see section 4.5 *Modelling a solid piece.*



4 Handbuilding



Modelling solid lumps of clay was probably the first and most obvious way of shaping amorphous clay: the oldest examples to have been excavated were unfired figurines. Understanding that clay pieces could be made durable by firing the clay and could be used to create functional pieces led to other ways of forming; making hollow pieces by pinching (a method of shaping a hollow form by making a hole in a ball of clay and pinching up a thin wall), or the method of using coils came about.

In this chapter several methods of handbuilding will be discussed – coiling, slab-building, the throw-and-coil method and the method of modelling a solid piece. Also an approved alternative method of making larger slabs or tiles is covered. Extruding and constructing a multi-segmented piece will be addressed briefly. With all these methods the malleability of the clay body allows an immediate response and improvisation during making. The consistency of the clay body determines the speed of building. Finding an equilibrium between building speed and required stability during making is essential, especially when building three-dimensional pieces.

4.1 Coiling and slab-building

To build a hollow piece **coils, wads** or **(small) slabs** can be used to build a wall from the bottom, step-by-step all the way up. An indication about a possible wall thickness related to the dimension of the piece can be found in *Table 1.2*. A gradual tapering of the walls towards the top is advantageous for stability and it will also lead to a reduction in the total weight (a tapering of 0.5 cm per 50 cm (¼ in. per 24 in.) could be used as a starting point). Coils can be rolled by hand or extruded.[1] Small slabs can be made by slamming a lump of clay between the hands, larger slabs can be made by pounding clay on a piece of cloth with the palms of the hands or fists. The surface on which a work will be made should be slightly porous to prevent the piece from sticking. As has been pointed out in Chapter 3, decisions about the foundation base will need more thought as the size, complexity and vulnerability of the work increases. **NB:** Incorporating enclosed air spaces should be avoided: this could cause shattering of the piece during the first part of the firing.

The coils, wads or small slabs should all be of a similar consistency and should be attached firmly to each other while building the piece. To ensure good adhesion the coils or slabs are placed in such a way that they partly overlap. Next they are squeezed together while pressure is brought upon the inside and outside simultaneously, forcing

OPPOSITE:
Antony Gormley (England), No title, 1994. Ht: approx. 95 cm (37¼ in.). Slabs made from a terracotta sculpture body were pressed around the artist's body. After being removed the slabs were allowed to dry to the plastic-leatherhard stage and then joined together.
(Photo: Peer van der Kruis)



Norbert Prangenberg (Germany), *Figur*, 1998. Ht: 189 cm (74 in.). A coiled piece made from a coarse-grained sculpture body. A rough and fast use of plastic coils is an intrinsic part of the piece. A base glaze containing a variety of pigments and a cadmium red glaze were applied by brush at times in layers. Collection: Bild–Kunst, Bonn, Germany.
(Photo: Peer van der Kruis)

the clay slightly upwards. The popular method of placing coils on top of each other and smoothing only the outside may not give sufficient adhesion unless extra attention is paid to a proper adhesion where the coils touch. This is more true if the wall thickness exceeds 2 cm (¾ in.). One can choose to work with a slightly wetter clay body to allow a more direct way of working. A clay body of plastic-stiff consistency (see Table 4.2) makes it possible to continue building or modelling somewhat longer as the piece will become unstable less quickly. The shape can be more controlled, but at such a consistency care is needed to ensure newly added layers adhere well.

Making hollow pieces out of somewhat **larger slabs** needs another approach. The slabs are allowed to dry (ranging from the plastic-stiff up to the leatherhard stage) before they are joined; this makes them more stable to handle. The extent to which the slabs have firmed-up largely determines the nature of the work. Clay slabs in the plastic-stiff stage lend an organic quality to the work because they are still reasonably flexible: alterations in shape can be made by pushing from inside or from outside the piece. This way of working demands even more attention in relation to stability. If slabs are made on top of a cloth, this cloth could stay attached during building in order to provide a little more firmness.

As the size increases more care should be taken in the way slabs are made (see section *4.3 Slabs and tiles*). The way of **joining larger slabs** needs extra attention as well:

- All slabs should be equally dry: difference results in dissimilarities in shrinkage and as such increases the chance of cracks.
- The places of contact should be large. When the wall thickness is less than 1.5 cm (⅝ in.) the line of contact could be cut slantwise, (for example slabs forming a 90° corner would each be cut at an angle of about 45°).
- The joints should be scored with a toothed kidney (see *Figure 4.14*), a fork or the milled side of a screw, and lightly moistened with water.
- An adhesive slip (see *Table 4.1*) should be applied at the place of contact.
- The joints should be pushed together thoroughly by moving them against each other until 'suction' bonds them together.
- The edges of the segments are welded together by pushing reasonably deeply into the clay with the point of a knife, or with the thumb. To make the seam invisible it is pressed over its entire length with, for instance, the handle of a brush. The resulting groove is filled with clay of a similar consistency. See *Figure 5.24a–b*. The seams are then covered with a thin plastic sheet to ensure a controlled drying process.

Drying the slabs to the leatherhard stage allows a more controlled way of making and more geometrical and straight forms can be achieved.



Jim Melchert (USA), *Words in an Unknown Tongue*, 1998.
Ht: 55 cm (21½ in.). A fine-grained sculpture body containing flax fibres was used for this piece. The slabs were placed into a wooden frame when at the plastic stage. This allowed a combination of an organic quality with a defined outline. An opaque base glaze containing zirconium silicate and a small amount of stains were used on the surface.
(Photo: Peer van der Kruis)

4.1.1 Flat-based pieces

A piece with a flat base is preferably left open at the bottom. An open bottom, as opposed to a totally closed bottom, will allow more even drying and firing of the piece. To provide strength to the form and make it less prone to deformation, during both drying and firing, **a flange** should be added. A flange is a rim at the base of the form, see *Figure 5.4*. This will also increase the strength of the final piece.[2] During drying and firing stress will accumulate at the bottom of the piece, therefore attaching layers of clay while making the flange, and attaching coils, wads or slabs on to the flange, should be given extra attention. If a closed bottom is to be implemented extra attention should be given to the way of making the bottom part as extra tension is more likely to occur resulting in an increased chance of cracking. See section *4.3 Slabs and tiles* for a way to make the bottom part.

4.1.2 Non-flat-based pieces

A work with a non-flat base could be built in two sections. The piece is started somewhere one third or halfway up, building upwards to what will ultimately be the bottom (see *Figures 4.1 a–d*). As a foundation, a flat, firm wooden board is used covered with two layers of thin plastic sheet. The part resting on the plastic sheet is kept wrapped up firmly during the entire building process of the first section in order to keep it damp.

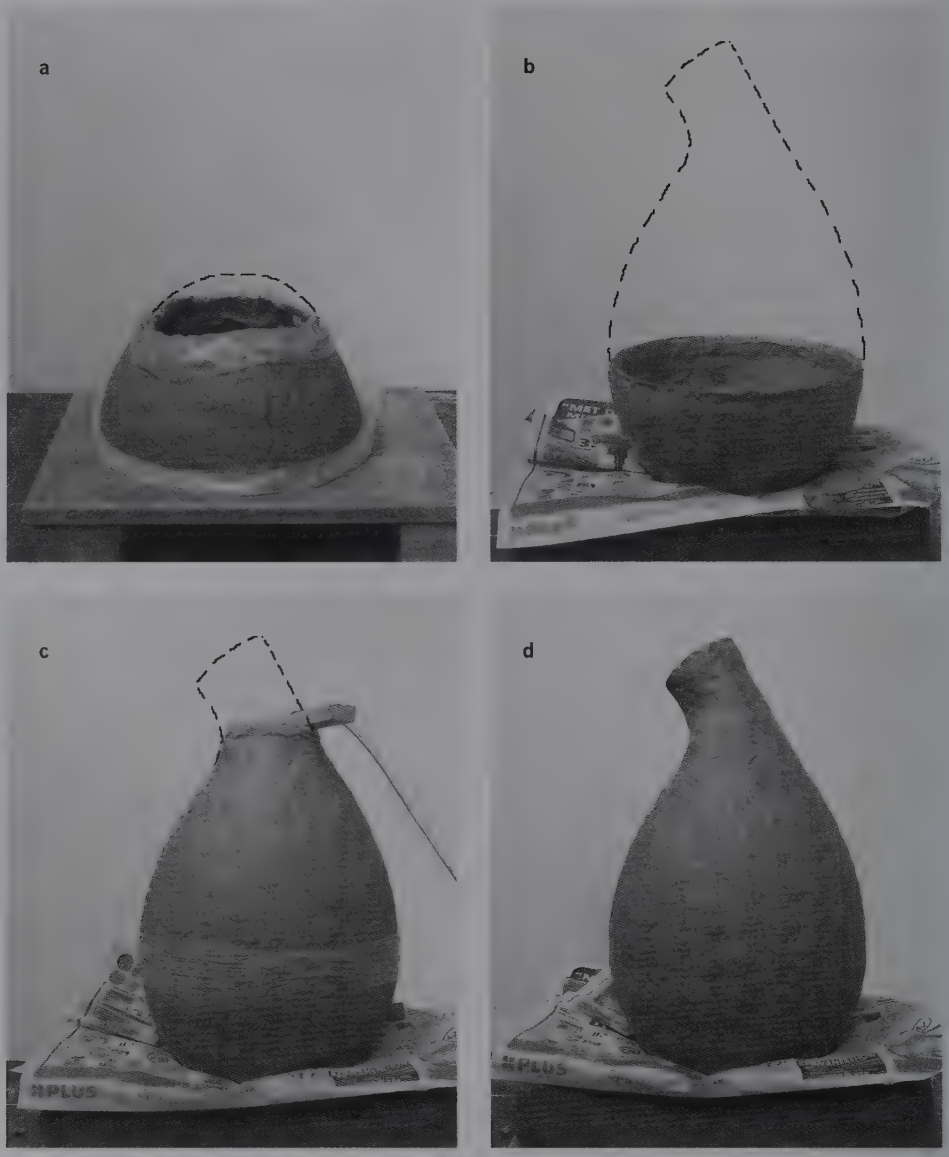


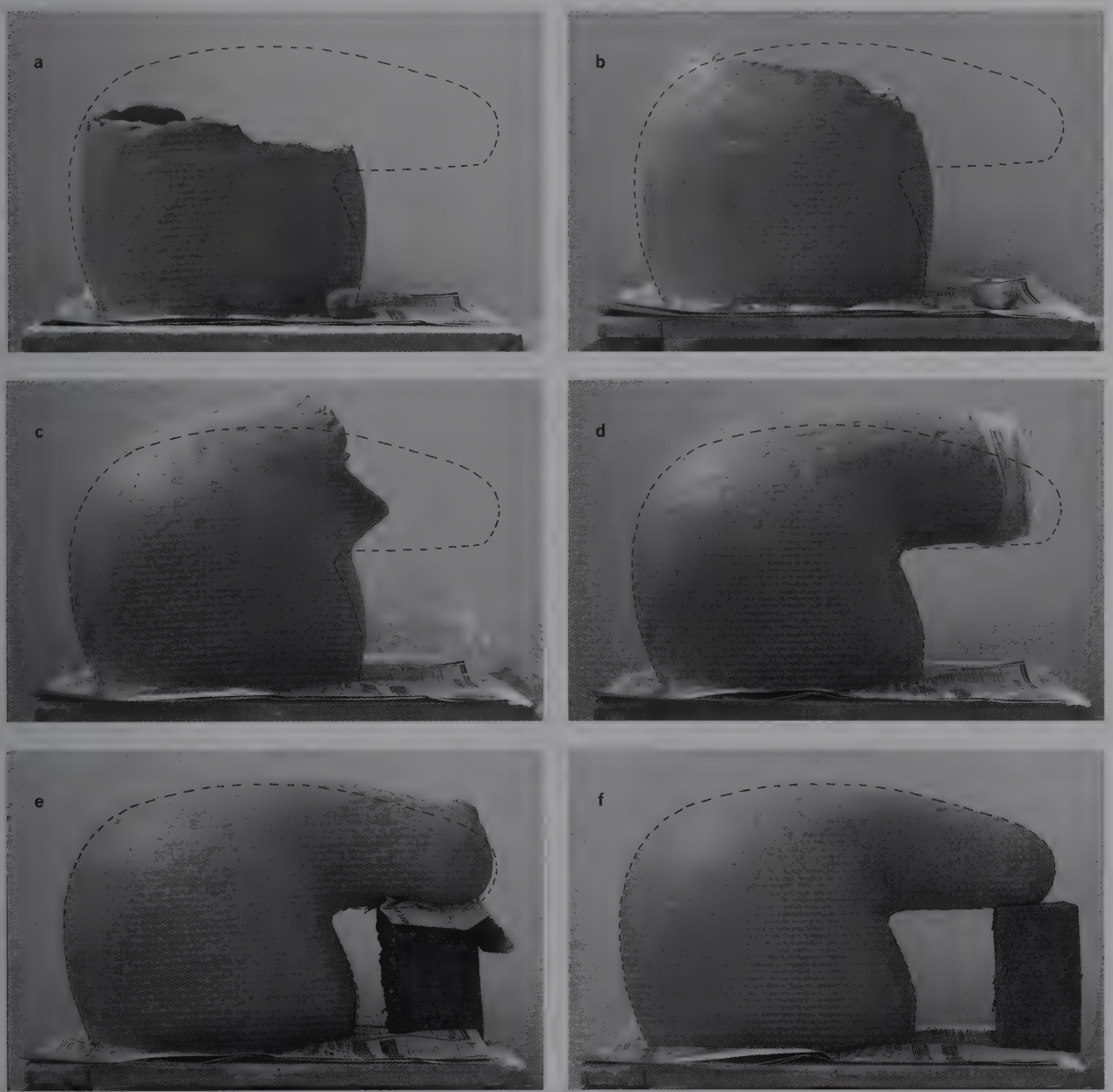
Figure 4.1 a–d
A piece with a non-flat base built in two sections.
a) The part resting on the plastic sheet is kept wrapped up firmly during the entire building process of the first section in order to keep it damp.
b) Once the first section has become sufficiently stable it is turned on foam rubber in order to provide stability. The wall is cut away slantwise and scored.
c) The area where the first and second sections meet is wrapped with a thin plastic sheet, to allow a balancing out of drying. A light bulb is hung in the piece to speed up the drying which also speeds up the building process.
d) The completed shape. Work in progress by Anton Reijnders. (Photos: Anton Reijnders)

After finishing the first section the part that ultimately will become the bottom is allowed to dry. In the case of small pieces to the plastic-leatherhard stage and in the case of larger pieces to the leatherhard stage. This will provide the necessary firmness to the bottom to support the piece. Covering with newsprint and subsequently with foam rubber and a wooden board allows the piece to be flipped. By cutting a form that matches the bottom part out of the foam rubber the necessary support will be achieved. Due to the fact that the lower end of the first section has been kept damp, getting the new layer of clay to adhere should be easy. As the rim has been prevented from drying, pressure causes the edge to become thicker. This edge should be cut away slantwise and scored. Mix the surplus clay body with the plastic clay body to achieve an in-between consistency. Apply water or adhesive slip (see section *4.9 Joining and mending*) before building is continued. The area where the first and second sections meet should be wrapped with a thin plastic sheet, to allow a balancing out of consistency.

4.1.3 Providing stability during building

Always keep an eye on the speed of working to ensure the required stability while building. This will prevent the piece from deforming or collapsing. The composition of the clay body, the wall thickness and the shape of the work will also affect stability. Shaking the wall gently from time to time will give an indication: if the wall moves easily, building should be stopped. The edge should be moistened with water (use a brush) and then covered with a strip of thin plastic sheet. The strip is folded over the edge overlapping approximately 5 cm (2 in.) on both the inside and the outside. This will retard drying and ensures good adhesion of successive layers. The lower part of the piece should be left open to gain sufficient firmness. Checking stability from time to

Figure 4.2 a–f
Any part of a work that leans over should be done in stages to avoid collapsing of the piece. First the vertical part of the wall should be built. Only when this wall has gained firmness can it be given its definitive shape by exerting pressure from the inside. Work in progress by Anton Reijnders.
(Photos: Anton Reijnders)





Thom Puckey (England/The Netherlands), *Imitatio Christi*, 1996. W: 280 cm (109 in.). A piece consisting of three sections. The drapery was coiled, using an adjustable support system during building. The figure was modelled solid and then hollowed out. A base glaze containing zirconium silicate was used on the surface. Collection: Museum voor Religieuze Kunst, Uden, The Netherlands. (Photo: Peer van der Kruis)

time by shaking the wall gently will provide information about whether building can be continued. Regaining stability will take more time in a damp and cold environment. In a room equipped with central heating (very low humidity), the timespan between stopping and restarting will be much shorter as the drying process will move along faster. Generally a clay body with a dense structure and high plasticity, or thick-walled pieces, will take more time. **NB:** The upper edge should not dry out beyond the plastic-leatherhard stage, as this will increase the chance of a poor bond between the layers. In order to speed things up a light bulb (60W) can be positioned inside the piece, see *Figure 4.1*c. The bulb should be positioned an equal distance from all the sides. Regular checking is important to prevent the wall becoming too dry. Forced drying by using a hair dryer could be implemented as well.

After sufficient stability has been gained the edges should be roughened. A tooth-edged metal kidney, a fork or the milled side of a screw may be used for this. Next the edge should be moistened with water using a brush (avoid adding so much water that it runs down the edge). If the upper edge has dried out somewhat after a longer interruption, an adhesive slip should be used, see section *4.9 Joining and mending*. The new layer of clay being added should have the same consistency as the part of the work being added to.

If the building process is to be interrupted for several hours, it is recommended that the entire work be wrapped in newsprint in addition to the strip of plastic mentioned before, but leaving the inside uncovered. If building will be stopped for a day, the entire work should be wrapped in plastic, after having been covered as previously described. If building will be continued only after a longer period of time the following method is used: the top part of the unfinished piece is lightly sprayed with water by using a plant

spray (do not use an excess of water resulting in water running down the piece: this may create an increased chance of tension in the piece causing cracks). Next the piece should be covered with a thin plastic sheet sealed onto the surface by lightly smoothing with the hand. This cover is lightly sprayed with water as well. Then a further layer of plastic is added. In this way a buffer of damp air is created around the work.

Building a **leaning form** requires a specific method of making. Building should be done in little steps to ensure sufficient stability in those parts that are moving away from the vertical axis into a more horizontal plane, see *Figures 4.2 a–f*. To ensure stability the lower part of the form that has to carry extra weight is altered only step-by-step into its final shape. This is done after more firmness has been gained: usually the plastic-leatherhard stage is best. Adding on to the horizontal direction can be continued after the point at which the shape has reached at least the leatherhard stage.

Closing the top of a work should be done step-by-step as well. The piece is built somewhat higher than eventually intended. As soon as sufficient firmness has been gained, the top part can be tapped into its final shape by using, for instance, a small piece of wood.

Structural supports

Ribs supporting the work structurally from within should be used with caution as they may increase tension within the work during drying and firing. The tension build-up could be caused by differences in shrinkage during drying; and expansion, shrinkage and contraction during firing. If, nevertheless, structural supports are implemented, drying and firing should be very slow to reduce the extent of tension build-up. When a piece has a large span, **clay props** may need to be positioned within it to avoid deformation during making and firing. These props should be made of the same clay body. By using a few layers of newsprint between the prop and the piece a lesser degree of tension build-up will occur.



Figure 4.3
Detail of a support construction showing the adjustable pipes.
(Photo: Anton Reijnders)

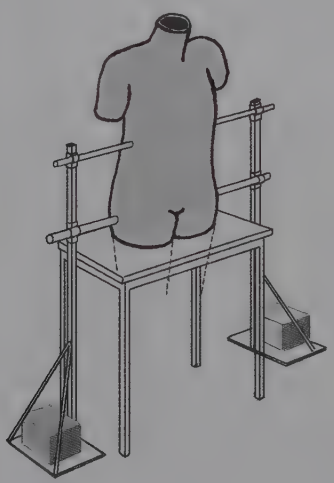


Figure 4.4
A piece built in two sessions. In the first instance building takes place on a table. During the second session the table is removed to allow completion of the piece while it is suspended from the bars.
(Image: Anton Reijnders)

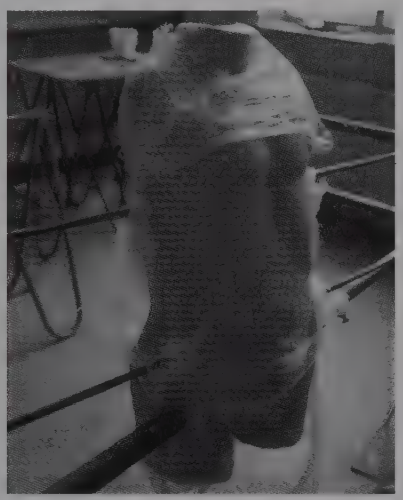


Figure 4.5
An example of a suspended work that has been modelled around three pipes. Work in progress by Antoine Berghs (The Netherlands).
(Photo: Anton Reijnders)



Figure 4.6
Supporting of a work during modelling. In this case three metal uprights are used to support two vertical pipes positioned in a V shape. The supports are stabilised by putting bags of clay at the base. Work in progress by Thom Puckey (England/The Netherlands).
(Photo: Anton Reijnders)

Temporary supports

Temporary supports used during building can render the use of ribs and possibly props unnecessary. Clay props can be used as **external supports** during making, drying and firing as well. **NB:** The clay props should dry at the same rate as the piece to ensure proper support. Placing two layers of newsprint between props and work will be sufficient to prevent them from sticking together. If a piece is fired up to vitrification, props should be dipped in silica sand to prevent the piece and props getting stuck and causing damage to the piece. A thin layer of plastic between the work and sand will prevent the sand from penetrating the wet surface and sticking to it. Temporary props may be necessary when a piece has, for example, a large opening. The prop will prevent the central part from deforming. To make it easier to remove the prop after firing it should be provided with a notch.

A **supporting form** made out of clay – in which a piece is made, dried and fired – could be used for creating work that would otherwise deform or collapse during making and firing. Such a support will be especially advantageous in the case of porcelain pieces. The supporting form is allowed to dry up to the leatherhard stage and should be treated with a bat wash (see *Table 11.1*) before the piece is started. This will prevent the porcelain and support from sintering onto each other.

Non-ceramic supports, such as wooden blocks, wooden slats, polystyrene (Styrofoam), balls of newsprint and/or foam rubber, can be used to support a piece during making. In cases where wooden blocks or slats are used, the work should be checked regularly to see whether the supports are hampering shrinkage; this will help prevent cracks occurring.

A more advanced method of temporary support is the use of an **adjustable support construction**, see *Figures 4.3* and *4.6*. Two or three vertical supports are connected with



Antoine Berghs (The Netherlands) *Time dancer*, 1998. H: 120 cm (47 in.). Ceramics and rope. This piece was made in suspension by using an adjustable support system. A base glaze containing zirconium silicate was used on top.
(Photo: Peer van der Kruis)

one or more metal pipes. These supports are stabilised with weights at the base. The pipes are not fixed to the supports, but are kept adjustable. The size and, particularly, the weight of the work will determine the weight of the construction and the number of pipes needed. The pipe or pipes are positioned at a height that will provide optimal support to the piece during building. The work is modelled around the metal pipes; the places of contact should be wrapped up to prevent them from drying out. Such a support will allow a good overview of the piece while building as large numbers of temporary supports will be unnecessary.

The adjustable support construction can also be used when **building a suspended work**, see *Figures 4.4* and *4.5*. This method is particularly suitable if one wants to build a piece from the middle section towards the outer parts. Again, the size and weight of the work will determine the weight of the construction and the number of pipes needed. The piece is built in several sections. The first section is started somewhere halfway and is built on a wooden board covered with two layers of plastic. The part resting on the plastic is kept wrapped up firmly during the entire building process of the section in order to keep it damp. The two vertical supports (stabilised with weights at the base) should be placed on opposite sides. The work is modelled around the metal pipes and kept wrapped up at places where the form will be extended. When the piece has gained enough stability (i.e. the area around the pipes has reached the leatherhard stage, or, if less weight is involved, the plastic-leatherhard stage) the wooden board can be removed allowing the work to be suspended. The modelling can then be continued outwards. If the bottom part of the first section has been kept damp, there should be no problem with joining a new layer of clay to it, provided the new layer has a similar consistency. This area is kept wrapped with thin plastic sheet to balance out the consistency. The pipes should be rotated regularly to prevent them from getting stuck in the piece. The area around the pipes should be kept wrapped up to prevent it from drying out. As soon as the bottom part acquires sufficient strength (leatherhard-brittle or dark stage) to carry the entire work, the pipes may be removed with a rotating movement. The holes are then filled with clay of the same consistency. This should be done with careful attention to ensure that the joints have proper adhesion, see section *4.9 Joining and mending* for more details about joining in relation to different drying stages.



Figure 4.7
A template made out of plywood is fixed to the wall in order to keep track on how the form evolves and to shape the form while revolving. Work in progress by Klaus Osterwald (Germany).
(Photo: Klaus Osterwald)

4.2 Throw-and-coil method

The throw-and-coil method can be used to obtain a continuous three-dimensional profile. The piece is shaped while the wheel is revolving very slowly. An electric potter's wheel is a very useful tool for this method. Using extruded coils (see section *4.4 Extruding*) will help to give even wall thickness. Keeping an eye on the building speed



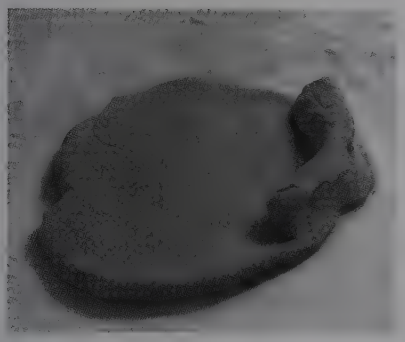
Klaus Osterwald (Germany), *Black Trumpet*, 2002. Ceramic and sound amplifier. L: 186 cm (73 in.). The throw-and-coil method using a template was used for this piece. During the making the wide bottom end was placed on a shrinkage slab. The outside was glazed with a shiny black high-lead base glaze. (Photo: Klaus Osterwald)

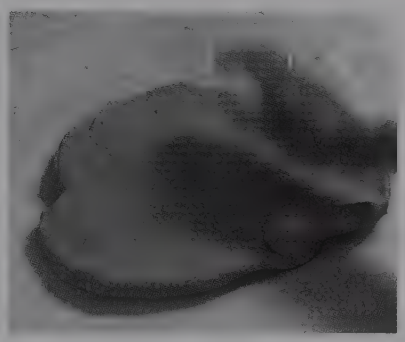
to maintain sufficient stability during making is also important for this method. Follow the instructions discussed under section *4.1.3 Providing stability during building*. A plywood **template** fixed to the wall can be useful, see *Figure 4.7*. The combination of template and revolving motion lends a specific non-organic quality to the piece. The clay body should contain slightly more water compared to previously mentioned methods of making to allow the piece to be shaped by the template. It is important that the wheel-head is level and as the size of the piece increases that the wheel is fastened to the floor.

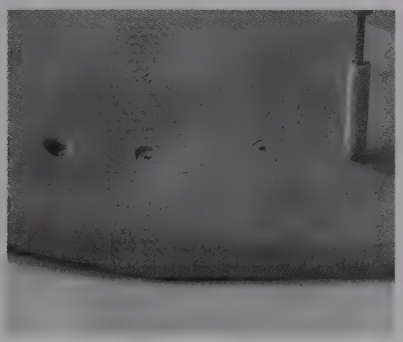
4.3 Slabs and tiles

As has been noted before, making a slab or tile needs extra care as tension is spread out more unevenly in a flat shape. This is more true as the size of the slab or tile increases. The following aspects are of importance:

- The right consistency to achieve proper adhesion (see section *2.6.5 Optimal consistency of a clay body*).
- A slab or tile is preferably made on cloth. Big folds should be avoided in order to prevent weak spots being formed, so make sure the cloth is smooth before starting.
- The slab or tile should preferably be made in one session.
- During making, the edges of parts that have not yet been finished should be kept covered with thin plastic sheet. This is especially necessary in the case of large pieces as the time between layer applications increases. Before adding a new layer these edges should be scored and made wet.







- The joins of layers of clay at the edge of the tile or slab should receive extra attention in terms of adhesion and compression; during drying and firing more tension build-up takes place in these areas.

LEFT:
Figure 4.8 a
The coil and slab are smoothed at the outer edge.

CENTRE:
Figure 4.8 b
The coil is then beaten onto the bottom part, causing it to expand outward.
(Photo: Anton Reijnders)

RIGHT:
Figure 4.9
By wrapping a nail or a needle tool with a piece of tape the thickness of the tile can be measured. The third hole from the left indicates the intended thickness.
(Photo: Anton Reijnders)

The following **method of making** ensures good internal adhesion and compression. A ball of clay weighing 1–2 kg (2–4 lb) is flattened with the palm of the hand or a rubber mallet to make a slab slightly thicker than the final slab: then the same amount of clay is rolled into a coil and placed on the first part (near the edge). Both are smoothed at the outer edge. The coil is then beaten onto the bottom part, causing it to expand outward, see *Figure 4.8 a–b*. By spreading out from the original slab, the slab or tile is constructed step-by-step. This procedure differs greatly from a commonly used method of pressing together lumps of clay and attaching them firmly at the top only. The bottom, and possibly the middle, of slabs made in this way will have poor adhesion as a result of this. There is an increased chance of cracks occurring, particularly in medium-sized or large slabs.

Checking thickness can be done by using a nail or a needle tool. Wrap a piece of tape around the tool at the point where the distance from the bottom edge of the tape to the point of the tool is the same as the desired thickness of the slab, see *Figure 4.9*.

NB: Turning the slab or tile over onto the other side after finishing will considerably reduce the chance of warping during drying, especially if a clay body other than a tile body has been used.

If the top of a slab or tile should be **levelled and smooth** a rolling pin could be used. Two pieces of wood (of appropriate thickness), positioned on either side of the slab, may be used as guides to level out the slab. For medium-sized slabs (30 x 30 cm/12 x 12 in. up to 60 x 60 cm/24 x 24 in.) a slab roller could be used. It is not recommended to flatten large lumps of clay with a slab roller in one go, as this will result in too much tension that could lead to drying cracks. The method of building described before yields the best results. The slab roller is mainly used to achieve a smooth surface.

In the case of **very large tiles** a rolling pin could be used as well but it is difficult to keep the tile levelled. Instead a metal L-profile and two pieces of wood (positioned at either side) can be used as guides. The metal profile is moved back and forth. Large slabs or tiles can be built on a strong, stiff cloth (canvas or jute). It is then possible to slide the slab (for more details see section *3.4.4 Foundation base for large tiles and slabs*).

To obtain **ultra-thin slabs** (for instance, thin porcelain slabs that should show distinct translucency) a slab of clay should be sealed on both sides with thin plastic sheet and rolled to a very thin gauge using a rolling pin. To minimise breakage, the plastic sheet is left in place and allowed to burn away during firing.



Figure 4.10
A hand-operated extruder.
(Photo: Anton Reijnders)

4.4 Extruding

A plastic clay body can be forced through a die to obtain coils, flat ribbon shapes and hollow round or square tubes. A simple hand-operated extruder (see *Figure 4.10*) could be used. By altering the die at the end of the chamber the shape, dimension and wall thickness can be altered. As uniformity in thickness and surface structure is linked to extrusion, a more industrial quality can be obtained. But freshly extruded pieces can easily be reshaped during handling. This allows a combination of organic and mechanical quality. If porcelain is used, the interior system should preferably be made of non-corrosive metal, or the interior should be totally cleaned before and immediately after extruding to avoid rust stains. Extrusion is a very useful method for making sections that can be used to construct a piece or to create repetitive elements. More advanced electric extruders could be used. Electric extruders can be equipped with a de-airing system. Such a system is used if high quality extrusion is aimed for, but is not suited for extruding coils that are to be used for coiling or elements that are used for constructing a piece. De-airing results in too much tension within the piece.

4.5 Modelling a solid piece

As pointed out before, modelling a solid piece by adding and taking away clay over the entire shape gives a freedom and a possibility of a rapid way of working. Two conditions are important: the piece should be prevented from drying until the modelling has been finished, and the form should be stable enough to carry added weight. If the piece is not stable by itself, ways of supporting as described in *Temporary supports* under section *4.1.3 Providing stability during building* or a method that will be described in section *4.6 Building around a core* could be used. As has been pointed out, a clay body with an open structure is preferred.

The piece can be begun by throwing balls of clay with reasonable force on top of each other, then forcing them together into a mound by beating with flat hands. This will create a stable mass with good mutual adhesion and reduces the chance of large air pockets occurring. This is more important as the work and final wall thickness increases in size. To prevent the surface from drying it can be sprayed from time to time with a plant spray. **NB:** Do not spray too much water as it will run down and make the piece too wet on the bottom. Also partial wrapping of the piece with thin plastic sheet could be necessary in order to secure good adhesion between the old and new layers.

Maja Spacova (Sweden), *4000 Feathers*, 2001, (work in progress). Ht (of feathers): 9 cm–18 cm (3½–7 in.), surface area 46–100m² (495–1076 sq.ft). A piece consisting of very thin feather-shaped porcelain slabs. The slabs were made by rolling porcelain between two layers of thin plastic sheet using a rolling pin. They were fired in oxidation up to full vitrification to achieve translucency.
(Photo: Corné Bastiaansen)





Trees De Mits (Belgium), *Sensory* (detail of installation), 1998. In this installation a combination of materials such as rubber, latex rubber, hair, plastic tubes and ceramics was used. Pounding, pulling and beating solid lumps of porcelain clay, created the organic ceramic shapes. The surfaces were treated with either transparent shiny glazes, a silky matt black glaze or terra sigillata; others remained unglazed.
(Photo: Peer van der Kruis)

Pounding, pulling and beating of solid lumps of clay are also interesting ways to begin pieces as these methods lend their own specific qualities to the final piece.

A pre-packed clay body or clay body mixed in a de-airing pug mill needs extra treatment as the clay particles lie in a spiral direction that could lead to tension within the piece. The extruded clay body should be cut into slices of about 0.5 kg (1 lb) each and these slices are then cut again. The slices are put back together with a medium force in another position than previously and compressed to a ball by tapping. This will break the spiral direction of the clay particles.

4.5.1 Hollowing out

Depending on the stability of the form and the clay body used, hollowing out could be started just after the plastic-stiff or within the plastic-leatherhard stage. If the work has dried out beyond the plastic-leatherhard stage, hollowing out is more laborious. When



Anish Kapoor (India/England), untitled, 1994. Ht: 53 cm (20½ in.). A combination of solid modelled and thrown elements (middle and to the right). The pieces were hollowed out from underneath. Partially glazed with a cadmium red glaze.
(Photo: Peer van der Kruis)

a clay body containing **flax fibres** is used, hollowing out should start during the plastic-stiff stage, otherwise it will become very difficult. A flat-based piece can be hollowed out from underneath or cut into sections (using a cutting wire, see *Figure 4.11*), hollowed out and assembled again (see section *4.9 Joining and mending*). A small piece can be tipped over if it is to be hollowed out from underneath; put it on a thick piece of foam and support it so as to minimise deformation and to stop it rolling away.

Middle-sized or **larger pieces** could be hollowed out from underneath in the position they were made. When a large piece has been modelled on top of a bed of metal bars (see section *3.3.4 Foundation base for large solid pieces*) at the plastic-leatherhard stage the piece sitting on top of the bars is lifted with a fork lift to a convenient height and the bars are (re)moved alternately so that the piece can gradually be hollowed out from underneath.

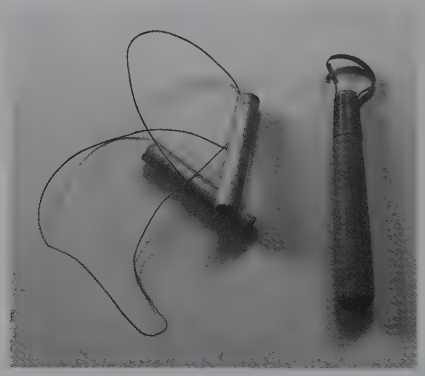


Figure 4.11
A cutting wire is used to slice open a form when it is in a plastic to plastic-leatherhard stage. The loop tool is used for hollowing out.
(Photo: Anton Reijnders)

A flat-based work is provided with a flange during the process of hollowing out (see *Figure 5.4*). For hollowing out, a loop tool may be used (see *Figure 4.11*). The work should be hollowed out to have walls of a specific and even thickness. As a general rule of thumb: the wall should not exceed 1.5 cm (⅝ in.) if a dense clay body with fine structure is used, and not more than 3.5 cm (1⅜ in.) with a body having an open structure. Hollowing out requires some experience. **Wooden cocktail sticks** can be used as guides to help arrive at wall thickness. The desired thickness is marked onto the sticks and they are pushed into the piece at well-chosen spots. Afterwards they are removed and the holes can be filled from the outside.

Flax fibres, more precisely **flax skeins**, not dispersed fully as fine cellulose fibres will hamper the hollowing out process considerably: they will get entangled around the loop tool. Therefore a prolonged mixing during preparation of the clay body is necessary. Provided the flax fibres are thoroughly mixed, hollowing out can be done without great difficulty at the plastic-stiff stage. Beyond this stage hollowing out will become more difficult.

Air can easily be trapped during the making of a solid piece. This could lead to pressure build-up during the first stage of firing (see *Pressure build-up during the water smoking stage* under section *7.3.1 What determines the way of firing biscuit?*). In order to minimise this risk the work can be riddled from the inside with holes reaching to about 1 cm (⅜ in.) from the outside (so they cannot be seen) after the hollowing out is finished.

4.6 Building around a core

If there is a clear idea about the final dimensions of a piece then it can be built around a core. The core is made out of a flexible material in order to be able to be compressed during drying shrinkage and will be approximately the shape of the final piece, minus the intended wall thickness. Alternatively, a combination of a core and a temporary support system (as described previously) can be used.

4.6.1 A core of clay

A core of clay acting as a former or stabiliser inside the piece during building provides the possibility to work vigorously (as compared to other flexible materials). It is not necessary to use the same clay body as for the intended piece (a clay body without flax fibres will make the scooping out of the core much easier). One or two layers of **coarsely woven (jute) fabric** are added on to the surface of the clay core (see section *5.2.4 Other materials* for more information about jute). The fabric is pounded into the wet clay in order to let it stick. On top of this the outer layer is modelled, see section *4.3 Slabs and tiles* for a way of working that gives good adhesion of the layers while modelling. The layer(s) of fabric will prevent the outer layer sticking to the inner core. **NB:** Prevent large folds or loose threads of the fabric getting stuck in the outer layer.

The core is removed after the piece has gained sufficient firmness (plastic-leather-hard to leatherhard stage). If the weight and size of the piece allows it, it is put on a thick piece of foam and supported in such a way as to minimise deformation and rolling. The piece can be cut open slantwise at the bottom part and the fabric layer(s) cut away with a sharp knife. Next the core is removed by using a loop tool. Removing the last part of the core can be done by pulling the fabric. The cut out piece can be fitted back together afterwards. See section *4.7.1 Joining segments* for a way of doing this. **NB:** A small hole should be made in the piece to avoid air being trapped inside.

A core of clay, jute and an **armature** can be used for pieces that cannot stand by themselves. A metal pin is firmly attached to a (wooden) base. A pipe that fits around this pin has several iron rods and pieces of wood attached to it. The clay body is added in such a way that pieces of wood are spread uniformly throughout the core resulting in a stable setting, see *Figure 4.12*. Jute is attached to the core as indicated previously. Once the piece is finished and sufficiently firm, the pipe is removed from the armature.



Figure 4.12
Using a core of clay and an armature. The clay body is kept in position by iron rods and pieces of wood attached to the armature. Two layers of jute attached to the core will make it possible to remove the core more easily.
(Image: Anton Reijnders)

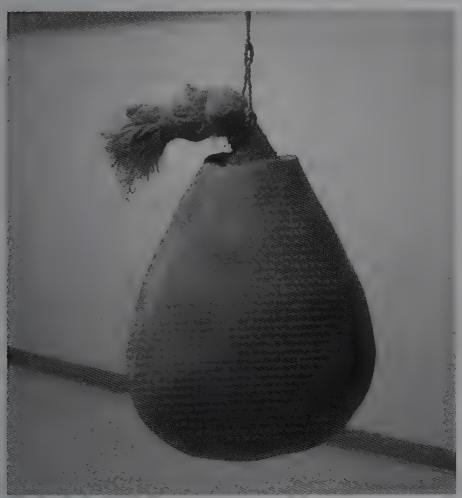




Figure 4.13 a–b
Jute has been wrapped around a core of clay and firmly fixed on a rope. A layer of clay has then been modelled around this. Having the piece suspended in this way makes it easy to alter the shape as required. Work in progress by Ted Noten (The Netherlands).
(Photos: Ted Noten)



Ewen Henderson (England), *Crocomeg*, 1991. Ceramics and steel. Ht:106 cm (41 in.). Slabs made from different-coloured clays were stained with å variety of stains and engobes pressed onto the wet surface. These slabs were modelled around a core of newsprint using temporary supports to give sufficient stability during making. (Photo: Peer van der Kruis)

Hollowing out is done as described previously. A larger piece could be kept positioned around the armature and cut in sections of a manageable size. The sections are removed from the core (at the leatherhard stage) in order to rejoin them again. Another option is to suspend the core by hanging it on a rope and model the clay around it. With this method the layers of fabric around the clay core are firmly fixed to the rope, see *Figures 4.13 a–b*.

4.6.2 A core of other materials

A core of **foam rubber, polystyrene,** or **balls of newsprint** can be used as well. All these materials have to be removed before firing (to prevent the formation of toxic fumes and to reduce the chance of possible pin-holing, especially if white glazes are used, see section *11.5.3 Glaze faults related to viscosity and surface tension*). How the core will be removed has to be taken into account from the start. Polystyrene sheets should be divided in such a way that they can be removed by sliding (wrapping the sheets positioned in the middle in thin plastic will make sliding easier. Balls of newspaper can be wrapped in tape and/or put in a textile bag; the shape of this bag should correspond largely to the inner form. In general, foam rubber is easy to remove. Once the piece has become firm the core can be removed as described in section *4.6.1 A core of clay*.

More organic shaped **clay tubes** could be made by adding the clay body around a pipe or broomstick. In this case, the pipe or stick is wrapped in newsprint first and the newsprint is taped (paper to paper) in order to be able to remove the pipe. One end of the pipe should be kept free in order to be able to pull it out. This is done after it has reached the plastic-stiff stage and before it reaches the leatherhard stage.

4.7 Multi-segmented pieces

Building a piece out of pre-shaped segments is also an interesting option. An (open) structure can be built by using slabs, coils, pipes and other pre-shaped segments. Each segment can be made according to any of the methods described in the previous sections or by using a mould. The segments are allowed to gain firmness; ranging from plastic-stiff (to give a more organic quality) to leatherhard (to give a neater, more finished quality). If necessary the sections are cut to the right size before joining. To build a multi-segmented piece the same approach is followed as for building a hollow work: the lower part should be allowed to dry to gain firmness before new segments are added and the area of the surfaces to be joined should be as large as possible to aid adhesion. **NB:** An open structure is preferably built, dried and fired on a shrinkage slab.

4.7.1 Joining segments

When segments are allowed to gain more stability before they are joined, the surfaces to be joined will need attention. An adhesive slip (see *Table 4.1*) is applied at the place of contact if the segments have reached the plastic-leatherhard stage (before this stage wetting down the point of contact will be sufficient). To increase the adhering surface area the edges to be joined will need to be cut slantwise. Before adding the adhesive slip, score the point of contact and moisten it with water. The segments should be pushed together thoroughly by moving them against each other until 'suction' bonds them together. To achieve a very good bond (especially important for joining larger segments), use the point of a knife, or a finger tip and push reasonably deeply into the clay until the edges are welded together. To make the seam invisible it is pressed over its entire length with, for instance, the handle of a brush. The resulting groove is filled

Table 4.1

Adhesive slip/Filling material

Powdered clay body	*Paper pulp[1] (1:15)*	*Dolapix PC 67 or Darvan 7 (or 811)[2]*	*Water*
100 g	+ 10 g[3]	+ 0.3–0.5 g	For joining and mending add water until consistency of yoghurt For filling cracks add water until consistency of stiff paste

Notes:

[1] A pulp made of 1:15 paper:water weight ratio.

[2] See section 8.8.1 Glaze additives *for more about polyacrylate type of deflocculants. 0.2 g–0.3 g of sodium silicate (water-glass) can be used instead.*

[3] Reduce this amount by half if cellulose fibres are already present in the clay body.

Mending and filling after the leatherhard stage should only be undertaken to hide cracks as achieving structural strength of the work may be more difficult at this stage.

with clay of similar consistency. See *Figure 5.24*. The seams are then covered with thin plastic film to allow safe drying.

4.8 Finishing and smoothing

Sharp ridges at the bottom of the piece should be removed if chipping the piece during handling (before and after firing) is to be avoided. Cutting away the bottom edge slantwise for a few millimetres will reduce the chance of chipping.

If a **smooth surface** is desired a so-called kidney is used (see *Figure 4.14*). To prevent staining use a stainless steel, rubber or wooden kidney (avoid iron or brass tools as they can leave a colour stain on the clay). Smoothing should start at the plastic-stiff stage and should be finished before the leatherhard stage has been reached. Starting earlier or waiting longer does not lead to good results. For this reason, finishing off at the lower end of the piece should often be started while the piece is still being built. At the plastic-stiff stage the surface is combed with a toothed kidney followed by smoothing with a straight kidney by brushing it over the surface at a slight angle. Holes and cavities are best filled with the remaining scrapings. If a very smooth result is desired, the surface should be treated again during the plastic-leatherhard stage. Here the kidney is held at a flatter angle while brushing over the surface.



Figure 4.14
Three different kinds of kidneys. The top two are made from stainless steel. The bottom one is made out of rubber. The middle kidney is used to comb.
(Photo: Anton Reijnders)

4.9 Joining and mending

To obtain a strong join a different method has to be implemented for each drying stage. *Table 4.2* provides an overview of all drying stages and the related actions. The area of adhesion should be covered with a strip of thin plastic sheet in order to allow the water content within to homogenise. **NB:** Joining at a stage beyond leatherhard needs great care, the joints could be less reliable.

4.9.1 Adhesive slip

Basically an adhesive slip is made up of the same clay body as the work itself,[3] paper



Jan Goossen (The Netherlands), untitled, 1995. Ht: 130 cm (51 in.). Extruded pipes made of a coarse-grained terracotta sculpture body. The pipes were allowed to dry to the plastic-leatherhard stage before joining. A sinter engobe with iron oxide was applied on the surface.
(Photo: Peer van der Kruis)

fibres and a deflocculant. **Paper fibres** are added to increase adhesion; a deflocculant to minimise the water content and so the shrinkage of the slip.

To obtain an adhesive slip the clay body is dried first and crumbled to a powder. Next the paper pulp is made. Ordinary toilet paper is ideal to obtain a homogeneous pulp within a short time. The toilet paper is added to water in a 1:15 ratio and blended with a (hand) blender. The pulp is mixed into the dried clay body. A fork can be used for mixing. Then a deflocculant such as Dolapix PC 67 or Darvan 7 (or 811) is added. More water is added until the right consistency is reached as indicated in *Table 4.1*. **NB:** Prevent the adhesive slip from drying out while working.

4.9.2 Mending (broken) parts and filling cracks

The adhesive slip can also be used for mending (broken) parts and filling cracks of an unfired piece. If a coarse clay body is used (grains larger than 0.425 mm) the dry clay powder should be sieved first (36's sieve) before the slip is prepared. See *Table 4.2* for an overview of all drying stages and the related actions.

Before the mending or filling starts the surface for joining, or the crack, is dampened slightly with the tip of a wet brush; the capillary force of the clay will cause the water to be sucked into the surface or into the crack. This will provide a better adhesion to the adhesive slip/filling material. In the case of cracks, the filling material is pushed into the crack as deep as possible with the point of a pointed knife. The clay around the crack is mixed with the adhesive slip by making weaving movements and



Ted Noten (The Netherlands), *Ring thief*, 2001. L: 60 cm (23½ in.). A terracotta sculpture body was added on top of a core of clay wrapped in two layers of jute. A rope was attached to the jute in order to be able to suspend the piece in the air. Visitors were allowed to use it as a boxing-bag. The biscuit fired surface was treated with a terra sigillata made from terracotta clay allowing all imprints to remain visible.
(Photo: Jan Sprij)

Table 4.2

Joining, mending and filling actions

Drying stages	*Characteristics*	*Joining layers of clay*	*Joining sections*	*Mending broken parts*	*Filling cracks*
Plastic stage	The surface of the piece feels sticky and can easily be dented with a fingertip.	No specific action needed.	Add water at places of contact.		
Plastic-stiff stage	The surface of the piece can still be dented with a fingertip, but does not feel sticky.	Add water at places of contact.			
Plastic-leather-hard	The surface of the piece cannot be easily dented with a finger tip. A mark can be made without any force with a fingernail.	Score and add water and adhesive slip at places of contact.	Score and add water and adhesive slip at places of contact.		Wet down the crack with the point of a brush. Push adhesive slip into crack with pointed knife. Weave clay body on both sides of crack with point of knife. Fill the gap with adhesive slip the consistency of a thick paste.
Leatherhard	Light pressure is needed to make a mark with a fingernail.				
Leatherhard-brittle*	Only with extra pressure is it possible to make a mark with a fingernail. A line drawn by a fingernail will show clear edges.		Score, add water, score again, add water again and add adhesive slip at places of contact.		
Dark stage*	A line drawn with a fingernail gives crumbly edges and clay dust occurs.				
Cold stage*	A colour change takes place. The clay feels cold.				
Dry stage*	The clay has the temperature of its environment.				

Note:

* *Mending and filling after the leatherhard stage should only be undertaken to hide cracks as achieving structural strength of the work may be more difficult at this stage.*

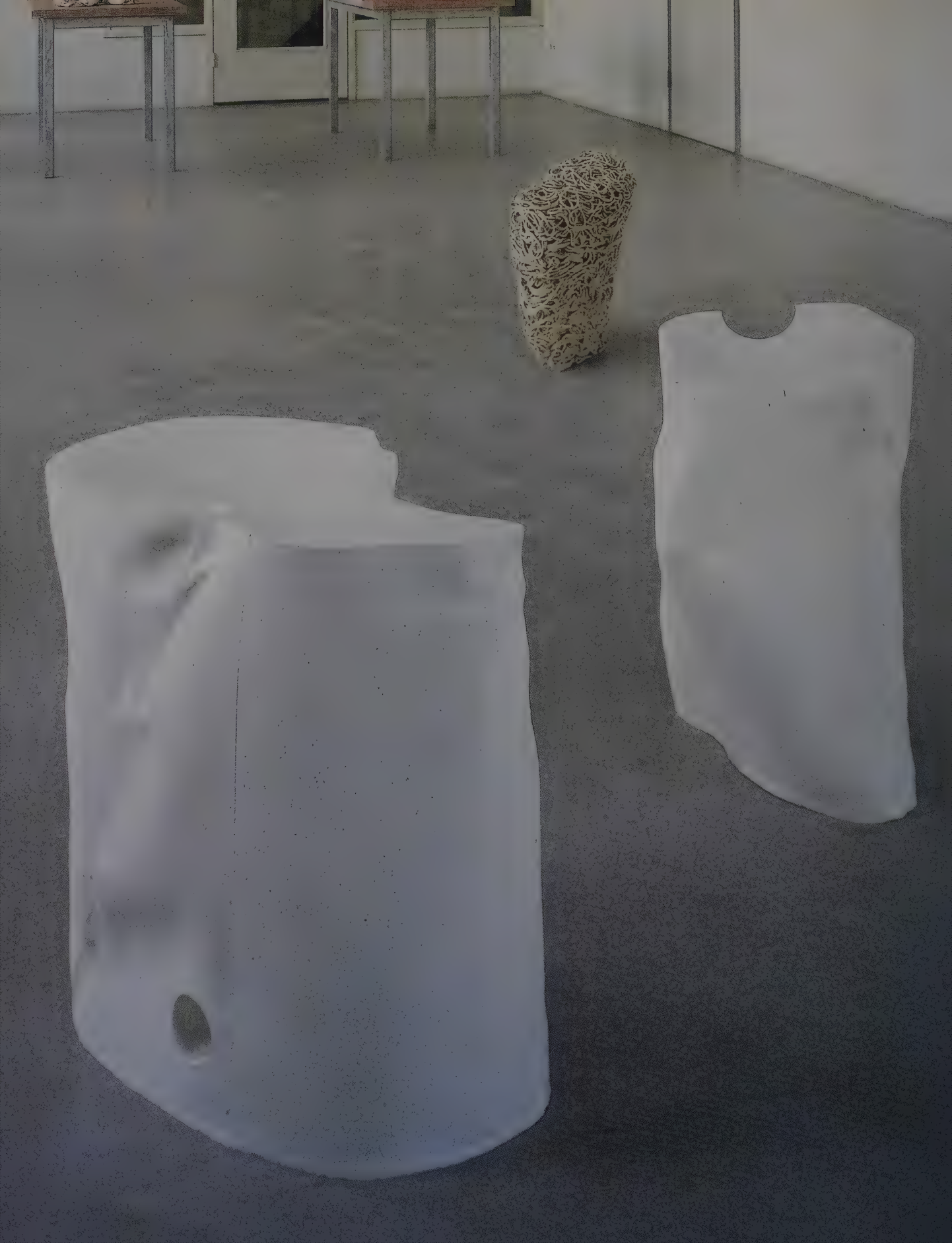
pushing the knife reasonably deeply into the clay. The seam is then pressed over its entire length with, for instance, the handle of a brush. The resulting groove is filled with several layers of the filling material until it protrudes. In order to allow the water content to homogenise the area of mending should be covered with a strip of thin plastic sheet. After the filled area has reached the same drying stage as the surrounding area the protruding part is removed.

Notes:

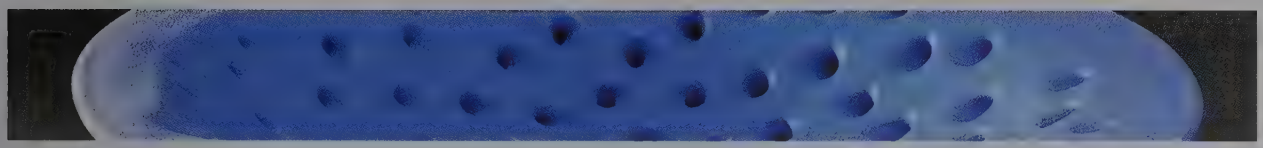
1 It is better not to use vacuum extruded coils pressed out of a de-airing pug mill. Experience has shown that extra tension within the piece arises, causing the piece to crack during firing.

2 A flange also makes it possible to hang a piece on a wall safely.

3 Although for visual impact, another coloured clay body could be used.



5 Using moulds



Moulds are often used for making ceramic forms. Many of these objects that we use in our daily lives are mass-produced using reproduction techniques such as casting or advanced hydraulic press systems. Furthermore, sculptural pieces can be made with the casting or press-moulding technique. This chapter focuses on casting, press-moulding and plemping techniques – all of which are very well suited for a studio situation.
The characteristics of different mould types and their suitability for a specific technique are discussed in the first section.This will help with making an informed choice of the most suitable mould type or mould system in relation to the intended outcome. Then descriptions are given of a range of materials and the way these materials are used for mould and model making. After this the making of a mould is addressed, and the final sections give more detailed techniques for the processes of casting, press-moulding and plemping.

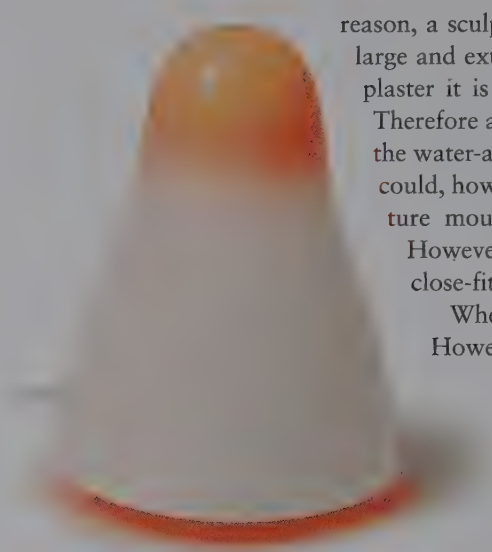
5.1 Moulds and mould systems

There are two main types of plaster moulds: the casting mould; and a piece mould, in this book referred to as a sculpture mould. The need for a specific reproduction technique determines which type of mould is best used, but also the size of the object and the degree of perfection required are determining factors. Generally speaking, slipcasting is best done in a casting mould: the best detail can be achieved. For press-moulding or plemping, a sculpture mould is very suited especially if medium-sized up to extra large pieces are to be made. A sculpture mould could be used for casting medium-sized or medium-large-sized pieces provided certain requirements are met. A mould can be equipped with a plug to facilitate the draining of the casting slip or with an air pressure system to facilitate the release of the form out of the mould.

A **casting mould** is made by pouring plaster into the space between a model (the original) and a retaining wall or cottle (coddle in American texts). Due to the fact that the plaster has been poured, a mould with high perfection and good water-absorbing properties can be achieved. Therefore a casting mould is very suited for **slipcasting**. A disadvantage is its weight: the outer form of the mould usually deviates a lot from the inner form resulting in extra volume. This, added to the fact that the mould has to be filled totally with casting slip, means that a casting mould is best suited for casting small to medium-sized work.

A **sculpture mould** is constructed by throwing or flicking layers of plaster onto the model by hand. One of the great advantages of a sculpture mould is that it can be a lightweight construction. It encases the form; no extra plaster is needed. For this

OPPOSITE:
Carlito Carvalhosa (Brazil), No title, 2000. Ht: max. 70 cm (27½ in.). The two front pieces were made from porcelain. They were made in a sculpture mould by using the plemping technique. To arrive at the cylindrical cavity at the lower end of the first piece a mould section provided with an air pressure system was used. On top a terra sigillata of porcelain and talc was applied by brush. The terra sigillata was burnished. Fired only to 1180°C (2156°F) a white silky marble finish was achieved.
The piece at the back was made by filling a mould with extruded coils. It was fired to 1220°C (2228°F).
(Photo: Peer van der Kruis)



Arjan Brekveld (The Netherlands), untitled, 1998. Ht: 15 cm (6 in.). Cast porcelain. A combination of good head resistance and translucency allowed these forms to be placed on top of a light bulb, creating a subtle play of light. (Photo: Peer van der Kruis)

reason, a sculpture mould is often used for medium-sized work, and it is a must for large and extra large work. Because the mould is made by slapping on and flicking plaster it is more difficult to achieve good and even water-absorbing properties. Therefore a sculpture mould is mostly used for press-moulding or plemping, where the water-absorbing properties of the mould are less important. A sculpture mould could, however, be used for slipcasting. Due to its lightweight construction a sculpture mould is specially suited for casting medium and medium-large work. However, it is important to achieve a high and even water-absorption as well as close-fitting mould sections.

When casting, the excess slip is usually poured out by tilting the mould. However, due to the great weight of both mould and casting slip, this is a tricky job when dealing with medium-large work. In this case, to facilitate the draining of surplus slip a section of a casting mould can be fitted with a **draining system**: a plaster plug or PVC pipe at the bottom. The pipe can also be equipped with a valve to control the speed of the flow. In large work, a drainage system also allows a slight increase in wall thickness towards the bottom by draining the slip more slowly. This becomes more beneficial as the work increases in height: it adds stability to the base without increasing the overall weight too much, and also reduces the chance of deformation. The consequence of a draining system is that a hole is created in the bottom of the cast object. This can sometimes be closed with a special provision, see *Fitting a drainage system* under section *5.5.3 Casting moulds for medium-sized work*.

Before a form can be taken out of the mould, it must have gained sufficient firmness. For this to happen the form needs to dry in the mould until it reaches this stage. However, drying means shrinkage. For this reason, the form is usually constructed in such a way that it can shrink in the mould without becoming jammed. This sets limits on the complexity of the form. An **air pressure system** is used in places where forms or parts of forms are difficult to remove from the mould. This is a practice derived from industrial mass production (Ram press systems) and is regularly used at the EKWC. With this system a form that would otherwise get jammed can be removed from the mould.[1] In other words, the air pressure system expands the possibilities of the reproduction technique. The air pressure system consists of a porous hose that is cast into a mould section. By connecting the hose to a compressor, air is pumped into the wall of the mould. The air pressure forces away the water present in the wall of the mould, creating a thin film of water between the work and the mould; as a result the form is pushed loose from the mould.

NB: Implementing an air pressure system in a sculpture mould can only be done by including a mould section that has been cast.[2] The air pressure system uses a specifically designed porous hose made from woven synthetic fibres – see Appendix 4 for suppliers.



Pieter Geraerdts (The Netherlands), untitled, 1995. Dia: 56 cm (21¾ in.). A galvanised wash tub was used as a mould and eventually formed an intrinsic part of the piece. A terracotta sculpture body was press-moulded in the bin. Collection: MEO, Budapest, Hungary. (Photo: Peer van der Kruis)

Table 5.1

Characteristics of the reproduction techniques

	Press-moulding technique	*Plemping technique*	*Casting technique*
Suitability of the reproduction technique related to size	Up to and including extra large work	Up to and including extra large work	Up to medium-sized work with a casting mould and up to and including medium-large work with a sculpture mould provided with a drainage system
Structure of the clay body	Coarse to fine	Fine to very fine	Very fine
Detail	Moderate detail	Fair amount of detail	Highly detailed
Finishing[1]	Might require a great deal of finishing	Might require some finishing	Does not require much finishing (in principle, only seam lines and spare)
Type of mould	Sculpture mould or possibly casting mould	Sculpture mould or possibly casting mould	Casting mould or sculpture mould provided that the water-absorbing properties are sufficient
Drainage system	No	No	Can be used for medium-sized work
Air pressure system	Use in parts of the mould if the form is difficult to remove	Use in parts of the mould if the form is difficult to remove	Use in parts of the mould if the form is difficult to remove
Required water-absorbing properties of the mould	No water-absorbing properties to reasonable water-absorbing properties	Moderate water-absorbing properties	Good water-absorbing properties

Note:

[1] *Much will depend on the skill and experience of the maker and the precision of the mould.*

To a certain extent, **moulds made of materials other than plaster** can be used for press-moulding and casting. For press-moulding, a mould may be made of wood (plywood), rubber or polyester. Existing objects may also be used if there are no undercuts (it must be possible to take the form out of the mould without damage caused by parts getting caught in the mould). It is relatively easy to make straight rectangular pieces of larger size by using a mould made of plywood. A silicon mould has the advantage that its flexibility allows the reproduction of forms that would be difficult to remove from rigid moulds. Casting very thin (porcelain) slabs can be done on kiln shelves (which are rather porous).

Table 5.1 can serve as a guide to help choose the most suitable reproduction technique appropriate to the specifics of the final work and the type of mould.

5.2 Materials for moulds and model making

This section describes the most important materials required for making a (plaster) mould and the way they are used. As many aspects are involved, a summary of the main points is given in *Tables 5.4–5.6*.

5.2.1 Plaster

Plaster is made of the mineral gypsum, which consists almost entirely of hydrated calcium sulphate crystals ($CaSO_4 . 2H_2O$). This gypsum undergoes various treatments, both thermal and grinding. Part of the water inside the gypsum crystal evaporates through heating. The chemical process of the preparation of pottery plaster is as follows:

$$CaSO_4.2H_2O \underset{\longleftarrow}{\overset{100°C–120°C}{\longrightarrow}} CaSO_4.\tfrac{1}{2}\,H_2O + 1\tfrac{1}{2}\,H_2O$$

This reaction of dehydrated calcium sulphate into semi-hydrated calcium sulphate takes energy. As the arrows in the chemical formula indicate, the dehydration process is a reversible reaction. This means that the semi-hydrated calcium sulphate is active. Mixed with water, a reaction takes place in the opposite direction: energy is released, **crystallisation** takes place and plaster heats up. During the crystallisation the crystals grow and expansion takes place. This expansion is caused by the chaotic growth in all directions of the gypsum crystals. Once the plaster has cooled down, the main part of the crystallisation and expansion process has taken place.[3] The extent of the expansion is different for each type of plaster and depends on the plaster:water ratio; an expansion of about 0.3% can be taken as a rough average.

Three aspects have to be considered when dealing with plaster: the working life of the plaster, the required water-absorbing capacity and the strength of the final mould. Modern types of plaster specially composed for making good-quality casting moulds combine these three aspects and can be used for making both models and moulds. The best **water-absorbing properties** and **strength** are obtained by following the plaster:water ratio indicated by the manufacturer of the plaster (if not stated otherwise the term plaster in this chapter refers to pottery plaster). However, the way the plaster is prepared and stored will also influence these aspects.

Working life

Freshly-mixed plaster is very fluid. The viscosity gradually increases until, minutes after being stirred, it can no longer be spread or poured: the plaster has set. Its working life depends on a number of factors, such as, the water:plaster ratio, the temperature of the water and the speed of mixing. During the preparation of the plaster it is important to use clean buckets, clean water and clean tools. If dry leftover plaster falls into the fresh mix the crystallisation process becomes accelerated and the setting time is reduced, resulting in a shortening of the working life. Cold water increases working life. Luke warm water reduces working life. Vigorous mixing will reduce working life. When making large moulds, especially sculpture moulds, working life is an important factor, because within a limited amount of time a number of actions need to be performed while the plaster is workable.

Quality and strength of the mould

If more than the recommended amount of water is used the mould will have greater water-absorbing properties, but at the same time, its strength will decrease because the gypsum crystals will have a less compact structure. In relation to the casting technique: if dry lumps of leftover plaster fall into the fresh mix and end up on the surface of the mould the chance of air holes being formed in the cast piece increases. These holes could become visible as pin-holes after glazing (see section *11.5.3 Glaze faults related to viscosity and surface tension*).



Wieki Somers (The Netherlands), *Mattress Stone Bottle*, 2001. Ht: 46 cm (18 in.) and 24 cm (9 in.). The original cast for this form was made by pouring plaster into large heavy-duty balloons wrapped in fishing net. The top part of a buoy was used as a model for the lids. They were cast in porcelain and fired to high biscuit and glaze fired to a low temperature. The piece on the left was glaze fired with a matt glaze containing a small amount of pink pigment. A ready-made onglaze decal was added after in a third firing. A transparent shiny glaze was applied to the piece on the right. (Photo: Corné Bastiaansen)

Preparing plaster

When preparing plaster, the following old rule of thumb can be applied:

- Sprinkle the plaster powder into water within one minute
- Leave for one minute (allowing the water to be absorbed by the gypsum crystals), then
- Mix for one minute gently to remove lumps and air bubbles.

Lumps and air bubbles will cause the mould to have uneven water-absorbing properties. Often lumps cannot be removed entirely through mixing. To ensure that all the lumps have been removed, it is best to pour the mixed plaster through a 30's sieve (0.6 mm) or kitchen sieve. A rough indication of working life: about 15 to 20 minutes after mixing. Generally, the plaster should be poured within 10 minutes, and used between 10 and 20 minutes after the plaster is mixed.

Storage

Plaster powder is hygroscopic (it attracts moisture) therefore it must be stored dry. Plaster stored in damp conditions may crystallise over time and become unusable. Long storage – especially in damp environments – affects both the strength and water-absorbing properties of the final mould. Keep stocks limited. Even unopened bags show a noticeable deterioration within a few weeks; open bags within days.

NB: Plaster powder, being highly water absorbent (hygroscopic), is harmful when inhaled. The mucus membranes can become dehydrated leading, with frequent inhalation, to chronic sinusitis. It is strongly recommended that a dust mask is worn during the preparation of plaster. Good ventilation in a workplace where plaster powder is frequently used is also important. The skin will become dry too. If plaster powder or



Ineke Hans (The Netherlands), Coffee-pot and cups (part of a modular black porcelain collection called *Black Gold)*, 2002. Ht: approx. 30 cm (12 in.). Cast porcelain stained with a black pigment. Handles and spout were cast separately and attached at the leatherhard stage. Unglazed.
Collection: Museum Boymans-van Beuningen, Rotterdam and Stedelijk Museum, Amsterdam, The Netherlands.
(Photo: Corné Bastiaansen)

mixed plaster gets in one's eyes it is essential to rinse thoroughly at once with water. Take care of your back also; make sure the mould sections do not get too heavy.

5.2.2 Clay

Clay can be used for making a model. An advantage of using clay is that it is relatively easy to make a model that is complex and rich in detail. A disadvantage is that it is less suited for making a very precise mould. This is due to shrinkage and to the fact that a clay model is more-easily damaged during the making of a mould. If details or a smooth finish are desired, it is best to use a clay body with a fine to very fine grain size structure: for instance, throwing clay with a grog size not exceeding 0.2 mm.

A clay body is also frequently used for building partition walls if the walls are not in a straight line (see *Figure 5.15*). It can be used as a base for embedding a model especially if the model has great detail or a complex shape.

NB: It is strongly advised to keep a clay body used for making moulds separate from other clay: clay contaminated with pieces of plaster can cause lime blowouts. For more information, see section *11.5.4 Other faults*.

5.2.3 Sealing agents

A sealing agent is mainly used on a model to prevent it from absorbing water from the plaster during the mould-making process, which would cause a less-absorbent layer on the surface of the mould. A sealing agent fills the pores, creating a layer on the surface that cannot be permeated by water. The choice of sealing agent is determined by the material from which the model is constructed and the desired quality/detail of the cast.

Sealing agent for plaster models

A model made of plaster has strong water-absorbing properties, therefore the use of a sealing agent is indispensable. A shellac/alcohol mixture; a soap/clay slip; or a soap mixture can all be used as sealing agents.

For a very precise cast, preserving as much detail as possible, a ***shellac/alcohol mixture*** is used. A ratio of 100 g shellac to 400 g ethyl alcohol produces a mixture that can be kept in stock.[4] The alcohol percentage of ethyl alcohol should be 98% or higher (lower concentrations limit shelf life). Before applying, methylated spirits is added: the ratio is 1 part shellac mixture to 1 part methylated spirits (with an alcohol percentage of 85%). This mixture has the property of being able to be absorbed entirely into the surface pores; nothing is left on the surface, as a result, optimal detail can be achieved. **NB:** This is accomplished only if the plaster model is fully dry. Two applications of the mixture should be rubbed into the surface with a supple brush. For a third layer, the mixture should be diluted again with methylated spirits and rubbed into the surface with a soft piece of cloth.

The surface gloss of a treated model indicates if the proper layer thickness has been applied. If the layer is too thin the surface will remain dull; if it has been applied too thickly the surface will have a high gloss. In the latter case, to get a satisfactory result, this layer will have to be completely removed using a soft piece of cloth dipped in methylated spirits (85%), after which a new layer can be brushed on with a more diluted shellac mixture. After the shellac/alcohol mixture a parting agent should be applied, see section *5.2.4 Parting agents*. A natural soap such as green soap or block soap can be used as a sealing agent on a plaster model or a model made of clay that has been dried beyond the leatherhard stage.[5] **NB:** No liquid soap of synthetic origin should be used. Synthetic soap dissolves more-readily in water during crystallisation of the plaster. Once dissolved it will react with the gypsum crystals, stopping crystallisation and causing a loose powdery layer to form. **Green soap** is a natural soap product with a jelly-like consistency. Olive oil used to be its basic ingredient, nowadays linseed oil is generally used. Its colour has become browner. The green soap is dissolved in a ratio of 110 g soap to 1 litre of hot water. The soap is 'whisked' until a firm foam is created consisting of minuscule bubbles. A thick round brush with a hair length of ±50 mm (pig's bristles), for instance a shaving brush, can be used. Natural **block soap**, such as olive oil block soap, can also be dissolved in hot water. An indication of the proper soap:water ratio can be obtained by observing the foam's behaviour after 'whisking'. If the foam remains stiff and dries into a satin matt layer in a relatively short time, the ratio is right. If the foam collapses and a liquid soap layer develops, too little soap has been used. The soap foam is applied to the plaster model with a brush, in a circular motion. The foam should be 'massaged' into the surface. After a brief adsorption period of 2 to 3 minutes the remaining foam can be removed by moving the brush in the opposite direction over the surface. The hairs of the brush should take up the excess foam. The surface is not treated with water or wiped off with a moist sponge afterwards, as this would rinse off the soap film that has formed. This procedure may be repeated to make sure a good sealing layer has been formed.

Models with rough surfaces are hard to remove from a mould. A ***soap/clay slip mixture*** can help in this case. This mixture forms an intermediate layer and fills the rough surfaces somewhat, which will make it easier to remove the model from the mould. To a green soap:water mixture (110 g green soap:1litre of hot water), (casting) clay powder is added in a weight ratio of about 1:1. An indication of the right soap:clay:water ratio is obtained by applying the mixture to a (dry) plaster test piece



Paul van Dijk (The Netherlands), temporary installation, 1995. Ht: max. 80 cm (31½ in.). Installation consisting of three groups and two individual pieces. The large and medium-sized pieces were press-moulded using the embossing method. A fine-grained sculpture body was used for these pieces. The smaller pieces were cast. The mould was fitted with a drainage system. A white earthenware casting slip was used. All pieces were fired to a low temperature. They were not glazed in order to exploit biscuit ware's characteristic quality of light absorption, causing light to reflect inside the forms. Collection: (group at the back left and right) Museum voor Hedendaagse Kunst, 's-Hertogenbosch, The Netherlands. (Photo: Peer van der Kruis)

with a brush. If the mixture contains too much clay, a relief will become visible on the model and the mould. If it contains too little soap and water, it will not be easy to apply and will become sandy during brushing. As has been pointed out before, clay particles will tend to hamper crystallisation of the plaster. The soap/clay combination will envelop the clay particles entirely in soap, preventing them from reacting with the gypsum. **NB:** To avoid possible traces on the surface of the fired piece, clay of a similar colour as the piece itself (after firing) should be used.

Sealing agent for models made of other materials

Polyurethane, acrylic or alkyd varnish can be used on a model made of wood. For soft materials the aforementioned varnishes and latex paint can be used. A soap/clay mixture can be used for a model with a hairy surface. A clay model need not be coated with a sealing layer, provided it has not dried beyond the leatherhard stage. In this case, only a parting agent is required.

5.2.4 Parting agents

Plaster has great adhesive power and sticks to virtually any material, including a model that has only been treated with a sealing agent! A parting agent prevents a newly-made plaster mould from sticking to the model and the model or mould from getting damaged. Furthermore, a parting agent prevents plaster from sticking to the spare,

partition walls, cottle or mould sections already in place. It also allows for the removal of plaster that has accidentally got onto parts of the model yet to be cast. A parting agent always contains a water-repellent component. This prevents the plaster from sticking. A parting agent is also used to prevent clay particles from becoming intermingled with plaster when clay is used for the model or separation walls. A '**mould soap**' is often used as a parting agent. Mould soap is commercially available. A proper mould soap shines if applied sufficiently thickly. If applied too thinly it will be absorbed into the mould and the surface will stay matt as a result. Other types of mould soap stay matt under all circumstances, making it more difficult to decide whether a sufficiently thick layer has been applied. Mould soap can also be made in the studio (see *Table 5.2*).

NB: If a cast with a great deal of detail is desired, a sealing layer consisting of a shellac mixture (or varnish for a model made of materials other than plaster) should be used, as it will render a thick layer of mould soap unnecessary and fine details will be preserved.

Table 5.2

Concentrated mould soap

		Preparation
Olive oil block soap (break into lumps)	100 g	Bring water to the boil, add soap and keep at a simmer for at least 30 minutes. The soap must have dissolved completely.
Water	650 ml	Do not allow to cool but directly whisk oil through the dissolved soap mixture with a whisk, until a mayonnaise-like substance is created.
Sunflower oil	300 ml	

Note: Add 30–50% water to this mixture before use.

5.2.5 Miscellaneous materials

Instead of using a clay body for making partition walls they can be made of metal or plastic shims. These are mainly used for sculpture moulds, when it is not necessary for the sections to fit exactly. With metal shims it is relatively easy to make a wall on a clay model quickly. Sculptors often use **brass stock** (0.25 mm thick) for this. Alternatively, **galvanised sheet metal** with a similar thickness and reasonable elasticity may also be used. Shims can also be cut out of **flexible sheet plastic** (max. 0.5 mm thick to prevent large gaps between the mould sections). A partition wall or cottle can be made of waterproof **wooden boards**. Board material commonly used in building as shuttering when casting concrete can be used repeatedly. To make a two-sectioned or multi-sectioned mould with a straight parting line, a partition wall consisting of a cheap material (for instance chipboard) may be used, provided it is treated to make it waterproof. **Plasticine** can be used to fill the gap between a wooden partition wall and the model.

To reinforce a sculpture mould, **coarsely woven jute** (or hessian) **fabric** with threads approx. 4 mm (⅛ in.) apart can be used. It is helpful if the threads have an open structure to get a good grip on the plaster. If the jute has been coated it must be washed prior to use, to help the plaster soak in. Also flax fibres can be used (see *Flax fibres* under section *2.2.5 Cellulose fibres*). Synthetic fibres and glass fibre mats are less suitable, as they do not stick to plaster and the mould will not gain sufficient strength as a result. For bracing extra-large moulds suited for heavy loads, a metal corset made of intertwined steel bars 6–8 mm thick can be used. The metal should be painted with enamel paint or primer to prevent rust marks in the mould and consequently in the finished work. **Clamps** or **straps** can be used to hold together a cottle made out of wooden boards. For the air pressure system a specifically designed **porous hose**, made of woven synthetic fibre, is used. (See *Appendix 4* for more information on where such a hose can be ordered).

5.3 The model

A mould is made from a model. In principle, the model can be anything: an existing object, such as a pillow or fruit, or a form made from clay, plaster or other material. Take into account that the final work will be much smaller than the model. Depending on the clay body and the temperature to which the work is fired, linear shrinkage can differ widely. It will be at least 4% but may be up to 17% (with porcelain). If the work needs to be a certain size, this shrinkage will have to be taken into consideration during the construction of the model. If the clay body has a total shrinkage (drying and firing shrinkage) of 10%, this means the model will have to be enlarged by a factor of 1.11 (divide 100[%] by 90[%] = 1.11). As vertical shrinkage will never be the same as horizontal shrinkage (height versus width), predetermining the dimensions exactly is difficult, see more about shrinkage in section *6.1 Drying shrinkage*.



Juana Valdes (USA), *Remember Your Dreams*, 2002. W: approx. 30 cm (11¾ in.). A cushion was used as a model to make a mould. The piece was cast using porcelain. A mother-of-pearl lustre was applied on top of a transparent shiny glaze. Collection: EKWC (Photo: Corné Bastiaansen)

5.3.1 Clay model

As discussed before, a model can be made relatively easily with clay. Preferably a clay body with a fine to very fine grain size structure is used. The core of the piece may be made of a coarser clay body, onto which is added a layer of approximately 1 cm (⅜ in.) of finer clay. Section *5.12 Smooth surface* describes a method for finishing the surface. It is preferable to allow the model to dry to the **leatherhard stage** (see *Table 5.9*). This has several advantages. The model is less vulnerable during construction of the partition walls. A partition wall of clay can easily be removed afterwards, without the chance of the two sticking together. During construction of the mould the model will shrink very little (drying shrinkage is almost over at this stage). And finally, the chance of intermingling clay particles and plaster is less likely at this stage. If the finished work needs to be of a more or less exact size, shrinkage from the plastic to the leatherhard stage should be taken into account during construction of the model (especially the height, due to the model's own weight). The model may shrink between 3% and 5%. This shrinkage is in addition to the shrinkage that will occur during drying and firing the piece. Use a clay body that is similar in colour to the work after firing to avoid traces of clay of a different colour in the final piece.

5.3.2 Models made of other materials

If more exact measurements are aimed for, the model should be made of, for instance, plaster or wood. These materials do not shrink and are less prone to damage during the application of partition walls. A model may also consist of very soft materials (such as mattress foam or textiles). However, during the construction of the mould, deformation may occur due to the weight exerted by the mould. The material can become compressed, resulting in staggered mould seams.

5.3.3 Spare

A mould designed for the casting process is usually provided with a '**spare**': a reservoir for the casting slip (see *Figure 5.5*). The plaster mould absorbs water from the casting slip, causing the level of the casting slip to go down, and the spare works as a reservoir.



Christoph Zellweger (Switzerland/England), no title, 2001. Porcelain and leather bands. Ht: 27 cm (10½ in.) (each piece). Cast porcelain pieces fired in oxidation. Talc was rubbed on the outside before firing to give a soft sheen when fired. Glazes inside the forms were then fired to a lower temperature.
(Photo: Corné Bastiaansen)

This has the advantage that there is no need to add casting slip every time the level goes down, and that a sufficiently thick wall is formed at the edge of the cast as well. For this purpose, a conical form is fitted onto the model. The volume of the form determines the spare's size: approximately 10% of the volume to be cast can be taken as a guideline. If there is enough room to make a sufficiently large fill opening, the spare can be narrower at the top and wider closer to the model, see *Figure 5.5*. This allows shrinkage in both the mould and the spare keeping the form from getting stuck. If there is too little space for a sufficiently large fill opening, the spare should taper towards the form. If no pouring hole is to be seen in the final piece, a plug may be applied that fits into the spare, for further information see section *5.9.2 Emptying a mould*. In this case, the spare should taper towards the form as well.

5.4 Considerations before making a mould

In this section general points to be considered before beginning the actual making of a mould will be discussed. In the following sections more specific aspects related to making a casting mould or sculpture mould will be addressed as a number of choices must be made related to the required wall thickness and the manageability of the mould during construction of the work. Finishing and health concerns are other aspects deserving attention.

5.4.1 Required wall thickness

In general, wall thickness should be at least 3.5 cm (1⅜ in.) to obtain the required strength. In relation to the casting process an average thickness of 3–4 cm (1¼–1½ in.) yields the best water-absorbing capacity. For more information see section *5.5.1 Optimal water-absorbing properties*. Wall thickness may be reduced to 2 cm (¾ in.) when a sculpture mould for the plemp and press-moulding techniques is used, provided the mould wall is reinforced.

5.4.2 Planning mould sections

The positioning and size of the mould sections need careful planning as several factors are involved. If the model and, consequently, the final form cannot be taken out of the mould without damage, more than one mould section is required. Each **undercut** (a curve in the form which makes it impossible to remove the mould section without damaging the form) makes another mould section necessary. Apart from prevention of undercuts, **manageability** of the mould during construction of the work is another factor determining the placement of mould sections. The weight of each mould section and of the entire mould plays a role, as does the way the mould is filled and (in the casting technique) emptied again. Getting the clay body into the mould using press-moulding or plemping techniques requires that the furthest inside wall section of the mould should be no more than three-quarters of an arm's length from the opening. Due to its weight, a mould intended for the casting process can become unmanageable as the size increases, because the entire mould is filled with casting slip.

Provided the form allows it, another option is to make separate moulds of each section of a form. In this case all cast, pressed or plemped sections will be assembled to construct the final piece.

Both **stability and strength** are essential with multi-sectioned moulds for large pieces. The mould sections should be held together tightly. Straps are ideally suited for tightening the mould sections and keeping them together. If the exterior surfaces of adjoining mould sections will not stay in line, a ridge could be implemented at places to prevent the straps from shifting.

It is better to dry the work inside the mould until it has gained sufficient firmness; this prevents the form from deforming or collapsing entirely. This becomes increasingly important as the work increases in size and thereby in weight. Therefore, well thought-out **positioning of the mould sections** is very important. If the mould sections are spaced in such a way that they can be removed gradually from the top down, the mould will give the work due support at the bottom. However, the lower part of the work must be arranged so it will not get jammed as a result of progressive shrinkage as it hardens and dries. Mould sections might be placed in such a way that the work will sit directly on a kiln shelf when the mould is removed. To minimise the chance of deformation during the withdrawal of the piece from the mould it may be necessary for the form to rest on a



Claudia Fitch (USA), untitled, 1997. Ht: 45 cm (17¾ in.). All forms were made by press-moulding. A cadmium red glaze and sinter engobes were used on the surface.
(Photo: Peer van der Kruis)

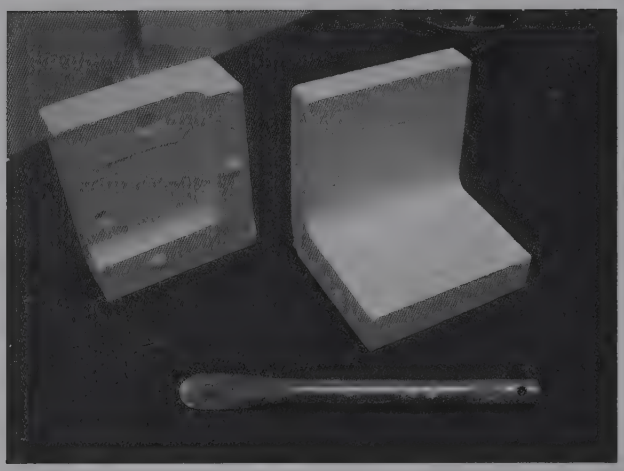
mould section that serves as a base, while the other mould sections are taken off sideways (see *Figure 5.5*).

A mould consisting of many sections tends to become unstable and therefore difficult to handle. A so-called **shell mould** (a mould encasing several smaller sections to achieve more stability) could be used.

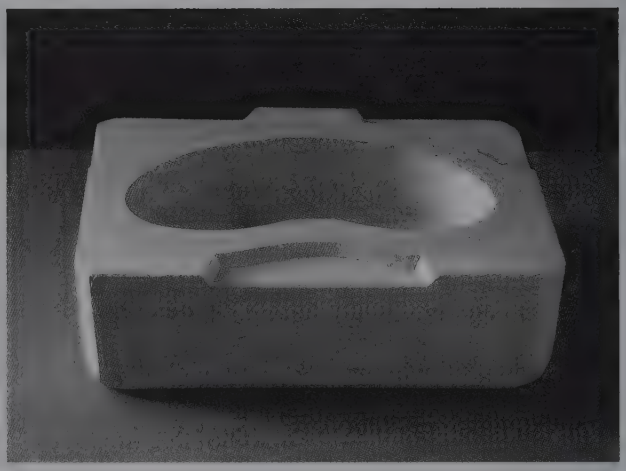
Finally, the number of mould sections should be kept to a minimum. As pointed out, plaster expands as a result of the crystallisation process. For this reason, the mould will be slightly larger than the model. If the final mould section is jammed between other mould sections, gaps due to expansion may occur between the mould sections already cast. Gaps may also be the result of different water:plaster ratios used in each mould section. As the number of mould sections increases, the number of visible seam lines on the work will also increase. If a perfectly smooth surface is desired, it must be borne in mind that protruding seam lines may remain visible after firing, even if they have been smoothed away completely. See section *5.9.5 Finishing*.

5.4.3 Using keys

Placing keys in the mould will ensure very accurate positioning of the mould sections. A key can be created in several ways, but is essentially a small dip in the mould which the opposite mould part fits into, thereby aligning the moulds correctly. During construction and drying of a mould the keys will keep the mould sections in place, reducing the chance of staggered seams. In addition, keys give the mould more stability during press-moulding, plemping or casting. **NB:** It is essential to the function of the mould that the form and position of the keys be chosen in such a way that the mould section can be opened in the desired draught direction (the direction in which the parts are removed, see *Figures 5.5 and 5.6*). Two types of keys may be used: keys made by creating a natch in the mould section and plastic keys.



ABOVE LEFT:
Figure 5.1
A half round natch is made in the first mould section. This will work together with the second mould section to act as key and lock. This picture also shows a tool especially designed for making a natch. It consists of a flat, half-round, sharpened 'knife'. A coin may also be used.
(Photo: Marc Kohlen)



ABOVE RIGHT:
Figure 5.2
A square natch made with a chisel.
(Photo: Anton Reijnders)

A natch

A simple natch made on the side of the first mould section can serve as a key. An advantage of using a natch is that its form can be adjusted to the desired draught direction. A half-round indentation, made with a coin or a sharp half-round knife in the side of the mould section is intended for mould sections that are separated more or less directly away from each other when the mould is opened, see *Figure 5.1*. A square, tapering natch on the side of the mould section made with a chisel is intended for mould sections that are to be opened sideways or at an angle, see *Figures 5.2* and *5.6*. A natch may also be made directly in a partition wall (see *Figures 5.8* and *5.16*).

Plastic keys

Plastic keys are ready-made products in various sizes and designs. A key of this type is provided with a round cap, a locknut and an opening. The round cap fits into the opening, making two keys interlock, see *Figure 5.3*. The locknut ensures anchorage in the mould section. Plastic keys are constructed in such a way that some force must be exerted to separate them. This lends extra stability to multi-sectioned moulds. Another advantage is that they do not wear out and do not break off easily. A plastic key is mainly used when a great deal of precision is required. A disadvantage is that the force that must be exerted to open the mould may damage the cast. It is difficult to know if this extra force is required, because a cast that is too wet will stick to the mould. Plastic keys are intended for mould sections that are removed more or less directly away from each other when the mould is opened.

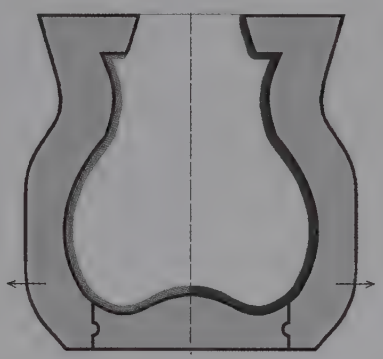


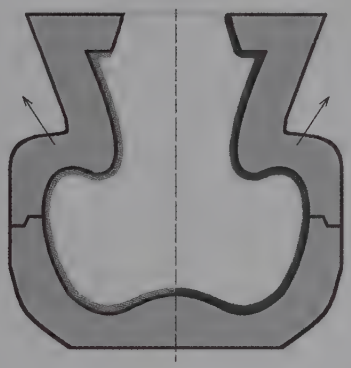
Figure 5.3
Plastic keys.
(Photo: Anton Reijnders)

5.4.4 Flanges

A form with a flat and open bottom is best provided with a flange. A flange is a ridge at the bottom of the form where it meets with the wall (see *Figure 5.4*). It lends strength to the form, making it less sensitive to deformation during both drying and firing. After firing, too, the work will be less vulnerable.[6] To make a flange, a recess can be made in the mould; in a mould intended for the casting process the spare may be combined with







this recess, see *Figures 5.5* and *5.6*. When the press-moulding technique is used, no extra arrangements will be necessary.

ABOVE LEFT:
Figure 5.4 Cross-section of piece in its final position. The form is provided with a flange at the bottom. (Image: Marc Kohlen)

ABOVE CENTRE:
Figure 5.5 Schematic presentation of a mould with spare, positioned in such a way that a flange is obtained. The mould sections are provided with keys. Mould sections are removed directly away from each other. The bottom mould section serves as a base, providing support to the form during removal of upper mould sections and preventing distortion.
(Image: Marc Kohlen)

ABOVE RIGHT:
Figure 5.6 Schematic presentation of a mould not provided with a separate mould section for the spare.The keys are placed in such a way that the mould sections can be removed at an angle.
(Image: Marc Kohlen)

5.4.5 Taking weight into account

As the size of an intended form increases, the weight of the mould (section) tends to increase rapidly. Therefore it is important to work out beforehand how much plaster will be involved and how heavy the mould (section) will become. The amount of water and plaster powder required for a mould or mould section can be determined by making a calculation. This calculation will also give a good idea of the eventual weight of the mould (section).

How to calculate the required amount of plaster powder and water

If the volume of a mould (section) to be cast is, say, 14.8 litres and 1 litre of mixed plaster weighs roughly 1.66 kg (a 1:1.5 water:plaster powder mixture), then to fill this volume 14.8 × 1.66 = 24.7 kg of mixed plaster is used. To compensate for the loss occurring during construction and processing and to keep a safe margin 10% is added: 24.7 + 2.47 = 27.2 kg mixed plaster is needed to obtain a mould with a volume of 14.8 litres.

The amount of **plaster powder** required to make this size of mould (section) is:

$$\frac{27.2}{2.5} \times 1.5 \text{ (a 1:1.5 mixture)} = 16.3 \text{ kg plaster powder}$$

The amount of **water** required for this is:

$$\frac{27.2}{2.5} \times 1 = 10.9 \text{ kg (or 10.9 litres) water}$$

Weight of the mould (section):

The eventual weight of the mould after drying can be calculated from the amount of mixed plaster required to make the mould. For example:

The calculation above shows that approximately 24.7 kg (excluding the 10% safety margin) of mixed plaster is required to make a mould (section) of a 14.8 litre volume. Approximately one third of the water will evaporate during drying.

$$\frac{10.9 \text{ kg water}}{3} = 3.6 \text{ kg} \quad \text{and} \quad 24.7 - 3.6 = 21.1 \text{ kg}$$

Table 5.3

Approximate weights of 1 litre (0.1 m³) of plaster, clay body and slip

Mixed plaster	*Press-mould body*	*Plemp body*	*Casting slip*
1.66 kg (3¾ lb)	2.2 kg (4¾ lb)	2 kg (4½ lb)	1.8 kg (4 lb)

Therefore, 21.1 kg is the approximate weight of the mould (section) after drying.

Determining the amount of clay or casting slip required
Apart from the weight of the mould itself, it is also useful to have information about the weight of a filled mould or mould section and so get an indication of the manageability of the work during production. This information can also be obtained through calculation. Determining the weight of a press-moulded or plemped form requires an estimation of the volume of the wall. Calculation of the required amount of casting slip requires an estimation of the volume of the mould (including 10% volume of the spare). The volume is determined in litres (1 litre = 0.1 cubic metre). The outcome is multiplied by the values presented in *Table 5.3*.

A calculation like this shows that the total weight (of the clay body and the mould) used in press-moulding and plemping is significantly more than for casting. **Example:** a sculpture mould of a cylindrical form 60 cm high and 25 cm in diameter, intended for press-moulding or plemping (thickness of the mould ± 2 cm), will have a volume of approximately 12 litres[7] resulting in a weight of approximately 17 kg (12 × 1.66 = 19.9 minus evaporating water 19.9 – 2.9 = 17). With the press-moulding technique and an average wall thickness of 1.5 cm, the weight of the clay body will be approximately 16 kg and the total weight approximately 33 kg. A sculpture mould suited for casting, including the spare, (thickness of the mould wall ± 3.5 cm) will weigh approximately 31 kg. Filling the mould will require approximately 58 kg casting slip, which means the total weight will be approximately 89 kg! The mould will be substantially heavier than this if the outer shape of the mould does not follow the form, as will often be the case in casting moulds.

5.4.6 Finishing the mould

The exterior of the mould and the edges at the outside of mould sections must be finished in such a way that no sharp burrs or edges remain. These can break off, as a result of which pieces of plaster might land in the clay body or clay slip. This can cause lime blowouts to occur (see section *11.5.4 Other faults*).

5.5 Making a casting mould

As discussed before, a casting mould is made by pouring plaster into the space between a model (the original) and a retaining wall or cottle. The pouring of properly mixed plaster will produce a mould with good and even water-absorbing properties: a homogeneous wall is created with an even division of pores. This makes these moulds well-suited for casting and allows for a high degree of precision in the final result. Plaster can be poured into the mould via a chute (e.g. a bisected PVC pipe) to prevent air bubbles from being formed. It is best to pour the whole mould with one batch of mixed plaster.

5.5.1 Optimal water-absorbing properties

As already mentioned, following the manufacturer's recommended water:plaster powder ratio is important. This will give the correct number of pores required to ensure



Alberto Peral (Spain), *Family*, 2002. Ht: 50 cm (19½ in.). Slipcast earthenware pieces. A mould is used to gain more control of the final shape and to create a group of identical forms with small adjustments and additions. Only small amounts of ceramic pigment were added to a base glaze in order to maintain transparency. Collection: Bank of Spain. (Photo: Corné Bastiaansen)

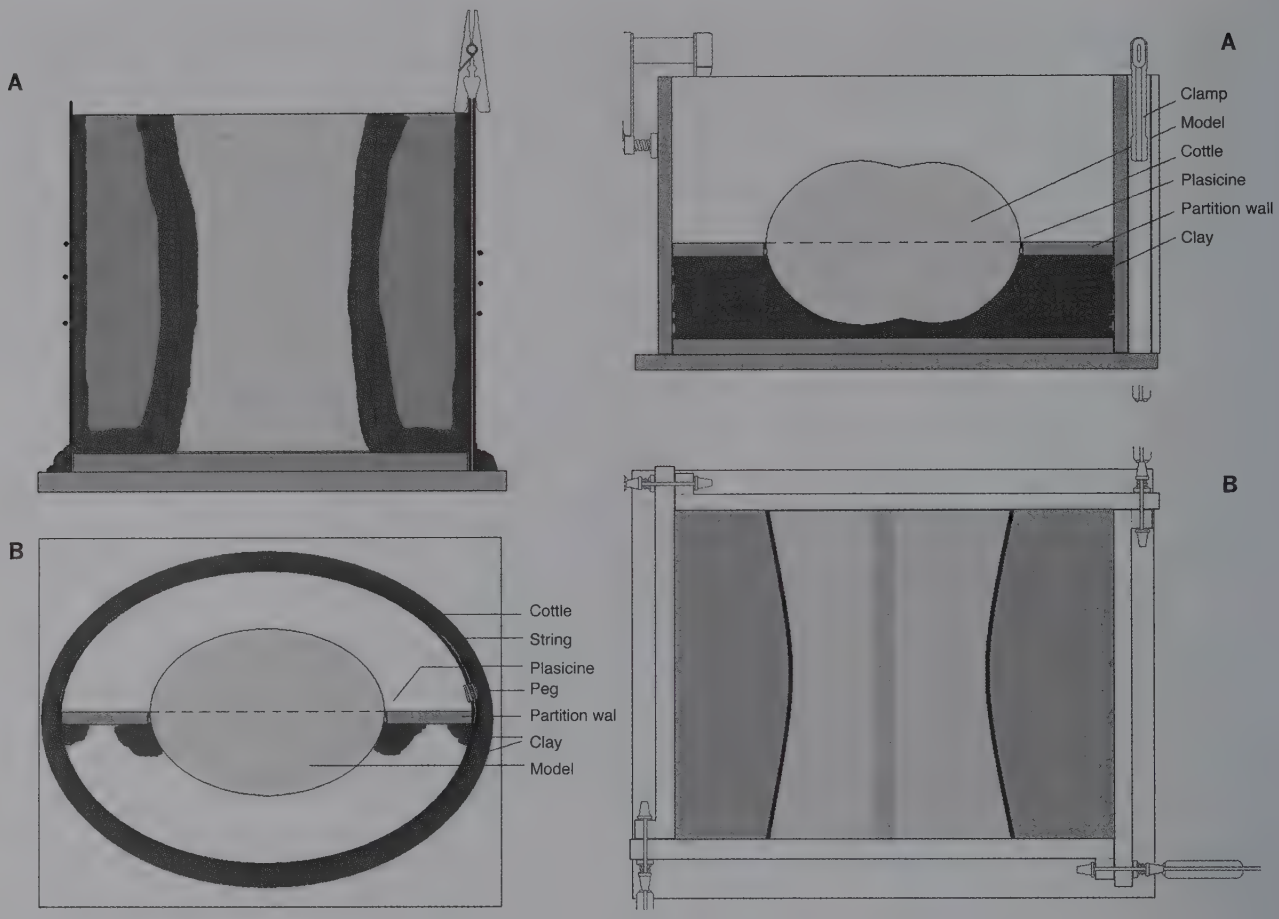
a proper migration of the water to the outer surface of the mould. The following aspects are also important:

- For each mould section, all the plaster required must be prepared at the same time. If a mould section has a greater volume than the content of a bucket, pouring from several buckets consecutively is an option, provided all the plaster required has been prepared at the same time. Uneven water-absorbing properties will lead to uneven wall thickness in the cast work, which may in turn lead to deformation during firing, especially in the case of porcelain pieces.
- A steady migration of water towards the outer surface where it can evaporate is essential. If the mould thickness exceeds about 4 cm (1½ in.) the capillary[8] force of the plaster is not strong enough to allow this steady migration. However, a wall much thinner than 3 cm will have comparatively fewer pores that can fill rapidly with water thus slowing the steady migration. A wall thickness of between 3.5 cm and 4 cm (1¼ in. and 1½ in.) is ideal.

5.5.2 Closely-fitting mould sections

If mould sections do not fit together properly, protruding seam lines may become visible in the finished piece, even though they have been carefully removed. This occurs particularly in porcelain (for more information see *Figure 5.21*). Mould sections will fit better if:

- The same water:plaster powder ratio is maintained for all mould sections; the expansion during the crystallisation of the plaster will then correspond.



LEFT:
Figure 5.7
A With a vertically-positioned model the partition wall needs to be stabilised at the back with rolls of clay.
B (View from the top) A cottle of flexible sheet material will follow the form of the model more closely giving a more equal wall thickness to the mould sections. A string or strap can be used to hold the cottle in place.
(Image: Anton Reijnders)

RIGHT:
Figure 5.8
A A horizontally-positioned model can be placed in a bed of clay.
B (View from the top) To achieve a close-fitting mould section a partition wall sawn out of wooden board should be used. A cottle constructed from wooden boards allows clamps to be used to make the base stable.
(Image: Anton Reijnders)

- Each mould section is cast in its entirety at the same time.
- The number of mould sections is limited to what is strictly needed.
- A model of plaster or, for instance, wood is preferred.
- If possible – wooden partition walls are used; allowing the fitting and finishing to be done with great accuracy.
- Keys are implemented; plastic keys are especially helpful in getting a close fit of the sections.

Partition walls

To cast a mould section the model can be placed either in a horizontal or vertical position. For a straight parting line, a partition wall can be made by sawing a wooden board[9] into the desired shape. The cutout form follows the shape of the model with a separation of approximately 2 mm between the wood and the model. The wall is placed on the parting line and the space between model and partition wall is filled with plasticine or clay, see *Figure 5.7*. If the model is placed in a vertical position the partition wall can be stabilised at the back with a roll of clay. The partition wall of a horizontally positioned model could be stabilised by placing it on a bed of clay, see *Figure 5.8*.

Plastic keys may be added to the wooden partition wall to obtain a firm fixing, see *Figure 5.9*. As stated previously a clay partition wall is used if the parting line of the mould section is not straight. The model can also be embedded in clay up to the

dividing line of the mould section. **NB:** Do not forget to apply mould soap to the model and the partition walls.

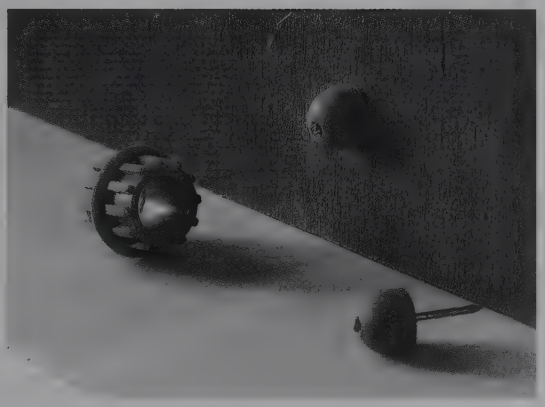


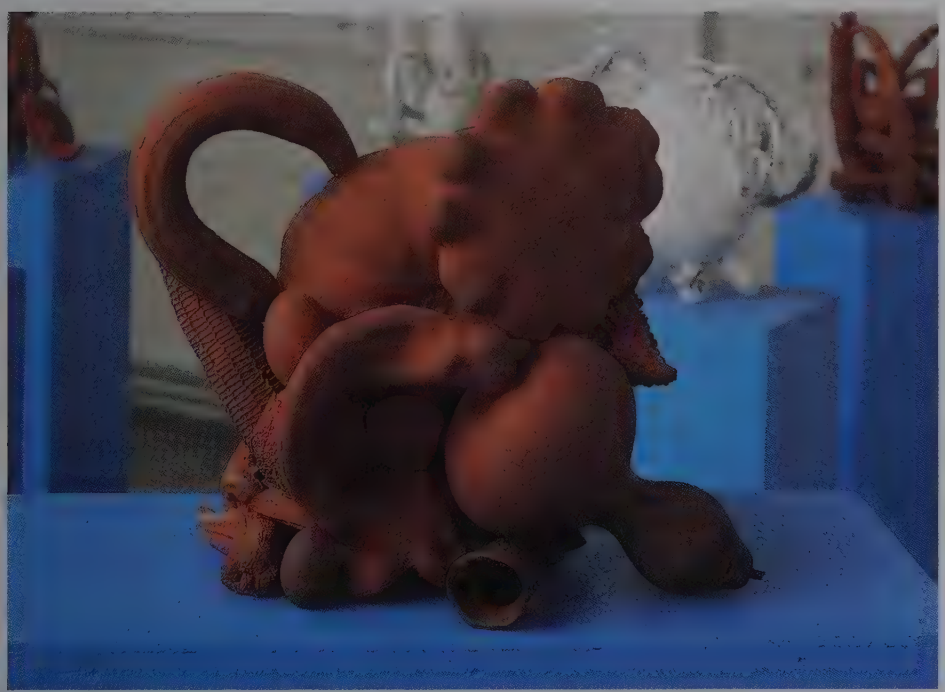
Figure 5.9
Adding a plastic key to a wooden partition wall. The top part is cut off and attached to the wooden partition wall with a nail. Next, the bottom part is attached to the riveted cap. This part will eventually serve as a key in the mould section still to be cast. (Photo: Anton Reijnders)

Cottle

A cottle may be constructed out of wooden boards or a thin zinc or polystyrene sheet. In principle, the cottle should follow the model as closely as possible, taking an optimal wall thickness of 3.5 cm to 4 cm (1¼ in. to 1½ in.) as a guideline. In practice, however, this will be the exception rather than the rule. In any case, a cylinder or rolled-up zinc or plastic (polystyrene) sheet may be used for round forms. Wooden boards are used for rectangular forms. As the cottle and the shape of the model follow each other only partially, wall thickness of the final mould will exceed 4 cm in places. Excess plaster can be removed by, for instance, sawing or rasping. Another option is to fill the excess space on the inside using clay, plasticine or polystyrene. This also helps to reduce the weight of the mould. **NB:** Care should be taken that the wall does not become too thin, as this would reduce the strength of the mould (for instance, when tilting the form to pour out the casting slip). Therefore, maintaining greater wall thickness (>4 cm) may be necessary in places.

To prevent plaster from leaking out when it is poured into the space between the cottle and the model, **fitting and securing** the cottle will require great care. This applies both to the seams around the wooden board and the overlapping of zinc or plastic sheet. The joint between the partition wall and the cottle also deserves attention. As size increases, the cottle will suffer considerable lateral pressure, increasing the chance of leaks.

Once mixed plaster starts leaking through a crack in the cottle, it will be hard (even impossible) to stop if large volumes are involved – it is the dreaded breach in the dike that



Pauline Wiertz (The Netherlands), *Muiterij op de Bounty*, 1998. Ht: 45 cm (17½ in.). Multi-sectioned pieces. Moulds made from fruits and vegetables. Earthenware casting clay was used for the pieces in the front, porcelain casting clay for the pieces behind. The casting clay was mixed with a small amount of cellulose fibres. All elements were cast separately and joined at the leatherhard stage. The cellulose fibres in the clay body helped to secure a good bond in the areas of contact. (Photo: Peer van der Kruis)

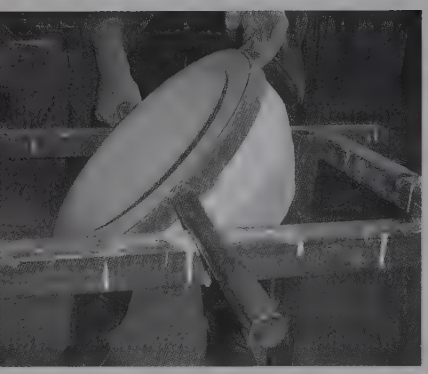


Figure 5.10
An example of a tilting construction intended for the casting process to facilitate the emptying of a mould. Work in progress by Seet van Hout (The Netherlands). (Photo: Marc Kohlen)

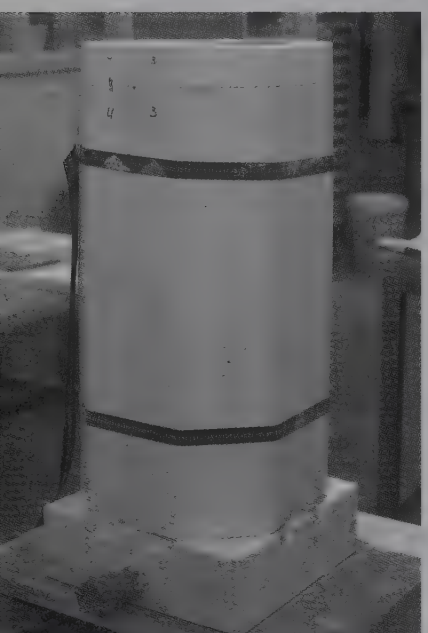


Figure 5.11
A draining system. The cast-in PVC pipe in the bottom mould section has a cross section of 4 cm (1½ in.). The pipe protrudes far enough to allow connection of a tap. Work in progress by Eduard Sweep (The Netherlands). (Photo: Anton Reijnders)

will necessitate mopping, scraping and chipping. Closing the seams with clay from the inside reduces the chance of leaks considerably. With the construction of elongated, standing moulds, downward pressure increases with length, increasing the chance that the cottle will be pushed upward. Putting weight on top of the cottle will prevent this. A wooden cottle is more stable as it can be clamped firmly. Placing it on a wooden base would allow the base and cottle to be screwed together preventing the cottle being pushed upwards.

5.5.3 Casting moulds for medium-sized work

As discussed before, a casting mould is not very well suited for larger than medium-sized work, due to the considerable combined weight of the mould and the casting slip. In medium-large work, pouring out excess casting slip will require considerable preparation. To facilitate pouring, the mould may be suspended in a tilting construction, see *Figures 5.10* and *5.19*. A draining system is another option.

Fitting a draining system

In order to be able to drain the casting slip without having to tilt the mould a draining system should be incorporated in the planning of the mould. A plug made out of plaster could be used to block a hole in the bottom of the mould itself or PVC pipe could be cast into the bottom of the mould (see *Figure 5.11*). When such a pipe is used, the drain hole will not clog up during draining, especially if the pipe diameter is 4 cm (1½ in.) or more. The pipe should protrude far enough to allow the connection of a cap or tap. A tap will give control over the draining speed. It also makes it possible to obtain a slight tapering of the wall towards the top by draining the slip slowly from the mould over a longer period of time. As previously mentioned, this will benefit the stability of the final piece. It is important that the cap or tap is attached firmly. A **plaster plug** works well for smaller work. Bear in mind that pressure may rise in places, therefore the cap or plug should be positioned in such a way that it can be kept in place properly (with a strap if necessary). The draining system can also be used when casting smaller forms or forms that are open on two sides, like a tube.

The use of a plaster plug allows the option of closing the draining hole in the piece after the slip has been drained, (see section *5.9.2 Emptying the mould)*.[10]

Applying an air pressure system

To install an air pressure system, a supporting structure that will keep the porous hose in place must be made prior to casting the mould section (see *Figure 5.12*). A metal frame should be constructed that starts at, and is supported by, the top edge of the mould. The metal frame whose form follows that of the negative space in the mould is suspended into the mould. There should be a space of about 2 cm (¾ in.) between the frame and the surface of the mould. The hose is then coiled on the metal frame. This distance of about 2 cm from the inner side of the eventual mould wall is necessary for the mould to withstand the pressure that will build up. If the air hose is too close to the surface the air pressure may blow off part of the mould. The hose should not be pinched at any point. One of the ends of the hose should protrude 5 cm (2 in.) from the exterior of the mould wall. A piece of non-porous hose should be slipped over this part and should extend a few centimetres into the final mould. This will prevent loss of pressure. This piece of hose makes it easier to put pressure on the porous hose, since it is easily connected to an air gun. For larger mould sections the air hose can be connected to a bayonet catch for air pressure systems. This catch makes it possible to connect the mould section directly to an air pressure regulating system without loss of pressure and allows a gradual rise in pressure.

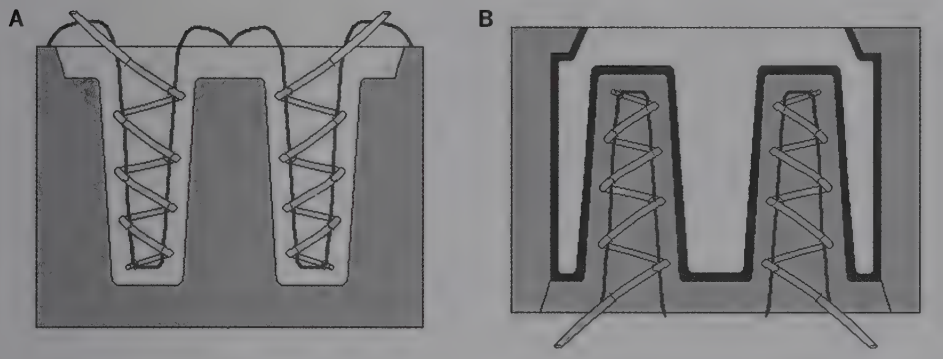


Figure 5.12
Air pressure system.
A A metal frame is supported by the top edge of the mould and is suspended into the provisional mould. There should be a space of about 2 cm (¾ in.) between the frame and the surface of the mould. The hose is then coiled on the metal frame. Plaster is poured into the provisional mould. Next the provisional mould is removed and the side parts of the mould are made.
B Shows the air pressure system in its final position and the situation after draining the mould. (Image: Anton Reijnders)

5.6 Making a sculpture mould

A distinction is made between sculpture moulds intended for press-moulding and plemping and those intended for casting. As sculpture moulds made for the casting technique differ in some aspects they will be discussed separately.

NB: Because of the time constraints due to the short setting time of plaster, and the number of actions to be undertaken, it is essential to have all the necessary tools near at hand and to be prepared to work quickly. When making a larger sculpture mould assistance will be required.

5.6.1 Sculpture mould suited for press-moulding or plemping

The mould sections of a sculpture mould for press-moulding or plemping should be positioned in such a way as to allow filling and joining from the inside of the sections already in place. This is possible only if the opening of the last mould section is sufficiently wide. An opening at the bottom means the mould can be tilted to allow filling and/or joining from the inside. To make this possible for larger moulds, a hoist is very useful as it allows turning of the mould after filling. In this case, the mould sections should fit together well and have the strength to be tightly strapped together. Moreover because large work requires some additional tugging and pulling when it is removed, the reinforcement of the mould must be geared to this and handles could be added to facilitate opening the mould.

Sculpture moulds are constructed from several layers of plaster. As the size of the mould increases, reinforcement is implemented in order to limit the weight. Reinforcement, in combination with a flange, will provide extra strength: the wall of the mould can be made around 2 cm (¾ in.) thick. Smaller moulds could be made without reinforcement, provided wall thickness is at least 3.5 cm (1⅜ in.).

Partition walls

Partition walls may be made from clay, metal (brass stock) or plastic shims. Generally, partition walls are placed in such a way that the form can be withdrawn without problems when a mould section is removed. The angle between model and wall is preferably 90°. Sharp angles make the mould edges vulnerable to crumbling. However, sometimes the angle may be less than 90° to allow the mould section to be pulled away at a specific angle.

Clay has many advantages over other materials for making a partition wall. It is easy to apply to models that have a lot of details, or to intricate forms when the parting line is not in one straight line. A clay partition wall can be used on clay models and on other



Figure 5.13
A partition wall made of plastic shims. Work in progress by Mrinalini Mukherjee (India). (Photo: Marc Kohlen)



Figure 5.14
Plywood as a partition wall. The work has been tilted to facilitate the application of plaster. Wall thickness of the mould is indicated on the plywood for orientation. Work in progress by Dick van Hoff (Netherlands). (Photo: Marc Kohlen)

materials. The thickness of a clay partition wall should be ± 2 cm, its height should be at least 5 cm (2 in.). The clay body should be plastic-stiff (see *Table 5.9*) when applied to the model. It is best to use a clay body with a fine to very fine structure.

Metal or plastic shims may be used when less precision is required. With shims it is relatively easy to make a partition wall on a clay model. The wall is constructed by pushing the shims into the still plastic clay model one by one, slightly overlapping and leaving ± 5 cm sticking out (see *Figure 5.13)*. There should be no gaps between the shims. Shims could be useful if the parting lines are not in one straight line, however highly irregular seam lines are more-easily followed with clay.

If the parting line is in one straight line, wood may be used as a partition wall (see *Figures 5.14* and *5.15*). Plywood or chipboard, for instance, (treated to make them waterproof) can be cut to conform to the shape of the model leaving an intermediate space of approximately 2 mm. This space between model and wood may be filled with clay or **plasticine** to ensure a smooth finish. To prevent the partition wall from shifting, a clay roll can be placed at the back in the corners where the partition walls and the model meet.

NB: After the partition walls and retaining wall have been put into place and before the construction of each next mould section, mould soap should be applied, this also applies to the contact surfaces of the mould sections already in place.

Mould flange

Mould sections provided with a flange are strong and allow the wall of the section to be thin. To achieve a flange the partition walls must be at least 5 cm (2 in.) high. This also offers sufficient space for keys (see *Figure 5.16)*. As mould sections increase in size, more pressure will have to be exerted on the mould sections to press them together properly. A firm mould flange makes it possible to connect the mould sections with clamps (*Figure 5.15*), nuts, washers and bolts (*Figure 5.17*). The mould flanges are built simultaneously with the first layer.

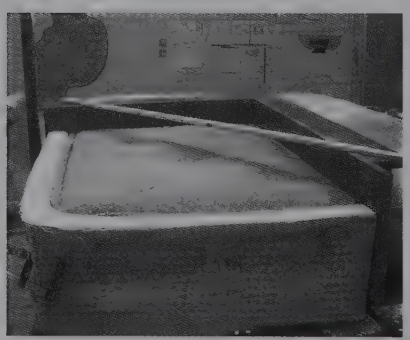


Figure 5.15
Plywood as a partition wall. A firmly constructed mould flange is also visible, making it possible to secure mould sections with clamps. Work in progress by Stefan Serneels (Belgium).
(Photo: Marc Kohlen)

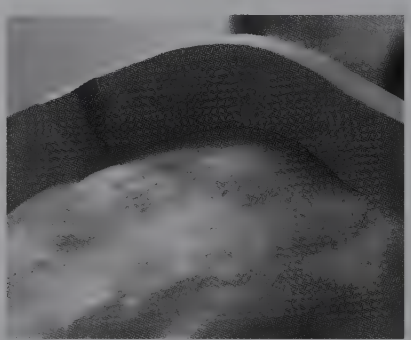


Figure 5.16
A key applied to a partition wall.
(Photo: Anton Reijnders)



Figure 5.17
A firm mould flange makes it possible to connect mould sections with clamps or with nuts, washers and bolts.
(Photo: Marc Kohlen)

First layer

The wall of a sculpture mould is built up from two or more layers. The first layer is just plaster. The second layer consists of plaster and a reinforcing material. The first layer is made by flicking plaster onto the model. Start at the highest point and work gradually down. Corners where the model and the partition wall meet need extra attention to avoid air pockets. Use a small container that can be held comfortably in one hand refilling it with plaster as required. Usually 10–15 minutes after mixing, the crystallisation process will have developed to such an extent that viscosity increases (see section *5.2.1 Plaster* for factors that will influence working life). Due to this, the plaster will run off the model less easily, especially on the vertical parts. A brush as shown in *Figure 5.18* can be used as well to apply the plaster onto the model. As stated before, the first layer should be about 1 cm (½ in.) thick.



Figure.5.18
A brush made from the bristles of a broom can be used for flicking plaster on a model. A broom for applying wallpaper glue was used for this.
(Photo: Anton Reijnders)

Adhesion of layers

As the wall is constructed from several layers, mutual adhesion of these layers deserves due attention. To **ensure good adhesion** the consecutive layers are best applied 'wet-on-wet'. This means the first layer of plaster will not have crystallised fully before the next layer is applied. Waiting too long between the application of the first and second layer will increase the chance of surface cracks on the form side, especially if the first layer is less than 1 cm thick. An already crystallised first layer that is too thin is very vulnerable and is likely to be crushed during application of the second layer, especially if jute reinforcement is used. In addition, the second layer will not adhere, and pieces of plaster will come off the inside of the mould during usage. Air trapped between the thin first layer and the second layer may also cause pieces of plaster to come off. If the first layer has crystallised considerably, adhesion with the second layer is only possible by roughening the surface and saturating it with additional water.

Second layer

The reinforcement is applied to the second layer. Good results are obtained with a reinforcement of coarse jute fabric. The jute fabric is cut in strips soaked in plaster and then applied, wet-on-wet, onto the first layer. The layers of jute should overlap slightly. Where flax fibres are used the fibres are sprinkled on top of the first still-wet plaster layer. **NB:** A sculpture mould provided with jute reinforcement will be subject to more tensile stress during the drying of the mould if the time between the applications of successive layers is extended.

In extra-large moulds that must be capable of withstanding heavy pressure, a metal corset of intertwined iron bars 6–8 mm (¼–⅜ in.) in diameter could be used. For large mould sections, wooden or metal handles can be attached to the outside of a mould section to facilitate placement or removal during the making of a piece. This can be done using plasterboard screws. If the mould is very heavy the handles can be



Dick van Hoff (The Netherlands), *Vaas*, 2001. Ht: 85 cm (33½ in.).
A styrofoam block was milled by using a semi-automated self-made milling system. A sculpture mould was made following the contours of the model to limit the total weight. Casting clay specifically formulated for medium-large pieces containing cellulose fibres was used. (Photo: Corné Bastiaansen)



Figure 5.19
An example of a tilting construction to facilitate pouring out of the casting slip. In this case, the mould has been fastened to a steel structure. The straps, that hold the mould sections in place when filled with casting slip, are clearly visible. Work in progress by Dick van Hoff (Netherlands). (Photo: Marc Kohlen)

attached to the jute reinforcement already in place. To ensure good adhesion when building the handles into the mould, soak the jute in plaster after attaching it to the handles and then apply it, wet-on-wet, onto the first layer of plaster. Both the wood and the metal parts should first be painted.

NB: Due to the time it takes to cast all the layers of an entire mould, differences can occur in the rate of expansion and the water-absorption of the different layers and sections. Differences in the rate of expansion could cause a less than optimal fit of the mould sections.

5.6.2 Sculpture mould suited for the casting technique

Most directions given above also apply to the casting technique, though the water-absorbing properties of a sculpture mould will be less compared to a casting mould. As a result, the mould may become saturated more quickly. Therefore the following need extra attention: To ensure the minimum necessary water-absorbing capacity, during preparation of the plaster, the **water:plaster powder ratio** recommended by the manufacturer must be strictly observed. Intervals between preparation and application of the layers must be as constant as possible. Wall thickness must be about 3.5 cm (1⅜ in.), for more information see section *5.5.1 Optimal water-absorbing properties*. Making the first layer 1.5–2 cm (½ – ¾ in.) instead of 1 cm will also improve the water-absorbing properties. The mould sections should fit well and shims should not be used for partition walls as gaps may lead to leakage. This is especially true for medium-large moulds due to the high pressure caused by the large amount of casting slip needed. To facilitate pouring out casting slip, the mould may be suspended to allow it to be more easily tilted (see *Figure 5.19*) and a draining system could be built into the mould itself.

5.7 Drying moulds

To dry a mould or mould sections without warping or loss of water-absorbing properties, the following conditions must be met:

- Mould sections should only be taken off the model when the last mould sections have crystallised (they no longer feel warm).
- The mould sections should be reassembled immediately. Sculpture moulds provided with jute reinforcement will be subject to more tensile stress during the drying. Reassembling will also protect the interior of the mould against damage.
- Depending on the thickness of the mould, drying may take 4 to 5 days. Forced drying of the mould by exposing it to additional heat should be done with care. Take care that the drying temperature does not rise too high, as plaster can 'burn': the crystal water starts escaping from the gypsum crystals causing a hard crust to form, reducing the water-absorbing properties. To prevent this, drying must take place below 40°C (100°F).

5.8 Summary of main points

Tables 5.4–5.6 summarise the general and specific points that should be taken into account when making a sculpture mould or casting mould.

Table 5.4

General points to note when making a plaster mould

Take shrinkage into account Depending on the clay body and the firing temperature, the final size of the work will be 5%–17% smaller than the model. If the size of the final work is important, this should be taken into consideration when planning the size of the model.

Clay model Use a clay body similar in colour (after firing) as the final work. Use a clay body with a fine structure if a smooth surface or fine detail is desired.
Let the clay model dry until the leatherhard stage has been reached. Bear in mind that this will lead to a reduced size of the final piece.

Partition wall of clay Use a clay body of the same colour (after firing) as the final work.

Sealing agents Use sealing agents on a water-absorbing model. In the case of a plaster mould, a shellac/alcohol mixture will help preserve surface details.

Parting agents Use a parting agent, like mould soap, to help remove mould sections without damage. When the partition walls are in place mould soap should be applied to the model and partition walls. Prior to making each new mould section, the contact surfaces of the mould sections already in place should be treated with mould soap as well.

Mould sections Make sure the mould sections are manageable in terms of their size and weight.
Mould sections are preferably positioned during press-moulding or plemping. Make sure the size of the mould sections allows the clay body to be applied properly and sections to be joined from within (max. three quarters of an arm's length).
A case mould could be implemented to provide more stability if a mould consists of many mould sections.
For large forms it is advisable to position mould sections in such a way that they have sufficient support while the mould is opened section by section.

Keys Use keys to ensure better fitting of the mould sections and to create a more stable mould.
The shape and position of the keys should be determined according to the planned draught direction (direction of removal) for opening each mould section.

Large moulds Plan to have extra assistance when making a medium-sized to large mould. Attach handles and ensure good tightening of the mould by using straps or clamps.

Draining casting slip If the total weight (mould filled with casting slip) exceeds 25 kg (55 lb), use a tilting construction or a drainage system.

Tapering of the wall in larger work To develop tapered walls the mould should be provided with a drainage system.

Table 5.5

Points to note when making a casting mould

Spare Use a spare to achieve an even wall build-up at the outer end of the final piece. The spare volume is approximately 10% of the form's volume.

Wall thickness of the mould Optimal wall thickness of the mould for the casting process is 3–4 cm (1¼–1½ in.).

Cottle Prevent the cottle from being pushed upward or bursting open sideways.

Supporting the form during drying and firing Consider additional moulds for casting accessories for work that is sensitive to deformation.

Work with a flat, open bottom Provide the mould with a separate section for a mould flange on the work.

Table 5.6

Points to note when making a sculpture mould

	Press-moulding and plemping	*Casting*
Partition walls		Due to the risk of leakage, do not use metal or plastic shims.
Water:plaster ratio	Less sensitive with these techniques.	Always observe the recommended water:plaster ratio.
Consecutive stages of layer construction	Time taken to prepare and apply plaster need not be kept constant for each mould section, as getting even and optimal water-absorbing properties is not so critical with these techniques.	Time taken to prepare and apply plaster must be as constant as possible for each mould section to get even and optimal water-absorbing properties.
Mould wall	Thickness of the first layer must be 1 cm (⅜ in.).	Thickness of the first layer could be up to 2 cm (¾ in.), to improve water-absorption properties.
	Reinforcement and mould flanges should be used for medium-sized to large moulds.	
	Total wall thickness of a sculpture mould may be limited to 2 cm (¾ in.) if reinforcement is used and mould sections are provided with mould flanges.	Total wall thickness should be 3.5 cm (1⅜ in.) to optimise water-absorbing properties.
Medium-large or large moulds	Add any devices that allow good tightening of the mould by using straps or clamps. Add handles to facilitate opening of the mould.	
Spare		Implement a spare.
Filling a medium-sized to large sculpture mould	Make mould sections (and mould flanges) sufficiently strong to allow them to be pressed together with extra pressure.	Because of the high pressure exerted by the required amount of casting slip, it is important that mould sections fit closely together and can be held together tightly.

5.9 Slipcasting

The size and shape of the work determine which preparations must be made for casting. As made clear before, casting larger pieces involves heavy weights. By making a calculation one can get an indication of the amount of clay body or casting slip required to make a piece (for more information see section *5.4.5 Taking weight into account)*. It is important to consider all the required actions thoroughly: filling the mould, pouring out the casting slip, taking the form out of the mould, and also drying and firing of the work.

If a multi-sectioned mould is used for the first time, it is recommended to assemble it completely to check if all sections fit together. To get rid of traces of mould soap the first cast should be left to dry in the mould.[11] If casting slips of different colours are to be used consecutively, one should expect traces to be left in the mould, which may be included in the surface of the piece the next time the mould is used. This could be especially noticeable on porcelain. This may be used intentionally, but if one wishes to avoid it, it is better to start with a light-coloured casting clay before using a darker coloured slip. Talc can be used when pieces are difficult to release from a mould. A very thin layer will work satisfactorily. Thicker layers will show after the firing (white traces

will be visible on a coloured earthenware body, shiny traces on a clay body fired to the mid-temperature range or higher).

To achieve good results the following requirements should be fulfilled:

- The mould should be sufficiently dry to ensure a proper build-up of wall thickness and to avoid casting faults.
- The casting slip should be mixed in such a way that no air is included.
- A newly mixed casting slip should stand for 24 hours before it is used.
- The casting slip should not be stored over a long period of time as this will cause a weak cast (the cast deforming during handling).
- Before pouring the casting slip should be stirred well (stirring should take place in such a way that air inclusion is avoided).
- The slip should not be poured too fast, as this could cause inclusion of air. The slip should not be poured too slow or with a pause as this could create horizontal lines on the cast.
- Recycling casting clay scraps is possible provided not more than 20% is added. Exceeding this percentage could cause casting faults.
- Plaster moulds wear out; as a result, details become less clear and sharp edges become more rounded. After 50 casts replacing the mould could be necessary to maintain a high-quality cast.

For more information on casting faults and ways to overcome these faults see section *13.3.2 Overview on casting faults*.



Iris Eichenberg and Jeroen Bodewits (Germany/The Netherlands), *Table with Red Earthenware*, 2002–2003. Earthenware, porcelain, glass, steel, rubber, wool and rope. W: 110 cm (43 in.). Part of installation. The moulds were rubbed with talc before casting. After firing the traces of talc have become clearly visible on the red brown body. (Photo: Jeroen Bodewits)

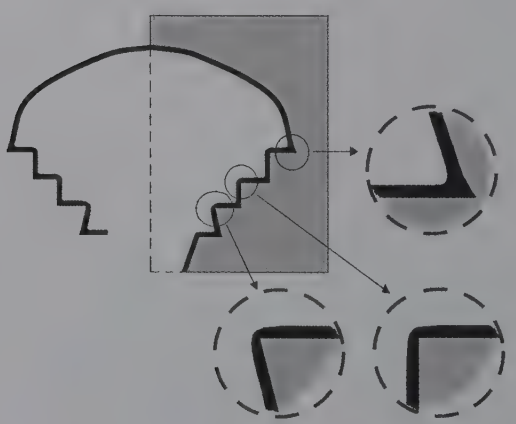


Susan York (USA), 497 *Shards*, 1997. Ceramic and steel. W: 167 cm (65½ in.). Porcelain slip was poured onto a plaster board resulting in thin slabs. The slabs were peeled off, then cut into shapes. Temperature differences during firing caused a slight variation in colour of the unglazed slabs. (Photo: Peer van der Kruis)

After pouring the slip into the plaster mould it is left for a certain amount of time until a sufficiently thick wall has been formed. Wall thickness of small pieces usually does not extend beyond 5 mm (3⁄16 in.), medium-large cast work must be at least 8 mm (5⁄16 in.) to achieve sufficient strength during drying, moving and firing, but also after firing. Regularly cutting tiny pieces off the spare is a way to check. However it should be noted that wall thickness tends to decrease at the top part of the spare. Wall thickness will increase until the pores in the mould are fully saturated with water.

The way a mould must be filled or drained depends on the volume of the mould. As volume increases, the mould can no longer be filled with one bucket of casting clay, and stopping and starting the casting will show on the outside of the final piece. Assistance will be required to be able to cast uninterruptedly. A storage tank (provided with a tap and a hose) placed higher than the mould could be used if working alone. In larger moulds, the mould sections must be bound very thoroughly. The pressure from the inside increases with size, as does the chance of casting slip leaking out of the seams or the mould breaking open.

Figure 5.20
A thinner wall will be formed around a corner as a result of quicker saturation of the mould in these places. This phenomenon will be more pronounced as the sharpness of the angle increases. The opposite occurs with obtuse angles. (Figure: Marc Kohlen)



5.9.1 Limitations in shape

The following phenomenon is characteristic of the casting process; the formation of the wall in a mould that has (sharp) angles will vary, as saturation of the mould will be different in places (see *Figure 5.20*). Angles on a horizontal plane – especially in the bottom part of the form – may lead to an increased chance of deformation as the thinner parts will have to carry the weight of the upper parts. Such a work will require more support if fired to vitrification, especially true for porcelain pieces.

5.9.2 Emptying the mould

Once the required wall thickness has been achieved, the remainder of the slip must be removed from the mould. Pouring out must be done evenly and with care. If it is done too slowly a slightly uneven wall could be formed (especially unwanted in the case of porcelain). Pouring too quickly could cause the newly formed wall, which is still soft, to separate from the mould and collapse inward. The chance of the form collapsing inward is also present in moulds with a relatively small pouring hole, due to the occurrence of a vacuum within the cast form, which causes the wall to be sucked inward. Pouring slowly may reduce



Marek Cecula (Poland/USA), *Scatology Series*, set 3, 1993. Ceramics and stainless steel. W: 50 cm (19¾ in.). Cast porcelain. The mould for this form has a very small pouring hole. This often causes a vacuum during the draining process. A high-gloss glaze was used to give the piece a sanitary quality. (Photo: Len Prince)

this risk, but could possibly cause the formation of a wall of uneven thickness. If a spare is used which tapers toward the form, the spare cast must be cut loose, to prevent the clay cast from getting jammed. This is done after the mould has been emptied, or in the case of a **solid cast**[12] as soon as the clay cast is no longer sticky. If **the pouring hole** is to be closed (see section *5.3.3 Spare*), a small amount of casting slip should be poured back into the mould, a plaster plug is then placed in the spare and the form is turned upside down. The hole is thus filled. The amount of slip poured in should be well controlled. Adding too much slip will make the wall too thick, increasing tension. Too little slip will create a weak spot. **NB:** Make a hole in the work to prevent tension building up and causing an explosion during biscuit firing. Tilting large moulds manually is not an easy job. For this reason, a tilting construction (see *Figures 5.10* and *5.19*) is recommended.

Emptying a mould using a drainage system

The drainage system makes emptying a simple action. At the required moment the plug is taken out and the tap is opened, allowing excess slip to be drained from the mould.

Draining casting slip slowly and gradually from the mould will create a more gradual increase in thickness toward the bottom.

There will be a hole in the clay cast where the drainage hole is located. This hole can be filled (this is not an option if a PVC pipe is used). As soon as all casting slip has been drained and the wall that has formed in the drainage hole has been removed, the plaster plug is put back into place. A small amount of casting slip can then be poured into the mould to fill up the missing part. A calculated amount of slip must be poured in, to prevent too thin or thick a build-up of a wall.

5.9.3 De-moulding

After emptying, the form should remain in the mould until it no longer adheres to the sides of the mould and has gained sufficient firmness. When the piece is no longer sticky to the touch it is usually ready to remove. In general, the form will have gained sufficient firmness in the plastic-stiff stage. In the case of larger pieces the plastic-leatherhard stage would be safer (see *Table 5.9*). A form that gets jammed in the mould during drying will have to be removed from the mould before this stage and then temporary supports should be used to prevent deformation.



Niels van Eijk (The Netherlands), *Blown ups*, 2000. Ht: 14 cm (5½ in.). Cast porcelain glazed with a transparent shiny glaze. The pour-hole at the bottom was closed and a small hole was made to prevent pressure build-up during the biscuit firing. The pieces were glazed all over and so the holes were closed during glaze firing due to the fusion of the glaze. As a result of expansion the thin walls bulged. (Photo: Peer van der Kruis)

Using the air pressure system

Once the form has gained sufficient firmness, all mould sections can be removed, except for the sections that provide the necessary support and the sections that have been provided with the air pressure system. Next, the hose is connected to an air gun. If the air pressure system is equipped with a bayonet catch the catch is connected to an air pressure regulating system allowing a gradual rise in pressure.

The compressor used should supply a minimum of 3 bars of pressure. Starting at low pressure (0.5 bar) it is raised gradually, until the form releases. Releasing the form with as little pressure as possible is preferable, to prevent deformation or – in extreme cases blowing the piece apart, however if pressure is kept too low for too long, the water pressed out of the mould may weaken the clay cast.

5.9.4 Assembling

The assembling of separately cast parts ideally starts as soon as they have been taken out of the mould. The parts should preferably not become drier than plastic-leather-hard. Care should be taken that all parts are equally dry. The areas of contact should be scored and moistened with water. Scoring can be done by using a needle tool or the side of a screw, moistening by using a brush. Next an adhesive slip is added and the parts are put in place by moving them back and forth slightly until 'suction' bonds them together, see section *5.13 Joining and mending*. If assembly does not take place immediately, it is recommended to wrap the parts in a thin plastic sheet. Dry and warm conditions demand more care in wrapping, as the drying process will move along faster.

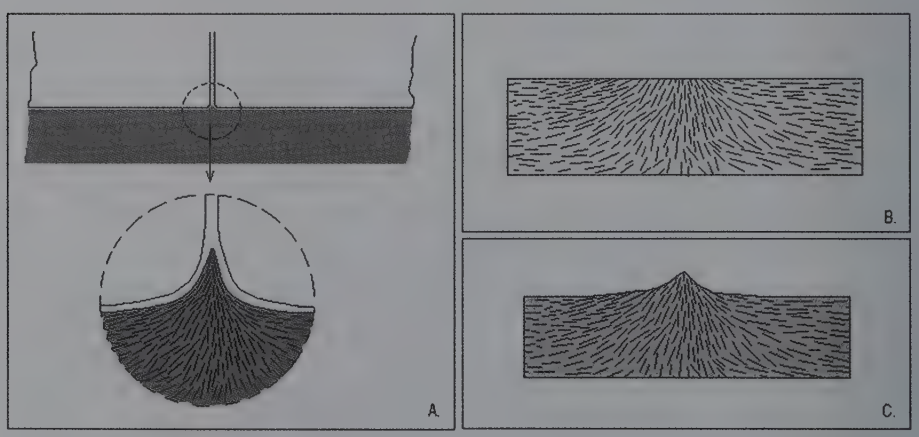


Figure 5.21
The orientation of the clay minerals (A) will remain after the seam line has been removed (B) causing protruding seam lines after firing (C).
(Image: Anton Reijnders)

5.9.5 Finishing

Except for the seam lines and the pouring hole, a clay cast usually requires little finishing. Excess clay from seams and the spare can be removed with a fettling knife (a long pointed knife). Next the surface can be smoothed with a slightly moist sponge. Do not sponge for too long as this may affect adhesion of the glaze (more on this in *Shivering* under section *11.5.2 Faults related to divergent expansion rates*). **Protruding seam lines** may become visible after firing, even if they have been smoothed away. This is caused by the orientation of the clay minerals. Clay minerals have a plate-like shape and show more shrinkage at a right angle than parallel to the direction of the plates, see *Figure 5.21*. This phenomenon occurs especially in a deflocculated slip.

Due to deflocculation the clay minerals are strongly orientated in one direction. Protruding seam lines will be more evident in smooth and straight plain shapes and if a piece has been fired to its vitrification point, especially noticeable in porcelain pieces.

5.9.6 Casting using kiln shelves

Casting very thin (porcelain) slabs, up to 3 mm, may be done on kiln shelves. Kiln shelves are reasonably porous. Placing them at an angle and pouring casting slip on them will produce very thin slabs. It is essential, however, that the cast slab comes off easily. To achieve this the shelf must be treated with a layer of bat wash (kiln wash in American texts) (see *Table 11.1*). This is usually applied to prevent glaze from sticking to the kiln shelf. The best results are obtained by using a clean kiln shelf: no traces of glaze or layers of old bat wash. An even coat of bat wash (approximately 0.5–1mm) is sprayed on the shelf and fired to approximately 1200°C (2192°F). Next, another very thin protective layer is sprayed on top and wiped lightly, producing a very fine layer of powder on the surface. Prior to pouring the casting slip, the shelf and protective layer should be completely dry. Every time the kiln shelf is used this procedure should be repeated. Clay slip drawings can also be made on a kiln shelf prepared in this way by using the slip-trailing method.



Robin Winters (USA), untitled, 1996. Ceramics/orange/drawing. Ht: 55 cm (22 in.). Installation of 'clay drawings'. Drawing with porcelain slip on a kiln shelf using a slip trailer. The pieces were fired to different temperatures resulting in a variation of colour tones.
(Photo: Peer van der Kruis)

5.9.7 Attuning the casting slip

Several flaws could occur during casting. They could be linked to the lack of absorption of the mould, the way of mixing, pouring and draining or too long a storage of the casting slip. A combination of close observation of the slip, the way pouring and draining evolves, examining the cast, and checking the **slop weight, viscosity** and **thixotropy** will provide clues to the best actions to be undertaken to attune the slip. See section *13.3 Testing a casting slip*, for a method of determining viscosity, thixotropy and slop weight and for an overview of the flaws that could occur during casting with advice on how to fine tune the slip.



Sasja Scherjon (The Netherlands), untitled, 1997. Dia: 39 cm (15 in.). This bowl was produced using the press-mould system. The cone-shaped elements would normally get stuck in the mould during removal. The form has been caught in a contra mould while de-moulding to allow it to be turned inside out: the bottom side transferred into the inside. A sinter engobe was applied on top. High biscuit, low glaze firing. (Photo: Peer van der Kruis)

5.10 Press-moulding

Before a multi-sectioned plaster mould is used for the first time, it is recommended to assemble it completely to check if all the sections fit together before the clay body is pressed into the mould. Talc can be used when pieces are difficult to release from a mould and a very thin layer will work satisfactorily. Thicker layers will show after the firing (white traces will be visible on top of an earthenware or stoneware body, shiny traces on top of a porcelain body).

Remember that producing large pieces involves heavy weights. The size and shape of the work determines which preparations must be made. By making a calculation one can get an indication of the amount of sculpture clay required to make a piece, for more information see section *5.4.5 Taking weight into account*. It is important to consider all the required actions thoroughly: filling the mould, taking the form out of the mould, and also drying and firing.

Before starting, the clay body should be checked for consistency and adjusted if necessary, see section *2.6.5 Optimal consistency of a clay body*. A plaster mould without strong water-absorbing properties will reduce the chance of parts (especially those at an angle) coming off prematurely during pressing. If lumps of clay are pressed into such a mould better mutual adhesion will be ensured as no quick drying is involved. The mould may be moistened using a plant sprayer or wet sponge before and during press-moulding to reduce absorption. Avoid saturation or it will take a long time before the form can be taken out of the mould. Mould sections should be press-moulded as much as possible with mould sections in place. If this is not possible the mould sections should be filled in the order of placement: the last mould section to be joined to the whole should be press-moulded last. This prevents a premature release from the mould. The wall of a large form should taper gradually toward the top. This

will reduce the total weight as well as the chance of distortion during drying and firing. A maximum tapering of 5 mm per 50 cm (¼ in. per 24 in.) could be used as a guideline. It is recommended to press and assemble the whole piece in one work session if possible. Long intervals will increase the difference in drying between successive sections and increase the chance of weak adhesion. Temporarily covering edges of the main piece while the other parts are press-moulded is recommended to ensure better mutual adhesion. In large works pressing each mould section could take so much time that roughening the joint surfaces becomes necessary to safeguard good adhesion. This can be done by using a toothed kidney (see *Figure 4.14*). After this, these surfaces must be moistened with water using a brush and covered with a strip of thin plastic wrap (at least 10 cm/4 in. wide). The whole piece should then be covered with another layer of plastic wrap.

A work with a flat, open bottom is best provided with a **flange** (in this case, a ring permanently attached to the inside of the piece which helps prevent distortion). Adhesion between the clay layers during construction of the flange edge deserves extra attention. There is an increased chance of cracks in this spot if it doesn't have proper adhesion.

Two press-moulding methods may be used: the embossing method implies the use of pieces of clay that are embossed into the mould, the slab method implies the use of clay slabs of the size of a mould section. In both cases the method of making is similar to that explained in section *4.3 Slabs and tiles*.

5.10.1 Embossing method

This is a reliable method especially suited for filling a mould that has sharp curves, angles or differences in levels and for large mould sections. Pressing is done directly into the mould or mould section. The embossing method works as follows: a ball of clay of 1–2 kg (2–4 lb) is placed into the mould and flattened with the palm of the hand or a rubber hammer into a slab slightly thicker than the final thickness of the wall. Next, the same amount of clay is made into a coil and placed on top near the slab edge. The coil and slab are smoothed at the outer edge. Next the coil is beaten into the first part, in such a way that it expands outward. See *Figure 5.22 a–c*. In this way, a (mould) section is pressed-moulded in spirals. **Checking thickness** can be done by using a nail or a needle tool. Wrap a piece of tape around the tool at the point where the distance from the point of the tool to the bottom edge of the tape is the same as the desired thickness of the slab, see *Figure 4.9*.

Lumps of clay that are pressed in the mould side by side and only smoothed at the top tend to have poor mutual adhesion so although this method is possibly suited for

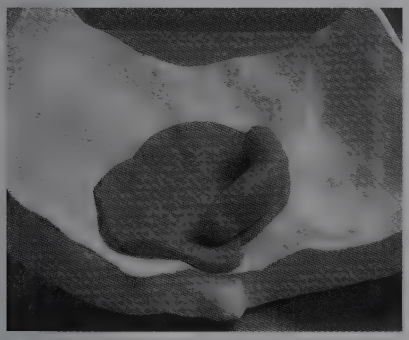


Figure 5.22 a
Embossing method: a coil of clay is placed near the outer edge of a mould section.

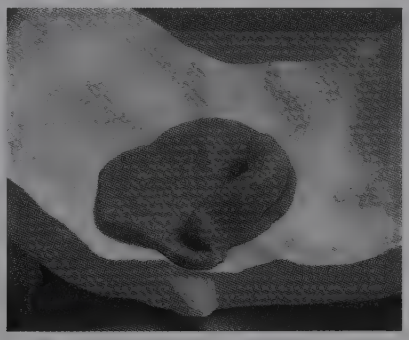


Figure 5.22 b
A slab with the coil partly smoothed at the outer edge.



Figure 5.22 c
Next the coil is beaten into the first part, so expanding the slab outward.
(Photos: Anton Reijnders)



Angel Carraza (Spain), *Emblemas*, 1992. Ht: approx. 200 cm (79 in.). A coarse-grained terracotta sculpture body was used for this piece. The disc shape was press-moulded. The folds and overlaps relating to press-moulding were not smoothed away and as such created a repetitive surface pattern. The black segment has been saggar fired. (Photo: Peer van der Kruis)

small and thin-walled pieces it is not recommended for medium-sized to large work or for work with greater wall thickness in general. This is because there is an increased chance of cracks occurring in places of contact. The embossing method is employed if a rough surface on the inside of a form is not considered a problem, as in sculptures that are entirely closed or open only at the back or bottom.

5.10.2 Slab method

This method works best with mould sections that are not too large (up to 40 × 40 cm/16 × 16 in.) and for shallow forms, but is less effective for mould sections with a strongly divided shape and for filling moulds and mould sections that are hard to reach. This method is also used if a smoother surface on the inside of a shallow form is desired. The clay slabs are made on a piece of cloth according to the embossing method described above and levelled and smoothed if appropriate. After the slab has been placed into the mould section, it is pressed into place from the centre working out with a rubber kidney (see *Figure 4.14*) to obtain a smooth surface if needed, or with the ball of the clenched fist if a less smooth surface is needed. In large mould sections, slabs tend

to become unmanageable so if the slab is placed into the mould while still attached to the cloth it will be easier to handle. The clay side should be laid directly on the mould and the cloth should be removed after the slab has been pressed into the mould.

Filling a large mould with a couple of medium-sized clay slabs is tempting, but extra attention should be given to the proper adhesion of the overlapping areas of the slabs, as these are potential weak spots that may lead to cracks especially in large and complex work. Overlaps also may show after firing, even if the surface seems to have a smooth finish. To safeguard good adhesion and avoid overlaps make sure the slab is larger than the mould or mould section to be filled.

If the mould is very segmented, there is a chance that the slab will become too thin in places during press-moulding or that large folds will be created. Abrupt differences in wall thickness make the work less stable when it is taken out of the mould and cause more tension during drying and firing. For this reason wall thickness should be checked and if needed an extra layer of clay can be added.

5.10.3 Joining

Mutual adhesion deserves attention when a piece is made of several sections. To obtain optimal mutual adhesion, sections should be joined as soon as possible after press-moulding, generally this will be at the plastic-stiff stage.

Joining from within

Joining sections from within the mould by pressing the joints together after the mould sections have been assembled will give the best results. Prior to assembling, the contact surfaces must be roughened and moistened with water. This will lead to better mutual adhesion. If the sections have passed the plastic-stiff stage, applying an adhesive slip becomes necessary (see *Table 5.8* for the adhesive slip).

All sections should be at the same drying stage to prevent the formation of cracks at the joints. As it is often hard, if not impossible, to see into the mould to know where the parts should be pressed together, a small ridge added inside to the edges of the press-moulded section may serve as an orientation. This ridge also gives additional clay needed to mould the sections together properly. See *Figure 5.24 a–b*. Medium to large sized assembled moulds with an opening at the bottom can be tilted to allow joining from the inside.

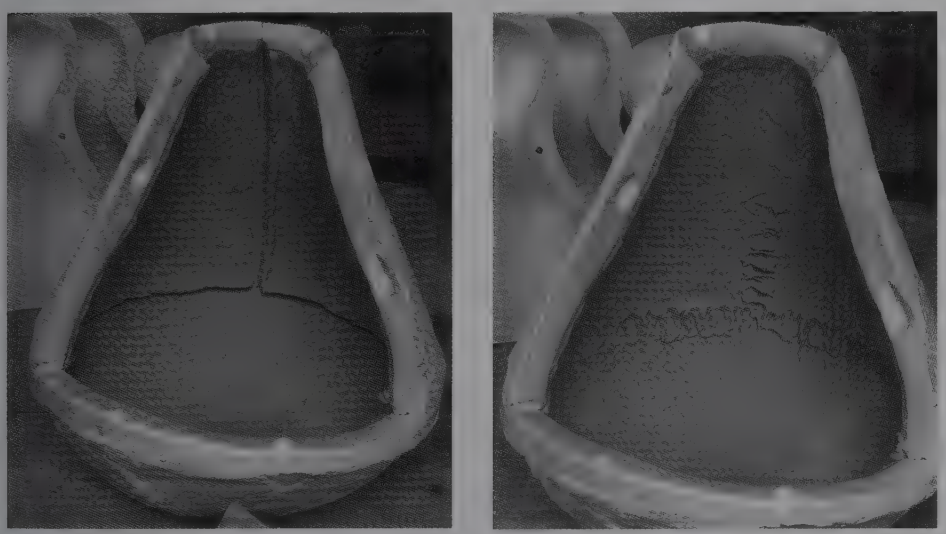


Figure 5.23
Joining from within.
(left) Shows the small ridge added to the edges of the press-moulded sections. This serves as an orientation and gives additional clay needed to mould the sections together properly.
(right) The joints are pressed together.
(Photos: Anton Reijnders)

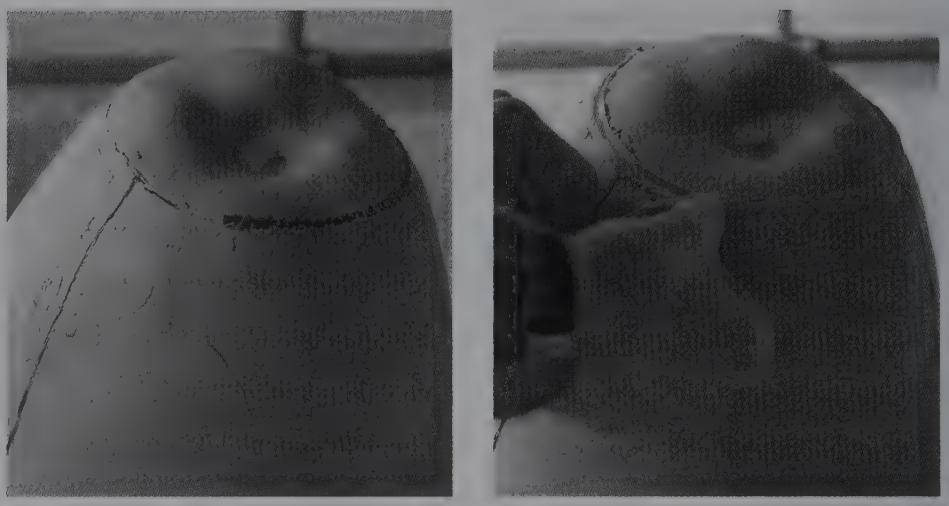


Figure 5.24
Joints that are difficult or impossible to reach are joined from the outside.
(left) The clay on both sides of the seam is scored with the point of a knife.
(right) A groove (made by the handle of a small brush) is filled with clay of a similar consistency.
(Photos: Anton Reijnders)

Joining from the outside

Joints that are difficult or impossible to reach deserve extra attention. This usually occurs when the final mould section is put in place or in the case of a closed two-sectioned mould form. Here joining is done in two stages. First, all the places of contact should protrude slightly and should be scored and moistened. After the sections are put together, they should be pressed tight using a strap or clamps to put the whole under pressure. After the mould sections have been removed, the seams on the outside undergo the final processing to ensure good mutual adhesion. With the point of a knife the clay on both sides of the seam is scored with weaving movements between the two parts, sticking the knife fairly deep into the clay (at least half the wall thickness). Next a thin layer of water or adhesive slip is applied on the seam. Water should be used if the parts have not dried beyond the plastic-stiff stage, adhesive slip if they have dried beyond this stage (see *Table 5.8*). The seam is then pressed down over its entire length with, for instance, the handle of a brush. Water or adhesive slip is applied in the groove thus created and the groove is filled with clay of a similar consistency. Before finishing the seams, they must first be covered with plastic wrap for 24 hours. This will give the entire piece the same consistency all over, and as a result the seams will be less obvious in the final work.

5.10.4 Using moulds made out of other materials

Press-moulding in moulds made from materials other than plaster is done the same way as described above but, due to poor water-absorbing properties, a parting agent should be used. Moulds made of (**silicon**) **rubber or polyester** do not absorb water at all. For this reason flour or a very thin layer of talc[13] is used as a n alternative parting agent. Using a mould made of untreated **plywood** works very well. Several casts can be made without the use of a parting agent. However, after several casts a parting agent will be necessary as fine clay particles will in time settle in the structure of the wood and cause the form to stick to the mould. With a mould of rough wood, the use of a parting agent is required right from the start and mould soap or a clay/soap mixture is recommended.

5.10.5 De-moulding

To obtain the necessary stability the form should be left to dry in the mould for a while. In the case of an open mould the edges at the opening should be covered with a strip

of thin plastic sheet 5–10 cm (2–4 in.). It is preferable to cover only the edges and not the opening, allowing the form to dry from the inside out. In general, the form will have gained sufficient firmness once it has reached the plastic-leatherhard stage (see *Table 5.9*). If the mould or mould sections are removed too soon, the work may deform under its own weight or collapse completely. However, waiting too long before taking the work out of the mould will lead to excessive shrinkage and if the form becomes jammed the chance of cracks occurring will increase, or parts may be caught in the mould when it is opened. If the mould has an open side, drying can be monitored. Large work may still be unstable at the plastic-leatherhard stage, especially the bottom part and leaning forms. Here, the leatherhard stage can be taken as a starting point. Multi-sectioned moulds may be dismantled step-by-step from the top down. This ensures more stability. Here, too, the lower parts should not be allowed to become jammed as a result of progressive shrinkage. Should the work get jammed, the mould will have to be opened prematurely and to prevent deformation, temporary supports will have to be used.

In the case of smaller work where the mould is to be turned upside down to remove mould sections, there is a chance one or several mould sections will be pressed into the work, or come off unexpectedly (and maybe fall to pieces). Only if the mould is sufficiently stable (for instance, if it can be held together easily with straps) should this method be used.

5.10.6 Assembling

The assembling of separate press-moulded pieces starts as soon as they have reached the plastic-leatherhard stage. The areas of contact should be scored and moistened with water. Scoring can be done by using a comb, fork, needle tool or a metal-toothed kidney tool; and moistening by using a brush. Next an adhesive slip is added and the



ABOVE:
David Smithson (USA/Germany), *Column II*, 1999. Ht: 208 cm (81 in.). The press-mould technique was used inside a plywood frame to obtain a perfectly rectangular form. An unbroken pattern of decals was fired on top of a satin glaze.
(Photo: Wolfgang Vollmer, Köln)



LEFT:
Kimpei Nakamura (Japan), *Even Stones Have Sap/A Series of an Exploration of Japanese Taste*, 1991. Ht: 60 cm (23½ in.). A multi-sectioned assemblage of press-moulded, thrown and modelled elements. Sinter engobes, glazes, onglaze, and platinum and gold lustre were used on top.
(Photo: Peer van der Kruis)

parts are put in place, moving them back and forth slightly until 'suction' bonds them together (see section *5.13 Joining and mending*). If assembly does not take place immediately after de-moulding, it is recommended to wrap all parts in a thin plastic sheet. Dry and warm conditions demand protection from warping as the drying process will move along faster. **NB:** The areas of contact should not dry out beyond the leatherhard stage and, to reduce the chance of a poor bond all parts should be equally dry.

5.10.7 Finishing

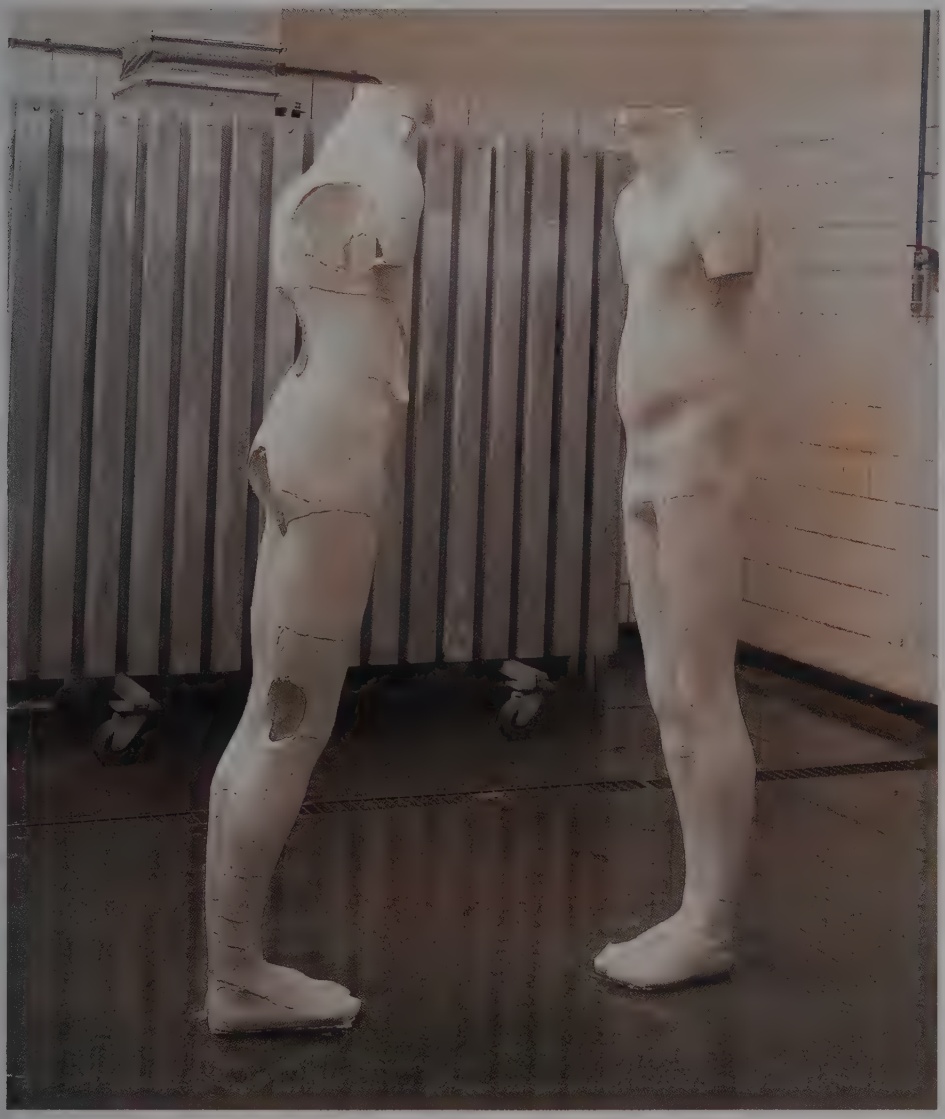
A press-moulded piece will tend to have a somewhat rough surface; folds and overlaps may show on the surface. Traces of the mould seams will be visible anyway if a multi-sectioned mould has been used. These impressions and folds are a feature of press-moulding and may be considered an interesting surface. If this is acceptable, there is no need to rework the surface, as the irregularities are only superficial. However, if a smooth surface is desired, it must be finished in a specific way (see section *5.12 Smooth surface*).

5.11 Plemping

The plemping technique entails spreading or rubbing a plemp body, which has a paste-like consistency, into a plaster mould. It is recommended to assemble a multi-sectioned plaster mould completely before starting this to check that all sections fit together. If clay bodies of different colours are to be used consecutively, one should expect residues to be left in the mould, which may be included in the clay the next time the mould is used. This may be used as an effect, but if one wishes to avoid it, it is better to start with a light coloured clay before using a darker clay body or slip. A very thin layer of talc can be used when pieces are difficult to release from a mould; thicker layers will show after the firing (white traces will be visible on a coloured earthenware body, shiny traces on porcelain fired to the mid-temperature range or higher).

The **consistency** of a plemp body determines whether fine details or rough surfaces will be achieved. If the mould contains fine details, a plemp body with slightly more water will do the details more justice. If the body is less viscous a thick layer can be applied more quickly. Spread the plemp body into the mould a handful at a time. Making a slightly fluttering movement with the hand during plemping will divide the plemp body evenly. Another way of applying the plemp body is with a brush, and this method may be used if a very thin layer is desired. However, it does result in a very fragile form, which must be taken out of the mould very carefully.[14] Because a smooth surface will be difficult to achieve, plemping is used if a rough surface on the inside of a form is not considered a problem as in sculptures that are entirely closed or open only at the back or bottom.

Choosing the plemping technique usually means that most of the mould sections can be put into place first after which they can be filled in, this will ensure the best mutual adhesion. Moistening the mould aids the good adhesion of the sections, reduces the chance that the mould parts come off prematurely and gives better mutual adhesion between applied layers. The mould or mould sections can be slightly moistened with a plant sprayer before and during plemping. If the mould is completely saturated with water then, of course, it will take longer before the form can be taken out of the mould. Forms with an opening at the bottom can be filled from underneath. **NB:** Plemping the work in one session is recommended. Long intervals



Karel Goudsbloem (The Netherlands), untitled, 1997. Ht: 170 cm (66 in.). A piece mould made from a cast of the body of the artist was used for this piece. Two sections were inserted to compensate the loss of height of the final piece caused by the high shrinkage of the porcelain body. The plemping technique was implemented using a porcelain plemp body that contained flax fibres. Holes were cut at the leatherhard stage. The surface was neither smoothed nor glazed, revealing all marks of making.
(Photo: Peer van der Kruis)

increase the possibility of large differences in water content between the various parts, and this in turn increases the risk of poor adhesion.

As discussed before, a work with a flat, open bottom is best provided with a **flange**. To create a flange a mould may be used that supplies this (see *Figure 5.5*). If the work is made directly on a kiln shelf, the flange can be made on the kiln shelf itself, which has sufficient water-absorbing properties. Mutual adhesion of the clay layers during construction of the flange edge deserves extra attention, as tension may increase considerably during drying and firing of large and heavy work.

Avoiding abrupt differences in thickness during construction of the wall will make the work less sensitive to deformation and is beneficial to even drying and firing. For this reason, wall thickness should be checked regularly (*Figure 4.9*) and systematically to maintain uniformity. A large work may be thick at the bottom and taper toward the top (max. 0.5 cm per 50 cm/¼ in. per 24 in.) as this reduces the total weight and the chance of warping during drying and firing.



Mireya Masó (Spain), *Mesas para entenderme*, 1999–2000. Porcelain and metal. W: 125 cm (49 in.). One of a series of four 'table tops'. Porcelain fired to a medium temperature range. A mould fitted with an air pressure system facilitated the release of the form from the mould. A combination of casting (outer layer) and plemping yielded a cast quality. The plemp body contained paper and flax fibres to ensure successful drying and firing. (Photo: Gasull)

5.11.1 Combining casting and plemping

In a shallow mould, or a mould that allows easy access in all places, it is possible to combine casting and plemping. The mould is first filled with casting slip and, after sufficient wall thickness has been formed (about one third of the wall thickness indicated in *Table 1.2*), the mould should be emptied of slip and a plemp layer applied. The entire action must be done quickly and the mould can be moistened slightly to achieve good mutual adhesion of the cast and plemp layer. A combination of the quality of cast work and the benefits of the plemping technique are possible: easy tapering of the wall and the use of flax fibres in the plemp clay body composition.[15]

5.11.2 Joining

If filling the mould is not possible while the mould sections are in place, the sections are plemped in order of placement and the final mould section is filled in last; this prevents them from prematurely coming off during placement of the final section. The plemp body is only applied to a point just below the edge of the first series of sections. Before the next series of mould sections are brought into position, the point of contact is roughened and moistened with some water, as these surfaces will dry quickly. Roughening and moistening will create better adhesion to the next layer, and temporarily covering these surfaces while other sections are moulded will prevent dehydration to some extent. The next series of mould sections are brought into position and the plemp body is applied. It is important to make sure that a good contact with the previous layer is achieved.

Sections that cannot be joined from within require extra attention. Pressing the mould sections together tightly will not achieve sufficient adhesion and so extra finishing is required in the places where the seam lines are located. Follow the directions in section *5.10.3 Joining*.

5.11.3 De-moulding

To obtain the necessary stability of the piece and prevent deformation, the form is left to dry in the mould for a while. In the case of an open mould, the edges of the piece should be covered with a 5 cm to 10 cm (2–4 in.) strip of thin plastic film which should not cover the total opening, in order to allow the form to dry from the inside out. In general, the form will have gained sufficient firmness once it has reached the plastic-leatherhard stage (see *Table 5.9*). If the mould or mould sections are removed too soon, the work may deform under its own weight or collapse completely. However, waiting a long time before taking the work out of the mould will lead to excessive shrinkage. If the form is jammed the chance of cracks occurring will increase, or pieces may be caught in the mould when it is opened. If the mould has an open side, drying of the form can be monitored. Large work may still be unstable at the plastic-leatherhard stage, especially the bottom part and leaning forms. Here, the leatherhard stage must be taken as a starting point. Multi-sectioned moulds should be dismantled step-by-step from the top down, as this ensures more stability. Here, too, the lower parts must not get jammed as a result of progressive shrinkage. Should the work get jammed anyway, the mould will have to be opened prematurely and, to prevent deformation, temporary supports will have to be applied.

5.11.4 Assembling

The assembling of separate plemped pieces starts as soon as they have reached the plastic-leatherhard stage. The place of contact should be scored and moistened with water. Scoring can be done by using a comb, fork or a toothed kidney; and moistening by using a brush. Next an adhesive slip is added and the parts are put in place by moving them back and forth slightly until 'suction' bonds them together, see section *5.13 Joining and mending*. If assembling does not take place immediately after de-moulding, it is recommended to wrap all parts in a thin plastic sheet. Dry and warm conditions demand protection from warping as the drying process will move along faster. **NB:** The areas of contact should not dry out beyond the leatherhard stage and to reduce the chance of a poor bond, all parts should be equally dry.

5.11.5 Finishing

The surface of a plemped form will generally be smoother compared to the press-moulding technique; however, air bubbles may show on the surface, which were created during application of the plemp body, and the impression of the mould seams will be visible in any case. This appearance and the possible air bubbles may be considered an attractive surface, but if a smooth surface is desired the instructions in section *5.12 Smooth surface* can be followed. As already pointed out, the inside of a plemp form will have a rough surface, especially if flax fibres have been added to the clay body, and a smooth finish is not easily achieved in this case.



Daniel Kruger (South Africa/Germany), untitled, 1997. Ht: 27.5 cm (10¾ in.). Cast porcelain vase and various elements assembled at the leatherhard stage. A porcelain terra sigillata was applied on top of the vase to achieve some shininess. The bottom rim and 'photo part' was glazed with a shiny glaze. A decal was applied on the glazed part and a gold lustre on the bottom rim. Collection: Museum voor Hedendaagse Kunst, 's-Hertogenbosch, The Netherlands.
(Photo: Peer van der Kruis)

5.12 Smooth surface

If a smooth surface is desired a kidney is used (see *Figure 4.14*). To prevent staining (this will occur if, for instance, iron or brass tools are used) a stainless steel, rubber or wooden kidney is used. Smoothing should start at the plastic-stiff stage and should be finished before the leatherhard stage has been reached. Starting earlier or waiting longer does not lead to good results. At the plastic-stiff stage the surface is combed with a toothed kidney and then smoothed with a straight kidney by brushing it over the surface at a slight angle. Holes and cavities are best filled with the remaining scrapings. If a very smooth result is desired, the surface should be treated again during the plastic-leatherhard stage, with the kidney held at a shallower angle while brushing over the surface.

5.13 Joining and mending

To obtain strong joints while constructing a piece out of segments it is essential to avoid cracks occurring during drying and firing. For all techniques, including the casting technique, an adhesive slip is used for joining separate parts from the plastic-leatherhard and leatherhard stage onwards. Scoring the place of contact will improve adhesion considerably. *Table 5.9* provides an overview of all drying stages and the related actions. In order to allow the water content within the area of adhesion to homogenise this area is covered with a strip of thin plastic sheet. **NB:** Joining at a stage beyond leatherhard is not recommended; the joints will be less reliable.

5.13.1 Adhesive slip

In principle, an adhesive slip is formed of the same clay body as the work itself, paper fibres and a deflocculant. **Paper fibres** are added to increase adhesion, a deflocculant to minimise the water content and as such the shrinkage of the slip. Because a plemp body contains, by definition, cellulose fibres and deflocculant it is ready to be used as an adhesive slip. So, for the **plemping technique**, no adhesive slip is necessary: the plemp

Table 5.7

Adhesive slip for the casting technique

Casting slip	*Toilet paper*	*Consistency*
		For joining no action needed
1000 ml	+ 7.5 g* (= dry weight)	For filling cracks allow to dry to consistency of stiff paste

Note:

* *Reduce this amount accordingly if paper fibres are already present in the slip.*

Table 5.8

Adhesive slip for the press-moulding technique

Powdered clay body	*Paper pulp*[1] *(1:15)*	*Dolapix PC 67 or Darvan 7 (or 811)* [2]	*Water*
			For joining and mending add water until consistency of yoghurt
100 g	+ 10 g [3]	+ 0.3–0.5 g	For filling cracks add water until consistency of stiff paste

Notes:

[1] *A pulp made of 1:15 paper:water weight ratio.*

[2] *See more about polyacrylate type of deflocculants under section* 8.8.1 Glaze additives. *Instead of a polyacrylate type of deflocculant 0.2–0.3 g of sodium silicate (water-glass) can be used.*

[3] *Reduce this amount by half if cellulose fibres are already present in the clay body.*

body itself can be used to adhere. If no cellulose fibres are present in the press-mould body or casting slip, up to 0.6% of paper fibres may be added (calculated over *dried weight* of the clay body).

To obtain an adhesive slip suited for the **press-moulding technique** the clay body is dried first and crumbled to a powder. Next the paper pulp is made. Ordinary toilet paper is best suited to obtain a homogeneous pulp within a short time. The toilet paper is added to water in a 1:15 weight ratio and blended using a (hand) blender. The pulp is then mixed with the dried clay body (a fork can be used for mixing). Then Dolapix PC 67 or an alternative deflocculant is added, and finally water, until the right consistency is reached as indicated in *Table 5.8*. **NB:** Prevent the adhesive slip from drying out while working.

To obtain an adhesive slip suited for the **casting technique**, toilet paper is torn in bits

Table 5.9

Joining, mending and filling actions

Drying stages	*Characteristics*	*Joining layers of clay*	*Joining sections*	*Mending broken parts*	*Filling cracks*
Plastic	The surface of the piece feels sticky and can easily be dented with a fingertip.	No specific action if clay body has the right consistency.	Add water at places of contact.		
Plastic-stiff	The surface of the piece can still be dented with a fingertip, but does not feel sticky.	Add water at places of contact.			
Plastic-leather-hard	The surface of the piece cannot be easily dented with a finger tip. A mark can be made without any force with a fingernail.	Score and add water and adhesive slip at places of contact.	Score and add water and adhesive slip at places of contact.		Wet down the crack with the point of a brush. Push adhesive slip into crack with pointed knife. Weave clay body on both sides of crack with point of knife. Fill the gap using adhesive slip with the consistency of a thick paste.
Leatherhard	Light pressure is needed to make a mark with a fingernail.				
Leatherhard-brittle[1/2]	Only with extra pressure is it possible to make a mark with a fingernail. A line drawn by a fingernail will show clear edges.		Score, add water, score again, add water again and add adhesive slip at places of contact.		
Dark stage[1/2]	A line drawn with a fingernail gives crumbly edges and clay dust occurs.				
Cold stage[1/2]	A colour change takes place. The clay feels cold.				
Dry stage[1/2]	The clay has the temperature of its environment.				

Notes:

[1] Parts that have been mended after the leatherhard stage tend to have less structural strength.

[2] Repairing cracks that occur after the leatherhard stage will not increase the structural strength of the work. In those cases mending is primarily intended to hide the crack.



Harry Boom (The Netherlands), untitled, 1994. Ht: 100 cm (39½ in.). Various 'found objects' were used to make moulds. The pieces were made by press-moulding slabs of clay into the moulds. They were glazed with a low-temperature shiny base glaze with an addition of zirconium silicate.
Collection: Harry Boom Foundation
(Photo: Peer van der Kruis)

and added to the slip. A (hand) blender is used to mix the slip: a homogeneous slip will be obtained in a short time.

5.13.2 Mending broken parts

An adhesive slip can be used to mend broken parts. Before the parts are mended the places of contact are scored and wetted down with a brush. Repeating scoring and wetting will provide better adhesion for the adhesive slip. *Table 5.9* provides an overview of all drying stages and the related actions. In order to allow the water content within the area of mending to homogenise it is covered with a strip of thin plastic sheet.

5.13.3 Filling cracks

An adhesive slip can also be used for filling cracks that occur before firing. For a very fine crack in a piece made of a coarse clay body (grains larger than 0.425 mm/36's), as can be the case with a clay body used for press-moulding, the dry clay powder should

be sieved first (36's sieve) before the slip is prepared. The crack to be filled is dampened slightly with the tip of a wet brush; the capillary force of the clay will cause the water to be sucked into the crack, providing a better adhesion to the adhesive slip. The adhesive slip is pushed into the crack as deep as possible with the end of a pointed knife. The clay around the crack is mixed with the slip by making weaving movements and pushing the knife reasonably deeply into the clay. The seam is then pressed over its entire length with, for instance, the handle of a brush. The resulting groove is filled with the adhesive slip (having a consistency of a thick paste) in several layers until it protrudes. In order to allow the water content to homogenise the area of mending is covered with a strip of thin plastic sheet. After the filled area has reached a similar dryness to the rest of the piece, the protruding part is removed.

Notes:

1 Forms with an undercut cannot be removed using this method. In such cases a multi-sectioned mould should be used.

2 The air pressure construction will obstruct a decent build-up of a wall if done by flicking layers of plaster as is the case with a sculpture mould.

3 By the time the plaster has cooled down 98% of the entire expansion will have taken place. It will take 24 hours before crystallisation is completed and expansion comes to a full stop.

4 It is recommended to use a pure shellac (which has an orange colour) and not the shellac used for gold leaf.

5 Intermingling of plaster and clay is more likely to happen if the clay model gets drier than this and it will affect the quality of the plaster negatively. Due to the fact that the clay particles settle where the water should combine with the gypsum crystals, crystallisation cannot be properly achieved. This may cause the surface to be mechanically very weak in places and the top layer to be powdery. This renders the mould unusable if details are important in the final cast.

6 A flange also makes it possible to hang a piece on a wall safely.

7 This figure is the outcome of standard volume calculations. It is beyond the scope of this book to go into more detail.

8 The absorbent force of a porous material resulting in the ability to attract water.

9 If a cheap sheet material like chipboard is used it should be treated to make it waterproof.

10 This is not an option if a PVC pipe is used.

11 Therefore the first cast might fail.

12 A piece of limited width (up to a maximum diameter of 2.5 cm/1 in.) could be cast solid; the slip is not drained from the mould.

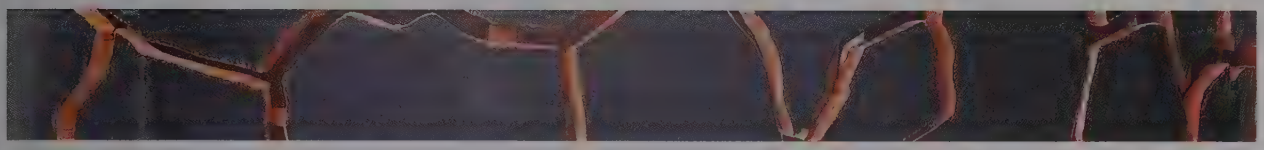
13 A thicker layer would show after the firing: white traces on a coloured earthenware body, shiny traces on stoneware and porcelain bodies.

14 If this method is used, the plemp body must not contain a high percentage of paper fibre (not more than 0.8%), as this increases the chance that the form will be more difficult to remove.

15 Casting slip cannot contain flax fibres; they counteract casting properties.



6 Drying



Drying is a very important link between making and firing and, as it happens naturally, often not much attention is paid to it. In general, small round thin-walled pieces can be dried without needing much attention, but larger, rectangular or complex pieces require more attention. The importance of controlled drying of these large, thick walled, and complex pieces is often underestimated, so experience which has been gained at the EKWC of drying these kinds of pieces is used as a starting point in this chapter. It also will become clear that aspects not directly related to the drying process itself will have an important influence on the outcome.

As a piece is drying a constant exchange of water between the clay particles and the surrounding air is taking place as well as between the clay particles themselves. This exchange can be thought of as a continuous process of striving for an equilibrium. Drying takes place in several stages. As moisture evaporates the clay particles come close together and shrinkage occurs, then at a certain point the particles come into contact with each other, shrinkage stops and more and more pores appear. Although it can take a long time, even a thoroughly wrapped piece will dry. Only when the moisture content in the clay has become equal to that in the surrounding air does the process stop.

6.1 Drying shrinkage

Shrinkage is inevitably linked to drying. The amount of shrinkage depends on several factors. Some factors will lead to an increase of shrinkage, others will reduce the amount of shrinkage. As has been discussed extensively in Chapter 2, the composition of a clay body (specifically the amount of **plasticity** and the **packing density**) determines to a large extent the amount of shrinkage of the piece, but besides the clay body composition there are also other factors that will determine the final shrinkage.

- During the first part of the drying process, up to the end of the plastic-stiff stage, 65% of the shrinkage takes place (see *Table 6.1*). But this will only take place to its fullest extent where shrinkage can continue uninterrupted. In principle, shrinkage is least obstructed at rims and at the edges of a piece.
- Owing to the flexibility of clay at the first stage of the drying process, **weight** determines the amount of shrinkage as well. As the weight of a piece increases the vertical shrinkage of an oblong piece will also increase. On the other hand, shrinkage in

OPPOSITE:
Alexander Brodsky (Russia), untitled, 2000. An installation of unfired clay elements. The pieces are left unfired to exploit the characteristic qualities of colour, texture and fragility of dry clay. (Photo: Peer van der Kruis)

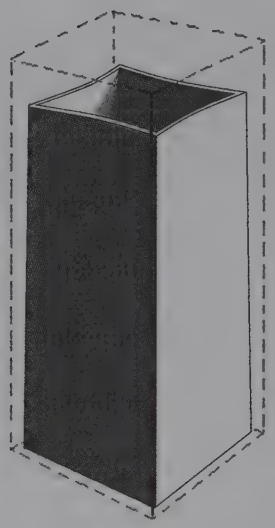


Figure 6.1
Schematic drawing showing the differences in shrinkage. More shrinkage occurs at the top and horizontally than at the bottom. Due to the slower drying on the inside of the piece, the walls could warp; this is more likely to happen if a clay body with a dense structure and high plasticity is used.
(Image: Anton Reijnders)

a horizontal direction at the bottom will decrease; the weight will locally hinder the shifting of the piece towards the centre.

- The way a piece is exposed to the open air also influences shrinkage. The upper parts, the edges of a work and the exterior of an enclosed hollow piece, that are most exposed to the open air, will dry faster and tend to shrink more during the leather-hard stage and up to the dark stage (see *Table 6.1*).
- The **shape** of a piece also appears to influence shrinkage. In general, tiles or slabs that are more long than wide tend to shrink more in the longitudinal direction. (The reason why this happens is not yet understood. It could partly be linked to the method of making (like extruding) and orientation of the clay minerals (like casting), but it also occurs with other methods of making.)

Because of all these factors, the question of how much a piece will shrink is not that easy to answer. The usual way to go about it is to determine the so-called linear shrinkage of the clay body (see Chapter 13). *Figure 6.1* shows what consequences the above-mentioned factors can have on a form during drying.

6.2 Tension build-up

As has been pointed out **rims, edges, top parts** and the **exterior** of a piece tend to shrink more compared to areas further down or inside. If large differences in shrinkage occur within a close proximity in a piece, extra tension will arise. **Flat pieces** are especially subject to tension build-up due to the fact that the top part and edges are exposed to the surrounding air and the bottom part is closed off: as a result warping can occur.[1] Tension build-up also occurs if shrinkage is obstructed. The **bottom parts** of large heavy oblong pieces are especially prone to this. At a certain point tension will exceed what can be absorbed within the piece and cracks will appear. The fact that **rectangular pieces** are less able to absorb tension uniformly in combination with other previously mentioned aspects, makes rectangular and flat pieces more subject to warping and cracking. **Thick-walled pieces** are more prone to tension build-up compared to thin-walled pieces.

6.3 Drying stages

Several stages can be identified during drying. Each stage can be recognised by specific characteristics. All stages are listed in Table *6.1* where an indication as to how these stages can be recognised is given together with approximate percentages of evaporation and shrinkage. These percentages are based on experiments and will differ depending on the clay body used and the specific drying circumstances. In practice, all stages smoothly merge into each other.

6.4 Critical drying phase

A piece is usually well covered once it has been finished but after it has been left to dry for a while impatience wins and the work is uncovered. Often this happens at a critical phase in the drying process and, especially for larger and complex pieces, this could

Table 6.1

Different stages of drying

Stages	*Indications*	*Loss of water*	*Shrinkage*	*Consequences for the piece*	*Drying time*
1. Plastic stage	The surface of the piece feels sticky and can easily be dented with a fingertip.	Up to the end of this stage 20% of the total water loss takes place.	Up to the end of this stage 50% of the total shrinkage (where it takes place freely) takes place.	The movement of water to the surface of the piece is happening without difficulty.	All these stages take ± ¼ of the total drying time, provided drying circumstances stay unchanged.
2. Plastic-stiff stage	The surface of the piece can still be dented with a fingertip, but does not feel sticky.	Up to the end of this stage 25% of the total water loss takes place.	Up to the end of this stage 65% of the total shrinkage (where it takes place freely) takes place.		
3. Plastic-leatherhard stage	The surface of the piece cannot be easily dented with a finger tip. A mark can be made without any force with a fingernail.	Up to the end of this stage 35% of the total water loss takes place.	Up to the end of this stage 75% of the total shrinkage takes place.		
4. Leather-hard stage	To achieve a clear mark light pressure is needed to make a mark with a fingernail.	Up to the end of this stage 40% of the total water loss takes place.	Up to the end of this stage 95% of the total shrinkage takes place.	Clay particles move closer to each other and start to come into contact. There is a chance of the formation of cracks.	
5. Leather-hard-brittle stage	Only with extra pressure is it possible to make a mark with a fingernail. A line drawn by a fingernail will show clear edges.	Up to the end of this stage 45% of the total water loss takes place.	Up to the end of this stage 98% of the total shrinkage takes place.	Clay particles are in contact. The work shows only a little flexibility. This is a critical phase because of an increased risk of cracks occurring.	
6. Dark stage	A line drawn with a fingernail gives crumbly edges and clay dust occurs.	Up to the end of this stage 60% of the total water loss takes place.	Up to the end of this stage shrinking stops.	The work is not flexible any more. This is a critical phase.	This stage takes ±¼ of the total drying time, provided drying circumstances stay unchanged.
7. Light-cold stage	A colour change takes place. The clay feels cold.	The last 38% of water evaporates.		The chance of cracks occurring is reduced.	This stages takes ±½ of the total drying time, provided drying circumstances stay unchanged.
8. Dry stage	The clay has the same temperature as its environment.	The drying process stops. Approximately 98% of the release of water has taken place. Held water is still present.	Readsorption could take place in a work made out of a clay body containing montmorillonite.	If readsorption takes place a slight expansion occurs and cracks could arise.	



Mark Manders (The Netherlands), *Isolated Bathroom*, 2003. W: approx. 450 cm (175½ in.). Painted ceramics and painted cast aluminium, plastic foil, wigs, wood, bathtub, water and pump. The pieces are painted with acrylic paint and then moistened with water and covered with plastic foil. The result is a simulation of the plastic stage of the clay. Collection: Sammlung Goetz, München. (Photo: Wilfried Petzi)

lead to tension and a potential risk of the formation of cracks. Research has shown that there is an increased chance of cracking from the leatherhard stage onwards, and especially at the leatherhard-brittle stage. Before these stages the work has flexibility; all the clay particles are covered with a continuous film of water and all the pores are filled with water, hence any tension caused by uneven drying can be absorbed. Also the movement of water to the surface will be fairly even during the first part of drying. Cracks that do occur before the leatherhard stage are often related to insufficient care in making, such as lack of adhesion between layers or joints and abrupt differences in wall thickness. In the leatherhard, and especially in the leatherhard-brittle stage, the flexibility of the body decreases rapidly due to the absence of a continuous film of water around the clay particles. On top of that the movement of water to the surface is becoming more difficult. As a result, the surface tends to dry faster and shrink more than the inner part of the piece, increasing the build-up of tension. This is a critical stage. Uneven and fast drying during this stage will swiftly lead to cracks even when care has been taken in the making of the piece.



Anne Ausloos (Belgium), *Settled Suspension: Curls*, 2000–2001. Glass, sediment of clay and glaze materials. Ht: 6 cm (2¼ in.). A mixture of clay, iron oxide, feldspar and quartz allowed to settle very slowly. The top layer consists of ultra-fine clay minerals. Due to the extreme differences in shrinkage the form curled during drying and firing. (Photo: Sarah Blee)

6.5 Drying conditions

Avoiding uneven drying conditions is important especially if a dense clay body is used and also when large, rectangular, complex or thick-walled pieces are involved. The following drying conditions will cause uneven drying:

- A heat source on one side over a period of time.
- Draughty conditions.
- Two or more pieces set close together causing more humidity in between them.
- Dry (50% or less humidity) and warm conditions will speed up the drying. Only if humidity is high (85% or more) will drying under warm conditions be more even.
- Exposing a fully dried piece to a very humid environment if a highly plastic clay body containing a fair amount of montmorillonite is used.

6.6 Controlled drying

Equal drying conditions can be created by specific ways of covering the piece and applying a heat source in a controlled way. The following actions will be the key to the successful drying of a piece.

6.6.1 Partial covering with thin plastic sheet

It is important to cover rims, edges of tiles and slabs, rims of cut out holes and protruding areas right from the beginning of the drying process. Also any joints demand extra attention. Covering can be done by sticking strips of thin plastic sheet[2] onto these parts while the piece is still wet. Latex (liquid rubber) applied with a brush could also be used. This works especially well when applied on delicate pieces, or to replace plastic sheet when that no longer adheres because the piece has become too dry. Although the rubber layer can be removed before the firing, it may be better to leave it on to avoid damaging the piece. It will burn away in the firing (but beware of fumes as they can be unpleasant and hazardous).

6.6.2 Newspaper and plastic sheet

After placing plastic sheet around the edges, tiles and slabs are best covered (right from the beginning, or at least from the plastic-stiff stage onwards) with newspaper. This encourages the parts prone to drying slowly (i.e. not the rims and edges) to speed up their drying process. Non-flat pieces are best covered with a 'sack' from the plastic-leatherhard stage onwards. This sack is made by taping together sheets of newspaper with adhesive tape and can be used to cover the entire piece. Avoid gaps between the sheets of newspaper.

6.6.3 An extra layer of plastic

Flat pieces dry very slowly at the bottom. To achieve even drying a sheet of plastic should be added over the top of the newspaper. A work to be dried under dry and warm conditions should be covered as previously described. In the case of open (vessel-like) forms it is enough to hang the newspapers and plastic sheet just over the rim and leave the top opening uncovered. The inside of a piece will always dry slower than the outside and certainly slower than the rims. To increase drying speed the plastic sheet can be removed at regular intervals (for instance, twice every day for 1 to a maximum of 2 hours, after that four times a day and so on). Every time the piece is covered again the moisture distribution within the work will even out. The work can finally be left totally uncovered when the colour change from dark to light has taken place throughout the whole piece.

6.6.4 Drying tent

In dry, warm conditions, or when there is a heat source on one side, or a draught, a very safe way of drying is to construct a drying tent, especially if large and complex pieces are involved. A drying tent is a temporary construction of wooden sticks and thin plastic sheet placed around a piece (see *Figures 6.3* and *6.4*). The idea behind a such a tent is to create an atmosphere of high and even humidity. As a result the difference between the moisture content in the clay and the humidity of the air captured in the tent will be minimised. A drying tent can be constructed around a piece immediately after the piece has been finished or at least at the plastic-leatherhard stage. It is important that the tent is not made too spacious as this could lead to more unevenness in drying. The distance between the tent and the piece should be more or less the same throughout (about 10 cm/4 in. is ideal). Also the tent should be totally sealed. As soon as the clay reaches the 'dark' stage the humidity can be reduced by making some holes at the top of the tent.

6.7 Controlled fast drying

Drying a piece may take a lot of time if tension build-up is to be minimised, however drying pieces faster without this risk is possible as long as the piece is dried uniformly. Drying time can be reduced by keeping the bottom part of the piece open to the air, or by applying an extra heat source by means of a light bulb, hot plate or fan heater. **NB:** Fast drying will require close monitoring; and regular checking that the piece is drying uniformly is important.

6.7.1 Keeping the bottom part open to the air

The bottom part of a piece (where the drying process tends to go slower) can be dried



Sigurdur Gudmundsson (Iceland/The Netherlands), *Blue Planet – Red World*, 1996. Ceramics and steel. Ht: 300 cm (118 in.). Terracotta sculpture clay was placed on top of a metal construction with a thin top layer of plaster. Due to shrinkage and subsequently cracking, separate parts were formed. The cracks allow a sculpture placed inside the piece to be seen. A shiny base glaze was used to which black and blue pigments were added. Collection: Provinciehuis Den Haag, The Netherlands. (Photo: Peer van der Kruis)

faster by placing the work on wooden slats or blocks. This should only be done after the leatherhard stage to avoid deformation. Large tiles, slabs or flat pieces can be placed, or made, directly on a bed of metal bars. At the leatherhard stage every other bar is removed to allow better drying from underneath.

6.7.2 Applying a light bulb

The inside of a work always dries more slowly. If the work has an opening at the top, the drying can be speeded up by positioning a light bulb (40–60 W) centrally inside the piece although, to ensure equal drying, the height of the bulb should be altered regularly.

NB: A light bulb should not be used in combination with methods mentioned in the following sections as due to the condensation of water a short-circuit could arise.

6.7.3 Drying tent and electric hot plate

A drying tent in combination with a hot plate positioned under the piece is ideal for accelerating the drying process without too much of a risk of cracks occurring. The combination of increased humidity and a higher temperature gives faster as well as even drying. This occurs as a result of the following four factors:

- The temperature of the air: warm air is able to contain more water.
- The moisture content of the surrounding air: the moisture content of the air in the tent during the drying process will be very high, therefore differences in moisture content within the piece and at its surface will be minimised.
- The temperature of the work: the higher temperature of the work increases the speed of moisture migrating to its surface.
- The positioning of a hot plate underneath the work will accelerate the drying of the bottom part of the work where normally it dries very slowly.

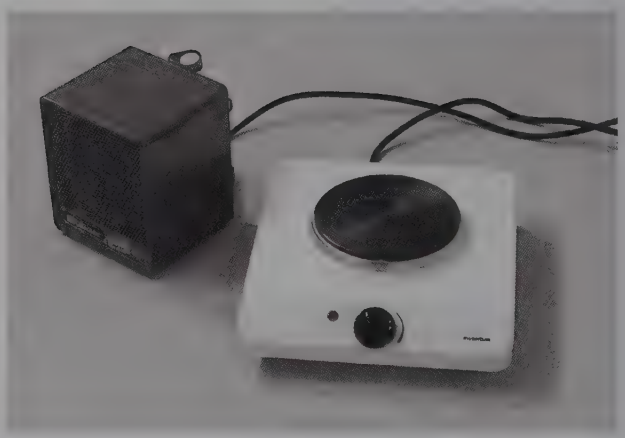


Figure 6.2
A small fan heater and electric hot plate. Both can be used in combination with a drying tent for a controlled fast drying. (Photo: Anton Reijnders)

Because heat is involved, the work is placed on a kiln shelf and each corner of the kiln shelf is placed on wooden blocks. The height of the blocks should allow a minimum of 12 cm (5 in.) between the top part of the hot plate and the kiln shelf. The electric hot plate (provided with a thermostat, see *Figure 6.2*) is placed centrally under the kiln shelf. The hot plate is set on a low setting[3] and the area of the kiln shelf above the hot plate should become warm but not hot. The plastic tent is sealed well to avoid unnecessary loss of heat. NB: A lot of condensation is produced and to avoid water falling on the piece the drying tent should be constructed a bit higher in the middle (see *Figure 6.3*), water can then roll off down the sides. Especially in the beginning, the moisture content of the air in the tent must be kept high but as soon as water droplets become visible little holes should be made at the top to stabilise the amount of condensation. In the 'dark stage' of the drying process the holes can be widened.

NB: During the first two days the hot plate is switched on at regular intervals for a total amount of 8 hours. After two days, 12 hours, and so on. Check the piece regularly to make sure that the bottom is not drying too fast in relation to the rest of the piece. If the drying does proceed faster at the bottom part in comparison to the middle or top part, the total time the hot plate is switched on should be reduced. To stay on the safe side the drying speed could be reduced at the critical stage.

6.7.4 Drying tent and fan heater

As indicated in *Table 6.1* a piece will still hold 40% of the total water content when the light-cold drying stage starts. Due to the fact that water will migrate to the surface with more difficulty the drying process will slow down during this stage. By applying a fan heater (see *Figure 6.2*) the drying time can be considerably shortened. Three important conditions should be addressed: the fan heater should not point directly towards the piece; there should be a large hole at the top of the drying tent (approxi-





mately 5 cm/2 in. in diameter); and the fan heater should be installed in such a way that air is extracted from the room and blown into the tent (see *Figure 6.4*). Initially, the fan heater should not be switched on higher than a quarter of its maximum power.

LEFT:
Figure 6.3
A drying tent construction including an electric hot plate. To avoid drops of condensation falling on the piece the drying tent should be constructed a bit higher in the middle. The space under the kiln shelf is kept intentionally spacious, this then allows room for the use of a fan heater at a later stage during drying. Work in progress by Marien Schouten (The Netherlands).
(Photo: Anton Reijnders)

RIGHT:
Figure 6.4
Drying tent plus fan heater. The heater has been installed in such a way that the air is extracted from the room and blown into the tent yet no heat is blown directly towards the piece.
(Photo: Anton Reijnders)

6.8 When is a piece dry?

Drying of a piece can take a few days or weeks depending on the composition of the clay body used, the size, wall thickness and the drying conditions. However, at what point a piece can be considered to be dry is less easy to answer than one would think. As stated earlier, drying stops when the water content of the piece is equal to that of the surrounding air but if a piece has been dried in a damp and cold environment and then it is moved to a dry atmosphere, the drying process continues again. Also, as pointed out before, the reverse can happen: when a piece is moved from a dry atmosphere to a damper one it can reabsorb water. As a rule of thumb, if the piece no longer feels cold (no colder than the surrounding air) it can be called dry and if it still feels cold the process has not yet been completed. Strictly speaking, the drying process is only really completed during the first stage of firing and this will be discussed in the next chapter.

Notes:

1. The chance of warping is increased if a slab or tile is dried in the same position that it was made; turning after making will result in less warping.
2. Thin plastic sheet obtainable at a hardware store works very well.
3. A higher setting and positioning too closely below the kiln shelf could lead to cracking of the shelf and the hot plate being prematurely subjected to wear.



7 Firing Biscuit



Firing is the essence of the ceramic process. During firing an irreversible transformation takes place; the transformation from clay to ceramic. Clay, once fired, loses its plasticity and, with an increase in temperature, the clay particles (clay minerals and other components) form a strong bond creating a new and durable material. The biscuit firing is the first firing cycle and if a glaze is applied then a second firing, the glaze firing, usually follows it. In this chapter some kiln types will be discussed, followed by aspects related to loading a biscuit kiln and then the firing process itself will be covered.

7.1 Kilns

A so-called front loader (a kiln fitted with a door at the front) is a very common studio kiln design. Most medium to large-sized studio kilns are of this type and small kilns are more often of a top loader type. A front loader with a floor that rolls into the kiln chamber, known as a trolley kiln or cart kiln, makes monitoring from all sides possible during stacking. This is especially advantageous in the case of large and extra large work. The same is true for a so-called top hat kiln: where the entire kiln mantle can be raised and lowered.

This book focuses on two kiln systems: gas kilns and electric kilns. In general, a **gas kiln** is considered to be more suited for firing large and extra large pieces. The radiant heat[1] from the elements of an electric kiln radiates inward from the sides; in a gas kiln, convection circulates heat throughout the entire kiln and therefore creates a more equal temperature distribution (as long as both the kiln design and the method of stacking enable the flames to spread out evenly from the start). One other big advantage of a gas kiln is that it can be used for reduction firing in order to achieve a colour shift in the body and the glaze (see more about this subject in section *11.4 Reduction firing*). Gas kilns can be equipped with different kinds of burners, the main types being: **atmospheric burners** (relying on atmospheric pressure) and **forced air burners** (relying on boosted pressure supplied by a fan). At the EKWC, kilns equipped with a **high velocity burner system** are used: here no burner ports are present as the fan connected to the high velocity burner(s) is the source of the draught in the kiln and the chimney is used mainly for venting combustion gases. This results in less variables to be dealt with, hence firing can be more easy controlled than in more conventional types of gas kilns. Another advantage of this system is that it is well suited to be connected to an integrated safety system, a (semi) automated control system or sometimes even to a programmer or computer that allows controlling of the whole firing from start to

OPPOSITE:
Irene Vonck (The Netherlands), *EKWC # 3*, 1995. Ht: 37 cm (14½ in.). A fine-grained sculpture body used in a fairly wet stage making it very responsive to pushing and cutting. A layer of sinter engobe was sprayed on the surface. Because the piece is almost solid, slow drying and firing were required to reduce tension build-up. A sinter engobe was sprayed on top.
(Photo: Peer van der Kruis)



Figure 7.1
Two gas kilns located in the kiln room at the EKWC. These kilns are fitted with chimneys with double walls serving as a heat exchanger: thus outside air is preheated and led to the high velocity burners. The kilns are entirely computer controlled and have high-quality insulation. All these provisions ensure high energy efficiency.
(Photo: Anton Reijnders)

finish. Because a controlled firing is easier on **electric kilns** a variety of controllers and programmers are available on the market for these types of kilns.

NB: Indoor kilns should be well vented as during firing all kinds of gases are released that can be hazardous to health and an electric kiln especially, having no connection to an outlet, emits all these gases into the room! Gas kilns are by definition connected to a chimney or placed under a hood[2] but still gases will be released as they escape through vents, spyholes and chinks. Therefore, with any type of kiln, the room in which firing takes place should always be well ventilated.

There are two major types of kiln insulation: insulating bricks and fibre blankets. The latter especially have high insulation properties and are therefore very energy efficient. **NB:** Ceramic fibre blankets are suspected of increasing the risk of lung cancer as ultra-fine ceramic fibre dust is formed. This is another reason for ventilating well.

7.2 Loading a kiln for biscuit firing

Due to the fact that unfired pieces tend to be very fragile, loading a biscuit kiln is a precise operation and loading large and complex pieces can be very demanding. The means of transport and the kind of kiln furniture at hand will determine the latitude during stacking. Remember the way a kiln is stacked will have an impact on temperature distribution within the kiln and also within the pieces themselves.

7.2.1 Kiln furniture

The use of kiln furniture makes it possible to stack a kiln with multiple levels making more efficient use of the available space. A large variety of kiln furniture materials is available. The choice for a specific type depends on factors such as peak temperature, carrying capacity (the ability to resist deformation related to the weight of the load), firing speed and budget.

Kiln shelves

Fast firing and cooling will put a higher demand on a kiln shelf. Good quality kiln shelves have a high ratio of aluminium oxide content (over 36%) making them resistant to thermal shock. Conventional kiln shelves increase considerably in thickness as their size increases, this results in more carrying capacity. However, thick kiln shelves (more than 2.5 cm/1 in.) have some great disadvantages:

- High-energy consumption.
- Slow heat absorption during firing and slow release of heat during cooling (causing temperature differences between the point where the piece touches the shelf and higher up in the piece, which worsens as the firing speed increases).
- A higher risk of overburdening one's back when loading and unloading the kiln.

Hollow kiln shelves, so-called extruded batts (see *Figure* 7.2), can be a useful alternative. They combine high strength with lower weight. Another option is shelves made out of re-crystallised silicon carbide (ReSiC) or silicon infiltrated silicon carbide (SiSiC). These types of shelves can be made relatively thin, as they warp less easily. A very important characteristic in their support is even heat distribution within the work due to their good thermal conductivity, thus making fast firing and cooling possible. They are however, quite costly.

Through daily use, kiln shelves can get contaminated with traces of glaze. Ways to prevent shelves from getting damaged will be discussed in section *11.1.1 Protecting kiln shelves*.

Kiln props

Kiln props come in different sizes. Tube props 4 cm (½ in.) in diameter are generally used for small stacks and props 7 cm (2¾ in.) in diameter for medium-sized stacks. For tall multiple-level stacking, firebricks are better to ensure stability: especially if a trolley kiln is used. As firebricks consume a lot of energy, insulating bricks (not the very soft type) could be used instead provided no heavy weight is involved.

Ceramic bars

At the EKWC bars made of ceramic material are frequently used to bridge large spans with a series of kiln shelves resting on them (see *Figure 7.2*). Bars are also used for the firing of large tiles and slabs which rest immediately on the bars, resulting in an even temperature distribution within the work (see *Figure 7.8*). A great deal of experience has been gained with SiSiC bars. Again, the disadvantage is that the bars are very costly. The less expensive high-alumina oxide bars or extruded supports could be used instead.



ABOVE:
Figure 7.2
Packing using extruded batts in combination with SiSiC bars, refractory bricks and refractory columns. Hollow kiln shelves combine high strength with lower weight. The SiSiC bars give support over a large span. Work in progress by Stefan Serneels (Belgium).
(Photo: Anton Reijnders)



LEFT:
Jun Kaneko (Japan/USA), *Expansion*, 1996. Ht: 185 cm (73 in.).The wall of this piece was made by piling and joining pre-shaped slabs. An off-white sculpture body with a coarse grain size fraction was used. A high biscuit and low glaze firing was implemented. Glaze stripes of cadmium red and a shiny base glaze with a whole range of different pigments were added by brush, exploiting the interactions where the lines overlap.
Collection: Museum Jun Kaneko, Omaha, NE, USA.
(Photo: Takashi Hatakeyama)



Mrinalini Mukherjee (India), *Totem I (R) & II (L)*, 1996. Ht: max. 131 cm (51¼ in.). A combination of press-moulding (column) and slab-building (outer forms) was used. Sculpture clay containing terracotta clay and manganese oxide was used for these pieces. Firing to a temperature slightly higher than its vitrification point resulted in a dark brown colour and a slight sheen on the surface. *Totem I*, Collection: Glenberra Art Museum, Jihoji Himeji, Japan (Photo: Peer van der Kruis)

7.2.2 Stacking a kiln

The way a kiln is stacked will influence the heat distribution in the kiln, and also within the piece. The size of the kiln shelves in relation to the inner size of the kiln is an especially important factor. A temperature deviation between top and bottom exceeding 40°C–50°C (100°F–125°F) should be avoided as this increases the risk of tension build-up within a large piece. Using kiln shelves of a smaller size often makes a lot of difference although the work should preferably not extend beyond the shelf as if it gets too close to the burners the chance of cracks occurring is increased considerably. Work positioned close to the elements of an electric kiln will make it necessary to slow down the firing speed. Also the distance between flat pieces and a kiln shelf positioned above, needs attention. If not enough space is left open, and even more so if thick kiln shelves (over 2.5 cm/1 in.) are used, the difference in temperature within the work itself (between the edges and the centre) will increase considerably. As the surface area of a flat piece increases more distance should be kept between the piece and the next shelf. As a general rule of thumb, at least a tenth of the length of the piece should be used to obtain a safe distance (60 cm/24 in. length demands at least 6 cm/2½ in.) of space between the piece and the next kiln shelf). As pointed out, using SiSiC bars is a safer method for firing large slabs and tiles, but expensive.

To obtain a better head distribution the position of a kiln stack could be altered. Altering the distance between the bottom of the kiln and the first kiln shelf could solve the problem.

Placing kiln props or firebricks in line with each other from the kiln floor up will prevent warping or cracking of the kiln shelves. Using three props at a time always gives a stable stack, but if heavy work is placed too near an unsupported corner there is an increased risk of the shelves warping. With four props per shelf one corner is often not well supported,[3] destabilising the stack. To overcome these irregularities and stabilise the stack a thin wad of a refractory clay body can be placed on top of the

props or firebricks before the kiln shelves and/or bars are put into place. By beating each kiln shelf with the fist or a rubber hammer the kiln shelves can then be easily aligned and, as a result, the whole stack will be more stable. It is important to roll the clay wads first in dry aluminium oxide powder, Molochite or silica sand as this makes it easier to remove them after the firing, especially if heavy weights and/or high temperatures are involved.

NB: Because a piece will expand[4] during firing, a space between the top of the piece and the ceiling of the kiln should be left in order to allow this to happen. To stay on the safe side, allow 2% of the total height of the stack or of a single large piece that fits to the height of the kiln.

Loading a combination of kiln shelves and bars

Positioning a combination of kiln shelves and bars, as described in section *3.4.1 Kiln shelf construction*, needs extra attention to avoid torsion and tension in the work, because the forks of a forklift will most often not be perfectly parallel to the stack construction.

Lifting

It is important to neutralise the difference in space between the construction and forks by using, for instance, wooden wedges. To this end, the forks are lifted slightly first, until one fork touches one of the bars. The spaces that exist at the other points, where the forks will touch the bars, should be filled with wedges. Another option is to lift the construction with straps (strong textile bands for lifting great weights) see *Figure 7.3*. In this case, too, the forks should be lifted step-by-step and, to prevent twisting the load, large wooden wedges are inserted between the straps and fork to compensate for any uneven stretching.



Figure 7.3
Placing a construction of kiln shelves and bars with the aid of a forklift truck and straps. Two members of the EKWC technical staff, Rob Ruimers and Peter Oltheten, are discussing the way the piece should be placed. Work in progress by Fortuyn/O'Brien (The Netherlands).
(Photo: Evette Lardinous)

Placing

Before the stack construction is placed the position of the firebricks should be checked: they should be positioned in such a way that the kiln shelves are well supported on each corner, see *Figure 7.4A*. The bricks should be sufficiently high to allow both forks and bars to be removed after loading. During placement into the kiln, twisting of the stack should be prevented by first placing clay wads on the firebricks; this will even out small irregularities. As soon as the stack is lowered and touches one of the bricks lowering is stopped in order to fill in the gap between the shelf and the other bricks. Ceramic wedges, cut out of an old piece of kiln shelf, with an angle grinder, could be used. If

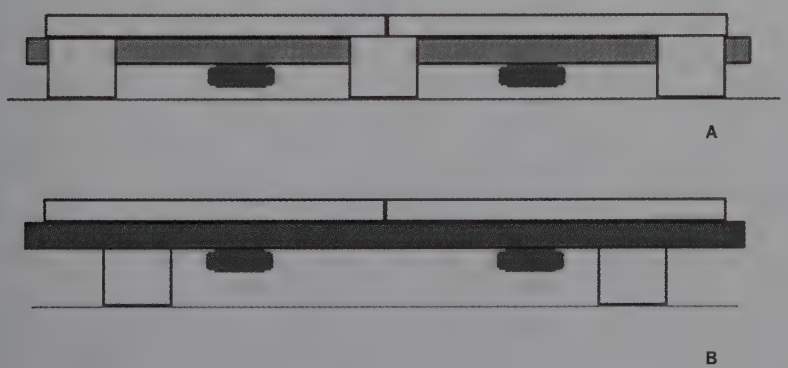


Figure 7.4
A. shows the positioning of a construction of kiln shelves and metal bars on the kiln floor. The bars are removed after placing.
B. shows a construction using SiSiC bars. The bars are positioned on top of firebricks.
(Figure: Anton Reijnders)



Gijs Assmann (The Netherlands), *Self-caricature*, 1997. Ht: 145 cm (57 in.). A coiled piece using a sculpture body provided with extra grog and flax fibres. The glaze surface consists of several layers of coloured glazes on top of which a layer of copper-saturated glaze was poured. Collection: RABO Bank, Amsterdam, The Netherlands. (Photo: Peer van der Kruis)

SiSiC bars are used the bars are positioned on top of the firebricks, see *Figure 7.4B*. Again, to avoid twisting of the stack follow the same instructions as given previously.

7.2.3 Supporting a piece and facilitating shrinkage

Expansion, shrinkage and a possible chance of deformation during firing, call for extra guiding and support of the piece. If shifting during shrinkage is obstructed – often the case at the bottom part of heavy pieces – tension build-up occurs that could ultimately lead to cracking. Therefore the shifting of a piece has to be aided, and supporting a piece during firing is necessary if distortion is expected. The chance of deformation increases as more vitrification occurs, with the weight of a piece and particularly if the weight is concentrated on one spot (for instance overhanging shapes). **NB:** Distortion occurs more readily and at a lower temperature than expected if pressure caused by weight is concentrated on one area of a piece.

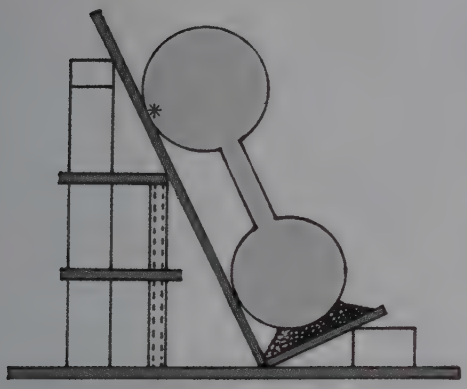
To determine the best position for supporting a piece, the **direction of shrinkage** has to be taken into consideration and as shrinkage is always directed toward the centre of the base on which the work rests a piece can be guided and supported in the ways explained below.

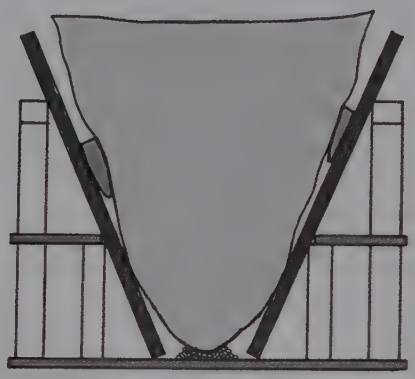
Silver sand (silica sand)

Silver sand is an excellent aid for allowing a work to expand and shrink during firing. The work with a flat base is placed on a number of small piles or rows of silver sand that have been poured on the kiln shelf. If the work is subsequently moved to and fro the form will settle in the sand and find sufficient support. Work without a flat bottom can also be adequately supported by settling it on a pile of sand (see also *Figures 7.5* and *7.6*). Alternatively, a work can be placed in a ceramic 'box' filled with silver sand. The box can be constructed out of clay or kiln shelves (seal up the seams with clay and support the outside with firebricks). First a layer of sand is put into the box, the work is placed on top of the sand, and then more sand is added so that the form is well supported. **NB:** Be sure to wear a dust mask when pouring sand. As the volume of sand that is used increases, the firing speed has to be slowed down to achieve an even temperature distribution within the work. Also a colour difference in reduction firing could occur, as the reduction tends to less easily reach parts that are fully covered with sand.

Kiln shelf strips or bars

Kiln shelf strips or SiSiC/aluminium oxide bars placed at an angle corresponding to the direction of shrinkage can often give good support to the work. In the case of work with a round base, kiln shelf strips may be used along with silver sand. An elongated and sensitive work that is likely to warp can also be supported at a 45° angle or more by an accumulation of kiln bricks, kiln shelf strips, entire kiln shelves or SiSiC bars (see *Figures 7.5* and *7.6*). To obtain support in specific places, clay wads (rolled in aluminium oxide powder, Molochite or silver sand) can be used. A layer of thin plastic





Left:
Figure 7.5
Support by a construction of kiln shelf strips, bricks and props at an angle, using silver sand. To ensure stability the highest point of contact, where the kiln shelf strip supports the work (see asterisk in figure), should be lower than the highest point where the construction supports the kiln shelf strip.
(Image: Rob Ruimers)

Right:
Figure 7.6
Prop with SiSiC bars. The space between the bars and the work may be filled with the prepared clay wad mixture. Between the work and this filling a thin layer of plastic is inserted to prevent damage.
(Image: Rob Ruimers)

should be inserted between the clay wads and the dry work to prevent the work from absorbing water from the clay wads. This will avoid the formation of cracks.

As discussed before, uneven temperature distribution in the work will create tension, especially in large tiles and slabs. Supporting the tiles or slabs with kiln shelf strips instead of placing them flat on the kiln shelf will create a somewhat better heat distribution. Tube props can be used to facilitate shrinkage of the work, reducing the risk of tension (see *Figure 7.3*). The tile can be rolled into the kiln on these tube props while new ones are added. At the EKWC good results have been achieved by placing large tiles on SiSiC bars, see *Figure 7.7*. Leaving ample space between the bars and the kiln floor, kiln shelf, or other work in the kiln will give a more even temperature distribution. A tile or slab can be slid onto the SiSiC bars or, if built on metal bars the tile can be placed into the kiln with the aid of a forklift in such a way that the bars can be replaced one-by-one by SiSiC bars.

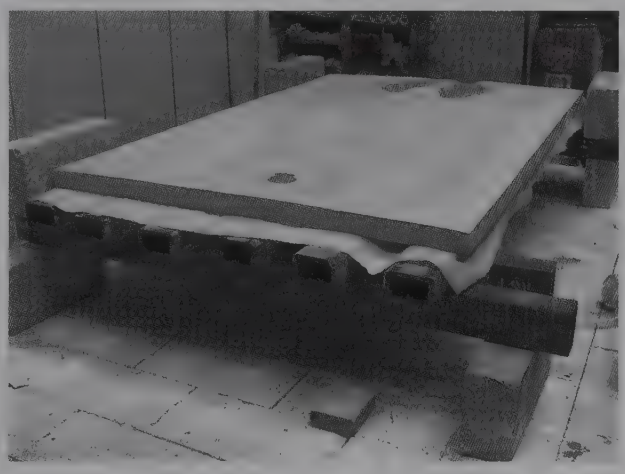


Figure 7.7
Supporting a large tile using SiSiC bars. A layer of silver sand is first put on the bars to facilitate expansion and contraction. The tile has been made on strong canvas cloth. The cloth makes it safer and easier to slide the tile onto the bars. Work in progress by Canan Dagdelen (Turkey/Austria).
(Photo: Anton Reijnders)

Clay props

Clay props are very useful to support a piece, because they shrink similarly to the work. To match the shrinkage they should be preferably made out of the same clay body as the work itself. If the work is fired to a low temperature little sintering will occur and, in this case, placing two layers of newsprint between props and work will be sufficient to prevent them from sticking together during firing. If vitrification is to occur, silica sand can be put between the work and the props to prevent the surface from being damaged when the props are removed after firing.

To prevent the work and props from shrinking in opposite directions during drying or firing, it may be necessary to use the props in combination with a shrinkage slab. A **supporting form** made out of clay, in which a piece is made, dried and fired, could be used for work that would otherwise deform or collapse during making and firing. Such a support is a great advantage, especially for porcelain pieces. The supporting form should be treated with a bat wash (see section *11.1.1 Protecting kiln shelves* and *Table 11.1*) before the piece is started. This will prevent the porcelain piece and support from sintering onto each other. To support a cast work and/or prevent distortion it may be necessary to cast parts which will serve as supports, see *Figure 7.8*.

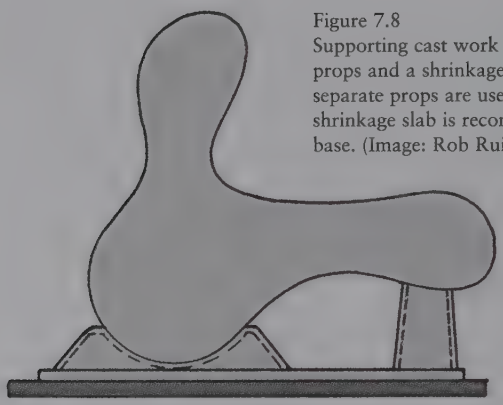


Figure 7.8
Supporting cast work using cast props and a shrinkage slab. As two separate props are used, a (cast) shrinkage slab is recommended as a base. (Image: Rob Ruimers)

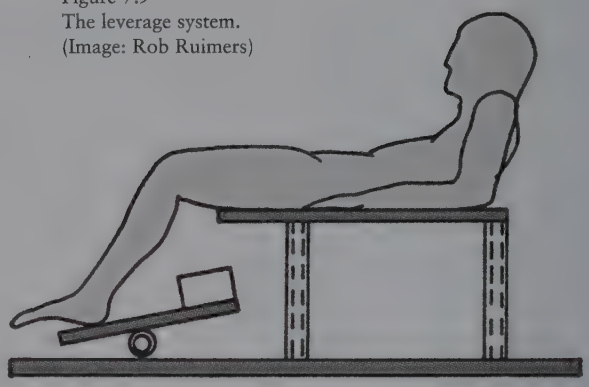


Figure 7.9
The leverage system.
(Image: Rob Ruimers)

Leverage system

With the leverage system the work can also be supported in the direction of shrinkage. Sufficient counterweight will prevent deformation, see *Figure 7.9*.

7.2.4 High biscuit/low glaze firing temperature

Unglazed work is easier to support properly than glazed work if one wants to avoid marks (with glaze at the place of contact the piece and support will melt together). In view of this, work that has to be supported to avoid distortion could be fired first at a high enough biscuit temperature to obtain the desired vitrification, and subsequently glaze fired to a lower temperature. There are several advantages:

- The distortion and the occurrence of marks can be kept to a minimum or avoided altogether as the work can be fully supported during the biscuit firing. Then only

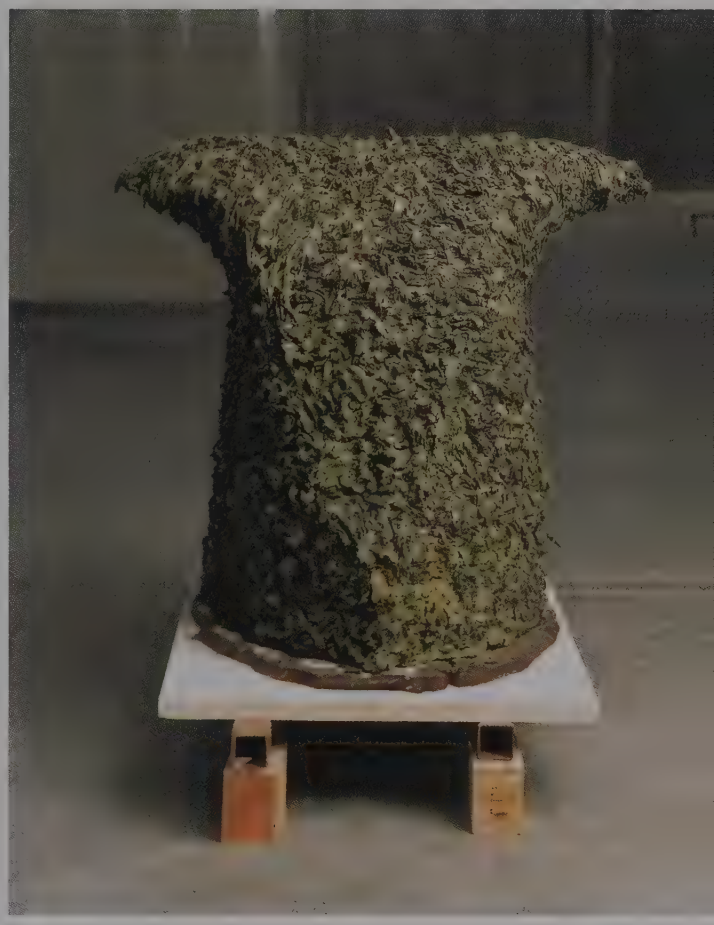


Helly Oestreicher (The Netherlands), *Engels Drop*, 2003. W: 40 cm (15¾ in.). Extruded pipes and coils using a porcelain body containing paper fibres. The coils were flattened using a slab roller. The porcelain was partially stained with yellow and black pigments. All parts were made and fired in a ceramic form to support the piece during drying and firing.
(Photo: Tom Haartsen)

minor or no support is needed during glaze firing as little or no deformation is to be expected at a lower temperature glaze firing.
- High strength of the body can be combined with the larger range of colours of low-temperature glazes.
- Also, some glazes require a more vitrified body anyway to eliminate the possibility of glaze faults occurring (see *Shelling* under section *11.5.2 Faults related to divergent expansion rates*).

7.3 Biscuit firing

It is common practice to have two firing cycles: a biscuit firing and a glaze firing. Compared to once-firing, a piece can be handled more easily during glazing, and a biscuit firing reduces the chance of glaze faults occurring. What is the best way to fire a piece? Evenly increasing the temperature to top temperature and letting the kiln cool naturally is regular studio practice and will often lead to good results in the case of round shapes like pots and small thin-walled sculptures. This, however, will not be the case if larger pieces, flat-shaped and thick-walled pieces are to be fired. At specific stages during firing various reactions take place that could lead to an increase of tension build-up within these kind of pieces and to what extent tension build-up does take place is determined by several factors.



Stina Ekman (Sweden), *The Beast*, 1998. Ht: 85 cm (33½ in.). A plemp body was used to build up this hollow piece. The wall was built by flicking layers of plemp body on top of each other. Due to its fluid consistency and the presence of flax fibres a textured surface was achieved. (Photo: Peer van der Kruis)

7.3.1 What determines the way of firing biscuit?

The composition of the clay body, the dimension and shape of the piece and the speed of firing and cooling are the most important factors that determine the outcome of a biscuit firing. The amount and way water is released during firing (this is linked to the kind and size of clay minerals present in the clay body), the rate of expansion (and contraction) and to what extent gases are formed during firing are also factors. This section will cover the most important reactions and specific aspects that have to be taken into account in order to plan a successful firing cycle. An overview is provided in *Table 7.1*. **NB:** Besides the points already mentioned often insufficient homogeneity of the clay body, constructional flaws and poor drying practice are the cause of faults that may show only after the firing!

Pressure build-up during the water smoking stage

One of the most de-motivating incidents that could happen during the first part of firing, the so-called water smoking phase, is the shattering of parts of the piece or even the whole piece. The reason that this happens is often linked to the build-up of pressure in the piece caused by steam. Water is always present even if the piece has dried fully. The remnant of non-structurally-bound **water of plasticity** present in the tiniest pores between the clay particles, will fairly easily evaporate as the temperature rises. However, **held water** (also known as adsorbed water) and **interlayer water** are bonded



Tony Cragg (England/Germany), *Laibe*, 1991. Ht: 60 cm (23½ in.). For these solid thrown elements a fine-grained sculpture clay containing manganese oxide was used. The brown colour is a result of the low temperature firing. Due to slicing, the piece was not subjected to the great tension build-up during the first part of the biscuit firing that would normally occur in such a solid piece. Collection: Museum voor Hedendaagse Kunst, 's-Hertogenbosch, The Netherlands.
(Photo: Peer van der Kruis)

in a more structural way around, and in, clay minerals (for more information see section *13.1.5 Water/Clay mineral relation*). It takes up to at least 110°C before held water will be fully evaporated and up to 250°C (230°F–482°F) before interlayer water will be evaporated. Air pockets within the piece are often considered to be the main reason for shattering but this is only part of the reason. Too fast a firing at the first stage is the main reason. The chances of a piece shattering will increase considerably, even if no air pockets are present, when the pores are filled with water. Pore water, held water and interlayer water will first of all accumulate in larger pores and in the space between layers of clay (due to a poor bond between layers during making). However, if air pockets or enclosed spaces are present accumulation will of course also take place within these spots. The moment water reaches a temperature of 100°C (212°F) steam is formed and **pressure build-up** begins and as the temperature rises the pressure will increase. If a lot of water is present and/or water cannot escape fast enough the pressure gets too high. As a result cracks form, parts of the work shatter or a total shattering of the piece occurs. More water will be present, and it will take more time for it to reach the surface, if the structure of the clay body is very dense, if a clay with high plasticity is used (where more (ultra) fine clay minerals like disordered kaolinite, illite and montmorillonite are present), or if the wall thickness of a piece is uneven and the piece has not fully dried. If two or more of these factors are present even more pressure build-up will occur and there is a very good chance of the piece being damaged. Only an adjusted speed of firing will then prevent shattering. Research at the EKWC has shown that shattering happens from 160°C (320°F) onwards. A reason why this happens at such high temperatures and not around 100°C (212°F) is linked to the so-called temperature lagging effect.

Temperature lagging effect

The temperature lagging effect is a phenomenon that can considerably influence the outcome of a biscuit firing. It is a variation of temperature within the wall of a piece and between the piece and the kiln atmosphere. A very large difference between the temperature registered on the pyrometer of the kiln and the actual temperature within a piece can occur during biscuit firing; a difference of 50°C (122°F) or more is no exception! There are two reasons for this: (1) heat is very poorly conducted in a piece during biscuit firing (especially up to 700°C/1292°F) and (2) the occurrence of endothermic reactions that take place during biscuit firing.

Endothermic reactions

An endothermic reaction only occurs if energy is present: it uses energy. For example, the release of water during the water smoking stage and during the ceramic change are typical endothermic reactions. As soon as water is released out of the pores, and from the clay minerals, a temperature drop within the piece takes place and as a result a difference in temperature between the core of the work (in the case of hollow work the core of the wall) and its surface arises. *Diagram 7.1* shows clearly two temperature dips as a result of these endothermic reactions. The first one during the **water smoking stage** between room temperature and approximately 200°C (400°F): the release of water of plasticity, held water and interlayer water. The second endothermic reaction occurs during the so-called **ceramic change** between 450°C and 750°C (842°F and 1382°F): the removal of structurally bound water. **Structural water** (also referred to as crystal bound or chemically-combined water) is bound in the structure of the clay minerals. In fact, it is not real water but is formed by the hydroxyl (OH) molecules linked in the structure of the clay minerals. During the ceramic change hydroxyl is released from this structure and forms water molecules. The amount of structural water varies: kaolinite for instance contains much more structural water than illite and montmorillonite (more background information on how water is bound structurally to clay minerals is provided in section *13.1.5 Water/clay mineral relation*). Therefore this reaction is most pronounced if large amounts of kaolinite are present as in a porcelain body. During the ceramic change the structural water in kaolinite is released between 450°C and 650°C (842°F and 1202°F) and it transforms into **metakaolinite**. The release of structural water in illite takes place at similar temperatures, and in montmorillonite between

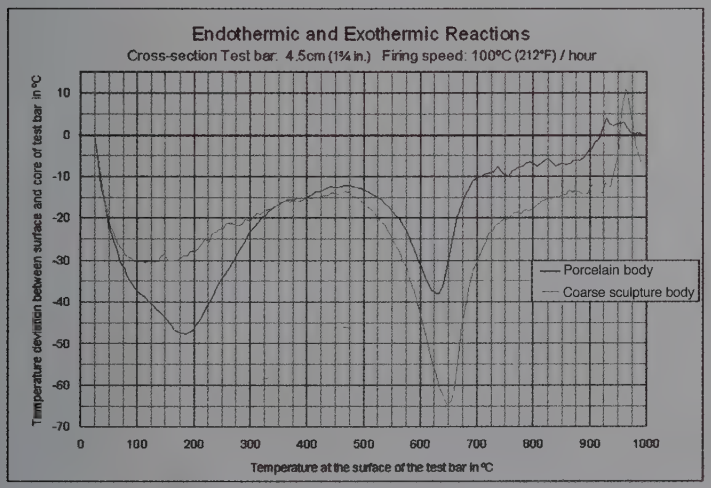
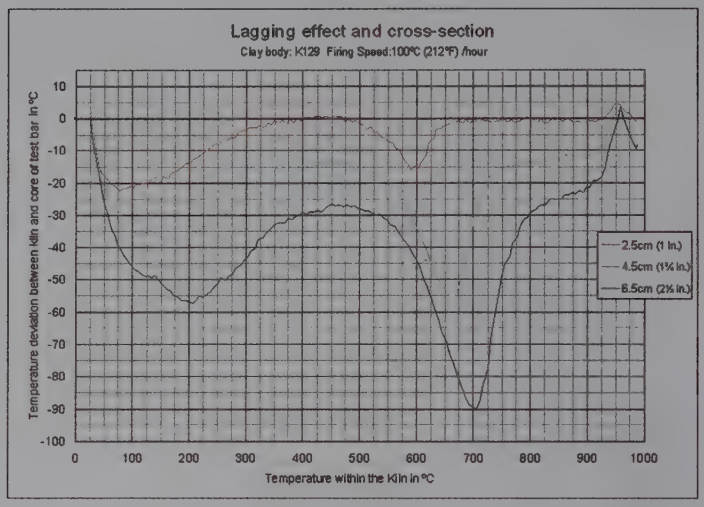


Diagram 7.1
The endothermic and exothermic reactions within two test bars (cross-section 4.5 cm (1¾ in.), one of a sculpture body and the other of a porcelain body. The test bars were fired on a linear slope of 100°C per hour (212°F per hour) up to 990°C (1814°F). The diagram should be interpreted as follows: the X-axis shows the temperature of the surface of the test piece, the Y-axis shows the temperature deviation between the surface and the core of the test bar. It will be seen that, for example, when (after approximately 1 hour of firing) the surface of the test bars has reached 125°C (257°F), the core temperature for the coarse sculpture body bar is 30°C (86°F) below this and for the porcelain bar it is 40°C (104°F) below.



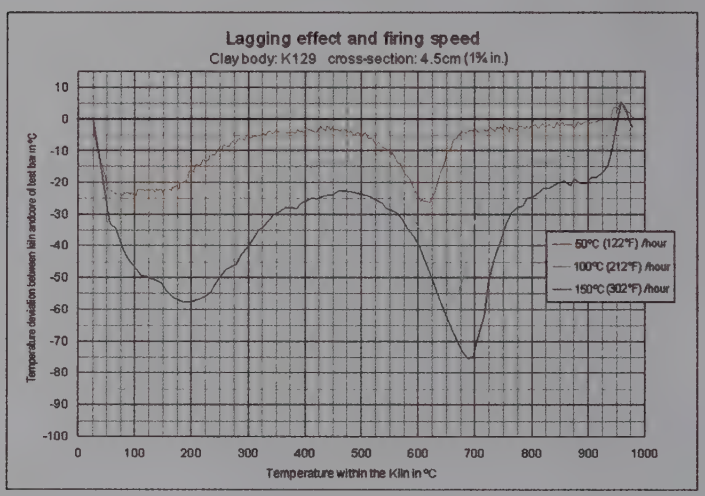


Diagram 7.2 and 7.3
Differences in temperature between the core of a test piece and the temperature of the kiln atmosphere will increase if wall thickness or firing speed increases.

600°C and 750°C (1112°F to 1382°F), but both in a much less pronounced way. This process is referred to as ceramic change because it is an important step in the change from clay into ceramic: clay fired up to 650°C (1202°F) has lost its plasticity.

Also, the structural water will accumulate in pores, spaces between layers of clay, and air pockets. Some pressure build-up takes place but only in extreme cases will this lead to the piece shattering because at this stage of firing the body attains the highest porosity.[5]

Exothermic reaction

Diagram 7.1 also shows two so-called exothermic reactions. An exothermic reaction generates energy, hence the temperature of the core and the outside of the work become more equalised; the core could even become hotter. From 225°C to 600°C (437°F to 1112°F) the disintegration of organic matter takes place, from 500°C (932°F) onwards this reaction is outstripped by the endothermic reaction of the ceramic change.

The second exothermic reaction is the so-called **spinel phase** between 925°C and 975°C (1697°F and 1787°F). Silica is ejected out of the crystal structure of metakaolinite. A clay containing more illite and/or montmorillonite will show a much less pronounced exothermic peak.

Diagrams 7.2 and *7.3* show how an increase of wall thickness and the firing speed have an effect on the lag of temperature between the core and the temperature within the kiln. It is clearly shown that an increase of wall thickness, as well as an increase of firing speed, will result in large temperature differences. The data of these diagrams cannot be relied on directly in practice; the heat distribution in a work, especially at the bottom where a piece sits on a kiln shelf, will not be as even as has been shown during firing of a test piece. Also the inside surface of a hollow form tends to be cooler throughout the firing compared to its outside. Therefore the lagging of the temperature within a wall of 2.5 cm (1 in.) will be even more extreme than in a test piece with comparable thickness.

Quartz inversion

As has been discussed in section *2.1.5 Properties related to firing*, quartz increases the expansion of the body during firing. This expansion does not evolve gradually; instead a sudden increase of expansion occurs during the so-called quartz inversion and is linked to the fact that silicon and the oxygen atoms in the mineral structure of quartz rearrange. It's an inversion from the so-called '**alpha quartz**' (a structure that exists at temperatures lower than 550°C/1022°F) to '**beta quartz**' (a structure that exists only at

temperatures higher than 575°C/1067°F). The peak of the quartz inversion will be at 573°C (1063°F). Whether this will be a critical stage in the firing process depends on the amount of quartz present in the body, the extent of the temperature lagging effect during the quartz inversion, and the shape and size of the piece. A large amount of quartz, in combination with a large variation of temperature within the piece, will result in conflicting expansion in different parts of the work. As a result, an increase of tension build-up within the piece will occur, especially in the case of large tiles or slabs and rectangular, thick-walled and large pieces.

NB: The temperatures provided are not related to the temperatures indicated on the pyrometer of the kiln but are referring to temperatures at which reactions take place within the quartz grains or particles. As has become clear there can be a great difference between the temperature of the kiln atmosphere (indicated by the pyrometer), the actual temperature of the work and within the work itself, due to the temperature lagging effect.



Yang Zhiling (China), *Bad Dream*, 1996. 12 elements (L: approx. 25 cm/10 in. each). A variety of off-white, terracotta and black coloured sculpture bodies were used for these solid modelled pieces. Chinese characters were imprinted at the plastic-stiff stage. All elements were fired to full vitrification. (Photo: Peer van der Kruis)

Vitrification

The composition of the body (and the firing speed) will determine up to what point and at which temperature vitrification starts. Especially where clay minerals like illite and montmorillonite are present it will be noticeable that vitrification starts at relatively low temperatures: approximately 850°C/1562°F. However, if mainly kaolinite and feldspar or nepheline syenite is present, the formation of the liquid melt will start at approximately 990°C (1814°F). As soon as vitrification starts ultra-fine pores are being filled up with a liquid melt resulting in a gradual decrease of porosity. As pointed out, silica is ejected out of the crystal structure of metakaolinite at the spinel phase (between 925°C and 975C°/1697°F and 1787°F). The ejected silica will support the formation of the liquid melt. At this stage the bigger pores and pockets are still inter-connected but as the temperature rises they will all eventually be filled and will no longer be inter-connected; porosity has then reduced to its minimum.

Release of gases

At several stages during firing certain components in the body will decompose (oxidise) and will form new compounds, and hence gases. The most common components are calcium carbonate (limestone or whiting) which oxidises between 800°C and 900°C (1472°F and 1652°F), iron sulphide (e.g. pyrite) which oxidise between 380°C and 800°C (716°F and 1472°F) and organic materials which oxidise between 225°C (437°F) and 650°C (1202°F). A clay or clay body with a light colour after firing but a dark grey/brown colour before firing often contains large amounts of organic material; also, added cellulose fibres increase the total amount of organic material. Large amounts of these components will increase the formation of gases. It is therefore important that



Mark Manders (The Netherlands), *Suitcase with Dog and Pillows*, 1992. W: approx. 80 cm (31½ in.). A solid modelled piece made from a coarse-grained sculpture body. Partly hollowed out. After firing the piece was painted with acrylic paint to obtain the visual quality of unfired wet clay. (Photo: Mark Manders)

these components are fully oxidised before vitrification starts as otherwise the gases will have difficulty escaping from the body, especially a body with a dense structure and/or that vitrify at an early stage (850°C–960°C/1562°F–1760°F). The body becomes pyro-plastic when it is fired up to its vitrification, allowing the pores and pockets to expand: firing shrinkage ceases and expansion will occur if the body is fired beyond its vitrification point. A body that is fired close to or beyond its vitrification point could also be subject to **bloating** (pockets becoming visible on the surface of a piece). Bloating can be caused by the local reduction of iron oxide due to carbon (non-oxidised organic matter) trapped in the closed pores and pockets, and/or the presence of manganese oxide and calcium compounds. The accumulation and formation of gases in the body at higher temperatures also increases the possibility of pin-holes or blisters forming in a glaze that has been applied on top.

Formation of cristobalite

Beyond 1100°C (2012°F), but especially above 1200°C (2192°F), quartz can convert into cristobalite. Cristobalite and quartz are chemically identical but their molecular structure is different (a slightly different position of oxygen atoms in relation to the silicon atom). This conversion is an irreversible and gradual process: once cristobalite is formed, it remains cristobalite. The conversion to cristobalite will lead ultimately to an increase of contraction during cooling, this will be discussed in more detail under *Cooling speed* below.

Expansion, contraction and firing shrinkage

Heating will cause most materials to expand at a specific rate and cooling will result in contraction again, so this is a reversible process and most materials used to compose a clay body will conform to this. The amount of expansion and contraction is referred to as the **expansion rate**, and varies for each material, therefore the composition of the clay body determines the rate of expansion and contraction. A high expansion rate requires an adjusted firing and cooling speed to reduce tension build-up within the piece. As has been pointed out, quartz and cristobalite will increase the expansion rate considerably whereas Molochite will reduce the expansion rate of a body. Provided a piece is fired to a sufficiently high temperature (generally this will be above 1100°C/2012°F) nepheline syenite will fuse a substantial amount of quartz and, if present, also cristobalite. Quartz and any cristobalite will be fused even more actively, and at a lower temperature, if a clay is used containing a fair amount of illite. This fusion will be very beneficial as during cooling and possible next firings the piece will be less subjected to the quartz and cristobalite inversion.

Besides expansion and contraction, **firing shrinkage** due to vitrification also occurs. Vitrification causes all particles and grains, that make up the body, to move closer together and the body becomes more dense. Shrinkage due to vitrification is an irreversible process unlike contraction that will be followed by expansion as soon as the piece is heated again.

Expansion, firing shrinkage and contraction will result in the shifting of the piece during firing and can cause an increase of tension build-up within the piece.

Firing speed

As has become clear, firing speed should be slowed during the water smoking phase in order to allow water to evaporate and prevent pressure build-up. Because shattering does not occur before 160°C (320°F) soaking at 140°C (284°F) could be implemented, and this will be more effective compared to, for instance, 90°C (194°F) as water will evaporate more readily at a higher temperature. Slow firing should then be continued up to approximately 275°C (527°F) to allow interlayer water to escape. During the ceramic change (450°C–650°C/842°F–1202°F) and especially during the quartz inversion (550°C–575°C/1022°F–1067°F) the firing speed should again be slowed down, especially in the case of thick-walled pieces, tiles, and large and complex work. This will reduce the temperature difference caused by the endothermic reaction and conflicting expansion in different parts of the work will be minimised due to less tension build-up within the piece.

The rate of temperature rise will also influence the extent of vitrification, particularly crucial is the rate of temperature rise during the last phase, approximately the last 200°C (400°F) up to the top temperature. Very slow firing is supposed to increase the rate of cristobalite formation.



Thomas Ankum (The Netherlands), *Temporary installation*, 1994. Various dimensions. Press-moulded pieces. A black sinter engobe was applied on the surface of the vertical pieces. A shiny glaze and platinum lustre was used on the horizontal pieces. The multiple-sectioned piece on the left and the rectangular piece demanded a controlled firing and cooling to reduce tension build-up. Collection (the piece at the back): Museum voor Hedendaagse Kunst, 's-Hertogenbosch, The Netherlands.
(Photo: Peer van der Kruis)

Fast firing and improper stacking of the kiln tend to increase temperature differences within the kiln. A **temperature difference** of more than 40°C–50°C (100°F–125°F) between 500°C–650°C (932°F–1202°F) will also contribute to tension build-up within a large piece.

Cooling speed

During the first part of cooling, vitrification will still continue; a slow cooling will therefore result in a slightly more vitrified body. Components that have been fused into a glassy state and filled up the fine pores make the body somewhat flexible, hence the body is fairly stress resistant in the first stage of cooling. From 750°C–700°C (1382°F–1292°F) downwards the body becomes more rigid and, as such, much less resistant to stress.

Natural cooling

In a down-draught kiln provided with **atmospheric burners**, the burner ports, vents and spyholes should be closed from 750°C (1382°F) downward to avoid any cold draughts. From there on the temperature difference within the kiln should be less than 30°C–40°C (86°F–104°F) as otherwise this will contribute to an uneven temperature distribution within a piece. Closing the damper of the chimney will slow down the cooling speed and reduce differences in temperature distribution. **NB:** Closing the

chimney is not necessary in the case of gas kilns equipped with high velocity burner(s) – there are no burner ports so no draughts can occur. The vents of an **electric kiln** should also be closed from 750°C downwards.

All quartz that has not been taken into fusion with other components or has not been converted into cristobalite will invert around 560°C (1040°F) and because the body is less resistant to stress a fast cooling during **quartz inversion** could lead to a tension build-up and as such to the formation of cracks. If **cristobalite** is present in the body[6] it will invert around 225°C (437°F). If it is suspected that cristobalite is present, extra-slow cooling will be necessary for larger and complex pieces during these stages to prevent extra tension build-up.

Natural cooling will be fast in small kilns; if the kiln is only partially filled, not many kiln shelves are used; or, one work fills the whole kiln. Also the type of kiln insulation will influence the cooling speed. Kilns constructed out of insulation bricks tend to cool much slower than those with fibre blanket. Fast cooling may cause an uneven temperature distribution within the piece and in those cases a controlled cooling could be necessary, see section *7.3.2 Planning a biscuit firing cycle.*

Opening the kiln

The moment of opening the kiln should be chosen carefully because a cold draught will hit the work on one side as soon as a vent or door is opened. This may cause conflicting contractions in different parts of the work, creating extra tension. At what temperature the kiln can be opened safely depends on several factors: the amount of tension that has built up during the firing and cooling; the expansion rate and therefore the rate of contraction of the body (see section *13.2.7 Determining the expansion rate* to get a rough indication of the expansion rate); the wall thickness and complexity of the work; and whether thick kiln shelves have been used. To stay on the safe side it is best to open the kiln at a low temperature (possibly as low as 100°C/212°F or even 50°C/122°F in the case of large pieces).

7.3.2 Planning a biscuit firing cycle

There are no strict rules on how to fire a piece. As has been pointed out, small pieces could be fired in a simple linear slope to the top temperature followed by natural cooling. As the size and complexity increases, and for slabs and tiles, a reduced firing and cooling speed at specific phases could be implemented. Slowing down when necessary and speeding up where possible will reduce the tension build-up within the piece and will reduce the total firing time and firing costs considerably. *Diagram 7.4* shows

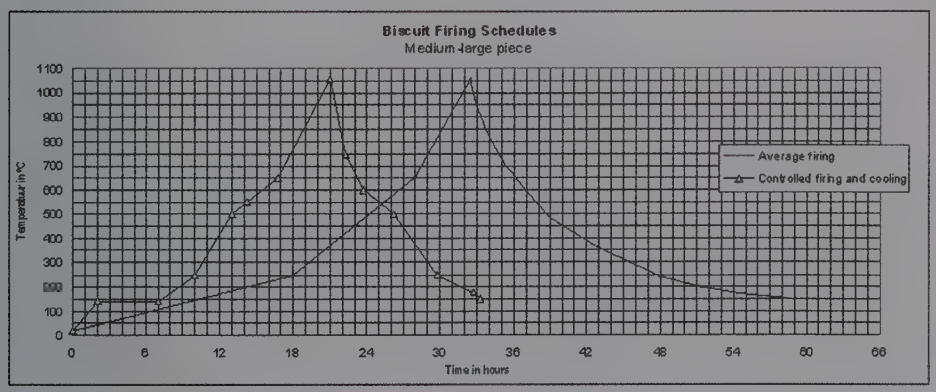


Diagram 7.4

Table 7.1

Phases during biscuit firing

Temperature	*Reaction within the body*	*Firing and cooling speed*
20°C–140°C (68°F–284°F)	Release of water of plasticity and held water. Interlayer-water starts to vaporise.	Moderate firing speed as wall thickness increases and body is more dense.
140°C–180°C (284°F–356°F)	Release of interlayer-water. Increased build-up of pressure. This is a critical phase. Soaking will reduce the chance of too much pressure and the temperature lag within the piece.	Prolonged soaking needed as wall thickness/complexity of the piece increases, in the case of tiles and if the body is more dense. This will prevent the piece from shattering.
180°C–250°C (356°F–482°F)	Release of interlayer-water. Increased pressure in the case of thick-walled pieces. From 225°C (437°F) onwards organic materials in the clay body start to oxidise.	Moderate firing speed as wall thickness/complexity of the piece increases, in the case of tiles and if the body is more dense.
250°C–500°C (482°F–932°F)	Organic matter and iron sulphide oxidise, there should be sufficient oxygen in the atmosphere to support oxidising.	As the amount of organic matter and iron sulphides increases firing speed should be moderate, otherwise firing speed can be increased.
500°C–550°C (932°F–1022°F)	Release of crystal bound water begins causing a temperature lag within the piece.	Firing speed should be slowed down as wall thickness/ complexity of the piece increases, in the case of tiles and if the body is more dense.
550°C–650°C (1022°F–1202°F)	Increased release of crystal bound water. Around 575°C (1067°F) quartz inversion begins. Possible release of gases due to oxidation of limestone, organic matter and iron sulphides.	This is a critical phase. Slowing down the firing speed will reduce tension and temperature lag within the piece. If a high proportion of free quartz is present in the body the firing speed should be extra slow.
650°C–850°C (1202°F–1562°F)	Release of gases due to oxidation of limestone, organic matter and iron sulphides continues.	A lot of organic matter present in the body calls for a moderate firing speed to allow full oxidisation. This is especially important with thick-walled pieces (more than 2.5 cm/ 1 in.), enclosed pieces and dense bodies. To reduce the chance of pin-holes occuring soaking at 850°C (1562°F) could be implemented. Otherwise firing speed can be increased.
850°C–top temp. (1562°F–)	At temperatures higher than 1100°C (2012°F) an increased conversion of cristobalite will occur. Possible fusion of quartz and cristobalite depending on the clay body composition.	Firing speed can be increased. The top temperature should exceed at least 900°C (1652°F) to achieve a minimum of firing strength.
Top temp.–750°C (–1382°F)	Components that have been fused into a glassy state and filled up the fine pores make the body somewhat flexible.	Fast cooling possible.
750°C–600°C (1382°F–1112°F)	Components that have been fused into a glassy state become rigid.	In the case of small pieces, natural cooling could be implemented. Medium-large and larger pieces, complex pieces and tiles will need a controlled cooling.
600°C–500°C (1112°F–932°F)	Increased contraction takes place around 565°C (1049°F) due to quartz inversion. This is a critical stage.	Slowing down the cooling speed will reduce temperature lag; as a result less tension will occur within the piece. This is especially important if the amount of quartz present in the body is high and in the case of large and complex pieces and tiles.
500°C–250°C (932°F–482°F)		Cooling speed can be increased.
250°C–175°C (482°F–347°F)	If cristobalite is present in the body cristobalite inversion takes place, usually around 225°C (437°F).	Slowing down the cooling speed will reduce temperature lag; as a result less tension will occur within the piece. This is especially important if cristobalite is expected to be present in the body and in the case of large and complex pieces and tiles.
175°C–50°C (347°F–122°F)	Premature opening of the kiln door can cause tension in the work, especially if the body has a high expansion rate.	

Table 7.2

Biscuit firing cycle of medium-sized pieces

Medium-sized pieces Body: dense structure/average expansion rate **If controller has limited amount of sections**	
Temperature	*Time[1] (hr:min)*
20°C–250°C (68°F–482°F)	5:00[2]
250°C–500°C (482°F–932°F)	1:30
500°C–650°C (932°F–1202°F)	3:00[3]
650°C–Top temperature (1202°F–Top temp.)	100°C (212°F)/hour
Natural cooling Open kiln preferably below 150°C (302°F)	

Medium-sized pieces Body: dense structure/average expansion rate	
Temperature	*Time[1] (hr:min)*
20°C–140°C (68°F–284°F)	1:00
140°C (284°F)	1:30[2] soaking
140°C–250°C (284°F–482°F)	1:00
250°C–500°C (482°F–932°F)	1:45
500°C–550°C (932°F–1022°F)	0:30
550°F–650°C (1022°F–1202°F)	1:30[3]
650°F–Top temperature (1202°F–Top temp.)	100°C (212°F)/hour
Natural cooling Open kiln preferably below 150°C (302°F)	

Medium-sized tiles Body: dense structure/average expansion rate	
Temperature	*Time[1] (hr:min)*
140°C (284°F)	1:00
140°C (284°F)	2:00[2] soaking
140°C–250°C (284°F–482°F)	1:25
250°C–500°C (482°F–932°F)	2:00
500°C–550°C (932°F–1022°F)	0:45
550°F–650°C (1022°F–1202°F)	1:45[3]
650°F–Top temperature (1202°F–Top temp.)	100°C (212°F)/hour
750°C–600°C (1382°F–1112°F)	250°C (482°F)/hour
Top temp–750°C (Top temp–1382°F)	0:45
600°C–500°C (1112°F–932°F)	1:45[3]
Natural cooling. Open kiln preferably below 150°C (302°F)	

Notes: Adjusted firing speed.

*[1] In the case of **simple forms**, multiply time in all sections by 0.9, **except sections indicated with darker shading**.*

*[2] If a body with an open structure is used, multiply indicated time by 0.7. For a body with a **very dense structure** the indicated time should be multiplied by at least 1.5 (see section* 13.2.10 Determining the structure of a clay body*).*

*[3] If the body has a **high expansion rate**, multiply indicated time by 1.5; a **low expansion rate** multiply indicated time by 0.7 (see section* 13.2.7 Determining the expansion rate*).*

a conventional way of biscuit firing a medium-large piece and a typical firing slope if the aspects discussed previously are taken into account. *Table 7.1* provides an overview of all phases and *Tables 7.2* and *7.3* can be used as a starting point to compose one's own firing cycle.

Despite a well-planned firing cycle the firing of medium and large pieces will still take a considerable amount of time so having a controller and programmer at one's disposal will makes things easier. Programmers have a variety of sections available, programming a firing schedule. For firing medium-large up to extra large pieces a controller with an option of 12 or more sections is preferable. As pointed out, the **cooling speed** is very much determined by the type of kiln and the weight of the load if natural cooling is implemented: cooling will be slower as the load increases. Natural cooling tends to be very slow from 500°C (900°F) downwards. If the kiln is not equipped with a system for controlling cooling (as is the case with most kilns) patience is required, because the natural cooling of a kiln becomes increasingly slower at low

Table 7.3

Biscuit firing cycle of medium-large up to extra large pieces

Medium-large pieces[1] Body: open structure/average expansion rate		***Large pieces*** Body: open structure/average expansion rate		***Extra large pieces*** Body: open structure/average expansion rate	
Temperature	*Time*[2] *(hr:min)*	*Temperature*	*Time*[2] *(hr:min)*	*Temperature*	*Time*[2] *(hr:min)*
20°C–140°C (68°F–284°F)	2:00	20°C–140°C (68°F–284°F)	3:00	20°C–140°C (284°F)	5:00
140°C (284°F)	5:00 Soaking	140°C (284°F)	8:00 Soaking	140°C (284°F)	13:30 Soaking
140°C–250°C (284°F–482°F)	3:00	140°C–250°C (284°F–482°F)	5:00	140°C–250°C (284°F–482°F)	8:30
250°C–500°C (484°F–932°F)	3:00	250°C–500°C (484°F–932°F)	5:00	250°C–500°C (484°F–932°F)	8:30
500°C–550°C (932°F–1022°F)	1:15	500°C–550°C (932°F–1022°F)	2:00	500°C–550°C (932°F–1022°F)	3:30
550°C–650°C (932°F–1202°F)	2:30[3]	550°C–650°C (932°F–1202°F)	4:00[3]	550°C–650°C (932°F–1202°F)	6:45[3]
650°C–Top temperature (1202°F–Top temp.)	100°C (212°F)/hour	650°C–Top temperature (1202°F–Top temp.)	60°C (140°F)/hour	650°C–Top temperature (1202°F–Top temp.)	60° C (140°F)/hour
Top temp.–750°C (Top temp.–1382°F)	250°C (482°F)/hour	Top temp.–750°C (Top temp.–1382°F)	200°C (392°F)/hour	Top temp.–750°C (Top temp.–1382°F)	150°C (302°F)/hour
750°C–600°C (1382°F–1112°F)	1:30	750°C–600°C (1382°F–1112°F)	2:00	750°C–600°C (1382°F–1112°F)	3:30
600°C–500°C (1112°F–932°F)	2:30[3]	600°C–500°C (1112°F–932°F)	4:00[3]	600°C–500°C (1112°F–932°F)	6:45[3]
500°C–250°C (932°F–482°F)	3:30[4]	500°C–250°C (932°F–482°F)	6:00[4]	500°C–250°C (932°F–482°F)	10:00[4]
250°C–175°C (482°F–347°F)	3:00[3/4]	250°C–175°C (482°F–347°F)	5:00[3/4]	250°C–175°C (482°F–347°F)	8:00[3/4]
175°C–150°C (347°F–302°F)	0:30[4]	175°C–100°C (347°F–212°F)	2:00[4]	175°C–50°C (347°F–122°F)	6:45[4]

Notes: Adjusted firing speed.

[1] *If a clay body with a* ***dense structure*** *is used the firing cycle for large pieces should be followed (see section* 13.2.10 Determining the structure of a clay body*).*

[2] *In the case of* ***simple forms****, multiply time in all sections by 0.9; for* ***tiles and slabs****, multiply time in all sections by 1.25; except sections indicated with darker shading.*

[3] *If the body has a* ***high expansion rate****, multiply indicated time by 1.5; a* ***low expansion rate*** *multiply indicated time by 0.7 (see section* 13.2.7 Determining the expansion rate*).*

[4] *Or natural cooling could be implemented if the cooling speed is similar or less than indicated and if temperature distribution within the kiln exceeds 30–40°C (80–100°F)*

temperatures. The chimney can be opened from 500°C downwards, but as already mentioned, this and opening the spyholes and vents prematurely could cause extra tension build-up within the piece, particularly with large or complex pieces.

NB: The firing schedules provided in *Tables 7.2* and *7.3* are based on the following provisos:

- The work has been dried fully under the following conditions: relative humidity not more than 60%, temperature 20°C (68°F) or more. If drying circumstances have been more humid the temperature rise up to 140°C (284°F) should be slowed down and soaking time at 140°C (284°F) should be prolonged.
- No large amount of organic matter or iron sulphide is present in the body. Otherwise, firing should be slow from 650°C (1202°F) up to 850°C (1562°F) and soaking at 850°C (1562°F) should be implemented.
- Wall thickness exceeding 3.5 cm (1¼ in.) calls for extra-slow firing and cooling. Internal ribs and structural support within the piece calls for slow firing and cooling as well.

7.4 Analysing faults apparent after biscuit firing

In this section some faults related to biscuit firing will be discussed in order to be able to identify the causes. Often a fault is not caused by just one but by a combination of reasons. It will become clear that some faults are not, or not exclusively, linked to the firing process itself and remedies are provided that could be used as a starting point to prevent faults occurring.

7.4.1 Cracking of the piece

Often a combination of causes lead to the formation of cracks. Besides the way of firing, weak spots in the work related to improper homogeneity and consistency of the clay body, inaccurate making and careless drying can also lead to cracks during firing. This is especially true in the case of large and/or complex work and tiles.

A network of fine cracks

These cracks are sometimes very difficult to detect on a biscuit fired piece and become clearly visible only after the glaze firing, as glazes (particularly glazes with a high surface tension) pull from the edges and accentuate the cracks. There can be several causes. Forced drying, causing the surface to dry faster with more shrinkage there than within the core of the wall of the piece. A combination of forced drying and a surface that has been smoothed increases the chance of network cracks occurring. Another reason could be that the work was still too wet when it was put into the kiln for the biscuit firing, and hence water has been driven forcefully out of the clay.



Flavio Titolo (Italy), *Big Cracking Piece*, 1999. Ht: 195 cm (76 in.). This column was built with coils. Holes were made at regular intervals. A black sinter engobe was applied on top. After firing, a layer of fine-grained throwing clay was applied on the surface of the column as well as in the holes. During drying, cracks appeared that widened during the second firing. The filled holes function as anchors. Collection: Stichting Flavio Titolo. (Photo: Peer van der Kruis)

Remedies:

- Slow or controlled fast drying especially if a dense clay body is used and/or a smooth surface.
- Prolong drying until the work no longer feels cold.
- The firing speed at the beginning (during the water smoking phase) should be slowed down, soaking at 140°C (284°F) must be prolonged.
- Use a clay body with a less dense structure.

Frayed cracks/shattered parts

A random crack in a sloping angle from the surface towards the middle, sometimes with pieces crumbling from the sides of the crack, or whole parts broken off from the work can have two main causes. Too much pressure build-up during the water smoking phase or the firing speed is too fast during the ceramic change causing the crystal bound water to be driven forcefully out of the clay. The latter can happen with thick-walled pieces made from a clay body with a lot of kaolinite and a dense or very dense structure. Large air pockets present in the clay body, improper adhesion of layers during making and enclosed spaces can be further causes.

Remedies:

- The work should be fully dry before being fired and the firing during the water smoking stage should be slowed down. Increase soaking at 140°C (284°F).
- Reduce the firing speed during the ceramic change phase (500°C and 620°C/932°F and 1148°F).
- Use a clay body with an open structure and mix it properly.
- Pay more attention during making: attach layers of clay well and avoid enclosed spaces.

Cracks in the middle of a work or at joints

Cracks following the direction of added layers during modelling and cracks at the place of contact where two sections were put together can have three main causes. A poor bond between the layers or joints. Too great a difference in the moisture content of sections during joining. Abrupt differences in wall thickness.

Remedies:

- Pay more attention to the attachment of the layers and joints.
- Layers or joined parts should have similar consistency.
- Avoid abrupt differences in wall thickness.

Cracks at the edge of a work

Cracks at the edge of a work are the most common and two kinds of cracks can be identified:

A. The crack is more open towards the edge of the piece, the direction is a bit random and the inside of the crack is not smooth (only visible when the piece is deliberately broken open). There can be several causes. An abrupt decrease of wall thickness towards the edge. Tension in the work due to fast and irregular drying. Because the crack is opened up at the edge there could be a link to temperature difference in the work caused by fast firing.

Remedies:

- Limit the difference in wall thickness: a tapering off of not more than 0.5 cm per 50 cm (¼ in. per 24 in.).

- Pay extra attention to the adhesion of clay layers at the edges of a piece.
- During drying the edges should be covered.
- Slow down the speed of firing from room temperature up to 250°C (482°F) and/or from 500°C up to 650°C (932°F–1202°F) as during those phases increased tension build-up takes place.
- Use a clay body with a more open structure and increase drying crack resistance.

B. Similar to A., but the crack is straighter and the inside of the crack is smooth (only visible when the piece is deliberately broken open). Causes could be: firing too fast during quartz inversion while the temperature was going up (possibly in combination with the use of a thick kiln shelf); or repeatedly re-firing, as every time a work is fired tension build-up takes place (quartz and cristobalite inversion).

Remedies:
- Reduce the firing speed between 550°C and 650°C (1022°F–1202°F).
- Use thinner kiln shelves.
- Use a clay body with a lower expansion rate.

Cracks at the bottom of a work

The crack occurs where the work makes contact with the kiln shelf. The crack is more open at the bottom of the piece than on the inside. Often linked to heavy and large work these cracks may be caused by tensions created by obstructed shrinkage, due to the piece's own weight.

Remedies:
- Guide the shrinkage at the bottom during drying and firing.
- Use a clay body with a greater drying crack resistance.

Hairline cracks

The crack is equally open along its total length and is sometimes difficult to detect but by knocking on the piece the sound will often reveal the presence of such a crack which can run over the entire work. The inside of the crack is very smooth and even the grog is split apart (only visible when the piece is deliberately broken open). Determining the moment the crack appeared could reveal the possible cause.

Hairline crack during firing

The piece is already cracked when the kiln is opened: too rapid cooling during the quartz and/or cristobalite inversion causing conflicting contraction within the piece, possibly in combination with the use of a thick kiln shelf.

Remedies:
- Cooling between 600°C and 500°C (1112°F and 932°F) and between 275°C and 150/50°C (527°C and 302/122°F) should be slowed down and/or a thinner kiln shelf should be used.
- Use a clay body with a lower expansion rate.

Hairline crack after opening the kiln

The crack occurs immediately after the work has been taken out of the kiln or some days after the firing. Cause: the work has been taken out of the kiln too soon, causing tension between the inside and outside of the work. Often there is also a combined link with fast and irregular cooling.

Remedies:
- Opening of the kiln should take place at a lower temperature.
- Cooling between 600°C and 500°C (1112°F and 932°F) and between 275°C and 150/50°C (527°F and 302/122°F) should be slowed down and/or a thinner kiln shelf should be used.
- Use a clay body with a lower expansion rate.

7.4.2 Other possible faults

The following faults are related to specific compounds or components present in the clay body and to improper mixing during the preparation of the clay body.

Bloating

Calcium oxide compounds, iron sulphide, and organic materials that have not been sufficiently oxidised below 850°C (1562°F) will lead to a release of gases during vitrification. These gases will accumulate in pockets. As the temperature rises and the vitrification point has been reached, or even more so if the vitrification point has been passed, these pockets could expand to such a degree that they become visible at the surface of the piece. Possible causes that increase the chance of bloating: fast firing up to 850°C (1562°F); not enough oxygen in the kiln atmosphere below 850°C (1562°F); and a clay body with a dense or very dense structure.

Remedies:
- Thorough mixing during the preparation of the clay body.
- Slow firing from 650°C up to 850°C (1202°–1652°F) and soaking at 850°C in a fully oxidising atmosphere.
- Reduce the top temperature.
- Use a clay body with an open structure.
- Use a clay with moderate amounts of calcium oxide and organic material.

Bloating related to manganese oxide

Manganese oxide added to a clay body (to obtain a dark brown or black body) can lead to bloating. The cause of this bloating is related to the manganese oxidising itself: it releases gases up to relatively high temperatures (1080°C/1976°F) and it also accelerates vitrification, causing these gases to be trapped. The type of clay used as a main ingredient is also of importance. Often manganese oxide is added to a red burning clay to achieve a dark brown up to black and if such a clay contains high amounts of calcium oxide compounds (for more information see *Choosing a powdered clay* under section *2.2.1 Clay*) the chance of bloating will increase. Slow firing from 850°C (1562°F) onwards (less than 100°C (212°F)/hour) increases the formation of gases. These gases will be trapped in the pores and pockets that will be closed as the temperature increases, due to the accelerated vitrification of manganese oxide and the calcium and magnesium oxide compounds in the clay.

Remedies:
- See previously mentioned remedies.
- After soaking at 850°C (1562°F) you can increase the firing speed to 100°C (212°F)/hour or faster up to top temperature.

Lime blows

During firing, whiting (limestone or chalk) if present in a clay body is converted into calcium oxide (from 800°C/1472°F onwards). Beyond 850°C (1562°F), calcium oxide

will react with other components in the body and if no or insufficient interaction takes place, due to larger inclusions, calcium oxide will remain and will hydrate (absorbing humidity out of the surrounding air) as soon as the piece is taken out of the kiln. **Lumps of plaster** present in a body will dehydrate during firing and hydrate after the firing and the hydration leads to expansion and can cause lime blows. Lime blows occur as soon as expansion exceeds the strength of the body, causing small slivers to shear away; a little hole will be seen with white powder at its base. It can take weeks or months before a lime blow occurs.

Remedies:

- Lumps of whiting should be avoided during mixing a clay body. Sieving and thorough mixing is needed for the whiting to be dispersed evenly.
- Separate the clay body used for mould making or model making from a clay body used for modelling, to avoid contamination with plaster.
- If using a pre-packed clay body, try switching over to another clay body.

Total disintegration of the work

Total disintegration of the work could take place if large amounts of calcium oxide are present in a body. Calcium oxide can be present as a natural compound in the clay or can be added (for instance using whiting) to an earthenware clay body. As stated before, calcium oxide will only interact with other components if fired beyond 850°C (1562°F). Fired only up to 800°C or 850°C (1472°F–1562°F) calcium oxide will remain and after being taken from the kiln it will hydrate. This will result in an internal pressure leading to the disintegration of the work.

Remedy:

- The top temperature of the biscuit firing should be at least 900°C (1652°F) preferably higher.



Jennifer Forsberg (Sweden), *House*, 2002. Ht: 70 cm (27½ in.). Coiled piece made from a coarse, black sculpture body. During the making, bits of clay body of altered composition were inserted in the wall. Whiting and extra manganese oxide was added causing bloating in places. (Photo: Corné Bastiaansen)

Notes:

1 Beyond 700°C/1292°F glowing of the interior walls, kiln shelves and other pieces in a kiln (either gas or electric) increasingly plays a role as a source of radiant heat.

2 Such a hood is not connected directly to the kiln, but is placed in such a way that sufficient cold air is mixed with combustion gases to provide the outlet with the necessary cooling.

3 Over the course of time kiln props may differ in height slightly and kiln shelves may warp slightly.

4 Up to ± 900°C/1652°F, the piece will expand; beyond this temperature shrinkage occurs due to vitrification.

5 A thick-walled piece more than 2.5 cm (1 in.) thick made out of a clay body with a high plasticity due to the presence of large amounts of very fine kaolinite in combination with a dense structure could shatter in this phase of firing.

6 How much cristobalite really will be present in a body during cooling is a subject of discussion. Research has shown contradictory outcomes.



8 Glazes and (sinter) engobes



The surface of a piece can be treated with a glaze, engobe, sinter engobe or slip for aesthetic reasons, in order to add extra meaning to the work, or for functional reasons. The surface qualities that can be achieved range from lustrous colourful glazes to the dry matt light-absorbing surface of engobes. Of special interest (especially for functional pieces) is the fact that glazes can be applied to increase durability and water resistance. For centuries, slips, engobes and glazes were developed using the method of 'trial and error'. The ingredients were found on site. As it turns out, the earth's crust consists largely of the same components as slips, engobes and glazes. It is therefore not surprising that they were developed at an early stage. The richness and beauty achieved through the ages is astonishing. However it is only within the last 150 years due to developments in chemistry and scientific research that we have come to understand how the components actually interact. This understanding can now be used to comprehend the world behind the extraordinary and beautiful glazes that have been developed over the centuries. It can also be used to develop one's own recipes.

A slip, engobe, sinter engobe and glaze can be distinguished by the use of basic ingredients. In general a slip is made up entirely of clay (see Chapter 10 *Terra sigillata* for more information about specific slip techniques). An engobe contains, besides clay, other ingredients in order to attune sintering. Sinter engobes contain more ingredients that support sintering and fusion. Glazes contain large amounts of ingredients to achieve full fusion. An engobe tends to give a dry–matt surface on its own and is generally used under a clear glaze. Due to fusion more pronounced results in terms of colour and surface are achieved with sinter engobes and glazes (the colour becomes deeper the more the ingredients fuse).

This chapter covers the processes that go on during firing of a (sinter) engobe or glaze sintering and fusion. Also general properties of glazes and (sinter) engobes, a select group of ingredients that can be used to formulate a glaze or (sinter) engobe will be discussed, followed by several examples of glaze and (sinter) engobe recipes. A distinction is made between a base glaze (a glaze meant to achieve a wide range of colours by adding ceramic pigments) and a special glaze (a glaze with a specific ingredient combination to achieve a certain colour by using colouring oxides). Finally, preparation of glazes, the use of glaze additives and ways of applying will be addressed.

OPPOSITE:
Torbjørn Kvasbø, Norway
Baghdad Blues, 2003. Ht: 125 cm (49¼ in.). Slab-built. The slabs are made out of two layers: a fine-grained clay body on top of a coarse sculpture body. Pushing the clay from within allowed a characteristic voluminous form and structure to arise. An Egyptian blue glaze was applied, the darker blue parts also contain cobalt carbonate. The low viscosity of the glaze clearly reveals all details in the body underneath.
(Photo: Frank Kouws)



ABOVE:
Har van der Put (The Netherlands), untitled, 2003. Ht: 60 cm (23½ in.). Coiled and modelled piece. A direct way of working made possible by using clay with a slightly wetter consistency. The glaze has been fired up to the first stage of fusion resulting in a typical matt finish. Collection: EKWC (Photo: Corné Bastiaansen)



RIGHT:
Gijs Assmann (The Netherlands), *Amorous Frog*, 1995. Ht: 150 cm (58½ in.). A hollow coiled piece. No internal support structure was used. A semi-opaque shiny glaze was painted on top of a grey coloured engobe. Different glaze thickness resulted in variations in the opacity of the glaze. Collection: ABN AMRO Bank, The Netherlands (Photo: Peer van der Kruis)

8.1 Sintering and fusion

The materials constituting a slip, engobe, sinter engobe or glaze mixture consist of countless particles, which in turn are composed of all kinds of molecular compounds. During firing these particles pass through several stages. First sintering takes place, followed by part fusion and full fusion; as the temperature rises the particles react with other particles and the molecular compounds are altered. The following stages can be identified:

1. At a certain temperature the individual particles stick together at points of contact without apparent fusion. Sintering starts (also referred to as the solid sintering phase because no fusion occurs).
2. As the temperature rises on the outside of the individual particles, fusion takes place (this phase is also referred to as liquid sintering because this fusion creates a liquid film on the outside of the particles). The less refractory and the smallest particles begin to fuse fully. An engobe is usually fired to this point. As the temperature rises other particles close by are taken into fusion and the sintering process accelerates. Especially in the last stage of the sintering process an increasing part of the molecular compounds is broken down and new compounds and gases are formed. At this

stage these gases and gases that are created within the body itself can escape through the glaze or (sinter) engobe layer. A sinter engobe fired up to the end of this phase will be rough to the touch.

3. In the next stage, apart from the most refractory particles and large grains, all non-refractory compounds are progressively taken into fusion. Entirely new molecular structures are formed. At the end of this stage the glaze or sinter engobe enters a liquid state of high viscosity (a liquid that does not tend to flow easily). Gases being formed during this glassy state tend to get trapped. Sinter engobes are usually not fired higher than this stage, glazes have to be fired at least up to this stage but often they are fired to a higher temperature to achieve satisfying results. The surface of a glaze or sinter engobe will show a stony matt; it feels like a pebble.
4. As the temperature rises almost all compounds are taken into fusion and dissolve in a homogeneous liquid melt, viscosity will be less at this stage and continuously decrease as the temperature rises. Bubbles of trapped gases will be able to migrate to the surface and pop open. Craters that are formed could remain or, where viscosity is sufficiently low, fill in resulting in a smooth surface. During this a layer between the glaze and the body underneath is formed: the so-called intermediate layer.
5. If the temperature keeps increasing, flowing occurs; the glaze becomes runny, also it is increasingly likely that components will start to volatilise. At this stage a glaze can become overfired.

The process of the breaking down of molecular structures (and the formation of new molecular structures) and its relation to fusion is discussed in more detail in section *14.1 What is a glaze?*

8.1.1 What determines the sintering and fusion range?

As has become clear there is not just one temperature during firing at which sintering or fusion takes place. Therefore the terms sintering range and fusion range are used. Besides temperature, time is also involved. The extent of the sintering and fusion range is determined by the composition of the (sinter) engobe or glaze, the 'eutectic mixture', the quality of the ingredients and the way they are fired.

Composition

An engobe, sinter engobe or glaze can be made from more than 170 different ingredients. The mineral structure of these ingredients is composed of a relatively small number of components, referred to as oxides. Different combinations of oxides provide each ingredient with its own specific characteristics. The most important oxides that are crucial in this chapter are: sodium oxide (Na_2O), potassium oxide (K_2O), lithium oxide (Li_2O), all three belonging to the so-called **strong alkalis**, lead oxide (PbO), calcium oxide (CaO), zinc oxide (ZnO), barium oxide (BaO), aluminium oxide (Al_2O_3), boron oxide (B_2O_3) and silica (silicon oxide SiO_2). Magnesium oxide (MgO) is sometimes present as traces in the ingredients that are mentioned in this chapter. According to their role during fusion these oxides can be characterised as glass-formers, fluxes or stabilisers. Silica is the most important **glass-former**. It supports the formation of a liquid film during sintering and the formation of a liquid glass during fusion. Its role is essential in the formation of the 'glass state' during cooling, which can be described as a solid material with the structure of a liquid.

However, because the melting point of silica is very high (1710°C/3110°F), **fluxes** are needed to lower the temperature at which fusion is achieved. Fluxes can be divided

into two categories: fluxes that are very active beginning at low temperatures (due to their low melting point) and those that are active at higher temperatures. The fluxes in the first category include; sodium oxide, potassium oxide, lithium oxide and lead oxide. Fluxes that are more active at higher temperatures are: zinc oxide, calcium oxide, barium oxide and magnesium oxide, although small amounts will support the fluxing action at low temperatures as well. A combination of only silica and fluxes tends to cause a relatively short sintering and especially fusion range. To obtain more reliable results a **stabiliser** should be present to a small or larger extent in a glaze. Aluminium oxide is the most important stabiliser. Boron oxide is considered to serve a combination of functions: it is a glass-former, but it can also assume the role of stabiliser. Although it is not a flux, boron oxide also contributes to lowering the starting point of fusion, due to its very low melting point.

The way the ingredients that introduce these oxides are balanced out will determine the course of the sintering and fusion range.

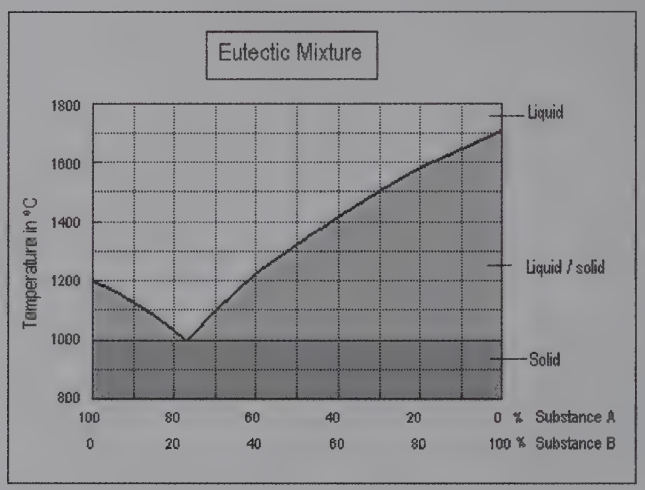


Diagram 8.1

Eutectic Mixture

An important and interesting phenomenon linked to fusion is the 'eutectic mixture'. Every ingredient has a particular melting point: melting occurs at a specific temperature. The temperature at which a mixture melts is not an average of the individual melting points: it is often considerably lower. This is referred to as being a eutectic mixture. *Diagram 8.1* shows a schematic image of a mixing series of two ingredients, one with a low melting point (1200°C/2192°F), the other with a high melting point (1700°C/3092°F). The diagram shows that the addition of substance B (having a high melting point) first results in a decrease in the temperature at which the mixture fully fuses. At a certain ratio the lowest temperature at which the mixture fuses has been reached (in the diagram this is located at ±77% for substance A and 23% for substance B). This is called the eutectic point. (As more ingredients are introduced the course of the graph will become more complex showing several eutectic points.) Due to this eutectic effect the fusion of a common glaze will occur within the temperature range of conventional kilns and maturing range of clay bodies.

Varations in ingredients

Variations in the composition of ingredients will affect the sintering and fusion range of a (sinter) engobe or glaze, causing them to begin to fuse prematurely or to be overfired earlier than expected. Differences in particle size tend to have an effect on the sintering and fusion range.

Many ingredients sold under the same name can vary in composition: they can contain (slightly) different amounts of oxides. This is especially true for naturally-occurring ingredients found in different locations throughout the world that are formed under distinct geological conditions. As a result, variations can be found from one manufacturer to another and from one batch to another, leading to different outcomes. In section *8.7 Testing glazes and (sinter) engobes* a testing method is discussed to attune the ratio of ingredients in such a way that variations can be compensated to a certain extent. Other ingredients can have a fairly stable composition but still will not be 100%



Andrew Lord (England/USA), *Profile vase (Picasso), 'Atlas of the World' and stretched Gauguin,* 2002. Ceramic, gold leaf, epoxy and wire Ht: 63.5 cm (25 in.). A press-moulded and modelled piece using a fine-grained sculpture clay. Slip, stained with various pigments, was painted on the leatherhard clay. A transparent high-lead glaze was used on top. Collection: Stedelijk Museum Amsterdam, The Netherlands. (Photo: Peer van der Kruis)

pure due to small amounts of impurities. The **particle** and **grain size** of the ingredients will have an influence on sintering and fusion. The rate of purity depends on the extent to which they have undergone purification after mining or during (chemical) production. During sintering (the stage before melting takes place) the surface of the particles and grains starts to fuse. Ultra-fine particles have a greater surface area in comparison to their volume than large particles and grains; hence the total area of surface contact is larger and they will be fused first. The least refractory and smallest particles will be fused first. As soon as these particles become fused, other particles close by are taken into the process faster, accelerating the sintering process. Large, more refractory grains will take more time to dissolve but eventually they are taken fully into fusion within the liquid melt that surrounds them if exposed to sufficient heat.

Way of firing

Temperature and **time**, in other words the energy input, sometimes referred to as **heat work** is also a determining factor in fusion. For instance, a glaze fired at 1200°C (2192°F) for two hours will fuse less than if it had been fired for two days at a similar temperature. The rate of the rise in temperature during the last phase, approximately the last 200°C (400°F) up to the top temperature, is especially decisive for most glazes. Soaking[1] (maintaining the temperature at the same level for a certain period of time) could have a noticeable effect on sintering and fusion as well. The cooling speed may determine the outcome as well. A very slow cooling during the first 100°C–150°C



Peter Otto (The Netherlands), *Votiv & Totem*, 2003.
Ht: 188 cm (73 in.).
This piece consists of a grouping of press-moulded elements. A sinter engobe was applied on the surface. Fired up to the first stage of fusion the sinter engobe obtained a silky-matt finish. Due to the thin application, the body shows through in some areas. After the glaze firing red iron oxide was rubbed into the surface.
Collection: ABN AMRO, The Netherlands.
(Photo: Tom Haartsen)

(200°F–300°F) below the top temperature will result in more fusion. In addition, slow cooling can also lead to crystallisation (the formation of numerous (ultra) fine crystals) from a certain temperature downwards resulting in a semi-matt surface (see section *8.2.3 Surface quality*).

NB: In practice, glazes fired in a similar way in a gas or electric kiln could turn out (slightly) more matt. Certain low temperature glazes are more prone to this, see section *11.5.4 Other faults*.

8.2 Properties of a glaze and (sinter) engobe

Several properties like viscosity, surface tension, surface quality, thermal expansion, hardness/durability and, finally, colour will be discussed in this section. Some are only applicable to glazes. Ingredients capable of influencing these properties will be mentioned specifically. Under section *8.3 Ingredients* they will be discussed in more detail. Some properties can give rise to glaze defects: this is discussed only briefly in this section and more thoroughly in section *11.5 Analysing faults apparent after the glaze firing*.

8.2.1 Viscosity

Viscosity is directly linked to fusion. This occurs when a sinter engobe or glaze is fired high enough to cause a viscous liquid melt[2] to be formed. In general, viscosity will decrease as the temperature rises; the applied layer will become more fluid. A **glaze** is composed in such a way that an appropriate amount of viscosity will occur at an intended temperature. Depending on the ingredients used, a low or high viscosity will occur. A glaze layer with low viscosity will tend to run off raised and sharp edges, leaving behind a very thin layer in those areas and with coloured glazes this could lead to colour differences. As viscosity decreases further, the glaze could eventually run off the piece onto the kiln shelf. High viscosity results in a stiff, non-fluid liquid glaze layer. The viscosity also determines whether (ultra-fine) bubbles will be trapped in a glaze layer and to what extent pin-holes (small craters on the surface of a glaze layer as a result of burst bubbles) will occur. A **sinter engobe** is composed in such a way that at an intended temperature either the last stage of sintering or the first stage of fusion takes place. In the last stage of sintering, no real viscosity appears and a rigid dry matt surface is formed. In the first stage of fusion a stiff, non-fluid liquid layer will be formed having a high viscosity.

8.2.2 Surface tension

Surface tension is linked to fusion. As soon as the applied layer fuses and starts to become more fluid, surface tension occurs. After all the particles have been totally fused and the temperature still increases, the surface tension will decrease. The surface tension of a **glaze** can vary a lot and is related to the ingredients used and the temperature at which it is fired. Glazes with a low surface tension show a more smooth surface. A glaze that has a high surface tension is more likely to have pin-holes. Bubbles that migrate to the surface and burst but do not completely fill are the cause of pin-holes. Poor adhesion or cracks in an unfired glaze layer combined with high surface tension will increase the chance of the contraction of the glaze in places during firing: leaving a bare area on the surface of the piece. This results in the glaze defect called 'crawling'. A **sinter engobe** fired to the beginning of its fusion range often is not



Akio Takamori (USA), *Path*, 1996. Ht: range 26 cm–62 cm (10¼–24 in.). Hollow-built figurines using a fine-grained sculpture body. They were fired below the vitrification point resulting in a buff-coloured body. Black stained engobe was painted on top.
(Photo: Peer van der Kruis)

subjected to high surface tension because at this stage a stiff, non-fluid, liquid layer is being formed. An increase in temperature will make the sinter engobe more fluid, hence surface tension develops and the chance of crawling increases.

8.2.3 Surface quality

A whole range of surface qualities can be obtained; from shiny to dry matt, from transparent to opaque. What is essential is the rate of fusion that takes place: if fired to the sintering stage the surface usually will be dry matt. A stony matt surface could be achieved if fired to the first stage of fusion, because some of the refractory components will not be fused and a highly viscous liquid state will result. At the stage of full fusion a great variety of surface qualities can be achieved, ranging from shiny to matt and transparent to opaque.

A **matt glaze** is a glaze that having been fired to a high enough temperature to cause the fusion of all or almost all ingredients is then subjected to crystallisation during cooling; tiny crystals are formed in the molten glaze layer. These crystals are often not visible to the naked eye, but they reflect light in an irregular way resulting in a matt surface. In some cases, crystals can develop to such a degree that the glaze surface becomes rough to the touch or that they become clearly visible. **Satin matt glazes** are formed if sufficient matting agents are present and if the cooling speed is slow. A **sinter engobe** fired to a sufficiently high temperature will have a **stony matt surface** (a surface resembling that of a pebble). As stated before, some underfired glazes can have a stony matt surface too when only fired up to the first stage of fusion. Due to a high viscosity traces of application, like brush strokes, tend to be visible in such a glaze. A **dry matt surface** occurs if a sinter engobe is fired up to the last part of sintering. An engobe tends to have a dry matt surface too.



Marca van der Linden (The Netherlands), untitled, 1996. Ht: 38 cm (15 in.). Stoneware. A crackle satin matt glaze with a small amount of zirconium silicate to increase opacity was used. Ink was used to enhance the crackle. (Photo: Peer van der Kruis)

A glaze layer, in which for some reason no homogeneous or complete fusing occurs, will be less transparent or entirely opaque. **Opaque glazes** may be either matt or glossy. Conducive to opacity is a moderate to high viscosity and/or the presence of not fully dissolved particles. Matt glazes tend to be opaque due to crystallisation. A glaze will be more opaque as the viscosity and thickness of a glaze layer increases.

A **satin gloss** can be achieved if countless ultra-fine bubbles are present in a glaze layer. These bubbles, caught during fusion, also disturb light reflection, resulting in (slight) opacity. Another reason for the occurrence of a satin gloss is related to moderate crystallisation during cooling.

Shiny glazes are formed if all components are fused and the glaze layer has moderate to low viscosity. **Transparent glazes** have been completely and homogeneously fused and so no crystallisation during cooling should take place. Therefore fully transparent glazes are shiny glazes. To achieve transparency, neither viscosity nor surface tension should be high, in order to minimise the presence of bubbles in the glaze layer. For this, it is best if a certain amount of strong fluxing agents are present.

8.2.4 Thermal expansion

Most materials expand during heating (and contract during cooling). This phenomenon is referred to as thermal expansion. A glaze and body tend to have different thermal expansions due to the fact that they do not have the same chemical make-up. Expansion and contraction are also influenced by the degree to which the ingredients have fused and formed new components. Sinter engobes and especially engobes are closely related in composition to a clay body therefore their thermal expansion is somewhat similar.

The differences in expansion (and as a result a difference in contraction during cooling) between glazes and body determines the so-called **glaze fit**. As long as the fused glaze layer is in a fluid stage no tension build-up will take place. But during the last part of the cooling process, the glaze solidifies and becomes more rigid (usually from 650°C/1202°F downward). Also the body becomes more rigid. As cooling proceeds, a difference in contraction between the glaze and the body will increase tension. If the difference in tension becomes too big a range of faults can occur. A very common example is 'crazing' (small hairline cracks in the glaze). This frequently occurs on low temperature glazes applied to sculpture bodies. Also 'shivering' (slivers of glaze may shear away on edges and rims of a piece) and 'shelling' (shelling of entire strips of glaze) are related to differences in tension between glaze and body.

8.2.5 Durability

The composition and firing temperature determines whether a glaze or sinter engobe will become more or less sensitive to damage, for instance from acids or scratches. Sufficient fusion is vital. Durability is important, especially for functional ceramic objects and outdoor sculptures. **Low temperature glazes** are often less durable largely because the addition of strong fluxes reduces durability. A high silica and especially

aluminium and calcium oxide content supports durability. Therefore **medium** and **high temperature glazes** can be made durable more easily. If a **sinter engobe** is fired to the last stage of sintering less durable results will be obtained. Fired at the first stage of the fusion range, it can be durable; this is related to the high aluminium oxide content and the fact that sinter engobes generally do not contain large amounts of strong fluxes. **Engobes** by themselves are not very durable; despite an aluminium oxide ratio, no apparent fusion takes place, resulting in a vulnerable surface. Durability only can be achieved if covered by a glaze.

8.2.6 Colour

Colour in ceramics comes from ceramic pigments or colouring oxides. The composition of a glaze or (sinter) engobe does affect the formation of colours, however. Another important factor is to what extent the pigments or colouring oxides are taken into fusion. A **glaze** will have a strong colour if fired to full fusion. The strongest colours are often obtained in shiny glazes; generally the colour is less intense as the glaze becomes more opaque and matt. If overfired some ceramic pigments may be affected: the pigments could dissolve showing weaker colours, or the colour could even disappear. The colour of the fired clay body on which the glaze is applied also affects the final colour. The darker the body and more transparent the glaze, the more the body colour will influence the colour of the glaze. Fired to a temperature lower than the beginning of fusion the coloration of a **sinter engobe** will be less pronounced, but fired to the first part of the fusion range, reasonably strong colours (although less strong than most shiny glazes) can be achieved. A sinter engobe is opaque (provided a sufficient layer is added and it is not overfired), therefore the colour of the body underneath will not be much of an influence. The colour of an **engobe** on its own is often subdued. The cover glaze determines the colour range to a large extent. Shiny, fully transparent glazes will provide the best results. An engobe can be less opaque if applied as a thin layer and especially if it is taken (partly) into fusion by the cover glaze. In this case, the colour of the clay body underneath might influence the outcome.



Betty Woodman (USA), *Balustrade Vase*, 1993. Ht: 95 cm (37¼ in.). Thrown, cut and assembled elements using a red earthenware clay body. The surface was treated partly with an engobe and partly with a terracotta terra sigillata (unglazed areas) which was applied with a brush. Ceramic pigments and zirconium silicate were added to the engobe. A shiny high-lead glaze was applied, then resulting in strong colours.
Collection: Museum voor Hedendaagse Kunst, 's-Hertogenbosch, The Netherlands. (Photo: Peer van der Kruis)

8.3 Ingredients

There are a large number of different ingredients that can be used to formulate a (sinter) engobe or glaze. Whatever characteristic an individual ingredient may have, the final result is ultimately determined by the amount of each ingredient added, by the other ingredients present in the recipe and, last but not least, the firing temperature. Consequently, as the number of ingredients rises it becomes increasingly complicated to deduce the effect of a specific ingredient. This is one of the main reasons why this

book deals only with a fraction of the potentially applicable ingredients. All the ingredients (or their equivalents) referred to in this book are generally available. Above all, with this select group of ingredients a very wide range of glazes and (sinter) engobes suited for a broad temperature range (1000°C–1280°C/1832°F–2336°F) can be achieved. They have in common that bright colours are supported if ceramic colour pigments are used.

The ingredients are divided into four main groups: basic ingredients, strong fluxing agents, feldspathoids and matting agents. As discussed previously, ingredients can vary in their composition. For each ingredient some average indications of the existing compounds are given. The unity molecular formula and percentage analysis of all ingredients are presented in *Appendix 1*, *Tables A1* and *A2*.

NB: The safe handling of these dust-producing materials requires the use of the proper safety precautions. Provide good exhaust ventilation and use a fine dust respirator during the preparation of glazes. If an ingredient is exceptionally hazardous to the health, it is stated separately. Precautions must be taken during the preparation and application of these ingredients.

8.3.1 Basic ingredients

Within the scope of this section, quartz and kaolin/clay are considered as basic ingredients. In almost any glaze or (sinter) engobe recipe in this book they are present in varying amounts as they provide silica (glass-formers) and aluminium oxide (stabilisers). In some low temperature glazes no kaolin or clay is used as aluminium oxide is provided in a sufficient amount by nepheline syenite, or a low aluminium oxide content is deliberately used to achieve a specific colour, as in Egyptian blue glazes.

Quartz

Quartz (SiO_2), as available from the ceramic supplier, is usually very pure; it contains only traces of impurities. Quartz increases the viscosity and durability of a glaze. **NB:** It is hazardous to breath the fine dust from quartz particles. For this reason always wear a fine dust respirator.

Kaolin

Kaolin is a refractory and white burning type of clay. Its composition varies considerably; its main compounds are aluminium oxide, silica and structural water. High-quality kaolin contains only small amounts of iron and titanium oxide (see *Choosing a powdered clay* under section *2.2.1 Clay*) therefore it will not influence the colour (as a lot of common clay tends to do). It is an excellent source of aluminium oxide and silica in a glaze. It increases durability and viscosity; it also increases surface tension. If used in a sinter engobe that is fired to the first phase of fusion, it increases durability. It can be difficult to get strong colours using colouring oxides when the percentage of kaolin is high because a large number of colouring oxides are unfavourably affected by a high aluminium oxide ratio. Ceramic pigments are, in general, not affected by the presence of high amounts of kaolin. Kaolin can be used in engobes suited for high temperatures. Due to its plasticity and hunger for water its addition should be limited to 25% if used for applying on biscuit as it will cause the applied layer to shrink during drying. Higher additions could lead to adhesion problems. If a higher amount of aluminium oxide is required, preferably **Molochite 200** or, if not available, **calcined kaolin**[3] should be added. Compared to regular kaolin, these ingredients have a slightly higher melting point.

Clay

Clay is also composed mainly of silica, aluminium oxide and structural water in various amounts plus a wide variety of other components. An HTR-clay (see *Choosing a powdered clay* under section *2.2.1 Clay*) can be used with good results.[4] In this chapter an **aluminous ball clay** is used. Compared to kaolin it is a less refractory ingredient. If used instead of kaolin it can be used to reduce the fusion range of a glaze or (sinter) engobe slightly.[5] An HTR-clay enhances the painting properties of a glaze or (sinter) engobe considerably and, provided the right kind of glaze additives are used, up to a maximum of 25% can be added if applying on to biscuit.

8.3.2 Strong fluxing agents

As has been pointed out, fluxes are essential to achieve sufficient fusion of silica at conventional temperatures. Especially at low temperatures (less than 1200°C/2192°F) a relatively large amount of strong fluxing agents are needed to lower the point at which the sintering and fusion range starts. A widely used ingredient especially in the low-temperature range (950°C–1120°C/1742°F–2048°F) is a glaze frit: an industrially manufactured material that is composed from varying amounts of fluxes, it often contains silica and sometimes some aluminium oxides as well. These ingredients can introduce oxides into a recipe that otherwise would be chemically unstable, soluble in water or very poisonous, such as, sodium oxide, potassium oxide, boron oxide and lead oxide. There are several manufacturers all over the world making frits, each making them according to their own recipe and often with different compositions (see *Appendix 1*, *Table A3* for a list of equivalent frits).



Vincent McGourty (England/The Netherlands), untitled, 1995. Ht: 35 cm (13¾ in.). A coiled piece using a coarse-grained black firing sculpture body. A sinter engobe was used on the surface and fired to 1120°C (2048°F).
(Photo: Peer van der Kruis)

Lead bisilicate

Lead bisilicate is a type of frit widely available although usually in (slightly) different compositions. It combines lead oxide and silica in an approximate 1:2 molecular ratio. The recipes in this book are based on Frit 3647 (64.9% PbO/1.5% Al_2O_3/33.6% SiO_2).[6] Lead bisilicate is a very useful flux in low temperature glazes, especially if a totally transparent glaze is desired. It reduces viscosity and surface tension and makes the glaze slightly more flexible, making a glaze slightly less subject to crazing. It also produces bright colours. Less satisfying results are achieved when it is added to engobes or sinter engobes (nepheline syenite yields better results colourwise).

NB: Despite the fritted form, lead bisilicate frits are poisonous. During preparation and application of a glaze containing this ingredient, prudence is called for. Formation of dust and direct contact should be avoided. For this reason always wear a fine dust respirator and latex gloves. It is strongly advised not to use this ingredient in glazes for functional ware, as lead compounds in a fired glaze may leach. Lead bisilicate frits are less or not suited for middle or high temperature glazes as lead oxide volatilises causing toxic fumes.



Figure 8.1
An opaqueness due to a calcium borate flush clearly shown on a dark brown body especially where the glaze (see *Table 8.10*) has been applied more thickly. (Photo: Anton Reijnders)

Calcium borate frit

Calcium borate frit 3221 contains only calcium oxide and boron oxide (44.6% CaO/55.4% B_2O_3). As has been pointed out, boron oxide has a low melting point and has glass-forming and stabilising properties, therefore a calcium borate frit brings in properties very well suited for low-temperature glazes as it combines a low melting point with an ability to extend the fusion range. It makes glazes less sensitive to uneven temperature distribution within the kiln, and reduces viscosity and surface tension. A boron-containing frit is an indispensable ingredient for lead-free glazes within the low temperature range. It can be used to compose a glaze with a moderate thermal expansion within this temperature range as well. In middle and high temperature range glazes (1200°C–1220°C/ 2192°F–2228°F) small amounts can be added to reduce viscosity and improve the transparency of a glaze. A high percentage of a calcium borate frit will offset the formation of a matt glaze. Small amounts can be added to a (sinter) engobe to alter the sintering or fusion range.

A high proportion of calcium borate frit and an average or low amount of aluminium oxide will increase the chance of a '**calcium borate flush**': a white opalescent flush in a glaze, sometimes turning into a pale blue especially noticeable on a red or black body. As a result the coloration of pigments and colouring oxides in a glaze will be affected: many become more pastel and/or are subject to colour changes. A high ratio of aluminium oxide will counteract a calcium borate flush and help to assure the desired coloration.



Lorna Lee Leslie (England), wash basin, 2001. Ht: 45 cm (17¾ in.). This wash basin was press-moulded using the embossing method. A sinter engobe was applied with a brush. Lithium carbonate in the sinter engobe adds to the richness in colour of the final result. (Photo: Frank Kouws)

Lithium carbonate

Lithium carbonate does not occur as a natural material but is industrially prepared from lithium ores. It does not vary much in its composition (40.4% Li_2O/loss (CO_2) 59.6%). It decomposes during firing resulting in lithium oxide and carbon dioxide (which escapes as a gas). It is a very active flux, considerably reducing the point at which sintering and fusion starts. It reduces the viscosity and surface tension of a glaze. Even small percentages (up to 5%) produce a strong effect. Small amounts increase the transparency of glazes as well. There is a tendency for it to dissolve ceramic pigments and, as such, lithium carbonate is less suited in a base glaze but it can be used in Egyptian blue glazes to enhance the blue colour. In a sinter engobe, lithium carbonate adds to the liveliness of the final result, this is especially true if a slightly coarser grained lithium carbonate is used. A very large amount of lithium carbonate gives matt results.

Lithium carbonate has an unpredictable effect on thermal expansion: if small amounts (up to 1%) are

used, the risk of crazing may decrease somewhat, because the glaze gains in flexibility. As the percentage of lithium carbonate increases to between 5% and 10%, so does the chance of crazing. The risk of shivering or shelling increases if larger amounts are used (more than 10%). The percentages mentioned, being highly dependent on the other ingredients in the recipe and the composition of the clay body, are rough estimates. Lithium carbonate is the only ingredient mentioned in this section that is soluble in water, though only to a small extent. Because of this, it could penetrate the body and as such create a body-glaze layer with a markedly different expansion rate. This could lead to shelling as well. For more information see section *11.5.2 Faults related to divergent expansion rates*.

8.3.3 Feldspathoids

Feldspathoids belong to the family of feldspars. They could be looked upon as natural frits and are used to introduce fluxes, as well as aluminium oxide and silica.

Nepheline syenite

The composition of nepheline syenite can vary considerably (4.5%–9% K_2O/6%–10% Na_2O/23%–24% Al_2O_3/56%–61% SiO_2). Two main sources of nepheline syenite are found; in Norway and Canada.[7] The Norwegian nepheline syenite (also referred to as North Cape) contains more K_2O. It is a very useful ingredient because it can be implemented in engobes, sinter engobes, shiny and matt glazes ranging from low to high temperatures. At middle and high temperatures, it can be introduced to increase fusion as it fuses to a viscous glaze at 1200°C–1220°C (2192°F–2228°F). At temperatures below 1200°C it supports the fluxing action.

Petalite

Petalite is a lithium feldspar. Its composition does vary a lot (an example of a specimen: 0.3% K_2O/0.4% Na_2O/4.6% Li_2O/0.1% CaO/16.3% Al_2O_3/77.8% SiO_2/0.5% Others). Due to its low expansion rate it can also be used to achieve a base glaze for the low temperature range that will be less subjected to crazing, provided the body has an average expansion rate. Of special interest is its use to achieve matt Egyptian blue glazes. As a source of lithium in a base glaze it is preferred to lithium carbonate as it does not dissolve pigments during fusion.

Cornish stone

Cornish stone is mined, and originated, in Cornwall, England. Its composition does vary a lot (an example of a specimen: 3.8% K_2O/4.1% Na_2O/2.1% CaO/14% Al_2O_3/72.9% SiO_2/3.01% others and igneous loss – a small percentage of lost material). It is useful in high-temperature reduction glazes, especially to obtain a waxy type of celadon glaze (see *High temperature glazes* under section *8.4.2 Glaze recipes*).

8.3.4 Matting agents

Matting agents form a separate group of ingredients as they mainly support the fluxing action at low temperatures, and beyond 1100°C/2012°F they become active fluxes. Generally the addition of a small amount will help to form a shiny glaze, but as the amount increases, the glaze tends to be more subject to crystallisation during cooling resulting in a matt or satin matt surface. (This is more likely to happen if a high ratio of aluminium oxide is present.) Additions of very large amounts of matting agents can have an anti-fluxing effect: the glaze does not fuse fully.

Whiting

Whiting (calcium carbonate), also referred to as limestone, does occur as a natural material in slightly varying compositions (± 56% CaO/± 44% loss (CO_2)). Good quality whiting contains only traces of impurities. It is an ingredient very commonly used in glazes and sinter engobes and it can also be added to an engobe. It decomposes at temperatures above 800°C (1472°F) into calcium oxide and carbon dioxide, which escapes as a gas during firing. From 1100°C (2012°F) onwards it becomes an active flux. It causes the viscosity to decrease slightly at low temperatures and may decrease viscosity considerably at high temperatures. It increases the durability and surface tension in glazes and the durability of a sinter engobe.

NB: Due to the great similarity of the names, calcium carbonate and calcium borate tend to get confused with one another.

Wollastonite

Wollastonite is a calcium silicate. It occurs as a natural material in varying compositions (an example of a specimen: 47.2% CaO/47.8% SiO_2/2.7 MgO/2.3% various other components and loss). It is a useful fluxing agent in high-temperature glazes and is an excellent ingredient to achieve a satin matt in low up to high-temperature glazes. If used to obtain a matt glaze the quartz content should be kept low to avoid too high a silica content. Wollastonite increases the durability and surface tension of a glaze and the durability of a sinter engobe.

Zinc oxide

Zinc oxide occurs as a natural material in varying compositions; small amounts of lead oxide are often present in non-purified specimens and this will greatly influence results. Therefore industrially-prepared zinc oxide (± 99% ZnO + various other components) is preferred. At temperatures above 1080°C (1976°F) it is active as a flux. To obtain matt glazes it is used in large amounts, but preferably not in combination with other matting agents and a moderate aluminium oxide content as the glaze could then turn out shiny. Small amounts in combination with small amounts of other matting agents will yield a shiny glaze. Introduced in small amounts viscosity will decrease, but an increase in viscosity will be gained if large amounts are used in a glaze fired below 1080°C (1976°F). At 1200°C (2192°F) and higher, viscosity decreases considerably even if large amounts are present. Generally zinc oxide increases surface tension somewhat. Zinc oxide is hungry for water, resulting in shrinkage of the applied layer during drying. This may increase the risk of poor adhesion and as such cause crawling if large amounts are used. It is added only in limited amounts in a base glaze because it affects the colour of most colouring oxides and some ceramic pigments unfavourably. There is an important exception: it enhances the blue colour of cobalt oxide and cobalt oxide containing stains.

NB: Zinc oxide is hazardous to your health: one should avoid inhaling dust. It is not suited for reduction glazes; it easily reduces to its single metal state and as such it will volatilise causing toxic fumes.

Barium carbonate

Barium carbonate (77.7% BaO/22.3% loss (CO_2)) supports the formation of strong colours. In this book it is used only in special glazes like (matt) Egyptian blue and copper red reduction glazes.

NB: Barium carbonate is very toxic and slightly soluble: wear a respirator and latex



Annette Sense (Austria), untitled, 1995. Ht: 220 cm (86¾ in.). Ceramics and steel. The pipes were press-moulded using the embossing method. A satin matt glaze was used. The zinc oxide in the glaze produced a vivid cobalt blue colour on the pieces on the right.
(Photo: Peer van der Kruis)

gloves while handling. It should not be used in low temperature glazes for functional work as it is suspected to leach if present in combination with boron oxide.

8.3.5 Ceramic stains

Using only the ingredients previously mentioned will yield colourless results. To obtain colour in a glaze or (sinter) engobe, stains should be added. The number of possible colourants is very large. Each has its own effect on the formation of colour but could also influence the sintering or fusion range. Ceramic colourants can be divided into two major groups: colouring oxides and ceramic pigments. In this book the most commonly used colouring oxides and a selection of ceramic pigments are discussed.

The major **colouring oxides** are: copper, cobalt, iron, chromium, manganese, nickel, zirconium and tin oxide. In addition, there are compounds of these metals used as carbonates and silicates, such as: copper carbonate, cobalt carbonate (both decompose to become oxides during firing) and zirconium silicate. **Ceramic pigments** are composed of various ingredients: usually a combination of a colouring oxide with non-colouring oxides added to them (see *Tables 8.4* and *8.5*) to achieve a stabilising effect during firing. The manufacturing process consists of the calcining or sintering (not fusing) of these components after which the resulting pigment is ground.

Colouring oxides versus ceramic pigments

Colouring oxides and ceramic colouring pigments have rather different properties, each with their own advantages and disadvantages. Whether these properties can be considered as advantages or disadvantages obviously depends on the extent of control and colouring range one wants to achieve.



Anna Oliver (England), untitled, 1998. Ht: (each tile) approx. 17 cm (6¾ in.). Black underglaze was printed on leatherhard tiles using the silkscreen technique. After biscuit firing a turquoise and clear glaze (silhouettes of the figures) was painted on top. A red and orange onglaze was painted on top of the clear glaze and fired for a third time. (Photo: Peer van der Kruis)

Advantages and disadvantages of colouring oxides

Advantages:

- The transparency of a clear glaze is better retained, as most colouring oxides (except chromium oxide, zirconium silicate and tin oxide) are easily dissolved during fusion and because usually small additions (0.5%–6%) suffice for a strong colouring effect.
- Colouring oxides used in specially formulated glazes can lead to unique results, for example Egyptian blue or celadon and copper red glazes.
- Copper oxide, cobalt oxide, iron oxide and manganese oxide could yield interesting effects, if used in (over-) saturation.

Disadvantages:

- The colouring effect of colouring oxides is greatly affected by the other components in the glaze or (sinter) engobe. If one is after a specific colour, a glaze will have to be specially formulated for this purpose (in this book referred to as **special glazes**).
- Colouring oxides alone added to a **base glaze**, usually produce a poor colour range.
- The colour of the colouring oxide is usually very different from the colour of the fired glaze. This makes it difficult to predict the final result during application.
- Colouring oxides, though sold under the same name, are mined as raw materials on different sites all over the world and therefore may show variations in composition. Variations may occur from one site to another and there may be varying degrees of purification. Using the purified, more expensive, colouring oxides will yield more repeatable results.
- Colouring oxides can have a strong effect on the sintering and fusion range of a (sinter) engobe and glaze. Some tend to raise the point at which sintering and fusion starts (**chromium oxide**) while others lower it to a great extent (especially **copper oxide**, **manganese oxide** and **cobalt oxide**).
- Colouring oxides could increase the chance of pin-holing (**cobalt oxide**) or even the occurrence of craters (especially **chromium oxide** and **manganese oxide**).
- Many colouring oxides are hazardous to health, chromium oxide is toxic.

Advantages and disadvantages of ceramic pigments

Advantages:

- Using ceramic pigments allows a broadening of the colour range at a wide range of temperatures that is difficult to achieve otherwise.
- Ceramic pigments are formulated in such a way that their coloration is less readily affected by other components present in a glaze.
- The colour of a pigment and the colour it gives to a fired glaze or (sinter) engobe are similar to some extent (except the cobalt blue pigment of the Co–Si type, see *Table 8.2*). This makes it easier to predict the final result during application.
- Pigments are industrially manufactured. Usually a consistent quality between the various batches by the same manufacturer can be expected.

Disadvantages:

- Pigments yield more predictable and less lively results.
- Most pigments increase the point at which the sintering and fusion range starts.
- Only a few pigments can be used in reduction (see *Table 8.2*).
- Larger amounts must often be added to get strong colours.
- The transparency of a glaze usually decreases if colour saturation is aimed for, because ceramic pigments are manufactured in such a way that they do not dissolve during fusion.
- Because of the manufacturing process, pigments tend to be more expensive than most colouring oxides.

Colouring oxides

Table 8.1 provides an overview of several colouring oxides and their colouring effect in relation to general types of glazes.[8] Descriptions of colours are only an indication; testing will be necessary. **NB:** Quite a few colouring oxides are hazardous; some are toxic (see *Table 8.1*). It is advisable to handle them carefully and avoid the formation of dust.

Over-saturation

Over-saturation implies passing the point at which colouring oxides dissolve in a glaze. During cooling, interesting crystalline and metallic effects can occur. Copper oxide, iron oxide and manganese oxide are the most suitable to achieve over-saturation. Also, cobalt carbonate can be used to give interesting results in glazes and sinter engobes with a high aluminium oxide ratio. Variations in layer thickness, top temperature and

Table 8.1

Main colouring oxides in glazes

Type of glaze	*High alkaline glaze*	*Lead glaze*	*Calcium borate flush glaze*	*Cone 9 reduction glaze*	*Notes*
Copper oxide	Blue	Green	Light blue/ Green	Red/Rose	*Copper oxide reduces fusion range. Hazardous to health*
Cobalt carbonate	Blue	Blue	Ultra marine	Blue	*Cobalt carbonate is preferred over cobalt oxide as it disperses more evenly in a glaze. Cobalt carbonate reduces fusion range. Addition of zinc oxide increases intensity of blue. Hazardous to health*
Iron oxide	Brown	Honey brown/ brown	Brown	(Grey) green blue/ (red) brown	
Chromium oxide	Green	Green	Light green	Green	*Chromium oxide increases fusion range and opaqueness of a glaze. Toxic*
Manganese oxide	Brown/ Aubergine	Brown	Brown	Brown	*Manganese reduces fusion range. Hazardous to health*
Zirconium silicate	White	White	White	White	*Zirconium silicate increases surface tension and makes the glaze opaque*
Tin oxide	White	White	White	–	*Tin oxide increases surface tension, makes the glaze opaque and is subject to flash ing, see section 11.5.4* Other faults. *In general, zirconium oxide is preferred over tin oxide.*



Nick Renshaw (England/The Netherlands), *Earthling Candyman*, 2001. Ht: 165 cm (64 in.). A handbuilt figure using the coiling method. The surface was treated partly with a glaze (light blue and black), partly with a sinter engobe (iron brown and light brown parts), and in places left unglazed. The glaze and sinter engobe were partly applied with a brush, partly by spray-gun. Fired at various temperatures. Collection: Prinsessehof, Leeuwarden, The Netherlands. (Photo: Corné Bastiaansen)



Bobby Silverman (USA), *Stacked Bowls with Vase*, 1998. Ht: 25 cm (10 in.). All elements were thrown. The bowls were fired to a high biscuit. A mixture of a lead-free base glaze and a cadmium red glaze was then applied and fired in a low temperature glaze firing. A shiny transparent glaze was used on the vase. Collection: EKWC. (Photo: Peer van der Kruis)

the way of cooling will all affect the outcome. **NB:** Apart from iron oxide, over-saturated glazes should not be used on functional ware as metal release during usage could occur. These glazes are of particular interest for sculptural pieces.

Ceramic pigments

There is a wide range of colour pigments: the composition of the colours varies from one manufacturer to another. The symbols of elements are international and are used to identify specific types of pigments. The oxides present in the pigments are presented in order of significance. *Table 8.2* presents the colour pigments most used at the EKWC. The Zr–Si type of pigments mix very well with each other. Interesting results may also be achieved by mixing the pigments with small percentages of colouring oxides. Recently a **new range of red** and **orange** pigments have appeared on the market. Surprisingly vivid colours can be achieved that previously were only possible with **onglazes** at very low temperatures (see *Figure 8.2*).

NB: Ceramic pigments are hazardous to your health. It is advisable to handle them carefully and prevent the formation of dust. One should wear protective gloves and a fine dust respirator.

8.4 Formulating a glaze

An important reason for formulating one's own glaze or (sinter) engobe, despite having to spend time on testing, is the desire to gain more insight and flexibility. Whether it is better to develop one's own recipe or just buy a commercial glaze or engobe, depends very much on the desired outcome. If a straightforward result is required, a large variety of **commercial glazes** and, to a lesser extent, (sinter) engobes are available.

Table 8.2

Ceramic colour pigments

Pigment	*Type*	*Less stable beyond*	*Unfavourable effects on colouring*	
			In general	*In reduction*
Prussian blue	Co–Al–Zn	1300°C (2372°F)		Better not used because of volatilisation zinc oxide
Cobalt blue	Co–Si	1300°C		
Turquoise	Zr–V–Si	1300°C		Less bright in reduction
Coral	Zr–Si–Fe	1240°C (2264°F)		Colour changes
Brown	Zn–Fe–Cr–Al	1300°C		Not suited
Yellow	Zr–Si–Pr	1300°C	High zinc oxide content	Not suited
Grey	Sn–Sb–V	1300°C		Not suited
Green (dark)	Cr–Co–Al	1300°C		
Bright orange	Cd–S–Se–Si–Zr	1300°C	Lithium carbonate in glazes with low viscosity	Colour changes possible
Orange	Cd–Se–S–Zr–Si–Pr	1240°C		Not suited
Bright red	Cd–S–Se–Si–Zr	1300°C		Colour changes possible
Red	Zr–Si–Cd–S–Se	1240°C		Not suited
Pink	Cr–Al–Zn	1300°C	Low aluminium oxide content	Not suited
Aubergine	Cr–Sn–Ca–Si	1240°C	Zinc oxide	Not suited
Purple	Sn–B–Co–Cr	1240°C	Zinc oxide	Not suited
Black	Co–Ni–Cr–Fe	1300°C	Zinc oxide	

Key to symbols of elements

Al: Aluminium	Cd: Cadmium	Fe: Iron	S: Sulphur	Si: Silicon	Zn: Zinc
B: Boron	Co: Cobalt	Ni: Nickel	Sb: Antimonium	Sn: Tin	Zr: Zirconium
Ca: Calcium	Cr: Chromium	Pr: Praseodymium	Se: Selenium	V: Vanadium	

Commercial glazes are regularly used at the EKWC. Especially interesting are the shiny fully-transparent lead-free glazes developed for the low temperature range as they are more difficult to achieve. Until recently, bright red glazes were also difficult to achieve. The only alternatives were the commercial cadmium selenium type of glazes. New types of bright red and bright orange pigments now make it possible to achieve bright colours in studio-made glazes as well.

There are several starting points for formulating a glaze. A glaze, either matt or shiny, should yield a wide range of colours by adding ceramic pigments and colouring oxides; a so-called **base glaze.** A glaze can be designed to be durable and suitable for functional pieces. A glaze can be formulated for a specific application, such as being fully transparent so it can be used on top of an engobe or *underglaze*. However, if a particular colour or surface quality is aimed at then a specific combination of ingredients is used with a colouring oxide to make a so-called **special glaze;** a typical example is an *Egyptian blue glaze*. Some colours/surface qualities are obtained by firing a certain ingredient combination in a specific way (e.g. reduction), for example *celadon* and *copper red glazes*.

Each temperature range gives very different results. The **low temperature range,** 1050°C–1080°C/1922°F–1976°F (Orton cone 04–03) is particularly interesting for its large and bright colouring range. The **middle temperature range,** 1200°C–1240°C/ 2192°F–2264°F (Orton cone 6–7) is the practical upper firing limit for sculpture

(because after this the risk of distortion is too high in large or complex pieces). In this middle-temperature range a strong off-white stoneware body can be obtained with a moderate risk of distortion while a relatively good colour range of glazes is still available (although this is somewhat limited compared to the low temperature range). It is also the lower limit for obtaining durable functional ware and soft paste porcelain. The **high temperature range**, 1260°C–1280°C/2300°F–2336°F (Orton cone 9) is very suitable for functional ware and is also the temperature range where **reduction glazes** can be used successfully.

8.4.1 The make-up of glazes

Here, the make-up of different types of glazes will be discussed in general. Glazes are often classified according to the component that has the greatest influence on their character. In this book the following classification is used: lead glazes, calcium borate glazes, high alkaline glazes (glazes containing a fair amount of the strong alkalis: Na_2O, K_2O or Li_2O) and lime-alkali glazes (whiting (limestone) or wollastonite and feldspathoids). Within these classifications a variety of surface qualities exists, each with its own specific make-up. In order to understand this make-up and for reasons of comparison, the unity molecular formula and percentage analysis are very useful. A unity molecular formula (also referred to as the Seger formula) is a very helpful tool to understand the make-up of a glaze. In a unity molecular formula a graph with three columns is used: the fluxes are recorded on the left (all set to one); aluminium oxide, the main stabiliser, is recorded in the middle; and silica, the glass-former on the right. Boron oxide is positioned in the middle group as it is supposed to add stabilisation, although it also acts as a glass-former and is active in fusion due to its low melting point. The aluminium oxide:silica ratio according to the unity molecular formula is especially helpful in comparing different glazes. In a percentage analysis (also referred to as the fired analysis or chemical analysis) all oxides that are involved in fusion are presented in percentages. The percentage analysis is also useful for the comparison of oxide ratios of different glazes.

Matt glazes

To achieve a stable matt glaze the percentage of matting agents should be sufficiently high as well as the aluminium oxide ratio (sometimes referred to as aluminium matt glazes). To prevent the glaze from becoming too refractory the amount of quartz in such a glaze should be limited; generally an aluminium oxide:silica ratio of between 1:4.5 and 1:6 according to the unity molecular formula, could be used as a starting point. This can be reached by adding kaolin, clay or Molochite. Combining the two matting agents whiting and zinc oxide will yield good results provided a substantially higher proportion of whiting is used. In relation to the aluminium oxide:silica ratio, calcium borate glazes and glazes containing large amounts of petalite react differently. It is more difficult to achieve a matt in a glaze with a high calcium borate frit content because borate oxide counteracts crystallisation during cooling (an aluminium:silica ratio of 1:5.7 could still give a shiny glaze). An interesting and stable high silica matt glaze (aluminium oxide:silica ratio as high as 1:14.5) can be obtained if a high percentage of petalite is combined with a sufficient amount of matting agents; lithium oxide supports crystallisation during cooling.

Satin matt glazes

Satin matt glazes have a fair amount of matting agents (but less compared to matt glazes) and a smaller amount of aluminium oxide. An aluminium oxide:silica ratio of



Tomas Weber (Germany), *Rolls*, 1994. Dia: (max.) 52 cm (20 in.). The rolls were made by coiling an extruded coil in a vertical position. After biscuit firing the rolls were glazed and fired in a horizontal position. Apart from some unglazed pieces a large variety of base glazes and a cadmium red glaze were applied. (Photo: Peer van der Kruis)

between 1:7 and 1:8, according to the unity molecular formula, could be used as a starting point. Partly or fully replacing whiting with wollastonite may turn a matt glaze into a satin matt as simultaneously the calcium oxide content will be reduced and the silica content will be increased. As has been pointed out, satin matt glazes tend to react more sensitively to the way the glaze is cooled.

Satin gloss glazes

Satin gloss glazes tend to be formed as a result of countless ultra-fine bubbles being trapped during fusion, due to a more-than-average viscosity. Generally these glazes have a high ratio of silica (aluminium oxide:silica ratio between 1:7.5 and 1:11) compared to the two previous types of glazes. Low temperature range satin gloss glazes generally have a fair amount of fluxing agents, but not enough to reduce viscosity too much. Nepheline syenite will support the forming of a satin gloss at all temperature ranges. The presence of sufficient matting agents could also lead to a satin gloss, if a (slight) crystallisation during cooling occurs.

Opaque glazes

Opaque glazes can be linked to crystallisation, due to a fair amount of matting agents like calcium carbonate or zinc oxide, and not fully dissolved particles due to the presence of **opacifiers** like zirconium silicate or tin oxide. Another cause could be the occurrence of countless ultra-fine bubbles due to a high viscosity or the appearance of a calcium borate flush due to a high calcium borate frit content in combination with a moderate or low aluminium oxide ratio. Additions of large amounts of pigments and certain colouring oxides will also cause opacity.



Hans van Bentem (The Netherlands), *Techno Buddha* (Japanese Icon Series), 1997. Ht: 100 cm (39½ in.). This piece was modelled solid and then hollowed out. A clay body with a coarse and open structure was used. It was glazed with a copper-saturated glaze. (Photo: Peer van der Kruis)

Shiny glazes

To achieve a **shiny glaze** sufficient amounts of fluxing agents should be present. An aluminium oxide:silica ratio of between 1:8 and 1:10 could be used as a starting point. However, calcium borate glazes can have a higher ratio of aluminium oxide and still remain shiny, as stated previously. Glazes with a high strong alkali content (especially in the case of large amounts of lithium carbonate), a low aluminium oxide content and a very high silica content (1:16) can still give a shiny finish. Low temperature range glazes always contain a fair amount of strong fluxing agents. At medium and high temperatures, a small amount of zinc oxide and especially calcium borate frit is useful to increase the gloss.

Transparent glazes

As stated before, to obtain a **transparent glaze** all components have to be completely and homogeneously fused and no crystallisation during cooling should take place. Therefore fully transparent glazes are shiny glazes. To achieve full transparency, and to keep the presence of bubbles in the glaze layer to a minimum, the glaze should neither be too viscous nor should the surface tension be high. Therefore the amount of nepheline syenite should be limited. At low temperatures lead oxide-containing glazes yield good results. A shiny lime-alkali glaze for the middle or high temperature range could be turned into a transparent glaze by adding a moderate amount of calcium borate frit.

Table 8.3 *provides an overview of the ingredients that are mentioned in this chapter and their relative effect on glaze properties. It can serve as a guide for further adjusting a glaze. There is no proportional relationship between the ingredients. By replacing one ingredient partly or totally with the next or the previous, the effect of a certain property could be increased or decreased. As has been discussed before, however, whatever property a specific ingredient may possess, the ultimate effect in the fired glaze is simultaneously determined by the other ingredients present in the glaze mixture.*

8.4.2 Glaze recipes

In this section several recipes are provided (that can be used as a starting point for further experiment) together with information about possible general and specific applications and suggestions as to how a recipe can be altered in order to gain more latitude in relation to its properties. All the base ingredients in the recipes are calculated to add up to a total of 100%, making comparison between recipes easier. Also for the sake of comparison, and as a means of reconstructing a recipe with the ingredients at hand, each recipe is provided with a unity molecular formula and percentage analysis. For more information about reconstructing a recipe see section *14.2.1 Glaze calculation*. *Table 8.4* provides general information about the amounts of stains that can be added to a base glaze. Along with some of the recipes, options of higher additions of colouring oxides will be discussed to achieve a particular over-saturation effect, and specific amounts of certain colouring oxides will be given in the case of special glazes. In general, implementing **double glazing** – two coats of different glazes or using the same glaze with different amounts of stains on top of each other – could be an interesting option to expand the possibilities.

Table 8.3

Basic ingredients and their relative effect on the properties of a glaze

Increases fusion	***Increases viscosity***	***Increases surface tension***	***Matt surface more likely to occur***
Lithium carbonate	Molochite 200	Molochite 200	Molochite 200
Lead bisilicate 3647	Kaolin	Kaolin	Kaolin
Calcium borate frit 3221	HTR-clay	HTR-clay	HTR-clay
Nepheline syenite	Quartz	Whiting[1]	Barium carbonate[1]
Petalite	Cornish stone	Zinc oxide[1/2]	Whiting[1]
Cornish stone	Nepheline syenite	Wollastonite[1]	Zinc oxide1
Zinc oxide	Petalite	Cornish stone	Wollastonite
Wollastonite	Wollastonite	Nepheline syenite	Petalite
Whiting	Barium carbonate	Barium carbonate	Nepheline syenite
Barium carbonate	Whiting	Petalite	Cornish stone
Quartz	Zinc oxide	Quartz	Quartz
HTR-clay	Calcium borate frit 3221	Calcium borate frit 3221	Lithium carbonate[2]
Kaolin	Lead bisilicate 3647	Lead bisilicate 3647	Lead bisilicate 3647
Molochite 200	Lithium carbonate	Lithium carbonate	Calcium borate frit 3221
Decreases fusion	***Decreases viscosity***	***Decreases surface tension***	***Matt surface less likely to occur***

Increases opaqueness	***Increases thermal expansion***	***Increases durability***	***Increases bright colour***
Molochite 200	Nepheline syenite	Molochite 200	Lead bisilicate 3647
Kaolin	Cornish stone	Kaolin	Petalite
Calcium borate frit 3221[1]	Whiting	HTR-clay	Nepheline syenite
HTR-clay	Barium carbonate	Quartz	Barium carbonate
Zinc oxide	Lead bisilicate 3647	Wollastonite	Cornish stone
Whiting	Wollastonite	Whiting	Wollastonite
Barium carbonate	Zinc oxide	Zinc oxide	Whiting
Wollastonite	Calcium borate frit 3221	Barium carbonate	Quartz
Cornish stone	Quartz	Calcium borate frit 3221	Kaolin[3]
Nepheline syenite	HTR-clay	Cornish stone	Molochite 200[3]
Petalite	Kaolin	Petalite	HTR-clay[3]
Quartz	Molochite 200	Nepheline syenite	Calcium borate frit 3221[1]
Lithium carbonate	Lithium carbonate[2]	Lithium carbonate	Zinc oxide[2]
Lead bisilicate 3647	Petalite	Lead bisilicate 3647	Lithium carbonate[2]
Decreases opaqueness	***Decreases thermal expansion***	***Decreases durability***	***Decreases bright colour***

Notes: [1] *If small amounts are used the opposite effect will occur*
[2] *See section* 8.3 Ingredients *for important additional information.*
[3] *This refers more specifically to the application of colouring oxide.*

NB: To obtain similar results as described low and mid temperature range glazes should be fired with an increase of **60°C (140°F)/hour** from 200°C (400°F) below top temperature to the top; no soaking should be done. The high temperature reduction glazes should be fired as indicated in table 11.5. The glaze recipes do not mention any glaze additive additions. Ways to improve the application properties of a glaze are discussed in section *8.8 Preparing and applying glazes and (sinter) engobes.*

Table 8.4

Colouring oxides and ceramic pigments for base glazes

Copper oxide 1–3%	Cobalt carbonate 0.2–1%	Iron oxide 2–4%	Chromium oxide 0.2–1%
Manganese oxide 2–6%	Zirconium silicate 10–15%	Tin oxide 10–15%	
Green (dark) Cr–Co–Al 2–6%	Turquoise Zr–V–Si 6–10%	Prussian blue Co–Al–Zn 2–4%	Cobalt blue Co–Si 1–3%
Purple Sn–B–Co–Cr 8–16%	Aubergine Cr–Sn–Ca–Si 6–12%	Red Zr–Si–Cd–S–Se 10–15%	Bright red Cd–S–Se–Si–Zr 8–10%
Pink Cr–Al–Zn 6–12%	Coral Zr–Si–Fe 6–12%	Orange Cd–Se–S–Zr–Si–Pr 6–12%	Bright orange Cd–S–Se–Si–Zr 6–8%
Yellow Zr–Si–Pr 8–12%	Brown Zn–Fe–Cr–Al 6–10%	Black Co–Ni–Cr–Fe 3–6%	Grey Sn–Sb–V 2–6%

Note: In general, middle temperature base glazes demand the maximum indicated percentages of pigments.



Bastiënne Kramer (The Netherlands) *Baby*, 2000. L: 230 cm (89¾in.). A hollow-built piece using the coiling method. Clay props were used inside the piece to support the span. The piece was glazed with a cadmium red and orange glaze and a range of high-lead and lead-free base glazes coloured with oxides. Collection: Sociale Verzekerings Bank, Zaandam, The Netherlands. (Photo: Peer van der Kruis)

Low temperature range base glazes

Low temperature range base glazes contain a relatively high proportion of strong fluxing agents that are preferably introduced by frits. The percentages of colouring oxides and pigments provided in *Table 8.4* can be used as a starting point. As has been pointed out before, pigments and colouring oxides each have their own effect on fusion, surface tension, shininess and the possible occurrence of pin-holing. Most glazes within this temperature range tend to craze (crackle) if applied to a sculpture body.

The recipe in *Table 8.5* will give a transparent shiny glaze with low viscosity. It has a tint of yellow/buff colour (usually linked to a high proportion of lead oxide and noticeable if the glaze is applied on a white body). With all the base glazes provided in this book the brightest colours can be obtained by adding ceramic pigments. **NB:** Not suitable for functional ware.

An interesting copper over-saturation can be achieved: metallic silvery black showing tiny crystals, by adding 12%–15% copper oxide. **NB:** There is a tendency for this glaze to run if copper oxide is added and it is applied thickly. A combination of 3% black stain, 1% cobalt carbonate and 3% copper oxide will yield a silvery mirror-like black. The same is true for a combination of 6% copper oxide and 4% iron oxide. By adding solely iron oxide (8%) a dark aubergine colour will be obtained.

The aluminium oxide:quartz ratio in combination with a large amount of calcium oxide causes the glaze in *Table 8.6* to crystallise during cooling, forming a matt surface. A more satin matt result can be obtained if whiting is (partly) replaced by wollastonite. Fairly bright colours can be achieved by adding ceramic pigments.

NB: Not suitable for functional ware.

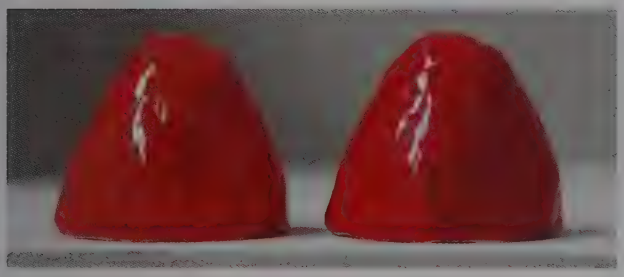


Figure 8.2
Both these test pieces are glazed with a high-gloss transparent lead glaze (see *Table 8.5*). The left one with an addition of 15% of the old type of red pigment and the right one with an addition of 10% of the new type of red pigment. (Photo: Anton Reijnders)

Table 8.5

High gloss transparent lead base glaze (Lf HG2-1)

1050°C–1080°C (1922°F–1976°F)
60°C (140°F)/hour Orton cone 04–03

Kaolin RM 225	13%	K_2O	0.02				
Lead bisilicate 3647	71%	Na_2O	0.05				
Nepheline syenite RM 094	7%	CaO	0.13	Al_2O_3	0.28	SiO_2	2.60
Quartz	5%	MgO	0.01				
Wollastonite	4%	PbO	0.79				

Al_2O_3:SiO_2 1:9.16

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
41.82	7.75	–	1.97	0.13	–	46.99	–	0.77	0.57

Table 8.6

Matt lead base glaze (LM Ns W 5-2)

1050°C–1080°C (1922°F–1976°F)
60°C (140°F)/hour Orton cone 04–03

Calcium borate frit 3221	4%	K_2O	0.04				
Kaolin RM 225	7%	Na_2O	0.13				
Lead bisilicate frit 3647	23%	CaO	0.58	Al_2O_3	0.25	SiO_2	1.54
Nepheline syenite RM 094	34%	MgO	0.00	B_2O_3	0.07		
Quartz	8%	ZnO	0.09				
Whiting	21%	PbO	0.16				
Zinc oxide	3%						

Al_2O_3:SiO_2 1:6.17

SiO_2	Al_2O_3	B_2O_3	CaO	ZnO	MgO	PbO	Li_2O	Na_2O	K_2O
44.09	12.14	2.48	15.35	3.34	0.05	16.66	–	3.95	1.95

Table 8.7

Calcium borate shiny semi-transparent base glaze (MM NE 1)

1060°C–1090°C (1940°F–1994°F)
60°C (140°F)/hour Orton cone 03

Calcium borate frit 3221	25%	K_2O	0.06				
EOBBY (Aluminous ball clay)	24%	Na_2O	0.14	Al_2O_3	0.44		
Nepheline syenite RM 094	27%	CaO	0.79	B_2O_3	0.62	SiO_2	2.49
Quartz	19%	MgO	0.01				
Whiting	5%						

Al_2O_3:SiO_2 1:5.72

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
50.41	14.97	14.72	15.03	0.09	–	–	–	3.02	1.76

To obtain a stable lead-free shiny glaze in the low temperature range, a borate-containing frit is often used as the main strong fluxing agent; this is true for the glaze in *Table 8.7* as well. Many lead-free commercial glazes are of this type. In spite of the high content of calcium borate frit no calcium borate flushing occurs due to the high ratio of aluminium oxide. Numerous hardly-visible bubbles trapped in the glaze layer result in a subdued gloss and slight opacity (only visible if applied on top of a dark body or under glaze painting). Due to a fairly low expansion rate the chance of crazing on a body with an average expansion rate is less. Reducing the nepheline syenite to 18% and introducing petalite up to 12% will lessen the chance of crazing even more. Fired in a gas kiln this glaze could turn more to a matt, rough surface, see more about this phenomenon in section *11.5.4 Other faults*.

Provided it is thinly applied the semi-opaque glaze in *Table 8.8* can be used on a body that has an average expansion rate to avoid crazing. Usually this glaze will be shiny if applied thinly and fired in an electric kiln. Depending on the pigment used, a satin gloss to shiny surface will be achieved if a thick layer is applied. Firing in a gas kiln will result in a satin gloss glaze. Aubergine and purple pigments will give pastel shades (other pigments give fairly bright colours). This glaze is suitable for functional ware. **NB:** Testing is necessary if used on a body that has a high expansion rate, as there could be a chance of shivering. At the indicated maximum temperature a more transparent result will be achieved, as well as a shininess, from gas or electric firing regardless of the layer thickness.

A combination of aluminous ball clay and a high percentage of nepheline syenite results in a high aluminium oxide ratio (*Table 8.9*). Lithium carbonate and the alkalis in nepheline syenite take care of the fusion. Adding calcium borate frit 3221 up to 3%

Table 8.8

Moderate expansion base glaze (Le P 2-2)

1070°C–1140°C (1958°F–2084°F) 60°C (140°F)/hour Orton cone 03–1

Calcium borate frit 3221	19%	K_2O	0.01				
Petalite	49%	Na_2O	0.02				
Kaolin RM 225	6%	Li_2O	0.22	Al_2O_3	0.33	SiO_2	3.46
Quartz	19%	CaO	0.62	B_2O_3	0.51		
Wollastonite	4%	MgO	0.01				
Zinc oxide	3%	ZnO	0.12				

Al_2O_3:SiO_2 1:10.38

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
62.78	10.26	10.71	10.50	0.11	3.04	–	1.98	0.30	0.33

Table 8.9

Lime alkali base glaze (MG SE 10 3E)

1060°C–1080°C (1940°F–1976°F) 60°C (140°F)/hour Orton cone 03

EOBBY (Aluminous ball clay)	15%	K_2O	0.07				
Lithium carbonate	5%	Na_2O	0.21				
Nepheline syenite RM 094	47%	Li_2O	0.18	Al_2O_3	0.42	SiO_2	2.51
Quartz	13%	CaO	0.38				
Wollastonite	16%	MgO	0.03				
Zinc oxide	4%	ZnO	0.13				

Al_2O_3:SiO_2 1:6.02

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
60.01	16.92	–	8.36	0.53	4.23	–	2.14	5.20	2.62



Kiran Subbaijah Ajikuttira (India), *The Fallen Lord* (detail of installation), 1995. Ceramics and copper wire. A hollow-built sculpture using the coiling method. A sinter engobe (bottom part), a bronze glaze and engobe (top part) were used. (Photo: Peer van der Kruis)

will result in a surface that is slightly less matt. Firing to the indicated maximum temperature and partly replacing wollastonite with whiting or replacing the ball clay with kaolin will give a more matt result. An addition of up to 4 or 5% of copper oxide will result in a bronze green colour.

Low temperature range special glazes

There is a wide range of glazes specifically for low temperature. In this section only a few examples are provided.

Calcium borate frit 3221 is the only strong fluxing agent in this glaze (*Table 8.10*). A calcium borate flush caused by the high amount of calcium and boron oxide in combination with a moderate amount of aluminium oxide (compared to the glaze recipe in *Table 8.7*) results in an opaque glaze. More pastel shades will be formed if ceramic pigments are used. An interesting copper over-saturation can be obtained: 8%–12% yields a lively mottled dark green, from 14% onwards there is an increased tendency to run and the green colour gets darker. Keep in mind that a thick application and firing above 1060°C (1940°F) increases the chance of pin-holing. Fired in a gas kiln it has a tendency to become less shiny, although this is less true for the over-saturated copper variation. **NB:** The over-saturated copper variation of this glaze should not be used on functional pieces.

An Egyptian blue is obtained by adding copper oxide to a glaze with a high sodium, potassium or lithium content and a low aluminium oxide content. A high alkaline frit is often used as the main ingredient. In the Egyptian blue glazes described below the main flux is lithium oxide. Sodium and potassium oxide, introduced by nepheline syenite, also add to the total of strong alkalis. The quality of the blue colour is also determined by the type of body underneath. A white body will give a more brilliant colour.

Despite the relatively high aluminium oxide content the glaze in *Table 8.11* produces a strong blue; this is caused by the high lithium oxide ratio.[9] The very high silica content, as compared to most common low temperature range glazes increases the viscosity to such an extent that running is somewhat counteracted, although the viscosity is still low: the glaze will flow if fired to the indicated maximum temperature and applied thickly. An increase of nepheline syenite and decrease of lithium carbonate will result in a shift towards green. Slow cooling could lead to crystallisation resulting in slightly matt specks on the surface. Crystallisation can be counteracted by partly or

Table 8.10

Calcium borate flush glaze (CaNs 8-2)

1040°C–1060°C (1904°F–1940°F)
60°C (140°F)/hour Orton cone 04

Calcium borate frit 3221	29%	K_2O	0.06						
Nepheline syenite RM 094	39%	Na_2O	0.20	Al_2O_3	0.28	SiO_2	2.88		
Quartz	32%	CaO	0.73	B_2O_3	0.72				
		MgO	0.00						
		Al_2O_3:SiO_2 1:10.38							

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
55.62	9.09	16.12	13.20	0.04	–	–	–	4.05	1.87

Table 8.11

Egyptian blue glaze (EBL Ns 8a1)

1050°C–1080°C (1922°F–1976°F)
60°C (140°F)/hour Orton cone 04–03

Lithium carbonate	16%	K_2O	0.04						
Nepheline syenite RM 094	30%	Na_2O	0.15						
Quartz	48%	Li_2O	0.63	Al_2O_3	0.20	SiO_2	3.37		
Wollastonite	6%	CaO	0.16						
		MgO	0.01						
+ 4–5% Copper oxide		Al_2O_3:SiO_2 1:16.62							

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
76.42	7.80	–	3.37	0.20	–	–	7.16	3.45	1.59

Table 8.12

Egyptian blue matt glaze (EBL NS 4-4)

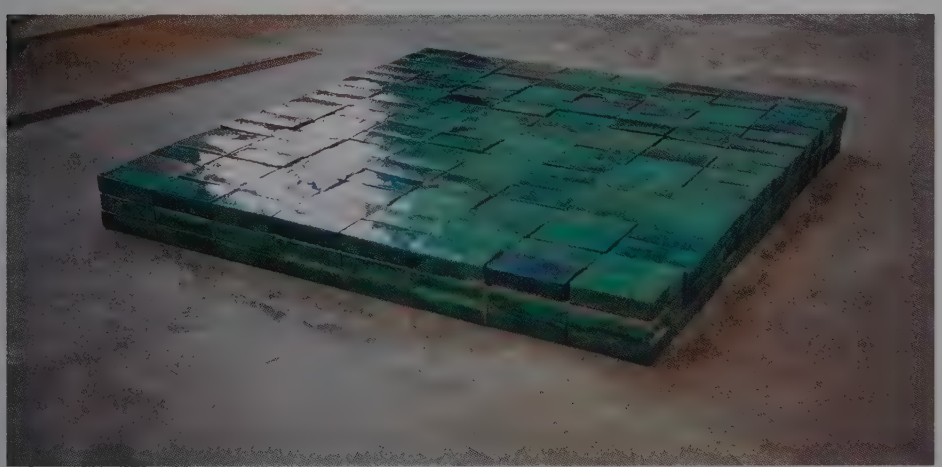
1040°C–1060°C (1904°F–1940°F)
60°C (140°F)/hour Orton cone 04

Lithium carbonate	16%	K_2O	0.01						
Petalite	48%	Na_2O	0.01						
Quartz	24%	Li_2O	0.75	Al_2O_3	0.20	SiO_2	2.88		
Wollastonite	6%	CaO	0.14						
Barium carbonate	6%	BaO	0.08						
		MgO	0.01						
+ 4–5% Copper oxide		Al_2O_3:SiO_2 1:14.12							

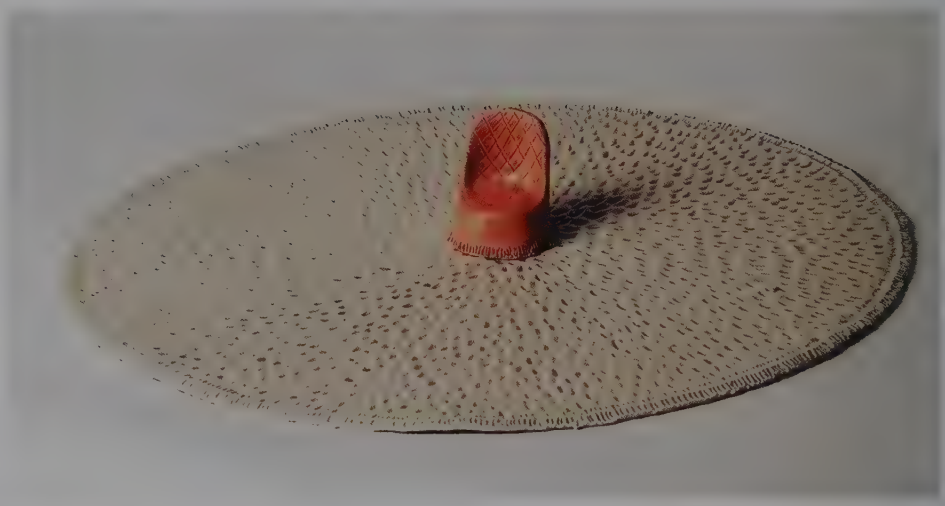
SiO_2	Al_2O_3	B_2O_3	CaO	BaO	ZnO	PbO	Li_2O	Na_2O	K_2O
72.61	8.72	–	3.20	5.28	–	–	9.46	0.32	0.24

completely replacing the wollastonite with barium carbonate; this will also increase the intensity of the blue slightly. **NB:** This glaze is not suitable for functional ware and should be applied on high bisque to avoid **shelling** (peeling), see section *11.5 Analysing faults apparent after the glaze firing*.

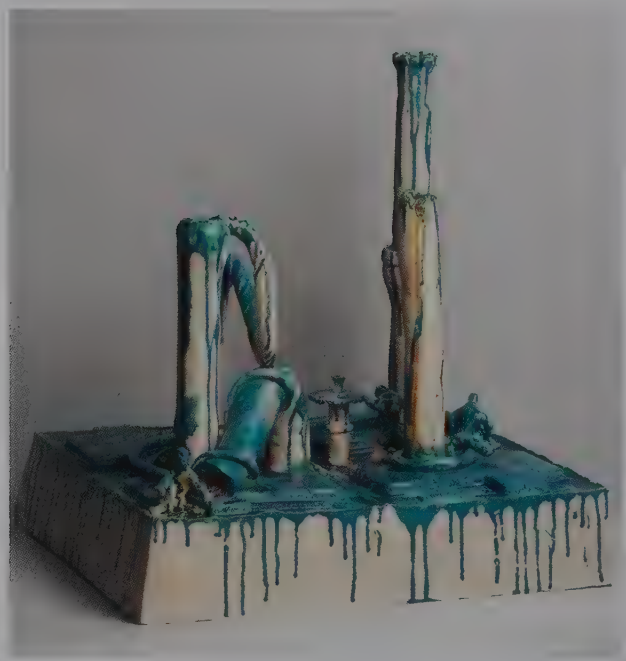
Table 8.12 provides a matt Egyptian blue glaze. A combination of a high lithium oxide ratio and the presence of barium carbonate will result in a bright blue matt glaze that is otherwise difficult to achieve. Lithium carbonate is essential to obtain the necessary fusion and support the bright blue, and petalite in combination with barium carbonate and wollastonite is essential to achieve the matt surface. An increase in barium carbonate and decrease in wollastonite will intensify the blue to some extent. The opposite will produce a slightly more greenish blue and reduce the chance of crazing. Fired to the indicated maximum temperature, the glaze will tend to run. To achieve a matt finish more than one coat should be applied (one coat will give a shiny result). **NB:** This glaze is not suitable for functional ware and should be applied on high bisque to avoid **shelling** (peeling), see section *11.5 Analysing faults apparent after the glaze firing*.



Hella Berent (Germany), *Sleeping Wall*, 2002. W: 168.5 cm (65¾ in.). The 48 bricks were made in a press-mould using fine-grained white sculpture clay. A variety of Egyptian blue copper glazes were applied in various thicknesses. To some of the glazes extra cobalt oxide was added. The glazes were fired to the mid temperature range resulting in a large variety of blue and blue green shades. The copper blue colour became greener in places when the thinly-applied glaze layer reacted with the aluminium oxide in the body.
(Photo: Hella Berent)



Paula Gallardo (Argentina), *Silloncito Bebé*, 2003. Ht: 7 cm (2¾ in.). Transparent glazes on porcelain, fired in oxidation. A small amount of pink pigment was added to the glaze applied on the element in the centre. As a result, the glaze remained transparent and clear colour differences due to layer thickness are visible. Collection: EKWC. (Photo: Corné Bastiaansen)



Rob Birza (The Netherlands), *No More Holidays No. II*, 2002. Ht: 65 cm. (25½ in.). A combination of press-moulding and modelling. High biscuit, low glaze firing. Semi-matt turquoise, with a high alkaline frit as the main ingredient, was used for this piece. In places there is a glaze containing iron oxide. Glazes were applied with a brush. (Photo: Corné Bastiaansen)

Middle temperature base glazes

A stable glaze at the middle temperature range can be achieved by using only four ingredients: kaolin, nepheline syenite, quartz and whiting. Zinc oxide can be added to reduce viscosity. Due to the fact that glaze and body can be more easily attuned craze-free glazes can be obtained more easily. The colour range of the glazes within this temperature range is generally reasonable. In general, a higher percentage of pigment must be added, compared to the low temperature range glazes, to get saturated colours, see *Table 8.2*. The following glazes could be used for outdoor sculptures as well.

A typical lime-alkali glaze recipe is given in *Table 8.13*: the main fluxes are nepheline syenite and whiting. Due to its high viscosity this glaze shows many very fine bubbles resulting in a subtle gloss and semi-transparency. It reacts well to ceramic pigments. An interesting silvery matt surface can be obtained by adding 27% manganese oxide and 3% copper oxide. A combination of 4–5% manganese, 5% copper and 9% cobalt carbonate will yield a shiny, silvery metallic result.

A recipe for a transparent glaze suited as a cover glaze over an engobe or underglaze is given in *Table 8.14* and is derived from the previous recipe: 3% calcium borate frit is added and the amount of kaolin is reduced. Replacing kaolin with HTR-clay will yield a slightly shinier glaze.

The recipe in *Table 8.15* gives a surface that varies from satin matt to matt (depending on the pigments used). A bronze coloured glaze can be obtained by adding 5% copper oxide and 25% manganese oxide. Reducing the quartz to 8% and increasing the whiting up to 17% can give a more matt surface.

The transparent shiny glaze in *Table 8.16* reacts very well to cobalt carbonate and cobalt-containing pigments. An addition of a Co–Al–Zn type of pigment (7%–9%) will yield a vivid ultra-marine matt blue. It could be used as a cover glaze over an engobe or underglaze, but due to the high zinc content it will not react well to all stains. The

Table. 8.13

Satin gloss base glaze (KL 1-0.3 Ns)

1200°C–1230°C (2192°F–2246°F)
60°C (140°F)/hour Orton cone 6–7

Kaolin RM 225	17%	K_2O 0.06			
Nepheline syenite RM 094	26%	Na_2O 0.17	Al_2O_3 0.46	SiO_2 3.81	
Quartz	37%	CaO 0.77			
Whiting	20%	MgO 0.00			

Al_2O_3:SiO_2 1:8.27

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
68.29	14.02	–	12.82	0.06	–	–	–	3.08	1.74

Table 8.14

Transparent base glaze (KL 1-0.3 Ca)

1200°C–1230°C (2192°F–2246°F)
60°C (140°F)/hour Orton cone 6–7

Calcium borate frit 3221	3%	K_2O 0.05			
Kaolin RM 225	14%	Na_2O 0.15	Al_2O_3 0.39	SiO_2 3.42	
Nepheline syenite RM 094	26%	CaO 0.79			
Quartz	37%	MgO 0.00			
Whiting	20%	B_2O_3 0.08			

Al_2O_3:SiO_2 1:8.88

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
66.40	12.69	1.87	14.26	0.05	–	–	–	3.06	1.67

Table 8.15

Aluminium matt base glaze (BO 4-16)

1200°C–1230°C (2192°F–2246°F)
60°C (140°F)/hour Orton cone 6–7

Kaolin RM 225	14%	K_2O 0.11			
Nepheline syenite RM 094	58%	Na_2O 0.32	Al_2O_3 0.60	SiO_2 2.92	
Quartz	12%	CaO 0.45			
Whiting	13%	ZnO 0.12			
Zinc oxide	3%	MgO 0.01			

Al_2O_3:SiO_2 1:4.85

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
58.14	20.35	–	8.33	0.09	3.25	–	–	6.56	3.28

Table 8.16

High zinc glaze (HZ 1-3)

1200°C–1230°C (2192°F–2246°F)
60°C (140°F)/hour Orton cone 6–7

Kaolin RM 225	4%	K_2O 0.05			
Nepheline syenite RM 094	43%	Na_2O 0.16	Al_2O_3 0.26	SiO_2 2.16	
Quartz	20%	CaO 0.39			
Wollastonite	20%	ZnO 0.36			
Zinc oxide	13%	MgO 0.03			

Al_2O_3:SiO_2 1:8.32

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
58.00	11.82	–	9.83	0.57	13.11	–	–	4.52	2.15

same is true if used as a base glaze. Replacing wollastonite with whiting will give a more matt surface.

High temperature glazes for reduction

High temperature glazes are very suitable for functional pieces. A strong intermediate layer will be formed reducing the chance of crazing and improving the strength of the fired piece. When fired in reduction at this temperature most ceramic pigments are not stable (see *Table 8.2*). Colouring oxides work better; cobalt carbonate, manganese oxide and chromium oxide could be used, and copper and iron oxide give especially interesting results. Besides two base glazes, examples of a copper red and celadon glaze will be discussed in more detail. See more about firing these glazes in section *11.4 Reduction firing*.

The recipe in *Table 8.17* gives a fairly transparent



Setsuko Nagasawa (Japan/France), *Installation*, 1991. Ht: approx. 75 cm (29½ in.). Cut fibreboard glazed with a shiny transparent glaze fired in reduction. The presence of traces of iron oxide in the glaze resulted in a light blue colour. The glaze crawled in places. Fragments of glaze (peeled from fibreboards due to thick application and large differences in thermal expansion) are on the floor. (Photo: Peer van der Kruis)

Table 8.17

High temperature shiny base glaze (LQ 7-4)

1270°C (2318°F)
100°C (212°F)/hour Orton cone 9

Kaolin RM 225	19%	K_2O	0.05			
Nepheline syenite RM 094	24%	Na_2O	0.14	Al_2O_3	0.43	SiO_2 3.28
Quartz	34%	CaO	0.80			
Whiting	23%	MgO	0.00			

Al_2O_3:SiO_2 1:7.64

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
65.77	14.60	–	14.96	0.06	–	–	–	2.91	1.70

Table 8.18

High temperature matt base glaze (Ns mat1-4)

1260–1280°C (2300°F–2336°F)
100°C (212°F)/hour Orton cone 9

Calcinated kaolin (RM 225)	9%	K_2O	0.08			
Nepheline syenite RM 094	33%	Na_2O	0.20	Al_2O_3	0.67	SiO_2 3.56
Kaolin RM 225	20%	CaO	0.67			
Quartz	16%	MgO	0.06			
Wollastonite	22%					

Al_2O_3:SiO_2 1:5.33

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
62.66	19.95	–	10.94	0.67	–	–	–	3.61	2.18

glaze if not applied too thickly. It can be used over an engobe. This recipe can also be used to obtain a shiny transparent celadon by adding 1.5%–2% of iron oxide. Applied on a porcelain body it will yield bluish shades. An addition of 10% iron oxide will yield a shiny black brown tenmoku[10] glaze if applied thickly, becoming rusty brown at thin spots. Adding 0.5% copper oxide and 1% tin oxide will yield a rose colour. The shininess and transparency of this glaze can be increased by adding 6% calcium borate frit at the expense of some of the whiting.

Due to the high aluminium:calcium oxide ratio this recipe (*Table 8.18*) gives a stony matt and very durable glaze. A cloudy opacity will be achieved if applied over an iron or cobalt-containing engobe, especially interesting on top of a porcelain body. Adding 12% iron oxide will result in an iron matt red. Cobalt saturation: 10%–12% cobalt carbonate will give a mauve blue colour.

Copper red

High temperature copper red glazes originated in China. The colour is not a signal red but tends to be more of a blood red, therefore the term 'ox-blood' is also used for these glazes. In principle, copper red glazes are fully fused glazes with low viscosity. A sufficiently **strong alkali** content will support the formation of the blood red colour. Nepheline syenite works very well as a source of the strong alkalis, but due to its high viscosity and tendency to form ultra-fine bubbles (which will counteract the formation of the red colour) an addition of extra flux is necessary. By adding calcium borate frit the necessary reduction of viscosity can be achieved. Wollastonite supports the formation of the red colour; it gives better results than whiting. Adding small amounts of barium carbonate or petalite tends to shift the colour to a darker red. In general, the best results are obtained if only small amounts of copper oxide are added in combination with some tin oxide and possibly iron oxide. Besides the ingredients, the layer thickness, the body beneath, the top firing temperature and the way the reduction takes place are all major factors in achieving the best results. Sufficient thickness is essential, as the red colour tends to disappear if applied thinly. However, used on a porcelain body it could yield a slightly brighter red if applied less thickly. Thick layers (>0.5 mm of unfired layer thickness) tend to be fairly opaque.

Table 8.19

Copper red (HGL 3-1)

1260°C–1280°C (2300°F–2336°F)
100°C (212°F)/hour Orton cone 9

Calcium borate frit 3221	10%	K_2O	0.07			
Nepheline syenite RM 094	50%	Na_2O	0.25	Al_2O_3	0.34	SiO_2 3.02
Quartz	24%	CaO	0.65			
Wollastonite	16%	MgO	0.03			
		B_2O_3	0.23			
+ 0.5% Copper oxide +1% Tin oxide		Al_2O_3:SiO_2 1:8.90				

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
62.11	11.84	5.57	12.39	0.46	–	–	–	5.21	2.41

The recipe in *Table 8.19* provides a lively blood-red



Seet van Hout (The Netherlands), *Art of Memory* (part of installation), 1999. Ceramics and textile. W: 125 cm (49 in.). Cast porcelain spheres. The first and third spheres (from the left) were glazed with a cadmium red glaze in high biscuit, low glaze firings. The second and fourth spheres were glazed with a copper red glaze and fired in reduction. Green dots are linked to lumps of copper oxide. In areas where the copper red glaze was applied thin, the colour disappeared. (Photo: Peer van der Kruis)

coloured glaze. The best result is obtained if the glaze has fully fused.[11] There is a tendency to run if applied very thickly. Increasing the calcium borate frit up to 12% and nepheline syenite up to 54%, and decreasing the amount of wollastonite, gives a darker veined result in thickly applied layers (see *Figure 14.3*). Without the addition of copper and tin oxide a copper red colour can be obtained by applying over a copper/tin engobe (see section *8.5 Formulating one's own engobe*). By reducing the calcium borate frit to 7% and introducing up to 3% of barium carbonate, or by introducing up to 6% petalite and reducing the amount of nepheline syenite a darker red can be achieved.

Celadon

Celadon glazes were also first developed in China. Celadon is a lime alkali glaze containing small amounts of iron oxide that will in reduction produce a light green/grey or blue/grey colour with a wide variety of surface qualities ranging from very shiny transparent to waxy opaque. The purity of the ingredients, layer thickness, the clay body, the way the reduction takes place and the extent of fusion, are the main factors that will influence the quality. In general, kaolin will produce bluish tones provided it has a low titanium and magnesium oxide content. As the titanium and magnesium content increases a shift towards green will occur. The use of HTR-clay or MTR-clay could produce grey/green or even brown/green shades. The purity of the iron oxide also affects colour: very pure, finely-ground iron oxide will give a slightly bluer tone. To achieve a waxy opaque celadon, Cornish stone (epecially P3419 from Potclays) works better than nepheline syenite. It is advisable to obtain samples from different suppliers of the ingredients listed in the recipes below to find out which combinations achieve the best results. A thick layer (at least 0.5 mm but preferably 1mm or more) will give better results as far as colour and opacity are concerned. The use of additives, as discussed in section *8.8.1 Glaze additives*, is strongly advised to reduce the chance of glaze faults linked to thick glaze layers. As for the clay body, a porcelain or white stoneware body, like a vitreous china, will support the formation of lighter colours. On a porcelain body, celadon tends to become somewhat shinier than on a stoneware body. Finally, the way the glaze is fired in reduction determines the colour to a great extent.[12] An underfired celadon glaze will give less clear colours.

The recipe in *Table 8.20* provides a Longquan type of celadon glaze: a typical waxy



Heringa/van Kalsbeek (The Netherlands), untitled, 1999. Ht: 70 cm (27½ in.). A collage of a readymade Chinese porcelain figurine with press-moulded and modelled forms using a porcelain sculpture body. Rubber moulds were used for the press-moulded elements. Due to the highly cohesive quality of the clay no drying cracks appeared between the clay parts and the already-fired figurine. A Longquan type of celadon was applied by brush on the unglazed clay parts and figurine. A light reduction during the first part of the firing resulted in a dark grey/green colour. Collection: Kröller-Müller Museum, Otterlo, The Netherlands. (Photo: Heringa/van Kalsbeek)

Table 8.20

Longquan celadon (LQ KrKwTi 1)

1260°C–1280°C (2300°F–2336°F)
100°C (212°F)/hour Orton cone 9

Cornish stone P 3419	47%	K_2O	0.08				
Kaolin RM 255	25%	Na_2O	0.11	Al_2O_3	0.55	SiO_2	2.94
Quartz	6%	CaO	0.81				
Whiting	22%	MgO	0.01				
+ 1.5–2% Iron oxide		Al_2O_3:SiO_2 1:5.36					

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
60.44	19.15	–	15.46	0.11	–	–	–	2.27	2.59

jade-like quality and fairly opaque if applied thickly. Provided optimal reduction is carried out a pale bluish-grey (duck-egg blue) colour can be obtained. A variety of nuances can be achieved with slight alterations of the recipe. Increasing whiting to 24% and reducing the quartz will result in a slightly more matt and opaque result. Increasing the percentage of whiting (up to a maximum of 25%) and quartz (up to a maximum of 12%) while reducing the cornish stone will reduce opaqueness. Replacing kaolin partly or completely with HTR-clay will result in a shift towards green/grey and a shinier surface, and applying over the copper red glaze (*Table 8.19*) will give interesting results.

8.5 Formulating an engobe

An engobe is composed in such a way that it will produce strong colours when applied under a transparent glaze. The degree of vitrification of the engobe and body on which it is applied should be similar. If a thickly applied engobe vitrifies much less than the body, the engobe including the cover glaze could **flake**. If it vitrifies excessively it will be overtaken by the fusion of the cover glaze. Therefore a balance between the right amount of fluxes and a sufficiently high ratio of aluminium oxide is essential.

The basic engobe recipe given in *Table 8.21* can be used from the low to high temperature range. A combination of HTR-clay and Molochite 200 takes care of the necessary high aluminium oxide ratio. Calcined kaolin could be used instead, but Molochite 200 is better for a fluid painting application and less pin-holes are also formed during application. HTR-clay is preferred over kaolin for the same reason and HTR-clay is preferred over MTR-clay in the case of a white engobe as a whiter result will be achieved. Nepheline syenite and whiting are added to achieve sufficient sintering, to obtain a good bond on the body and to support the formation of bright colours. A small amount of calcium borate frit is added to attune the fusion slightly. This will give colours that are a little bit more saturated when used under a transparent cover glaze. Replacing the frit by increasing the amount of quartz will produce more opaque results. **NB:** To achieve good adhesion, glaze additives have to be added. *Table 8.22* provides an indication of the amount of pigments or colouring oxides that can be used. The final colour will depend

Table 8.21

Basic engobe (Eng M1)

1040°C–1280°C (1904°F–2336°F)
60°C (140°F)/hour Orton cone 04–9

Calcium borate frit 3221	2%	K_2O 0.12			
EOBBY (Aluminous ball clay)	25%	Na_2O 0.22	Al_2O_3 1.38	SiO_2 4.65	
Nepheline syenite RM 094	24%	CaO 0.64	B_2O_3 0.08		
Molochite 200	30%	MgO 0.02			
Quartz	9%				
Whiting	10%	Al_2O_3:SiO_2 1:3.38			

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
57.34	28.81	1.21	7.34	0.21	–	–	–	2.78	2.31



Masayuki Inoue (Japan), *E-985*, 1998. W: 217 cm (85 in.). A coiled piece made of separate sections. On top of a fused sinter engobe a thick layer of a less vitrified engobe was applied. The top layer did not adhere in places revealing the dark coloured layer underneath.
Collection: Prinsessehof, Leeuwarden, The Netherlands
(Photo: Peer van der Kruis)

very much on the cover glaze. The recipes provided in *Table 8.5* (low temperature range) and *Table 8.14* (middle temperature range) can be used as cover glazes.

Using this engobe (*Table 8.21*) in **reduction** will also give interesting results. An addition of 10% iron oxide produces a range of tones if covered with the glaze provided in *Table 8.17*. Depending on the layer thickness, iron red (engobe thick and glaze thin), brown (glaze medium thick), and grey celadon (glaze extra thick) can be achieved. An engobe containing copper or tin will give rose tones under this glaze, and a copper red can be achieved if the copper/tin engobe is covered with the copper red glaze provided in *Table 8.19* (copper and tin oxide in the glaze recipe can be omitted).

Used on its own, **without a cover glaze**, this engobe will yield a dry matt surface. Colours will darken if fired at a higher temperature. Adding large amounts of pigments yields interesting results; the engobe will then merely act as a binder. However, the addition of extra calcium borate frit (+ 3%–5%) may be necessary to adjust the vitrification (although too high an addition could diminish the intensity of the colours). Up to 100% of pigments could be added to achieve a vivid dry matt surface, particularly

Table 8.22

Colouring oxides and ceramic pigments for the basic engobe

Copper oxide 1–10%	Cobalt oxide 1–6%	Iron oxide 5–10%	Chromium oxide 3–5%
Manganese oxide 15–25%	Zirconium silicate 15–25%	Copper oxide/tin oxide* 1%/2%	
Green (dark) pigment Cr–Co–Al 6–12%	Turquoise pigment Zr–V–Si 20–40%	Prussian blue pigment Co–Al–Zn 10–20%	Cobalt blue pigment Co–Si 7–12%
Purple pigment Sn–B–Co–Cr 20–40%	Aubergine pigment Cr–Sn–Ca–Si 20–40%	Red pigment Zr–Si–Cd–S–Se 20–40%	Bright red pigment Cd–S–Se–Si–Zr 12–25%
Pink pigment Cr–Al–Zn* 15–30%	Coral pigment Zr–Si–Fe 15–30%	Orange pigment Cd–Se–S–Zr–Si–Pr 20–40%	New orange pigment Cd–S–Se–Si–Zr 12–20%
Yellow pigment Zr–Si–Pr 20–40%	Brown pigment Zn–Fe–Cr–Al 20–40%	Black pigment Co–Ni–Cr–Fe 10–15%	Grey pigment Sn–Sb–V 15–30%

*Note: * Yields copper red in reduction.*

in the case of the Co–Al–Zn Prussian blue pigment. An addition of 150% (without extra calcium borate) yields the best results. The basic engobe recipe can also be used as a base for underglaze colours, see section *9.2 Underglaze* for more detail.

8.6 Formulating a sinter engobe

A sinter engobe is composed in such a way that it produces pronounced results on its own, therefore no cover glaze is used. If compared with the percentage analysis of an engobe the amount of flux is higher and the amount of aluminium oxide is lower. Lithium carbonate adds to the liveliness of a sinter engobe; because it is a very strong flux lithium carbonate particles take the surrounding components into fusion at an early stage creating other shades in some areas. This effect is clearly seen when lithium carbonate is added in small amounts (3% to 5%) and when colouring oxides are used. Higher amounts of lithium carbonate will take an increased amount of the other components into fusion leading to more even results. Molochite 200 is preferred over calcined kaolin as it will produce more lively results. Due to the high aluminium oxide ratio and relatively low silica ratio sinter engobes can be fired over a broad temperature range as compared to most glazes. Two recipes will be discussed; one for the low temperature range (1040°C–1140°C/1904°F–2084°F) and the other for the middle temperature range (1140°C–1230°C/2084°F–2246°F). *Table 8.23* can be used as a guideline for additions of colouring oxides and ceramic pigments.

Fired to 1050°C (1922°F) the sinter engobe recipe provided in *Table 8.24* will be at the last stage of sintering, yielding a lively dry matt surface. From 1070°C (1958°F) onwards the first stage of fusion begins producing a stonier matt up to 1140°C (2084°F). Especially **colouring oxides** give interesting results. At 1040°C–1070°C (1904°F–1958°F) percentages as low as 2% copper oxide will yield a matt black surface, percentages over 5% will create a metallic matt surface. The addition of 10%–12% iron oxide produces a rusty brown. A subdued mauve colour comes with

Table 8.23

Colouring oxides and ceramic pigments for sinter engobes

Copper oxide 0.2–1%	Cobalt carbonate 0.5–3%	Iron oxide 1–6%	Chromium oxide 0.2–2%
Manganese oxide 0.5–10%	Zirconium silicate 5–20%		
Green (dark) pigment Cr–Co–Al 2–4%	Turquoise pigment Zr–V–Si 8–20%	Prussian blue pigment Co–Al–Zn 3–5%	Cobalt blue pigment Co–Si 1–5%
Purple pigment Sn–B–Co–Cr 10–20%	Aubergine pigment Cr–Sn–Ca–Si 10–20%	Red pigment Zr–Si–Cd–S–Se 10–20%	Bright red pigment Cd–S–Se–Si–Zr 8–15%
Pink pigment Cr–Al–Zn 7–15%	Coral pigment Zr–Si–Fe 7–15%	Orange pigment Cd–Se–S–Zr–Si–Pr 10–20%	New orange pigment Cd–S–Se–Si–Zr 8–12%
Yellow pigment Zr–Si–Pr 10–20%	Brown pigment Zn–Fe–Cr–Al 5–10%	Black pigment Co–Ni–Cr–Fe 5–10%	Grey pigment Sn–Sb–V 4–6%

Table 8.24

Sinter Engobe SE 10 (Se 10 NS 2)

1040°C–1140°C (1904°F–2084°F)
60°C(140°F)/hour Orton cone 04–1

Kaolin RM 255	23%	K_2O	0.06		
Lithium carbonate	5%	Na_2O	0.16	Al_2O_3 0.47	SiO_2 2.59
Nepheline syenite RM 094	32%	Li_2O	0.20		
Quartz	22%	CaO	0.46		
Whiting	15%	ZnO	0.11		
Zinc oxide	3%				

Al_2O_3:SiO_2 1:5.49

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
59.73	18.46	–	9.89	–	3.44	–	2.32	3.87	2.22

Table 8.25

Sinter engobe SE 20 (Se 20 N NS)

1140°C–1230°C (2084°F–2246°F)
60°C(140°F)/hour Orton cone 1–7

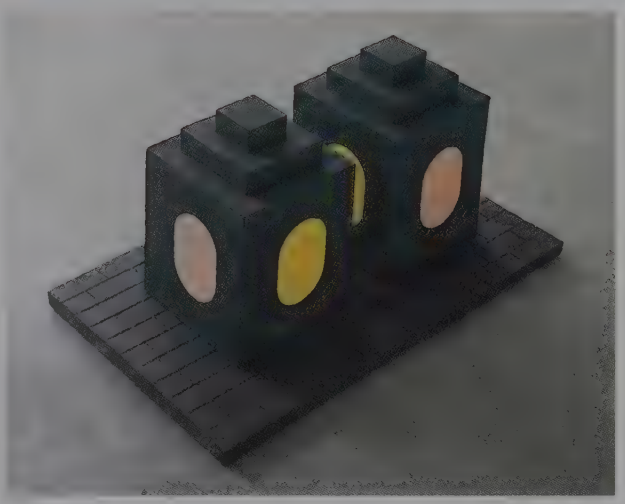
Kaolin RM 255	20%	K_2O	0.07		
Lithium carbonate	5%	Na_2O	0.17	Al_2O_3 0.60	SiO_2 1.99
Nepheline syenite RM 094	36%	Li_2O	0.19		
Molochite 200	15%	CaO	0.57		
Quartz	4%	MgO	0.01		
Whiting	20%				

Al_2O_3:SiO_2 1:3.30

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
50.56	26.07	–	13.45	0.14	–	–	2.37	4.44	2.78

an addition of 6% cobalt carbonate. When fired to 1120°C–1140°C (2048°F–2084°F), 2% copper oxide will produce a green and dark matt green, 6% will give a green with black spots. An addition of 1%–3% cobalt carbonate will produce a violet blue. An over-saturated cobalt effect can be gained by adding 10%–12% cobalt carbonate giving a mottled mauve. However, iron oxide yields less interesting results at this temperature.

At the indicated minimum temperature range the engobe provided in *Table 8.25* will give a dry matt surface; at the maximum temperature a more stony matt will be achieved. Interesting dry matt bronze-green mottled with black can be obtained with up to 2% of copper oxide at 1140°C (2084°F). Percentages over 5% will create a charred black metallic matt surface. An ochre brown is made with an addition between 1% and 2% iron oxide; 12% will make a rusty dark brown. At 1220°C–1240°C (2228°F–2264°F) a bronze green stony matt will appear with an addition of up to 2% copper oxide. Percentages over 5% will create a black metallic surface. A mustard brown is possible with an addition of between 1% and 2% iron oxide; 12% will yield a rusty dark brown. White spots will appear if pigments of the Zr–Si type are used (like yellow, turquoise, or the old and new type of red and orange pigments). This can be corrected by increasing the quartz content (up to 10% or 11%), reducing whiting (down to 15%) and lithium carbonate (down to 3% or 4%).



Ben Sleeuwenhoek (The Netherlands), *Lighthouse*, 1992. W: 92 cm (36 in.). Press-moulded pieces using white sculpture clay on top of a slab made of black sculpture clay. An engobe was sprayed on the surface of the two pieces by masking the oval-shaped parts. Firing up to a temperature where no fusion occurred resulted in a dry matt surface.
(Photo: Peer van der Kruis)

8.7 Testing a glaze or (sinter) engobe

If a glaze or (sinter) engobe recipe is used for the first time it is recommended to test its behaviour. It is advisable to test any new recipe for the following reasons:

- As pointed out in *Variations in ingredients* under section *8.1.1 What determines the sintering and fusion range?*, ingredients with the same name may have a different composition or different grain size. Properties like surface quality or colour may change because of this.





LEFT:
Ad Swinkels (The Netherlands), *Studio Over View*, 1994. Ht: approx. 95 cm (37¼ in.). The pieces were made of coarse sculpture clay and built hollow using the coiling method. The elements were separately made and joined at the leatherhard stage or glued after firing. Engobes and sinter engobes were applied by brush.
(Photo: Peer van der Kruis)

RIGHT:
Leiko Ikamura (Japan/Germany), *Stehende mit rotem Kleid mit rotem Miko*, 1995. Ht: 64.5 cm (25 in.). Coiled piece using a mixture of coarse-grained white and terracotta body. A shiny lead-free base glaze with ceramic pigments was used. Different layer thickness resulted in different colour saturation, shininess and coverage of the piece.
(Photo: Jochen Littkemann, Berlin)

- Layer thickness often greatly affects the outcome, notably as regards the opacity of the colours. For this reason, the appropriate thickness of an unknown glaze or (sinter) engobe must first be determined.
- The colour, composition and properties of a clay body (e.g. thermal expansion), the state of the piece (fired/unfired) and surface of the piece (smooth/rough) all affect the final result.
- The kiln, loading method, and the way of firing and cooling could all have a substantial effect on the glaze.

Testing a known glaze is also advised if ingredients from another supplier or a new delivery are used. To find out how a glaze or (sinter) engobe will behave, a **test piece** should be made. The most reliable result is obtained if a test piece meets the following requirements:

- It should be made from the same clay body as the final piece.
- Its shape should to some extent be similar to the final piece (convex, concave or flat) and have a similar surface texture (smooth or rough), in order to be able to evaluate the surface quality.
- It should be in the same state as the definitive work when glazed: unfired or biscuit fired. In an unfired state, the test piece and work should be equally dry at the moment of glazing. If the glaze is added to a biscuit fired piece, the test piece should be biscuit fired in the same way: at the same maximum temperature and with the same firing speed. Only then will the absorptive effect correspond, allowing the test piece to get an equal glaze thickness to the final piece.
- To be able to evaluate the glaze result properly, each test piece should be at least 10 cm x 10 cm (4 in. x 4 in.) and two or three test pieces should be made. This

allows the result to be checked at the coldest and the hottest area, and in the case of large temperature differences, also at the average temperature area in the kiln.
- Glaze additives as used in the final glaze or (sinter) engobe should also be used in the test mixture: they change the consistency of glaze slop and their absence could lead to the wrong impression regarding the glaze thickness, see more about glaze additives under section *8.8 Preparing and applying glazes*.
- The way of application of the glaze on the test piece should be the same as on the final work.
- The glaze is best applied in several layers, in order to evaluate the effect of layer thickness on the final result. If the amount of water added is monitored, the appropriate thickness can be easily repeated on the final piece.
- All relevant information should be recorded on the back of the test (using, for instance, a brush and iron oxide) in order to identify the test piece later and to evaluate the result.
- The test piece should be fired and cooled the same way the final piece will be.

Because the thickness of the glaze layer is so important, gathering this information is very beneficial. The following test could be used to obtain the desired reference. A test tile is broken in half (this is made easier by scoring the test tile on the back at the leatherhard stage, before it is biscuit fired) after three or four layers of glaze have been applied. One half will be fired, the other half will be used as a reference. By scratching into the surface in an unobtrusive area of the unfired glazes both on the test tile and the final piece an indication of the correct layer thickness can be obtained.

8.8 Preparing and applying glazes and (sinter) engobes

A glaze or (sinter) engobe has to be mixed with water before being applied to a piece. A glaze can be applied by brushing, spraying, dipping or pouring. Adding glaze additives will increase workability and reduce the chance of glaze faults occurring. The term 'glaze' as used in this section, refers to all types of glazes, engobes and sinter engobes, except when stated otherwise.

8.8.1 Glaze additives

Glaze additives are increasingly more available. Originally developed for the ceramic industry and to produce technical ceramics, glaze additives are used for several reasons. They increase general workability during application without influencing the properties of the final glaze. They give a brush-on glaze a good painting quality, and spraying, dipping and pouring properties can be improved. The settling of a glaze while working can also be counteracted and to a certain degree glaze additives can help prevent a glaze from solidifying on the bottom of a bucket. Altogether a dried glaze layer will be less vulnerable and the occurrence of glaze faults, like **crawling** and **pin-holing**, can be reduced.

Combining different additives with water makes it possible to apply a specific glaze on any kind of surface: unfired clay, a very porous biscuit, a vitrified body or even a glazed surface, provided the percentage of plastic components in the glaze is not too high.[13] The emphasis in this section is on minimising glaze defects, although for their own aesthetic qualities some 'defects' can be used intentionally.

Of the numerous kinds of glaze additives, the ones highlighted in this section are those most successfully used at the EKWC, although reference is made to some alternatives.



Hugo Kaagman (The Netherlands), *ME Ware*, 1996. Dia: 80 cm (31½ in.). Blue underglaze paint was sprayed on a white earthenware plate using an airbrush and paper cut stencils. A transparent shiny glaze was applied on top.
(Photo: Hugo Kaagman)

SCMC gum

SCMC (Sodium Carboxyl Methyl Cellulose) gum is a material made from cellulose. The ratio of sodium can vary in SCMC gums. A low ratio of sodium will yield a higher binding capacity as well as a high viscosity (however, extra water will be needed to make the glaze slop more fluid). A high ratio of sodium to water will produce a weaker binding, but due to deflocculation capacities proportionally less water will be needed to make the glaze slop fluid.

Optapix KG 25 is an SCMC gum designed especially to be used in glazes. It is a white powder containing moderate amounts of sodium; hence it acts mainly as a glue. It is added to achieve a good bond between the glaze layer and the piece and it makes the dried glaze layer less vulnerable and enhances the painting properties considerably. Due to the slowing down of the drying process, it is easier to achieve a smooth glaze during the application, whether painting or spraying. The settling of the glaze slop is counteracted, and to a certain degree it can prevent a glaze from solidifying on the bottom of the bucket. Add: 0.3%–1%.

Alternatives:
There are many kinds of SCMC gums available from different manufacturers. As stated before, a varying sodium ratio will have different effects on viscosity and binding capacity. Thorough testing is recommended.

Plasticisers

A plasticiser is added if a plastic component is needed when applying a glaze on an unfired piece. If applied in the right amount (and in combination with an SCMC gum) an equal shrinkage of glaze layer and the unfired piece can be obtained, resulting in good adhesion. On top of that plasticisers have the capacity to hold water for a long time, enhance the painting properties of a glaze considerably, and keep the glaze slop in suspension.

Bentone EW, a brand name, is a highly plastic material containing only traces of iron oxide; consequently it adds no unwanted coloration to a glaze. It consists of hectorite; a lithium-containing mineral of the smectite group, see section *13.1 What is clay?* Because Bentone EW is very active it should be added only in small amounts and for this reason it hardly influences the fusion properties of the glaze. Add: 0.3%–1%.
Alternatives:
Veegum (containing minerals of the smectite group) is the closest alternative. **Bentonite** (consisting mainly of montmorillonite) can be added as well (although larger amounts are needed to obtain the same results). Regular bentonite contains iron oxide and will affect the colour therefore the ferro-purified type is preferred. All alternatives will have different effects on the required amount of water and shrinkage; thorough testing is recommended.

Deflocculants

A deflocculant is added to a glaze slop to make it more fluid without having to add

more water. As a result the glaze layer shrinks less, reducing the chance of adhesion problems. It also improves the painting properties of a glaze.

Dolapix PC 67 is a polyacrylate type of deflocculant: it contains sodium polyacrylate. It is a brown liquid and it is a very useful material used in a wide range of applications like casting clay, plemp body, adhesive slips and terra sigillata. Add to a glaze: 0.3%–0.5%.

Alternatives:

Darvan 7, Darvan 811 (both sodium polymethacrylates) and Dispex (ammonium polyacrylate).



Arne Widman (Sweden), *The Boat*, 2002. Ht: 28 cm (11 in.). A sculpture made in two parts using a coarse sculpture body of a slightly wetter consistency allowing a direct and more organic way of working. A blue sinter engobe was rubbed on the surface in places. It was fired to the body's vitrification point. Collection: EKWC (Photo: Corné Bastiaansen)

Suspension agent

A suspension agent is added to prevent heavy particles in a glaze slop from settling. It is added especially to lead-containing glazes, when other additives are not sufficient. Particularly a combination of a plasticiser such as bentonite (or 15–25% of kaolin/clay in the base recipe) and a suspension agent yields good results. There are many suspension agents available. At the EKWC **Stellmittel ZS** is used in an addition of 0.1%–0.3%.

Alternative:

A small addition of saturated calcium chloride solution.

8.8.2 Additives:Water ratio

The amount of water and additives needed is determined by the kind of ingredients used in the glaze, the absorbing capacity of the piece (fired or unfired) and the method of application. *Table 8.26* provides general information about the additive:water ratio. The percentages provided are including the added stains. Generally, the amount of water should be limited to what is strictly needed. High quantities of water make it difficult to achieve a sufficiently thick layer of glaze and increase the chance of a poor bond between glaze and surface, especially if a large percentage of clay or kaolin is present in the glaze. Too little water makes it more difficult to apply a glaze evenly and



Hella Jongerius (The Netherlands), *Long neck and groove bottle* (Prototypes). 2000. Ht: max. 49 cm (19¼ in.). Cast porcelain combined with glass and packing tape. The base glaze, coloured with ceramic pigments, was applied after a high biscuit firing and fired to a low temperature. (Photo: Peer van der Kruis)

Table 8.26

Additive:Water ratio for glazes containing no kaolin or clay[1]

Condition of the piece	*Way of applying*	*Optapix KG 25[2]*	*Bentone EW[1]*	*Water*
Leatherhard-brittle/dark[5]	Brushing[3]	0.7%	1%	50–60%[4]
	Spraying[3]	0.7%	0.7%	55–65%[4]
	Dipping/pouring	0.5%	0.8%	55–65%[4]
Light-cold/dry[5]	Brushing[3]	0.7%	0.8%	55–65%[4]
	Spraying[3]	0.7%	0.4%	60–70%[4]
	Dipping/pouring	0.5%	0.6%	60–70%[4]
Biscuit–very porous[5]	Brushing[3]	0.7%	0.5%	60–70%[4]
	Spraying[3]	0.7%	0.4%	60–70%[4]
	Dipping/pouring	0.5%	0.4%	60–70%[4]
Biscuit–moderate porosity[5]	Brushing[3]	0.4%	0.4%	50–60%[4]
	Spraying[3]	0.4%	0.4%	50–60%[4]
	Dipping/pouring	0.3%	0.4%	50–60%[4]
Vitrified[5] or glazed body	Brushing[3]	0.3%	0.4%	45–50%[4]
	Spraying[3]	0.3%	0.4%	45–50%[4]
	Dipping/pouring	0.2%	0.3%	45–50%[4]

Notes:

[1] *In cases where the glaze does contain clay or kaolin, reduce Bentone EW by ⅕ per 5% kaolin or clay present in the recipe.*

[2] *Add 0.2% Optapix KG 25 in the case of a high lithium carbonate content (>10%).*

[3] *Add up to 0.5% of Dolapix PC 67 to regulate fluidity.*

[4] *Add 5%–10% less water to high lead glazes and 5%–10% more water to high alkaline glazes.*

[5] *See* Table 8.30 *for how to recognise these stages.*

more air will be trapped in the glaze layer. Trapped air can increase the chance of pinholing in a glaze with a high surface tension, see section *14.2.3 Testing surface tension and viscosity*.

The main ingredients in a glaze will determine whether the percentage of water should be increased or reduced and whether extra additives should be added (see *Table 8.26*). Less water should be added to **lead glazes** due to their high specific gravity and to counteract their tendency to settle more readily than other glazes. Stellmittel ZS can be added to counteract this settling. **High alkaline glazes** tend to have the opposite effect; large amounts of lithium carbonate (more than 10%) or petalite (40%) demand more water. The addition of extra Optapix KG 25 (+0.2%) will increase the workability of glazes containing a high amount of lithium carbonate as well. As for glazes containing **kaolin** or **clay** beyond 15% or **Bentone EW** beyond 0.5%, Dolapix PC 67 can be added to regulate the viscosity. Glazes containing kaolin or clay beyond 25% are better not applied on biscuit or a dry piece as the increased shrinkage will cause adhesion problems. If the amount of calcined kaolin in a glaze exceeds 10% of the total recipe, more water is needed due to its high absorbency. The painting fluidity of such a glaze tends to be poor. Using Molochite 200 instead will be beneficial.

NB: If alternative glaze additives are used the amounts to be added as well as the percentage of water will be different; testing will be necessary.

The viscosity of a glaze slop containing additives will differ widely from the usual, leading to the wrong impression that the glaze has been applied thicker than it actually has. Therefore, testing a glaze before using it is strongly advised, see section *8.7 Testing a glaze or (sinter) engobe*.

8.8.3 Preparing glazes

Table 8.27
Accuracy of the scale

Amount weighed	*Necessary accuracy*
50 g or less	0.01 g
50 g–1000 g	0.1 g
1000 g or more	1 g

The weighing of glazes needs careful attention if consistent results are important. The various ingredients of a glaze mixture should be weighed accurately. This is particularly important if small amounts of glaze are prepared: minor inaccuracies will be more significant to the result. Therefore the **accuracy of the scales** is of importance. An indication of the accuracy required of the scales is given in *Table 8.27*. Generally, only professional standard scales provide sufficient accuracy, and both analogue and digital scales are available. The greatest advantage of a digital scale is that the increase in weight is immediately readable after each addition. Professional standard scales can allow for the compensation of the weight of the container used to weigh the ingredients. **NB:** Dust is released during weighing. For this reason, it is important to ensure sufficient ventilation and wear a dust mask. Strong ventilation may destabilise very accurate scales (0.01 g) so a lightweight construction, closed on the back and the sides, will help prevent air disturbances by protecting the scale from draughts. The table on which the scales sit should also be stable.

Mixing glaze and water

Adding glaze additives and water should be done in several steps:

1. *Mixing dry*
   Glaze additives such as Optapix KG 25 and Bentone EW tend to form lumps if they are brought into direct contact with water. For this reason they are first mixed with other dry glaze ingredients. To mix, put all base materials into a plastic container with a lid and shake it thoroughly. The container and lid should be dry. In order to obtain sufficient homogeneity the container should not be filled more than ⅔ of its volume and shaking should last for about 15 seconds. **NB:** If the container is opened quickly, a lot of dust will spread out so wait a few minutes until the dust in the container has settled.
2. *Adding water*
   After the dry glaze ingredients are prepared as described above, they are added to another container (also fitted with a lid) and the right amount of water. As mentioned before, the amount of water given in *Table 8.26* is only an indication. Less water can be used depending on the absorption rate of the piece. It is best to add the lowest suggested percentage of water to an unfamiliar glaze, setting the remaining 10% aside.
3. *Mixing wet*
   The container is closed and shaken thoroughly again. It takes a while for the glaze additives to absorb the water; for this reason it is advisable to let the glaze slop sit for 2 to 3 minutes. Liquid additives such as Stellmittel ZS or Dolapix PC 67 may be added next. If quantities are too large (and heavy) for shaking, very thorough stirring by using a power drill mixer could be an alternative.
4. *Fine tuning of water*
   The consistency of a mixture, which has just been shaken, should initially be like thick yoghurt. If the consistency is thicker, add a small amount of water – from the remaining 10% – and shake again. In general, water should be added until an even coat is obtained (no brush strokes or traces of spraying) in two, preferably three, layers. Careful recording of the total amount of water added will gather valuable information for future preparation.

Table 8.28

Pre-mixed additive mixture[1]

For applying glazes containing 10%–15% kaolin on a very porous biscuit. Suited for approximately 10 kg of dry glaze

Optapix KG 25	80 g
Bentone EW	25 g
Dolapix PC 67[2]	50 g
Water	5000 g

Notes:
[1] Adding preservatives could be necessary, because such a mixture can become mouldy over the course of time.
[2] Optional.

Pre-mixed additive mixture

If a specific combination of ingredients is used frequently and the porosity of the biscuit is fairly similar each time, the use of a **pre-mixed additive mixture** could be an option. This mixture is preferably more concentrated by using less water than eventually needed. Fine-tuning the amount of water is then done after the additive mixture has been added to the glaze. *Table 8.28* shows an example of a glaze additive mixture suited for a glaze containing between 10% and 15% of kaolin or clay that will be applied by brush on porous biscuit. Up to 10 kg (22 lb) of dry glaze could be added to this mixture. It is prepared as follows:

- Hot water is poured into a container.
- The Optapix KG 25 and Bentone EW are sprinkled into it.
- The container is closed and shaken thoroughly.
- After 5 minutes the bucket is shaken again.
- Finally, the mixture is sieved through a 100's (0.15 mm) sieve.

Sieving

If consistent results are needed a glaze should always be sieved. Some ingredients will not fuse fully if they are present as coarse particles and may appear as lumps in the fired glaze resulting in speckles or causing glaze faults like pin-holing. A finer sieve will yield a more homogeneous result and sieving is a must if the glaze is to be sprayed, to prevent the spray-gun from getting clogged. If a homogeneous glaze slop is not important and the glaze is not to be sprayed, a coarse sieve can be used. Sieving is highly recommended if a glaze or (sinter) engobe contains whiting, as lumps of whiting could cause spit-out after firing. *Table 8.29* provides some indications about different sieve sizes and their use.

Sieving works best with a brush and/or a rubber scraper. Hard objects – such as metal spoons – cause the sieve to wear out rapidly. The last remnants of the glaze slop can be washed through the sieve with the remaining 10% of water that has been set aside. The brush or rubber scraper should then be cleaned before removing the remnants gathered at the underside of the sieve; this will prevent lumps or coarse grains that have collected in the brush ending up in the sieved mixture.

Table 8.29

Sieve sizes and the application of glazes

British sieve size	*Sieves according to the DIN norm (in mm)*	*Method of application*
36's (40*)	0.425	Brushing, dipping or pouring if a non-homogeneous result is required
60's/80's	0.25/0.18	Brushing, dipping or pouring
80's/100's/120's	0.18/0.15/0.125	Spraying, brushing, dipping or pouring if a more homogeneous result is required
200's	0.075	Spraying using an air-brush

*Note: * US sieve size*

8.8.4 Applying glazes

The method of application and especially the **layer thickness** will influence the visual quality of the final glaze.

Correct layer thickness

There are not many visual indications for determining if a layer has been applied sufficiently thickly; it takes a lot of experience to be able to judge the thickness of a glaze with the eye. So a way to achieve an indication is to score through the dried unfired glaze right to the body underneath using a needle tool or fingernail. As pointed out in section *8.7 Testing a glaze or (sinter) engobe*, a **test piece** will provide valuable information about the effect on the visual quality in relation to the method of application and glaze thickness. Most coloured base glazes containing pigments should have a layer thickness of between 0.3 mm and 0.5 mm (the approximate thickness of a fingernail) before firing. Generally colourless, transparent, shiny glazes can be applied in thinner layers (0.2 mm). Some glazes, like Celadon, should be applied very thick (up to 1 mm or more) to achieve the specific quality typical for those glazes. Glazes applied much thicker than 0.5 mm may have an increased chance of glaze defects especially if no glaze additives are used.



Thomas Stimm (Austria), *Drei Grosse Blumen*, 1995. Ht: 200 cm (79 in.). Thick-walled pieces built by modelling and coiling. A coarse sculpture body was used. A base glaze with ceramic pigments and zirconium silicate (white petals) was applied by brush. No glaze was used at the bottom of the pieces. (Photo: Peer van der Kruis)

To a glaze applied in more than one layer, a **distinguishing stain (dye)** could be added. A distinguishing stain comes from organic materials and as such it will burn away during the firing. Alternating a layer with dye with one without will give a better grip on the total layer thickness. Food colourings or aniline may be used, with aniline giving the best results. Aniline is expensive, but only a small amount is required as it is highly concentrated. **NB:** Aniline is hazardous to your health.

Different rates of porosity of pieces, caused by differences in temperature distribution within the kiln during biscuit firing or a different firing speed at each firing, will have an effect on glaze application and as such on layer thickness. If repeatable results are needed this should be taken into account.

Ideal condition of the body for applying a glaze

As has been pointed out, a glaze can be applied on pieces ranging from leatherhard to already glazed if additives are added. Experience has shown that the best results to avoid pin-holing and crawling are to glaze at the transitional phase from leatherhard-brittle to the dark stage if raw glazing (glazing an unfired piece) and medium porous biscuit when glazing biscuit fired pieces. See *Table 8.30* for more information about determining these stages.

The transitional phase from **leatherhard-brittle** to the **dark stage** is the best condition for applying a glaze on an unfired piece for three reasons. There is a better chance of adhesion because dry shrinkage has (nearly) stopped. In addition, a glaze can be easily and more evenly applied because the work is not yet very porous, and due to low porosity the amount of water absorbed into the surface of the piece will be limited.

A **medium porous biscuit** is the best condition for applying a glaze on a biscuit fired piece as it can be easily and more evenly applied. There is less chance of glaze defects like pin-holing compared to a very porous biscuit, and less chance of crawling compared to a non-porous piece.[14]



ABOVE:
Nicolas Dings (The Netherlands), *Bastian-Ruf-Mich-An*, 2001. Ceramics and metal funnels. Ht: 125 cm (49 in.). Press-moulded, using slabs. A shiny base glaze with a high percentage of yellow pigment was used. Copper oxide was applied in places. The high percentage of pigment resulted in a saturated colour and a completely opaque finish.
Collection: Kunst en Berdijf BV, Amsterdam, The Netherlands
(Photo: Corné Bastiaansen)

Methods of applying

There are several ways to apply a glaze: brushing, spraying, dipping, flicking (applying drops of glaze to achieve a specific effect), rubbing or pouring. Each method produces its own characteristic results, and combinations of these methods can be interesting.

Brushing

One of the advantages of using a brush is that there is very little loss of glaze compared to spraying, and no extra glaze needs to be prepared as is the case with dipping. Brushing also renders a spray booth unnecessary and this is especially advantageous in the case of large-scale pieces. In general, application with a brush is done in three layers if an even coat is desired. If the additives:water ratio suggestions in *Table 8.26* are followed, a brush-on glaze can be formulated that has good painting properties leading to a fluid application. If a lot of pin-holes form during application and/or the glaze flows poorly then (slightly) more water should be added. A small amount of Dolapix PC 67 can also be added to regulate fluidity (up to 0.5%). Extra water is often necessary when applying a second coat of glaze on a dried first layer if it was applied on a non-porous biscuit. If brush strokes are to remain visible, the amount of water needed according to *Table 8.26* can be somewhat reduced, and the glazing should be done in only one or a maximum of two layers. When painting different colours of glaze wet-on-wet (a la prima), an extra 0.3% Optapix KG 25 can be added.

Flicking

The ratios provided in *Table 8.26* under brushing can be used for flicking the glaze on a piece. If thick drops are to be achieved, the amount of water required can be slightly reduced.

Spraying

A well-applied sprayed glaze layer should have a smooth surface and it takes experience to obtain an even spray coat. The amount of water added should result in an evenly sprayed glaze that coats well in two or three layers. The spraying should be done at a speed that allows the glaze to be distributed evenly over the surface, like a wet film.



RIGHT:
Carolein Smit (The Netherlands), *Valse-Triste*, 1995. W: approx. 60 cm (23½ in.). A slab-built piece. Suspended during the making by using an adjustable support system. Underglaze applied by brush. On top, a transparent high-lead glaze.
(Photo: Peer van der Kruis)

Going too slowly can cause the glaze layer to run; going too fast can result in a bumpy surface especially if the glaze slop contains too little water; drops of glaze will (partly) dry out before reaching the surface of the piece causing the glaze layer to be built-up out of many flecks and a lot of trapped air. This could cause an 'orange peel' effect on the surface after the firing.[14] Extra water is the answer to prevent this from happening. Areas on the piece that are the most difficult to reach are preferably sprayed first in order to obtain an overall and even coat. **NB:** It is strongly advised to wear a fine dust mask while spraying.



Rein Dool (The Netherlands), untitled, 1994. Dia: 45 cm (17¾ in.). Two painting techniques were combined on this piece. The first layer was painted using the maiolica technique creating a subdued colour effect. Black, blue and orange onglazes were applied for the second layer. A brush was used for both applications. Collection: Museum voor Hedendaagse Kunst, 's-Hertogenbosch, The Netherlands. (Photo Peer van der Kruis)

Pouring and dipping

Glaze can also be poured over the work. To get the necessary thickness, the glaze must dry sufficiently fast to prevent dripping. The pouring technique can be used to obtain a distinctive visual effect. To obtain the best results from pouring a glaze, it is essential to have the right water content. This can be determined through testing. A combination of pouring and dipping or once-dipping is often used for glazing pots. For dipping, the entire work is submerged in a basin filled with glaze. One action should create an evenly spread coat of sufficient layer thickness: no rippling should occur. Dipping requires a large amount of glaze, so this method is only suitable for small pieces. To prevent the glaze from running off the top parts of the work Dolapix PC 67 should not be used because it enhances flowing. Testing is necessary to find out the optimal amount of water. It takes some practice, but a smooth and even glaze surface can be created through this method of application.

Reducing the chance of glaze faults

Glaze faults like crawling and pin-holing are very much linked to high surface tension in the glaze. White glazes are especially subject to this. But also the method of application will influence the likelihood of these glaze faults happening. The **first layer** is critical. The glaze should be diluted for this first layer. The porosity of the piece will determine the amount of extra water to be used, see *Table 8.30*. The following directions will reduce the chance of glaze faults occurring:

- Generally, the chance of pin-holing and crawling will be reduced if **subsequent layers** are applied while the preceding layer is still wet (still shiny). In practice, however, the first layer often dries quite quickly, especially if the glaze is being applied on a porous body and in the case of larger pieces. In these cases it is recommended to wait until the layer has dried completely (the colour has become light in shade).
- In the case of a rough textured, highly-absorbent piece (either an unfired dry piece or a low fired biscuit), a diluted first layer should be rubbed into the surface thoroughly; this will reduce the chance of pin-holing. This should be implemented when glaze application is done by brush or by spraying.
- After glazing, a piece should be allowed to dry before being fired, this will reduce the chance of crawling.

In the case of unfired work some additional suggestions are recommended:

- Applying a glaze at the transitional phase from leatherhard-brittle to the dark stage will avoid surface cracks forming on pieces made of a coarse sculpture body.
- To achieve a good adhesion of the glaze on an unfired piece quite a stiff brush should

be used to rub the diluted glaze thoroughly into the surface; this will reduce the chance of crawling.

8.8.5 General practical instructions

If a piece is not to be fired shortly after glazing, **covering it with newsprint** will prevent the surface from getting dusty. Covering a piece that has been glazed in an unfired state (leatherhard to leatherhard-brittle, see *Table 8.30*) allows the drying to continue evenly. To prevent the newsprint from sticking to the glaze it should not be put over the piece until the glaze is dry (i.e. no longer shiny). Do not use plastic sheet on a glazed unfired piece as this might create condensation, which would unfavourably affect the adhesion of the glaze to the surface.

Thorough stirring is necessary every time a glaze is used and especially if it has been left for a while. Glaze slop may settle over the course of time, forming a hard layer on the bottom. Depending on the composition, this phenomenon may occur after half an hour or sometimes only after a few weeks: high lead glazes and glazes that contain no clay or kaolin are more subject to this. The addition of a suspension agent can postpone the moment of settling to some extent but, to avoid having to scrape a settled glaze from the bottom each time, it is best to store a regularly-used glaze in powdered form then at the moment of glazing as much glaze as is required can be prepared. Another option is to add less water than necessary and store it that way. The glaze can then be brought to the proper consistency each time it is used. A disadvantage of this method is that it is more difficult to sieve a thick glaze mixture.

Table 8.30

Applying a first layer

Condition of the piece	*Add extra water**	*First layer*
Leatherhard-brittle stage A fingernail can make a clear imprint in the surface only with great pressure. A line made with the fingernail is sharp.	+ 20%	Rub the diluted glaze into the surface, especially in the case of a rough textured surface.
Dark stage A line made with the fingernail in the surface is crumbly and clay dust occurs.	+ 20%	
Light-cold stage The work is lighter in colour, but is still cool to the touch.	+ 50%	
Dry stage The work is at room temperature.	+ 50%	
Biscuit: highly porous The tongue 'sticks' to the surface.	+ 50%	
Biscuit: moderately porous The tongue sticks only slightly to the surface.	+ 20%	
Biscuit: sintered or glazed The tongue does not stick to the surface.	+ 0%	If the glaze is applied on a rough textured surface the glaze is first rubbed into the surface. No separate first layer is necessary on a smooth surface.

*Note: * Calculated according to the weight of the dry ingredients.*



Irina Zatulovskaya (Russia), *Psalm of David 103*, 1992. 19 cm x 15 cm (7½ x 6 in.). Sinter engobe painted on a red sculpture body. The lines were scratched into the leatherhard clay. The sinter engobe was applied by brush. Collection: EKWC (Photo: Peer van der Kruis)

A glaze slop stored for several months under warm conditions can get mouldy if it contains glaze additives. Using a preservative will prevent this from happening.

NB: Prevent the inhalation of dust during the preparation of glazes. A regular cleaning of the workplace is important: most glaze materials are hazardous, some are even toxic, see section *8.3 Ingredients*. Ensure there is sufficient ventilation in the room, and use a properly operating spray booth when necessary. Do not use a broom or sweeper, always wet clean. Ask your supplier for information on possible harmful properties of base materials and relevant safety regulations. For your personal protection, latex gloves and a respirator that protects against fine dust particles are strongly recommended.

Notes:

1 Soaking is often done to achieve a more even temperature distribution within the kiln and therefore a more even overall result.

2 A liquid that does not tend to flow easily.

3 Kaolin fired up to 975°C/1787°F or higher to get rid of its plastic properties.

4 In this chapter an aluminous ball clay is used.

5 An MTR-clay will be even more active but the coloration could be affected as these types of clay often contain more iron and titanium oxide compounds.

6 Frits P2950 (Potterycraft) and 2261 (Potclays) give almost identical results.

7 In the glaze recipes provided in this book Canadian nepheline syenite is used. Research on a Norwegian variety, with an ultimate analysis as provided in *Appendix 1*, *Table A2*, generally yielded fairly similar results.

8 This is only a selection of the many possible colouring oxides, for more information see *Appendix 2*, *Further reading*.

9 If sodium or potassium was the main flux this high aluminium oxide content would result in a greener colour.

10 Tenmoku is a Japanese name generally used for a dark brown to black iron reduction glaze.

11 A very heavy reduction from the start could reduce the brightness of the red colour.

12 Research shows that a strong reduction starting between 900°C (1652°F) and 950°C (1742°F) will result in clearer colours, see section *11.4 Reduction firing*.

13 The glaze and (sinter) engobe recipes provided in this book contain not more than 25% kaolin or HTR-clay in order to make this wide range of applications possible.

14 Especially in the case of glazes with a high surface tension.



9 Painting and decoration



Painted decorations on pots and painted sculptures have been part of ceramic history from the very beginning. Painting a three-dimensional object has always posed a challenge as it broadens the possibilities of giving extra meaning to the work. Only a few of the many techniques related to painting and decorating, such as maiolica, underglaze, onglaze and lustres (precious metal) will be discussed in this chapter, each of them providing specific possibilities and aesthetic characteristics. In addition to painting, silkscreen printing and using onglaze ink will be addressed briefly. (For more information on this subject see Suggested further reading *in* Appendix 2.*) References will be made regularly to glaze additives, and more information about these additives is provided in section* 8.8 Preparing and applying glazes and (sinter) engobes.

9.1 Maiolica

Maiolica as we know it today was developed in the Middle East (Persia, 9th century AD). It is a lead/tin glaze developed to serve as a white background for a painted decoration containing cobalt. This technique sets itself apart from the other techniques discussed in this chapter because the maiolica paint is applied on an unfired maiolica base-glaze layer. During firing, both paint and white background fuse together. Due to this fusion the edges of the paint blur slightly producing maiolica's traditional characteristic look.

NB: The maiolica recipes provided in this book include lead-containing frits. These materials can be hazardous to the health: be sure to wear a fine dust mask and latex gloves during preparation and application. Do not use these ingredients in glazes for functional ware; lead compounds may be released during everyday use.

9.1.1 White background/first layer

The first layer may consist of a gloss or satin gloss base glaze to which zirconium silicate or tin oxide has been added. For this, either a (commercially available) lead-free or lead glaze may be used. The percentage of zirconium silicate or tin oxide should preferably be between 12% and 15% (higher percentages increase the risk of crawling). At the EKWC zirconium silicate is usually used, as pink flashing results when tin oxide comes into contact with chromium oxide. (For more information about crawling and flashing see section *11.5 Analysing faults apparent after the glaze firing.*)

The maiolica base glaze, provided in *Table 9.1* can be used to obtain a white background. By adding very small amounts of blue or black pigment (0.025%–0.05%) the

OPPOSITE:
Bhupen Khakhar (India), *Portrait of Man*, 1994. Dia. 27 cm (10½ in.). A plate painted with several layers of maiolica. Various concentrations of maiolica paint were used resulting in a rich palette of colours.
(Photo: Peer van der Kruis)



ABOVE:
Figure 9.1
Clotting of maiolica paint due to the incompatibility of the maiolica paint and white base.
(Photo: Anton Reijnders)

Table 9.1

Maiolica white background layer

1050°–1070°C (1922°F–1958°F)
60°C (140°F)/hour Cone 04

Calcium borate frit 3221	10%	K_2O	0.04				
EOBBY (Aluminous ball clay)	8%	Na_2O	0.14				
Lead bisilicate frit 3647	21%	CaO	0.47	Al_2O_3	0.27		
Nepheline syenite RM 094	26%	MgO	0.00	B_2O_3	0.25	SiO_2	2.62
Quartz	24%	ZnO	0.15				
Whiting	7%	PbO	0.19				
Zinc oxide	4%						

+12–15% Zirconium silicate — Al_2O_3:SiO_2 1:9.61

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
53.11	9.38	5.80	8.96	0.05	4.17	14.26	–	2.84	1.43

Notes: Do not use for functional ware.
Add glaze additives, see section 8.8.1 Glaze additives.



RIGHT:
Figure 9.2
Brush for making fine lines. The top third of a high-quality brush is cut off at an angle each side leaving the hairs in the centre to come to a fine point.
(Photo: Anton Reijnders)

white will be less harsh and will resemble the tonal quality of traditional maiolica. To improve the workability during application and reduce the chance of glaze faults, glaze additives are added.

9.1.2 Maiolica colours/second layer

Maiolica colours (as used at the EKWC) consist of a shiny transparent base glaze (*without* zirconium silicate or tin oxide!) to which ceramic pigments and/or colouring oxides have been added. The fusion range of the maiolica colours must be well attuned to that of the white maiolica background, because if the background layer fuses too much the painting will sink in and start to 'clot' (see *Figure 9.1*).[1] On the other hand if the maiolica paint does not fuse sufficiently, a difference in gloss may occur: the paint will not fuse with the bottom layer and will appear shiny on top of a less shiny background. It is crucial that the paint fuses slightly more than the white background if clotting is not wanted, and to achieve this it is important to use a base glaze that fuses well. The recipe in *Table 9.1* (without zirconium silicate) can be used as a base to which colouring oxides or pigments can be added. Depending on the desired saturation of the colours, the percentage of pigments or colouring oxides may vary: an indication of the amounts is given in *Table 9.2*. As some pigments or oxides do affect the fusion range it may be necessary to add extra lead bisilicate to the base in order to prevent clotting. The amount of frit to be added may vary from 5% to 15%. Maiolica colours containing copper oxide will tend to sink fully into the white background glaze, resulting in softer fused edges. A Co–Si type of pigment (see *Table 8.2*) yields a strong blue,

Table 9.2

Additions of colouring oxides and ceramic pigments for the maiolica colours

Copper oxide 5–10%	Cobalt oxide 2–4%	Iron oxide 8–15%	Chromium oxide 2–6%
Manganese oxide 12–18%	Nickel oxide 6–14%	Old maiolica blue 6% Cobalt oxide 3–6% iron oxide	
Green (dark) pigment (Cr–Co–Al) 6–10%	Turquoise pigment (Zr–V–Si) 20–30%	Prussian blue pigment (Co–Al–Zn) 12–20%	Cobalt blue pigment (Co–Si) 10–25%
Purple pigment (Sn–B–Co–Cr) 18–30%	Aubergine pigment (Cr–Sn–Ca–Si) 18–30%	Pink pigment (Cr–Al–Zn) 18–30%	Red pigment (Zr–Si–Cd–S–Se) 24–35%
Bright red pigment (Cd–S–Se–Si–Zr) 15–20%	Coral pigment (Zr–Si–Fe) 18–30%	Orange pigment (Cd–Se–S–Zr–Si–Pr) 24–35%	Bright orange pigment (Cd–S–Se–Si–Zr) 14–18%
Yellow pigment (Zr–Si–Pr) 18–30%	Brown pigment (Zn–Fe–Cr–Al) 18–30%	Black pigment (Co–Ni–Cr–Fe) 10–15%	Grey pigment (Sn–Sb–V) 10–15%

Note: For more information on colouring oxides and ceramic colour pigments see section 8.3.5 Ceramic stains.

Table 9.3

Maiolica colour medium

Optapix KG 25 (SCMC gum)	2 g
Bentone EW (plasticiser)	0.8 g
Dolapix PC 67 (Polyacrylate deflocculant)	0.8 g
Water	100 g

whereas a more subdued blue, resembling the less pure cobalt ores used in the past, can be achieved by combining cobalt oxide and iron oxide (see *Table 8.1*). Iron oxide will also markedly enhance the painting quality.

Maiolica colour using a medium

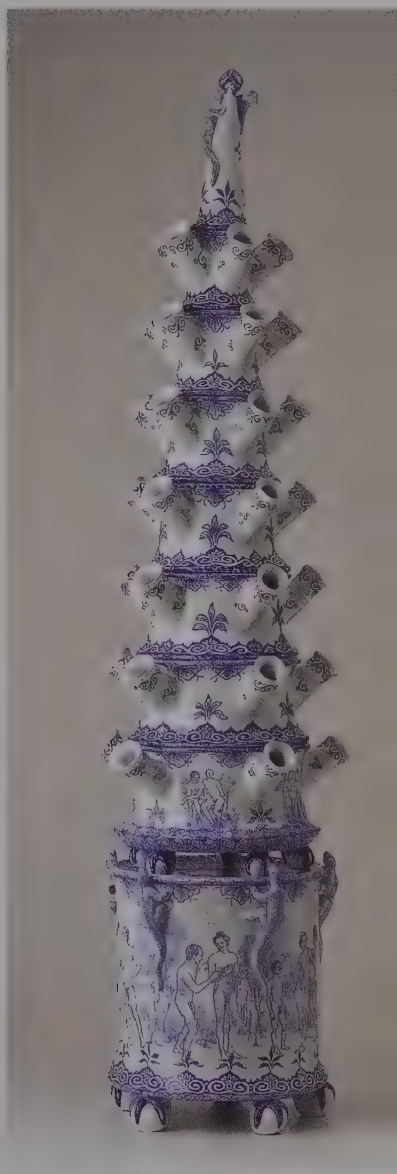
The painting properties of maiolica colours can be quite poor especially if pigments are added. To improve this, maiolica colours should be mixed with a medium instead of just water. *Table 9.3* provides a recipe for a maiolica colour medium.

The preparation of the maiolica medium is as follows:

- First Optapix KG 25 and Bentone EW are mixed together dry.
- Hot water is poured into a container (with screw-on lid) and the Optapix KG 25/Bentone EW mixture is sprinkled into it. The jar is closed and shaken thoroughly. After 5 minutes the jar is thoroughly shaken again.
- The mixture is sieved through a 100's or 120's (0.15 mm–0.125 mm) sieve.

The medium is added to the maiolica colour powder in a ratio of 50:50. Finally, the colour mixture is sieved again (100's–120's).

The colour will be slightly too viscous, but this consistency is best for storage. At the



Daniel Kruger (South Africa/ Germany), untitled, 1995. Ht: 114 cm (44½ in.). A traditional Delftware tulip vase. The vase consists of eight separate sections made using the slab-building method. A fine-grained sculpture body was used. On top of a white maiolica ground, blue maiolica paint was painted. A thin layer of coperta was sprayed on top.
(Photo: Peer van der Kruis)



Pieter Kusters (The Netherlands), no title, 2001. Ht: 200 cm (79 in.). Maiolica tiles, oil on canvas. Round tiles (20) painted with blue maiolica paint and a coperta layer on top, were attached to the oil painting. Collection: Ministry of Foreign Affairs, The Netherlands. (Photo: Hein Hage)

time of application, a small amount of water should be added to the required amount of colour to obtain the proper painting consistency: the colour should flow smoothly. The amount of extra water will be different for each pigment or colouring oxide used.

9.1.3 Using a coperta

More controlled results can be obtained by using a coperta: a thin, fully transparent glaze applied on top of the two unfired layers, and then fired. As previously mentioned, there is a chance that maiolica colours could clot or that there could be a difference in glossiness between the white background layer and the maiolica colour. The application of a thin third layer of coperta on top of the white background layer (that fuses less readily) and the maiolica colour, has several advantages:

- The painting, especially thin lines, remains more stable, as it sinks only slightly into the white background layer.
- The fusion range of the maiolica colour and the background layer need not fit so precisely because possible differences in gloss between the first layer and the maiolica colour painting are neutralised and the chance of clotting is reduced.
- If the maiolica is fired in a gas kiln, the glaze surface may be rough to the touch after firing (see section *11.5.4 Other faults*). This occurs especially if lead-free glazes are used as the first white background layer. The application of a thin lead-containing coperta layer will prevent this.

Table 9.4

White maiolica background to be used in combination with a coperta

1050°C–1070°C (1922°F–1958°F)
60°C(140°F)/hour Cone 04

Calcium borate frit 3221	4%	K_2O	0.06		
Kaolin RM 225	9%	Na_2O	0.16		
Lead bisilicate frit 3647	21%	CaO	0.38	Al_2O_3 0.43	SiO_2 3.20
Nepheline syenite RM 094	26%	MgO	0.01	B_2O_3 0.11	
Molochite 200	6%	ZnO	0.18		
Quartz	23%	PbO	0.22		
Whiting	7%				
Zinc oxide	4%				

Al_2O_3:SiO_2 1:7.36

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
55.70	12.84	2.33	6.16	0.06	4.18	14.29	–	2.85	1.59

Notes: Do not use for functional ware.
Add glaze additives, see section 8.8.1 Glaze additives.

Table 9.5

Coperta

1050°C–1070°C (1922°F–1958°F)
60°C(140°F)/hour Cone 04

Calcium borate frit 3221	16%	K_2O	0.04				
Kaolin RM 225	2%	Na_2O	0.13				
Lead bisilicate frit 3647	38%	CaO	0.39	Al_2O_3	0.21	SiO_2	2.24
Nepheline syenite RM 094	25%	ZnO	0.11	B_2O_3	0.38		
Quartz	16%	PbO	0.33				
Zinc oxide	3%						

Al_2O_3:SiO_2 1:10.66

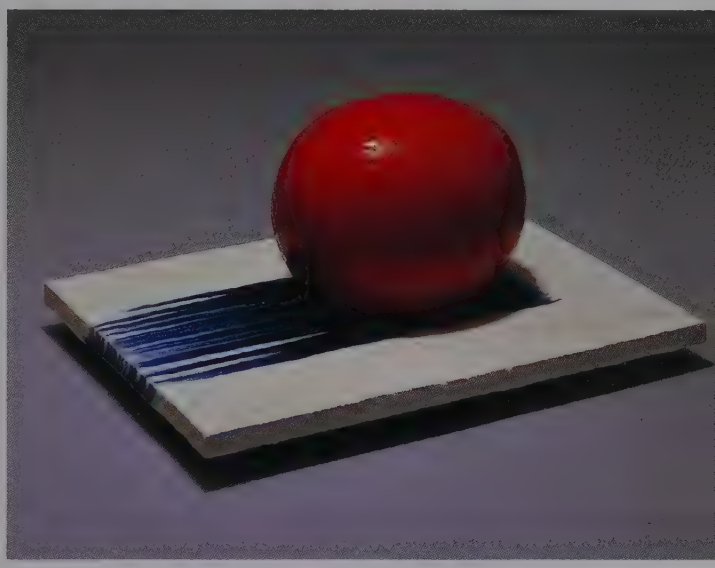
SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
44.95	7.16	8.91	7.32	–	3.00	24.77	–	2.61	1.24

Notes: Do not use for functional ware.
Add glaze additives, see section 8.8.1 Glaze additives.

The recipe in *Table 9.4* can be used to achieve a white maiolica background in combination with a coperta. The coperta recipe of *Table 9.5* is applied thinly over this white background layer and the maiolica colours. A spray gun gives the best results because it achieves a thin layer without disturbing the maiolica painting during application, as can be the case if the coperta is applied by brushing.

9.1.4 Flowing

The maiolica painting may run if both the maiolica colour and coperta are thickly applied. Flowing may be so strong that the glaze runs off the work and sticks to the kiln shelf during firing. Controlled use of this running (by placing the work on ceramic props and collecting the running glaze with the aid of a 'drip tray' made from clay) may yield very fine results.



Jun Kaneko (Japan/USA), *Italian Dream*, 1996. L: 72.5 cm (28½ in.). A piece consisting of two elements. They were fired in a high biscuit and low glaze firing. A cadmium red glaze was used for the egg shape. The tile was glazed with white maiolica background, thickly-applied blue maiolica paint and a thickly-applied coperta layer. The low viscosity of the glaze and the vertical position of the tile in the kiln resulted in the flowing of the blue maiolica paint. (Photo: Takashi Hatakeyama)

9.2 Underglaze

Painting with colouring oxides, often cobalt oxide, directly on a white body covered with a shiny transparent glaze also originated in Persia. This underglaze technique was then introduced to China where it was used in their famous blue and white porcelain. Underglazes are commercially available, but they can also be easily prepared in the studio. At the EKWC underglaze colours are made by adding pigments or colouring oxides to an underglaze base that is actually an engobe. The recipe provided in *Table 9.6* yields very good results from the low to high temperature range, although it is most suitable for the high temperature range with colouring oxides. The only difference with an engobe is the greater addition of pigments or oxides, see *Table 9.7*, and because of the relatively high amount of pigments, stronger colours are obtained in one stroke. The amount to be added depends on the colouring power of the pigment and its effect on the opacity so if a more translucent result is desired, comparable to, say, watercolours, the indicated minimum can be used. Copper oxide, in particular, dissolves easily into the cover glaze creating more translucent results in any concentration. Also, to obtain good painting properties Molochite 200 is preferred over calcined kaolin in the engobe recipe and this addition enhances the fluid application and reduces the chance of faults.

For proper layer thickness it is important to add the correct amount of water. In general, 50% to 60% (of the total of base + pigment or colouring oxides + glaze additives) water is added. This percentage is determined by the type and amount of pigments used, and the type of surface to be painted. The less absorbent the body, the lower the percentage of water needed. Underglaze can be silkscreened directly on a flat surface, like a tile, provided it has been sieved through a fine sieve, for instance 0.075mm (200's). Silkscreening is also possible on leatherhard tiles.

The final result of an underglaze is determined largely

Table 9.6

Underglaze colour base (Eng M1)

1040°C–1280°C (1904°F–2336°F) Cone 04–9

Calcium borate frit 3221	2%	K_2O	0.12						
EOBBY (Aluminous ball clay)	25%	Na_2O	0.22	Al_2O_3	1.38	SiO_2	4.65		
Nepheline syenite RM 094	24%	CaO	0.64	B_2O_3	0.08				
Molochite 200	30%	MgO	0.02						
Quartz	9%								
Whiting	10%								
+ Pigments or colouring oxides as provided in *Table 9.7*		Al_2O_3:SiO_2 1:3.38							

SiO_2	Al_2O_3	B_2O_3	CaO	MgO	ZnO	PbO	Li_2O	Na_2O	K_2O
57.31	28.81	1.21	7.34	0.21	–	–	–	2.78	2.31

Note: Add glaze additives, see section 8.8.1 Glaze additives.

Table 9.7

Colouring oxides and ceramic pigments for underglaze colours

Copper oxide 15–25%	Cobalt oxide 8–15%	Iron oxide 15–30%	Chromium oxide 8–15%
Manganese oxide 30–45%	Nickel oxide 15–30%	Zirconium silicate 30–50%	
Green (dark) pigment Cr–Co–Al 20–40%	Turquoise pigment Zr–V–Si 50–100%	Prussian blue pigment Co–Al–Zn 15–25%	Cobalt blue pigment Co–Si 15–25%
Purple pigment Sn–B–Co–Cr 50–100%	Aubergine pigment Cr–Sn–Ca–Si 50–100%	Pink pigment Cr–Al–Zn 30–60%	Red pigment Zr–Si–Cd–S–Se 50–100%
Bright red pigment Cd–S–Se–Si–Zr 25–50%	Coral pigment Zr–Si–Fe 30–60%	Orange pigment Cd–Se–S–Zr–Si–Pr 50–100%	Bright orange pigment Cd–S–Se–Si–Zr 25–50%
Yellow pigment Zr–Si–Pr 50–100%	Brown pigment Zn–Fe–Cr–Al 50–100%	Black pigment Co–Ni–Cr–Fe 25–50%	Grey pigment Sn–Sb–V 40–80%

Note: For more information on colouring oxides and ceramic colour pigments see section 8.3.5 Ceramic stains.

by the cover glaze used, and a fully transparent glaze will allow the underglaze to show through with the brightest colour. **Lead-containing transparent glazes** fulfil this purpose especially well for low temperatures, such as the recipe in *Table 8.5*. The recipes provided in *Tables 8.14* and *8.17* could be used for the middle temperature range and for high temperature reduction firing, respectively.

9.3 Onglaze

Onglaze is an application that emerged in China in the 13th century. An onglaze is a powerful stain and a finely ground glaze applied to an already-fired glaze layer. The best-known form of onglaze is used for relatively low temperatures (780°C–850°C/ 1436°F–1562°F). Onglazes are usually obtained directly from a ceramic supplier and are sold in liquid or powder form. A painter's medium is then added to the powdered form. **NB:** Onglazes contain toxic components. During preparation and application the utmost caution must be observed. The formation of dust and direct contact with skin must be prevented.

One of the great advantages of onglaze colour, compared to the painting and decoration techniques discussed so far, is that the newly applied painting is very similar to the final result. Another advantage is that very bright colours can be obtained although it is now possible to get signal red, for example, a colour that was until not long ago hard to obtain in a glaze, see *Ceramic pigments* under section *8.3.5 Ceramic stains*. A disadvantage of the onglaze technique is that the painting may have a lacquer-like look. This effect varies depending on the quality of the onglaze, and even more on the method of firing (see section *9.3.2 Instructions on firing onglazes*). Another type of onglaze, sometimes referred to as **inglaze**, is fired at a higher temperature, in general 100°C (212°F) below the top temperature of the glaze underneath, allowing it to sink more into the glaze layer underneath.

Onglazes are often used in **decals**: a silkscreen print is obtained by mixing onglaze and silkscreen medium and printing this on to decal paper (paper treated with gum) and covered with a cover coat (a thin plastic film). This cover coat holds the onglaze print as the decal paper is placed in water, where the gum softens enabling the film and the print to slide off the paper and then be transferred onto a glazed surface, the cover coat burning away during firing.

9.3.1 Preparing onglaze colours

Onglaze colours can be mixed by using a studio-made painting medium, which can be produced by mixing Optapix KG 25 and water in the ratio provided in *Table 9.8* as follows:

Table 9.8

Medium for onglaze colour

Hot water	100 g
Optapix KG 25 (SCMC gum)	1.8 g

- Hot water is poured into a container (with a screw-on lid) and Optapix KG 25 is sprinkled into it. The container is closed and shaken thoroughly. After 5 minutes the jar is shaken again.
- The mixture is sieved through a sieve with a 200's mesh (0.075 mm).
- This medium is added to onglaze powder in a weight ratio of 10 (onglaze) to 4 (medium) and sieved again (200's mesh).
- Usually, some extra medium must be added to the onglaze colour to produce the proper consistency for painting as the mixture should flow smoothly without running or streaking. The amount of extra medium will be different for each onglaze colour.



Philip Eglin (England), *St Anne with Virgin and Child*, 1990. Ht: 81 cm (32 in.).
This piece was made by using press-moulded slabs. A fine-grained sculpture body was used. Some of the slabs were made on top of a plaster slab on which a drawing using underglazes had been painted. After the biscuit firing the piece was glazed in parts using a transparent glaze; a glaze containing pigments; and a cadmium red glaze.
Collection: Mint Museum of Art, Charlotte, NC, USA.
(Photo: Peer van der Kruis)

NB: Prior to painting, the glaze surface should be made entirely grease-free (for instance with alcohol) in order to get good adhesion and prevent the paint from crawling.

9.3.2 Instructions for firing onglazes

The manufacturer indicates the minimum and maximum firing temperatures for an onglaze. The minimum temperature is intended for use on earthenware glazes (1000°C–1100°C/1832°F–2012°F), the maximum temperature for high temperature glazes (1260°C/2300°F and more). The onglaze and underlying glaze will fit optimally only if the right temperature is chosen. The underlying glaze softens slightly above a certain temperature, ensuring good mutual adhesion. As mentioned before, an under-fired onglaze may have a lacquer-like look but on the other hand exceeding the top temperature may reduce colour development: the glaze will melt too much as the

temperature rises and react with the onglaze. The red and orange onglaze varieties are especially susceptible to this: there is even a chance that the colours will disappear partially or entirely. (Cobalt blue, and especially, black onglaze colours are less susceptible to this effect.) For this reason, the correct top temperature needs to be established, as does the firing speed which also influences the outcome. A firing speed of 100°C up to 150°C (212°F–302°F) per hour from 650°C (1202°F) onward may be taken as a starting point. The kiln should be well vented up to 650°C. No reduction should take place during the firing of onglazes as this can affect the colour.

9.4 (Precious metal) lustre

Lustres provide an extra dimension within the ceramic techniques. A wide range of lustres can be obtained, such as gold, platinum, mother-of-pearl and copper. In addition, there is also a broad range of commercial lustre colours and lustre effects available. Commonly used are the brush-on lustres that should be applied to an already-fired glaze and then fired between 700°C and 750°C (1292°F–1382°F).

These kinds of lustres consist of the following components:

- Main metals: usually consisting of an alloy of (precious) metals.
- Binding agents: natural (turpentine) or synthetic resins.
- Solvents (such as 'Cyclohexanol' or 'Cyclohexanon').
- Adhesives: specific metallic compounds (such as rhodium compounds) for adhesion to the glaze surface and for obtaining a smooth surface.



Anita Wong (Canada), *Pillow (with claw feet)*, 1996. Ht: 21 cm (8 in.). A combination of engobe (drawing), cadmium red glaze, shiny and matt glaze, and gold lustre were used on this piece. The matt glaze on the feet gives the lustre a matt gold finish. (Photo: Peer van der Kruis)

- Additives: various ingredients that help the application of the lustre.

The lustre mixture is often a somewhat viscous liquid that is very different from the final fired result: the dissolved (precious) metal will deposit as a smooth, thin layer on the glaze surface during the firing (around 200°C–225°C/ 392°F–437°F). Adhesion of this layer on the glaze will be achieved if fired to the required temperature.

These lustres only yield shiny results if applied on a shiny glaze. If applied to a satin gloss or matt glaze, they will be satin or matt.

NB: The solvents and binding agents in the lustre are very volatile and hazardous to health and fertility, and may damage the unborn child. Take care that there is sufficient ventilation during application, drying and firing.

9.4.1 Requirements for application by brush

The application of lustres requires a number of specific things:

- Alcohol (methylated spirit) for cleaning and degreasing the glaze surface.
- A high-quality oil paint brush with synthetic hairs (as it does not absorb too much lustre and there is less risk of hair loss). If large surfaces are to be covered, a brush of about 1.5 cm (⅝ in.) is best. The brush should be well cleaned as traces of previous use may affect the quality of the lustre (most noticeably, traces of gold will affect mother-of-pearl lustre).
- A small (porcelain) bowl. The lustre is put into the bowl in small amounts, each time just enough to fill the brush. The bottle must be closed carefully every time the bowl is topped up, and any lustre left in the bowl should not be returned to the bottle. This will prevent the lustre in the bottle from being contaminated and drying too quickly. Lustre that has become thick is sticky and as a result hard to apply evenly.
- Kiln shelves and stilts or saddles. It takes at least 2 hours to dry lustre with good ventilation. Work that is to be lustred all around may be placed on a kiln shelf with stilts as soon as the lower part of the piece is finished. After the whole piece is lustred, the kiln shelf is placed into the kiln with the piece positioned on it, to avoid touching it after it has been lustred.
- A vapour filter mask (European norm type: EN405-2002), latex gloves and good air extraction and ventilation of the work place and kiln during firing, for safety reasons.



Miriam van der Lubbe (The Netherlands), *Tea Set*, 2000. Gold lustre decals of coffee stains on a standard porcelain hotel coffee set.
Collection: Stedelijk Museum, Amsterdam, The Netherlands. (Photo: Peer van der Kruis)

9.4.2 Application and layer thickness

Lustre should be applied carefully and evenly. It is important to have the proper layer thickness. Layers that are too thick use too much lustre unnecessarily and may cause the lustre layer to vanish (especially platinum lustre), or lead to the formation of a layer of powder that does not stick (especially mother-of-pearl lustre). Layers that are too thin may lead to streaks and eventually to a change in colour (gold and copper lustres



Johannes van Wetering (The Netherlands), *Tunnel*, 1998. Ht: 51 cm (20 in.). A coarse-grained sculpture body modelled on top of a core made out of polystyrene sheet. Black and red onglaze on top of a white base glaze.
Collection: Princessehof, Leeuwarden, The Netherlands (Photo: Corné Bastiaansen)

may turn purple in places). Only mother-of-pearl lustre should be applied very thinly.

In general, it is better if the brush is not too loaded with lustre to get a proper layer thickness. To avoid heavy strokes, allow some lustre to drip off the brush by resting it against the side of the bowl. Up to two strokes can be made before the brush has to be refilled. Repeated strokes will produce a layer that is too thin. A somewhat transparent colouring may serve as an indication. Conversely, a layer that is no longer transparent has been applied too thickly. The layer should be applied on the glaze surface in a criss-cross motion. Applying the lustre in orderly parallel lines may result in an awkward pattern. As mentioned before, mother-of-pearl lustre must be applied very thinly to achieve good results. Therefore the brush is filled with only a small amount of lustre and brushed out thoroughly to create a very thin layer. A layer that is too thick will result in a layer of powder that can be wiped off. The application of the lustre must be done in a very concentrated way, before the lustre layer has dried, because filling in areas that have been missed may leave traces that will become visible after firing. Correcting immediately gives the best results. The overlapping of the beginning and the end of a layer on a larger form that is lustred all around may also become visible after firing. The best thing to do is to position the overlapping on a less visible part of the piece if possible, or start the lustre layer from the top or the centre of the work and work systematically to the bottom or the edge in a spiral. Once applied, lustre is hard to remove; traces will remain in places that become visible only after firing. For this reason, working carefully is especially important if not all of the work is to be covered with a lustre layer.

NB: The instructions provided should be seen as a starting guideline. Testing is necessary as different batches of lustre could yield different results.

9.4.3 Instructions on firing lustres

As mentioned before, a (precious) metal layer is deposited on the glaze surface at around 200°C to 225°C (392°F–437°F). The medium in which the (precious) metals have been dissolved provides the right firing atmosphere in the area, creating the conditions for a very thin layer to be deposited. This process will only be successful if there is sufficient oxygen in the kiln. Keeping the temperature at 250°C (482°F) for two hours and allowing a sufficient air supply from the start up to 250°C including two hours soaking will support the formation of a good quality lustre layer. For this purpose, the damper at the top of an electric kiln is kept open and the kiln door is kept ajar (about 0.5 cm).[2] Gas kilns equipped with forced air or high velocity burners allow the input of excess air to supply sufficient oxygen during the first stage of firing. Depending on the type of kiln a recommended maximum quantity of lustred surface per firing should be in the kiln. If this maximum is exceeded satisfying results may be hard to achieve. A rough indication of the ratio for an **electric kiln**: for each gram of lustre a minimum volume of 25 cm^3 (1½ cu in.) kiln space should be available. In a **gas kiln**, equipped with **high velocity burners**, double the amount of lustre within this volume can be fired. A rough indication of the ratio of lustre to the surface to be covered: 1 g/0.035 oz of lustre covers a surface of approximately 120 cm^2 (18 sq in.). (A larger surface can be covered with mother-of-pearl lustre as it is applied more thinly.) Remember, the above data are only indications and must be tested. Leave sufficient space when packing: keep sufficient distance between the top of the work and the ceiling of the kiln or kiln shelf. If packing is too tight a deficiency of oxygen may occur even if the lustred surface does not exceed the maximum.

NB: As discussed before, gases released during the firing of lustres are hazardous to health. For this reason, both good air extraction in the kiln and good ventilation in the workplace where the kiln is located are necessary.

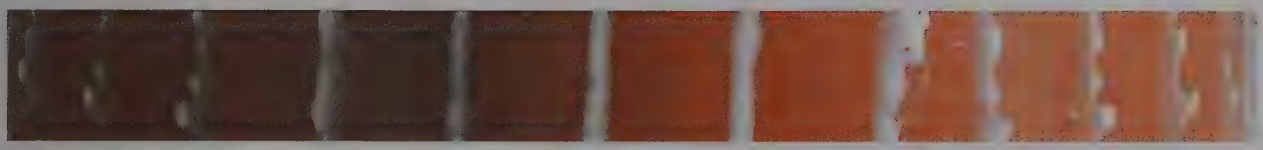
Notes:

1 A thickly-applied white background will increase the chance of clotting.

2 A body containing large amounts of cristobalite could be subjected to tension build-up causing the piece to crack.



10 Terra sigillata



Terra sigillata is a slip, more specifically a suspension of deflocculated very fine clay minerals in water. When applied to a piece a characteristic smooth and (semi)-shiny quality is produced, brought about by these fine clay minerals. The development of terra sigillata started in ancient Greece and flourished in Roman times. Eventually it fell into disuse resulting in the knowledge being lost but, due to research started at the beginning of the last century, terra sigillata was available once again by the 1930s. Terra sigillata consists entirely, or mostly, of clay. The very fine clay minerals that make up a terra sigillata can be obtained by separation through a sedimentation process of clay in water. Unwanted heavy particles settle, clay minerals float and can be syphoned off ready for the next stage. A very important characteristic of terra sigillata is the fact that it is applied only as a very thin layer, hence the texture of the work is not noticeably affected and an intimate relationship to the surface of the piece is retained. In this chapter a method of preparing will be discussed that could lead to a shiny terra sigillata within a few hours without the necessity of it being ball milled, or the surface of the piece being burnished after the terra sigillata is applied. It is important to note that terra sigillata is not a glaze, therefore it will not make a body waterproof.[1]

10.1 What makes a good terra sigillata?

There are several important considerations (discussed in the following sections) that will lead to a good terra sigillata; it is the connection between these points, which provides the quality of terra sigillata.

10.1.1 The kind of clay

Whether a clay is suitable for making terra sigillata depends on the kind of clay minerals and the fineness of these minerals. The most common clay mineral, (disordered) kaolinite, has a flat plate-like shape and presumably this shape enables it to reflect light, resulting in a fine and subtle gloss during application, a gloss that remains after firing. Most HTR-clays tend to be suitable as they often contain very fine kaolinite and to a lesser extent illite (see *Choosing a powdered clay* under section *2.2.1 Clay*). It is more difficult to obtain a shiny terra sigillata from kaolin types containing mainly 'coarse' and stacked kaolinite plates (see *Figure 10.2a*) as they disturb reflection of light. MTR-clays, and T-MTR-clays and other very plastic clays may give a higher gloss at low temperatures provided large amounts of montmorillonite or calcium oxide compounds are not present. In principle, provided sufficient suitable clay minerals are present, the clay

OPPOSITE:
Geert Lap (The Netherlands), Large white vase, 1996. Ht: 96 cm (37¼ in.). Piece made by using the throw-and-coil method. The base of the form was supported by a mould during making. A white terra sigillata was applied to the surface. Collection: Frans Hals Museum, Haarlem, The Netherlands. (Photo: Peer van der Kruis)



Satoru Hoshino (Japan), *Reincarnate/Pre-copernican Mud II*, 1998. W: 800 cm (312 in.). This piece was partly modelled (small elements on the floor) and handbuilt (standing forms) by using small slabs of clay. The rough surface was created by squeezing the clay during construction. A black terra sigillata was sprayed on the surface.
(Photo: Peer van der Kruis)

body that is used for making the piece could also be used as a basis for terra sigillata: the firing properties of the body and applied layer will relate resulting in a good bonding between the two. **NB:** A clay body containing cellulose fibres cannot be used as a basis as the cellulose fibres will float in water, where they intermingle with the fine clay minerals and thereby ultimately disturb the gloss.

10.1.2 The right amount of water

The amount of water to be used in the sedimentation/ separation process is very important. The sedimentation process can only be successful if the mixture is not too 'viscous' (not too many clay particles should be suspended avoiding the slip becoming thick). However, if a lot of water is used all particles, including the fine ones, settle relatively quickly. As this happens, optimum separation of the clay minerals and non-plastic particles does not occur. The amount of water needed is not fixed: it will differ for each clay. A clay or clay body with a high plasticity (containing a lot of fine and ultra-fine clay minerals) needs a great deal more water to be added compared to a clay body with lower plasticity (like kaolin or porcelain). Usually normal tap water will yield good results, but if it contains dissolved minerals (like calcium carbonate) deflocculation can be unfavourably affected. De-mineralised water can improve the separation process, especially with kaolin or if a porcelain body is used.

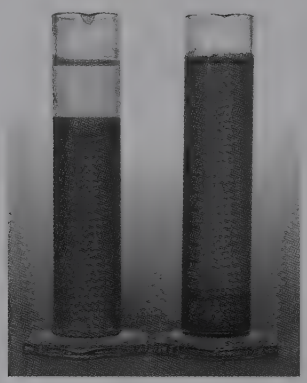


Figure 10.1
Two mixtures with the same water:clay ratio after 12 hours settling. Left without and right with an addition of Dolapix PC 67. Separation of the heavy particles (dark part at the bottom) has taken place clearly in the mixture at the right hand side. The mixture at the left side has settled without clear separation, moreover at the top part a layer of water has been formed.
(Photo: Anton Reijnders)

10.1.3 Deflocculation

Deflocculation is essential to obtain a terra sigillata. Provided the right amount of water and deflocculant is used coarse particles will be separated more effectively during the sedimentation, see *Figure 10.1*. Different deflocculants can be used – sodium metaphosphate (an active component in Calgon), sodium silicate (water-glass) or sodium carbonate (soda) are often recommended in ceramic literature. Research by the author has shown that polyacrylate types of deflocculants yield very good results: a combination of the right ratio of clay:water and a polyacrylate type of deflocculant can yield a good terra sigillata in less than one day, provided a suitable clay is used. There are several kinds of polyacrylate type of deflocculants available. At the EKWC sodium polyacrylate deflocculant **Dolapix PC 67** is used with very good results. Also **Darvan 811** (sodium polymethacrylate) gives very good results. Possible alternatives could be

Darvan 7 (sodium polymethacrylate), and Dispex (ammonium polyacrylate), although testing is recommended. If no polyacrylate types of deflocculant are available, **sodium silicate** (water-glass) can be used instead although the preparation takes more time and it also takes more time to obtain a comparable gloss and less terra sigillata is yielded. The amount of deflocculant needed is not fixed; it depends on the clay being used. Clays with high amounts of calcium oxide compounds, but especially montmorillonite, are difficult to deflocculate so this makes them less, or not, suitable. Clays with a high illite content need a greater amount of deflocculant. However, there is a maximum limit of deflocculant that can be added as too high an addition will counteract the separation process. Generally, the amount of polyacrylate type of deflocculant required lies between 0.5% and 4.5%. A method to determine the right ratio will be discussed in Chapter 15.

10.1.4 Sedimentation time

The time during which the clay/water/deflocculant mixture is allowed to settle is called the sedimentation time and the timespan implemented will influence the final quality of the terra sigillata. Non-plastic components (like quartz) will settle very fast. 'Coarse' clay minerals will settle in a short period of time. Very fine clay minerals take a longer time. The more coarse or medium-fine clay minerals there are present the more opaque and less shiny the terra sigillata will be.[2] A very long sedimentation time will lead to an unwanted settling of the very fine clay minerals. Provided the right water:clay:Dolapix PC 67 (or Darvan 811) ratio is applied, most non-plastic components will have settled in 2–3 hours.[3] Within 24 hours the less-fine clay minerals will also have settled and no further sedimentation is advised, to prevent the settling of the essential very fine clay minerals.



Teja van Hoften (The Netherlands), *Orientation*, 2003. Ht: 165 cm (64¼ in.). This piece was made by using slabs of a coarse sculpture clay. A silhouette was painted using a transparent terra sigillata made of an MTR-clay. The piece was fired in reduction up to the mid-temperature range. Due to the re-oxidation that occurred during cooling, the colour of the non-treated part changed slightly, resulting in the accentuation of the silhouette.
(Photo: Anton Reijnders)

10.1.5 Separation

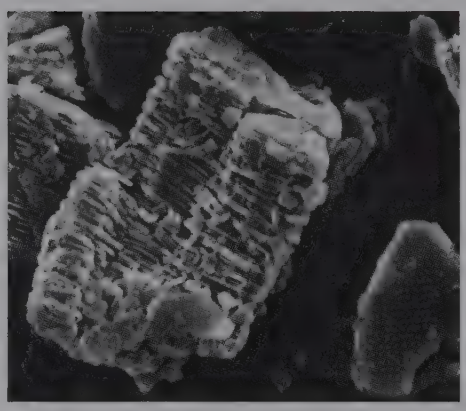
Separation will be a simple action if the right water:clay:deflocculant ratio has been applied. Syphoning or simply pouring the non-settled liquid part off into another container will be adequate. If done in a careful way no intermingling of fine and coarse particles will take place as the coarse particles will have formed a relatively stable layer at the bottom of the container.

10.1.6 Maturation time

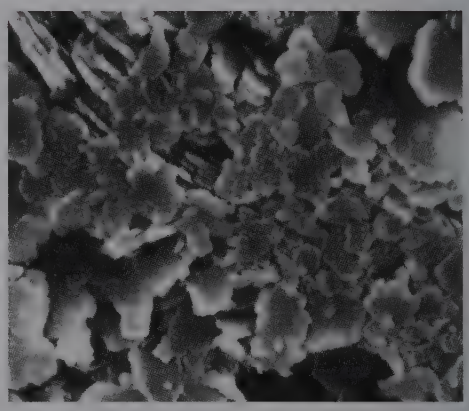
Maturation time is the time terra sigillata is allowed to stand before being applied. A prolonged maturing time will result in more gloss; a period of a few days or one week will have a noticeable effect. This will be the case whether a terra sigillata has a short



Torbørn Kvasbø (Norway), *Form 2003*, 2003. W: 129 cm (50¾ in.). Slab-built, consisting of two layers: a fine-grained white clay body on top of a coarse body. By pushing the clay from the inside a voluminous organic form was created. A number of coats of black terra sigillata were sprayed on the surface.
(Photo: Anton Reijnders)



RIGHT:
Figure 10.2a
Laminated stack structure typically for coarse kaolinite as found in kaolin.
Reprinted with permission of The American Ceramic Society, www.ceramics.org. © 1999. All rights reserved.



FAR RIGHT:
Figure 10.2b
Delaminated kaolinite. Delamination took place after it was treated with a deflocculant kind of material.
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or a long sedimentation time. An increase of the maturation time allows the clay minerals to be split up into smaller particles which reflect light even better (see *Figure 10.2*).[4]

10.1.7 Surface

The clay body used to make the piece, more precisely the structure of this clay body; the smoothness of the surface; and the dryness of the piece, will all influence the end result. Terra sigillata will appear more shiny on a smooth surface and on a piece made out of a clay body with a fine structure. It is best applied onto a fully dry piece. The quality of the gloss will be affected if applied on a leatherhard piece,[5] because during drying of the piece, shrinkage and water penetrating through the terra sigillata layer will reduce the gloss slightly.

10.1.8 Layer thickness

To achieve good results terra sigillata must not be applied too thinly: no satisfactory finish will be achieved because it will result eventually in an over-dry surface. Too thick a layer should also be avoided as it might increase the chance of shelling. A way to achieve an optimal layer thickness will be discussed in section *10.2.1 Determining density*.

10.1.9 The top temperature

Contrary to what is sometimes stated, the gloss of a terra sigillata will not disappear as temperature rises beyond a certain point.[6] At higher temperatures more vitrification will take place, gradually changing the character of the gloss. This will be shown most clearly in the case of MTR and terracotta clays. Also a less opaque or even transparent result will be achieved in the case of MTR and HTR-clays, especially if the maturing time is prolonged. The temperature at which this occurs differs with each clay body and can only be determined through testing. Some indications are provided in section *10.5 Firing temperatures*.

10.2 Preparing a batch of terra sigillata

As has become clear, the right water:clay:deflocculant ratio is essential to obtain a good terra sigillata, and every clay has a specific water:deflocculant ratio. Therefore it is not useful to provide one ratio. *Table 10.1* provides some general indications that could be

Table 10.1

Clay:water:deflocculant ratio to achieve terra sigillata

Powdered clay		***Pulverised clay body***[1]	
T-MTR-clay[2]		*Highly plastic red burning clay body*	
Powdered clay	1000 g	Pulverised clay body	1000 g
Water	2300 g	Water	2000 g
Dolapix PC 67 or Darvan 811	30 g[3]	Dolapix PC 67 or Darvan 811	30 g[3]
MTR-clay[2]		*Highly plastic stoneware body*	
Powdered clay	1000 g	Pulverised clay body	1000 g
Water	2100 g	Water	1900 g
Dolapix PC 67 or Darvan 811	25 g[3]	Dolapix PC 67 or Darvan 811	25 g[3]
HTR-clay[2]		*Medium plastic clay body*	
Powdered clay	1000 g	Pulverised clay body	1000 g
Water	1800 g	Water	1600 g
Dolapix PC 67 or Darvan 811	10 g[3]	Dolapix PC 67 or Darvan 811	10 g[3]
Kaolin[2]		*Porcelain clay body*	
Powdered clay	1000 g	Pulverised clay body	1000 g
Water	1500 g	Water	1400 g
Dolapix PC 67 or Darvan 811	5 g[3]	Dolapix PC 67 or Darvan 811	5 g[3]

Notes:

[1] *Less water is added if a clay body is used in order to compensate the presence of the amount of non-plastic components like grog or quartz.*

[2] *See* Powdered clay *under section* 2.2.1 Clay *for more information about these clay types.*

[3] *The right addition of an alternative polyacrylate deflocculant should be tested. If water-glass is used add 5 g extra.*

used as a starting point. However to achieve the best results the right water:deflocculant ratio to be added to the clay at hand should be determined by following the method discussed in Chapter *15, Advanced section: Terra sigillata*.

If a prepared clay body is to be used, first it must be divided into small pieces and then dried. The method of preparation of a batch of terra sigillata is as follows:

1. Place the deflocculant into an empty container, this will allow you to correct the amount if too much deflocculant is added by accident.
2. Add water and stir well.
3. Add the powdered clay or pulverised clay body (no lumps larger than 3 mm/⅛ in.) and stir well. Sometimes it happens that foam occurs on top of the mixture during mixing; this can be removed with tissue paper.
4. Allow the mixture to settle for between 3 and 24 hours. (Settling for 2 hours, mixing again and then settling for 3 to 24 hours will yield more terra sigillata.)[7]
5. Finally, syphon or pour off the separated liquid mixture. (The leftover sediment can be used as a slip). **NB:** once a terra sigillata has been syphoned off this process does not need to be repeated.

1000 g (2 lb) of dry clay or clay body will yield between about 1.5 and 2.5 litres (2½pt–4½pt) of terra sigillata. A highly plastic clay will yield a larger volume of terra sigillata compared to less plastic clays. Using sodium silicate will give less terra sigillata.

10.2.1 Determining density

Each clay and variation in sedimentation time will result in a different density, meaning a different clay:water ratio of the prepared batch of terra sigillata, and this density will influence the final result. A high density will easily yield too thick a layer resulting in an increased chance of shelling (for more information see section *10.4.1 Optimal layer thickness*). A low density will lead to a drier surface. By determining the **slop weight** of a prepared terra sigillata an indication of the density is achieved. To determine the slop weight, the following are needed:

- A 1000 ml graduated cylinder
- A scale (preferably with an accuracy within 1 g)
- The weight of the graduated cylinder (the cylinder should be dry and clean!).

Before determining the slop weight the terra sigillata should be thoroughly stirred to incorporate any parts that have stuck to the bottom of the container. The mixture is then poured into the graduated cylinder and weighed. The weight of the empty graduated cylinder is subtracted from the weight of the filled cylinder resulting in the slop weight. The slop weight should range between 1100 and 1140 per 1000 ml (this relates to a slop weight without further addition of stains).

In case stains are to be added, the final slop weight should be noted down on to the storage container of the terra sigillata.

Too high a slop weight

A slop weight above 1140 indicates too high a ratio of clay. This can be corrected by adding water, and the amount of water that has to be added can be calculated as follows: the target slop weight is deducted from the weight of 1000 ml terra sigillata, the outcome is multiplied by **6.25**.[8] For example:

The total volume of the prepared terra sigillata is 2300 ml (2.3 litres), its slop weight is 1165. The target slop weight is 1130. 1165–1130 = 35. The outcome is multiplied by 6.25. 35 × 6.25 = 218.75 ml more water should be added per 1000 ml. The total volume was 2300 ml, so an addition of: 218.75 × 2.3 =503.12 ml water to the total batch of terra sigillata.

Too low a slop weight

If the slop weight is less than 1100 adding dry clay is not advisable.[9] Increasing the slop weight is best attained by vaporisation, and this can be speeded up by making the terra sigillata warm (not hot or boiling, as this could create lumps).

10.2.2 Maturation

The terra sigillata mixture is ready for use immediately after syphoning but, as has been pointed out, the time between syphoning off and applying – the maturing time – does influence gloss: the terra sigillata will become more shiny in the course of time. After a certain amount of time the increase of gloss will cease. An indication of whether maximum maturation has been achieved can be obtained by test burnishing the surface. The surface is burnished with a fingertip shortly after applying the terra sigillata and if a higher gloss is achieved at the burnished spot maturation time could be prolonged to gain more gloss.[10] Terra sigillata tends to settle during maturation, therefore it is always advisable to stir well before applying, in order to guarantee a homogeneous composition. If the settled part sticks to the bottom it first has to be scraped before the terra sigillata is stirred. If maximum gloss is not aimed for, the maturation can be stopped at any time. The gloss can be consolidated by adding very small amounts of a glaze suspending agent. (At the EKWC, **Stellmittel ZS** is used successfully.) A very small addition of saturated **calcium chloride** solution will also give good results. Vinegar can also be used and only a few drops will suffice. The consistency could, however, change dramatically if a suspending agent or vinegar is added beyond a certain level, i.e. the terra sigillata suddenly becomes 'viscous', for further information see section *10.3.2 Counteracting settling*.



Jeannine Vrins (Belgium), *Bekkenschaal*, 1997. W: 90 cm (35½ in.). A fine-grained ochre-coloured clay body was used. Cellulose fibres were added to the clay body. The forms were press-moulded on top of a plaster mould. A terra sigillata made out of a combination of ochre-coloured and terracotta clay was applied on the inside of the left piece. A sinter engobe containing iron oxide was applied inside the right piece. (Photo: Peer van der Kruis)

10.3 Terra sigillata and colour

Clay has a limited natural colour range, therefore the amount of colours that can be obtained are limited, though intermixing of the various types of clay can produce interesting intermediate shades. The top temperature will also have an effect on the saturation of the final colour, see section *10.5 Firing temperatures*. Irrespective of the colour of the terra sigillata interesting black, or a range of brown/grey up to black, can be achieved by a **saggar firing**, see section *11.4.3 Saggar firing*.

Adding **colouring oxides** and **ceramic pigments** can extend the colour range (although the colour range obtained by terra sigillata is less vivid in comparison with



Jozefien Gronheid (The Netherlands), *Wooden Spoons*, 2003. W: 6–12 cm (2⅜–4¾ in.). Porcelain casts from a mould made of the knot of a tree. A thin layer of porcelain terra sigillata was sprayed on the surface to maintain the details of the cast. The black terra sigillata contained a large amount of cobalt oxide. Talc was added to the white terra sigillata. (Photo: Anton Reijnders)

a shiny glaze). In general, up to 30% of pigment or colouring oxide (for example cobalt oxide and iron oxide) can be added. **NB:** Pigments or colouring oxides are added only to a fully-prepared terra sigillata because these materials will settle immediately. Pigments and oxides are very coarse in structure compared to the fine clay minerals so adding these materials to a terra sigillata will be at the expense of the gloss. White-firing clay like an **HTR-clay** is recommended if somewhat brighter colours are aimed for and an **MTR-clay** if more saturated colours are aimed for. Also an increase of temperature tends to result in a shift from pastel to darker colours (see *Figure 10.4*).

NB: If a more **opaque result** is aimed for, a sedimentation time of not more than 3 or 5 hours (5 hours is including in-between mixing after 2 hours of settling and the use of a polyacrylate type of deflocculant) should be aimed for, resulting in a slop weight of between 1130 and 1140 per 1000 ml. If a reasonable gloss is aimed for a well-matured terra sigillata and moderate amounts of pigments and colouring oxides should be used in order to limit the loss of gloss. Sieving could be necessary if lumps are present in pigments or colouring oxides.

10.3.1 Determining the dry weight content

As pointed out previously, each clay and variation in sedimentation time will result in a different density of a terra sigillata batch. Due to the fact that pigments and oxides are added to the terra sigillata after it has been prepared, a straightforward addition of a certain percentage may each time lead to a different result, due to a different clay:pigment or oxide ratio. However, it is possible to calculate the right amount of the addition and to do this the **dry weight content** of a terra sigillata has to be determined. The dry weight content is the amount of dry material, meaning the amount of clay, suspended in one litre of water. In order to calculate the dry weight the following information is needed:

- The relative density of clay. It is set at 2.65 (average value).
- The slop weight of 1000 ml (1itre) terra sigillata (see section 10.2.1 *Determining density*).

The following formula (Brongniart's formula) will result in the dry weight content:

$$\frac{\text{relative density}}{\text{relative density} - 1} \times \text{slop weight} - 1000 = \text{dry weight content}$$

Suppose we have 1200 ml of terra sigillata having a slop weight of 1140 g per 1000 ml. The dry weight is calculated as follows:

$$\frac{2.65}{2.65 - 1} \times (1140 - 1000) = 225 \text{ g}$$

So 1000 ml of terra sigillata with a slop weight of 1140 g contains 225 g of clay. If 6% pigment is to be added, 6% is calculated over 225 g = 13.5 g of pigment is added to 1000 ml terra sigillata. We have a total amount of 1200 ml of terra sigillata, so 225 should be multiplied by 1.2 = 16.2 g of pigment has to be added to 1200 ml of terra sigillata.

10.3.2 Counteracting settling

Because the suspension capacity of pigments and most oxides is so little, they will quickly settle to the bottom. As has been pointed out, the addition of a suspending agent or vinegar (see section *8.8.1 Glaze additives*) will counteract settling. The amount to be added is very small and varies depending on the density of the terra sigillata. A high density calls for smaller additions. **NB:** Adding too much of a suspension agent will yield a terra sigillata that becomes too viscous and cannot be applied evenly. So, adding a little at a time and thoroughly mixing in between each addition will prevent this. Using vinegar has one disadvantage: the terra sigillata will become mouldy after a while. This will not counteract its abilities, but it will have to be sieved each time before applying.

10.3.3 Sulphate and chloride colorants

Compounds of metals like cobalt and iron as sulphate or chloride, often referred to as sulphates and chlorides, can be implemented with good results to achieve colours. These are soluble crystalline materials that preferably are not added to a prepared terra sigillata mixture because they could disturb deflocculation. The best results are obtained by dissolving the sulphates or chlorides in water and applying them on to an already-fired terra sigillata. As a starting point, a 100% solution could be used where the sulphates or chlorides are added to hot water and mixed until the crystals do not dissolve any more. This solution can be diluted by adding water in order to obtain a variation in colour saturation. The dissolved sulphates and chlorides are applied to a piece coated with a terra sigillata that is still reasonably porous, see section *10.5 Firing temperatures*. Brushing, pouring or dipping are possible ways of applying. Due to the fact that the sulphates and chlorides are dissolved they will be soaked into the piece. The shape of the work, differences in porosity and speed of drying all determine how the sulphates and chlorides will be soaked into the piece and, during drying, will migrate to the surface, hence the outcome tends to be rather unpredictable. The most clear colours are obtained if a white terra sigillata background is used (terra sigillata made from an HTR-clay, kaolin or porcelain). Interesting and fairly bright colour shades can be obtained at 1120°C (2048°F), see *Figure 10.3*.[11]

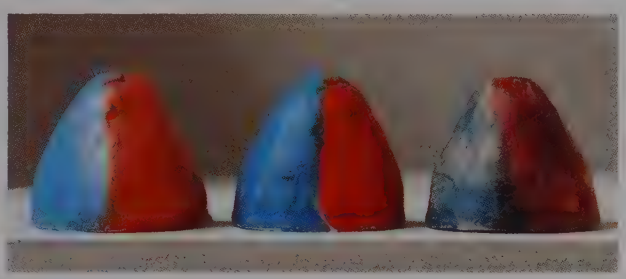


Figure 10.3
Cobalt and iron sulphates were applied on a fired HTR terra sigillata. The left test piece was fired to 1060°C (1940°F), the middle one to 1120°C (2048°F), the right one was fired to 1220°C (2228°F).
(Photo: Anton Reijnders)

NB: Colouring sulphates and chlorides are poisonous. Latex gloves should be used while applying. Do not use on functional ware.



Wim Borst (The Netherlands), *E 7-9 Regulation*, 1998. Ht: 33 cm (13 in.). A white-burning fine-grained sculpture body containing Molochite and flax fibres was used for this piece. The slab-building technique was used to make the form. Before joining, the slabs were left to dry to the leatherhard stage. After being biscuit fired and sanded a terra sigillata was applied by brush. A highly shiny terra sigillata made from terracotta clay with white terra sigillata brush marks made from an HTR-clay on top. Fired to 1120°C (2048°F).
(Photo: Peer van der Kruis)

10.4 Applying terra sigillata

A terra sigillata mixture is ready for use immediately after separating, or when sufficient maturation is achieved and, if applicable, after pigments or colouring oxides have been added. It is always advisable to stir well if the mixture has been left to stand for some time as settling may have occurred. As pointed out, the gloss will show better if the terra sigillata is applied on a piece made from a clay body with a fine structure and a smooth surface and is best applied to a completely **dried and unfired piece**.

Terra sigillata can also be used on a **biscuit fired piece** though it is preferable to use bisque that is not too porous; otherwise it will be difficult to apply an even coat; slightly moistening the piece first could help.

It is difficult to apply a terra sigillata to a surface that is vitrified; the terra sigillata mixture will run straight off although preheating the piece will prevent this. A new layer of terra sigillata can be applied to an already-fired terra sigillata.

10.4.1 Optimal layer thickness

The optimal layer thickness is of importance: terra sigillata should neither be applied too thin (no satisfying finish will be achieved) nor too thick (increased chance of shelling). The density of the terra sigillata mixture in combination with the amount of layers will determine the total thickness of the applied terra sigillata layer. As has been pointed out, density is first of all determined by the sedimentation time, but over time density will change as well; water will gradually vapourise even if the terra sigillata has been stored in a closed plastic bucket. The slop weight of a terra sigillata without stains should range between 1100 and 1140 per 1000 ml, and between 1112 and 1157 if a maximum addition of 30% of pigments or colouring oxides has been added. See section *10.2.1 Determining density* for how to adjust density.

Applying by brush

Terra sigillata is best applied with a soft brush. A slop weight of 1130–1140 per 1000 ml (1145–1157 including max. amount of stains) and the application of three coats, all 'weaving' over one another in a slightly random way, gives good results and will prevent too thick or too thin a layer. A slop weight of 1110 (1120 with max. amount of stains) will require more coats: probably up to five or six. Applying on a piece which has a relief surface will be more demanding. The layer tends to be too thin on the high parts and too thick in the cavities. This becomes visually more pronounced if the colour of the terra sigillata differs from the piece itself (another clay colour or due to added pigments or colouring oxides). In order to apply an even coat on such a surface, the brush should be reasonably saturated (but too much will easily result in the terra sigillata running), short strokes without much pressure will yield the best results. If a more opaque result is aimed for a short sedimentation time during preparation should be implemented and the slop weight should be between 1130 and 1140 (1145–1157: including max. amount of stains).

NB: Terra sigillata with a density between 1100 and 1140 has a very low viscosity (except if a suspension agent is added). Therefore it may give the misleading impression that too thin a coat has been applied; stick to the maximum amount of layers as indicated.

Applying by spraying

Terra sigillata can also be sprayed by using a spray gun. Again, too thick a coat should be avoided. Slop weight should be not higher than 1130 (1145 with max. amount of stains), the number of layers should not exceed three. Up to four or five layers can be applied in the case of a slop weight of 1100 (1112 including max. amount of stains).

10.5 Firing temperatures

The temperature at which terra sigillata is fired clearly influences the colour, gloss and whether the surface will be vulnerable or not. If used for functional work the firing temperature should be high enough so vitrification of both body and terra sigillata takes place. No melting is involved, as with a glaze, and this is very advantageous as the piece will not stick to the kiln shelf or support. Therefore the piece can be easily supported during firing if distortion is likely. Silver sand (fine silica sand) can be used for supporting a piece with a non-flat base. Some indications of possible results at different firing temperatures are provided that could be used as a guideline. **NB:** These indications are based on a terra sigillata with an optimal water:clay:deflocculant ratio, (see Chapter 15). Testing is necessary as each clay will react differently to temperature.

10.5.1 T-MTR-clay

Terra sigillata made of a T-MTR clay could show orange to brick red colours between **900°C and 1120°C** (1652°F–2048°F). At the lower end of this temperature range the surface is vulnerable. At the higher end the colours tend to be darker, less vulnerable and not easily stained.

10.5.2 MTR-clay

An MTR-clay terra sigillata can be fired between 900°C and 1220°C (1652°F–2228°F). Due to the fact that these clays generally contain a larger amount of iron and titanium oxide MTR-clay will yield a more off-white or buff colour between **900°C and 1100°C** (1652°F–2012°F). With a prolonged settling time (more than five hours) and maturation time (more than a week) the terra sigillata will be slightly less opaque. Compared to an HTR-clay, more saturated but less clear colours will be yielded if pigments or oxides are added, the surface will also be less vulnerable and less easily stained. At between **1120°C and 1180°C** (2048°F–2156°F) opaqueness will reduce considerably and the colour will become more buff. Colours obtained from pigments and colouring oxides become darker (see *Figure 10.4*), the surface is quite strong and not easily stained. Between **1200°C and 1220°C** (2192°F–2228°F) transparent results will be achieved, especially if a maturation time of more than a week has been implemented. Applied to a piece made out of a white-firing clay body a quality that resembles wet

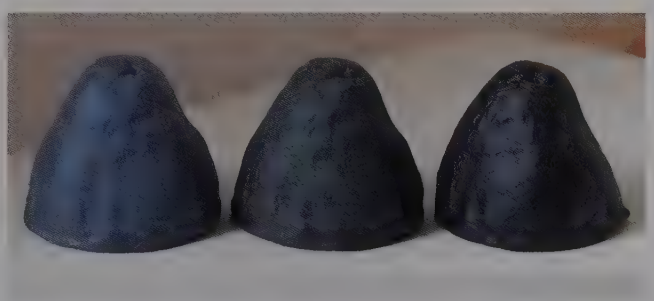


Figure 10.4
MTR-clay with an addition of 30% black ceramic pigments fired to 1060°C (1940°F), 1140°C (2084°F) and 1220°C (2228°F), showing clearly the effect of temperature.
(Photo: Anton Reijnders)

unfired clay results. Pigments and oxides show darker colours and the surface is dense and cannot be stained.

10.5.3 HTR-clay

An HTR-clay terra sigillata can be fired between 900°C and 1260°C (1652°F–2300°F). According to its purity (low amount of iron and titanium oxide content) an HTR-clay will give a fairly white colour between **900°C and 1100°C** (1652°F–2012°F). Given a prolonged sedimentation time (more than five hours) and maturation time (more than a week) the terra sigillata will be slightly less opaque. If pigments or oxides are added pastel colours will result. The surface is vulnerable and easily stained within this temperature range. At between **1120°C and 1180°C** (2048°F–2156°F) opaqueness will reduce slightly and the colour will be less white. Colours obtained from pigments and colouring oxides become more saturated, the surface is less vulnerable and not easily stained. Between **1200°C and 1280°C** (2192°F–2336°F) fairly transparent results can be achieved, especially if a sedimentation time of 24 hours and a maturation time of more than a week has been implemented. When applied to a piece made from a buff-firing clay body, a quality that resembles wet unfired clay results. Pigments and oxides show darker colours and the surface is dense and cannot be stained.

10.5.4 Kaolin and porcelain clay body

A terra sigillata made of kaolin[12] will remain fairly white and opaque up to 1180°C (2156°F). From 1200°C (2192°F) onwards opaqueness and whiteness decrease somewhat. Temperatures up to 1300°C (2372°F) could be tried.

Using a soft paste commercial porcelain casting clay powder (vitrification point 1220°C–1260°C/2228°F–2300°F) to make a terra sigillata can lead to interesting results. If such a terra sigillata is applied to a piece made of the same clay body, a finish at a lower temperature can be achieved that resembles high vitrification, without the deformation that usually accompanies a high temperature. Adding 25% **talc** will increase the gloss slightly and provides a marble-like quality to the surface. Talc is added in the same way as pigments or colouring oxides, only no glaze suspension agent is needed. It is also possible to apply a very thin layer of pure talc onto a dried piece and burnish the surface. This will lead to a satin gloss between 1200°C and 1260°C (2192°F–2300°F).

10.6 Terra sigillata recipes

Some recipes are provided in *Tables 10.2–10.5* that could be used as a starting point for further research. As has been pointed out the water:clay:deflocculant ratio will differ with each clay, therefore no indications about water and deflocculant ratios are provided.

Table 10.2

Black terra sigillata

(1100°C–1140°C/2012°F–2084°F)

T-MTR-clay

Black pigments (Cr–Co–Fe–Ni type)[1]	+ 12%	By varying the amount of cobalt oxide the tone will shift from brown black to black. More gloss will be obtained at higher temperatures due to sintering.
Cobalt oxide	+ 3–8%	

Note:

[1] Add after the terra sigillata has been prepared and add a suspension agent to counteract sedimentation.

Table 10.3

Black terra sigillata

(1120°–1220°C/2048°–2228°F)

MTR-clay

Black pigments (Cr–Co–Fe–Ni Type)[1]	+ 20–30%	Black will be less dark at the indicated minimum

Note:

[1] Add iafter the terra sigillata has been prepared and add a suspension agent to counteract sedimentation.

Table 10.4

Coloured terra sigillata

(1000°C–1220°C/1832°F–2228°F)

MTR/HTR-clay

Ceramic pigments or oxides[1]	+15–30%	To a great extent the result is determined by the choice of clay and the top temperature: more pastel shades are obtained between 1000°C and 1150°C (1832°F–2012°F), more saturated colours between 1150°C and 1180°C (2012°F–2156°F), darker shades will be achieved between 1180°C and 1220°C (2156°F–2228°F).

Note:

[1] Add after the terra sigillata has been prepared and add a suspension agent to counteract sedimentation.

Table 10.5

Porcelain/Talc terra sigillata

(1180°C–1280°C/2156°F–2336°F)

Porcelain casting clay powder

Talc[1]	+25%	Use an iron-free talc to obtain the best results. No suspension agents need to be added because talc has fairly good floating properties

Note:

[1] Add after the terra sigillata has been prepared.

Notes:

1 If a waterproof result is aimed for, the body has to be fired high enough to become waterproof.

2 Opacity is linked to the fact that the less-fine clay minerals tend to be more refractory.

3 In general, other types of deflocculant will take more time; sodium silicate requires twice as much time.

4 A comparable process happens in nature during weathering, but over the course of thousands of years.

5 A loss of gloss may occur if a less well prepared terra sigillata has been applied to a piece at the leatherhard stage and subsequently burnished.

6 A loss of gloss may occur when a less well prepared terra sigillata has been burnished.

7 Sodium silicate needs settling for 6–24 hours.

8 This figure is linked to the Brongniart's formula, see section *10.3.1 Determining the dry weight.*

9 Adding clay to an already-prepared terra sigillata will call for sedimentation and syphoning off once more.

10 An exception to this rule is a terra sigillata made out of soft paste porcelain fired to full vitrification: the effect of prolonged maturation becomes less noticeable because the effect of fusion will dominate.

11 For more on this subject see Elieson, Tulla in *Articles* in Appendix 2 under *Consulted Writings*.

12 Grolleg kaolin gives very good results.


THEY APPEARED FOR NEARLY AN HOUR ONE EVENING STREAMING ACROSS THE PLAINS — STRAGGLERS OF VARIOUS CRUSADES, NAZIS, ROYAL PROCESSIONS, TROOPS OF NAPOLEON, EARLY COLONISTS HEADING TOWARD AMERICA

11 Firing glazes



Aspects related to firing that will determine the outcome of the glaze or (sinter) engobe will be discussed in this chapter, as well as some examples of firing cycles. Besides glaze firing (the firing that follows the biscuit firing), once-firing (a firing that combines biscuit and glaze firing) will also be addressed briefly. Reduction firing and saggar firing, specific ways of firing intended to achieve a colour change in body or glaze, will be discussed as well. Also possible faults that could become visible after the firing will be dealt with, including suggested ways to overcome these faults. The term 'glaze' as used in this chapter, refers to all types of glazes, engobes and sintering engobes, except when stated otherwise.

11.1 Loading a glaze kiln

The way a kiln has been packed can have an impact on the final quality of the glaze. Some general remarks:

- An even temperature distribution within the kiln as well as within the piece is of importance (see also section *7.3 Biscuit firing)*.
- One has to be aware that combining the firing of glazes and biscuit in one kiln could influence the quality of a glaze. This is more likely with low temperature glazes (particularly shiny copper-saturated glazes which can turn matt, and cadmium selenium glazes which can become muddy), engobes and sinter engobes are less prone to this.
- The glazed surfaces of a piece should not touch other pieces or the kiln shelf as they will stick together.
- Some glazes, especially copper and chrome glazes, tend to influence the colour of neighbouring pieces due to volatilisation.

11.1.1 Protecting kiln shelves

Through daily use kiln shelves can get contaminated with traces of glaze, and some glazes (particularly low-temperature glazes with a lot of copper oxide) actually penetrate deep into the kiln shelves. Glaze remains may contaminate work during future firings, or in the worst cases, parts of the work may come off because the work has melted onto the kiln shelf. A piece can also crack due to the high tension that occurs during cooling as a result of the difference in shrinkage between the kiln shelf and the fired work stuck to it.

Brushing the kiln shelves with **'bat wash'** or 'kiln wash', (a protective coating), will prevent this from happening. This kiln wash should be very refractory and preferably

OPPOSITE:
Anne Kraus (USA), *They Appeared Streaming Across the Plains*, 1991. Dia: 36 cm (14 in.). Underglaze painting with a transparent shiny lead glaze on top. A coarse-grained sculpture body was used to make this piece, resulting in a slightly bumpy surface.
(Photo: Peer van der Kruis)

Table 11.1

Bat wash recipe

750 g	Aluminium oxide	Aluminium oxide can be replaced by aluminium hydrate; a less expensive material. The ratio should be altered: 8:2 Aluminium hydrate:kaolin.
250 g	Kaolin	
5 g	Optapix KG 25	Or an alternative SCMC gum. See section *8.8.1 Glaze additives.*

Note:
Add just enough water to achieve a sprayable consistency.

contain no quartz, as quartz is a glass-former and it will fuse more quickly with a glaze. *Table 11.1* gives a recipe that can be used with good results. This bat wash is preferably sprayed onto the kiln shelves to achieve an even coating with just enough water being added to make the mixture sufficiently fluid for spraying. Coating thickness should be approximately 1 mm (the thickness of the coating when dry). After coating and drying the kiln shelves should be fired to 1200°C–1220°C (2192°F–2228°F). **Drops of glaze** that fall onto the bat wash can be removed after the firing using a pallet knife or a small chisel and hammer. Pits that occurred in the kiln wash or, worse, in the kiln shelf after removing the glaze, can be filled with the bat wash mixture using a brush, and sanded down after drying (for instance with a piece of kiln shelf). Repeating this several times may be necessary if the pits are deep. Extra protection of the kiln shelf is needed in the case of **runny glazes** (see section *9.1.4 Flowing* for more information on runny glazes). A combination of a specially made clay slab or an old kiln shelf, with, for instance, saddles onto which the piece is positioned, is recommended. In the case of extremely runny glazes the piece is positioned on bits of insulation bricks and specially made clay trays are placed in such a way that the running glaze is collected.

11.1.2 Supporting a glazed piece

Supporting a glazed piece in order to prevent distortion needs extra attention as glaze and support will stick to each other due to fusion of the glaze. To limit any ensuing damage the contact surface should be kept as small as possible. **Stilts, spurs** and **saddles** may be used to support leaning forms, see *Figure 11.1*. These supports are also used in the case of all-over glazed earthenware pieces to prevent the piece from melting onto the kiln shelf. **NB:** Stoneware and porcelain pieces are better not glazed at the base as these pieces tend to deform due to vitrification when placed on stilts, spurs and saddles. In general it is preferrable for glazed pieces that will be once-fired (especially large and heavy pieces), to leave the place of contact unglazed even if the piece will be fired only within the low temperature range. An unfired body is very soft and supporting aids will penetrate deeply, leaving a large mark when removed after firing.

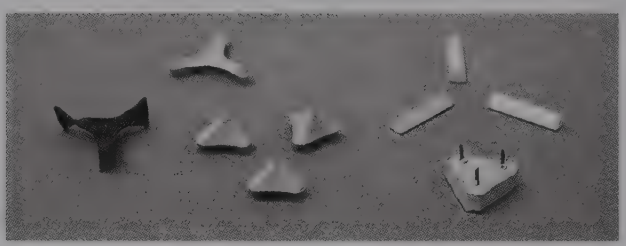


Figure 11.1
Aids for supporting the work during glaze firing.
(Photo: Anton Reijnders)

11.2 Glaze firing

A glaze firing follows the biscuit firing. Compared to once-firing, a piece can be handled more easily during glazing, and a biscuit firing reduces the chances of glaze faults occurring. What is the best way to fire a glazed piece? Regular studio practice is to follow a more or less straight ramp towards the top temperature, implementing soaking and letting the kiln cool naturally and this can lead to satisfying results. As the size and complexity of the piece increases, however, a more controlled firing and cooling is necessary and in the case of semi-matt glazes the way of cooling will have to be taken into account as well.



Viola Frey (USA), *Western Civilization Series*, 1993. Ht: 146 cm (57 in.). Hollow-built figures made from a clay body with a coarse grain size fraction. The figures were made as one piece, cut into sections at the leatherhard stage and reassembled after firing. A base glaze with different additions of pigments was painted on top. Collection: Museum voor Hedendaagse Kunst, 's-Hertogenbosch, The Netherlands (Photo: Peer van der Kruis)

11.2.1 What determines the outcome of the glaze firing?

The tension build-up in the piece, the difference in tension between glaze and body, and the firing and cooling speed are the dominant factors that will determine the outcome of a glaze firing. Factors like the shape of the piece and vitrification of the body, as described in section *7.3.1 What determines the outcome of a biscuit firing?*, are applicable to the glaze firing as well. The way of firing can give rise to the occurrence of glaze defects: this is discussed only briefly in this section and more thoroughly in section *11.5 Analysing faults apparent after the glaze firing*.

Biscuit firing

To what extent the conversion of quartz into cristobalite or the fusion of quartz and cristobalite occurred during biscuit firing will determine any possible tension build-up during glaze firing. On top of that, a piece that has been exposed to a lot of stress during biscuit firing and/or cooling but survived without cracking, could still crack during the glaze firing as a result of the accumulation of tension built-up within the piece. The extent of vitrification during biscuit firing can determine to what extent the glaze will be subjected to crazing, shivering or shelling.

Any components in the body that are not fully oxidised during biscuit firing will increase the risk of the formation of gases during glaze firing. These gases are trapped (increasingly so in the case of a body vitrified at low temperatures (from 850°C/1562°F) and will be released during the fusion of the glaze and could cause blistering, pin-holing or orange peel, especially in the case of white glazes with a high surface tension.

Unequal temperature distribution in the kiln

An unequal temperature distribution within the kiln during the last stage (150°C–200°C/300°F–400°F before the top temperature has been reached) will cause differences in fusion. Some temperature deviation will be inevitable; a difference of 10°C (50°F) throughout the kiln is considered to be acceptable. Often larger deviations occur, related either to the way of packing the kiln (see section 7.2 *Loading a kiln for biscuit firing*) or to the speed of firing, as fast firing increases the chance of unequal temperature distribution. Some kilns will show more deviation than others and oxidation firings tend to be more unequal than reduction firings. Soaking at the top temperature is implemented in an attempt to reduce temperature differences, but whether this will be effective depends entirely on the type of kiln and the way the kiln is packed.

Firing speed, top temperature and cooling speed

During the application of a glaze the body will absorb water. If there is little time between applying and the moment of firing and a fast rise of temperature occurs during the beginning of the firing, water will be driven out of the body with force causing an **insufficient adhesion of the glaze to the body** resulting in the occurrence of crawling. During glaze firing a **temperature lagging effect** will occur. Compared to the biscuit firing no strong exothermic and endothermic reactions occur, hence temperature fluctuation within the piece will be more moderate. The lagging of temperature is mainly caused by the poor heat conduction of the body. As the wall size increases, and the firing and cooling speed increases, the temperature lag will be more pronounced. This could become a source of tension build-up because the liquid melt that filled up the fine pores during biscuit firing will be rigid (at least up to 700°C/1292°F) making the body less resistant to stress. A reduced firing speed may be necessary to reduce firing tension around 225°C (437°F) if cristobalite is to be expected, and during quartz inversion around 575°C (1067°F).

From a certain temperature onwards the glaze and the surface of the piece start to react. The surface starts to dissolve bit by bit into the glaze and an intermediate layer is formed, often referred to as the **body-glaze layer**. Achieving a good body-glaze layer (a bond between glaze and body) is an important step. How well the body-glaze layer is formed, and at what temperature, depends on the composition of the glaze, the clay body, the firing speed and the top temperature. In general it can be stated that a moderate speed of temperature rise (no faster than 100°C/212°F per hour) will support the build-up of the body-glaze layer and at temperatures beyond 1180°C (2158°F) a substantial body layer will be formed. The rate of temperature rise will influence fusion as well. For instance, a glaze fired up to 1200°C (2192°F) in two hours will fuse less compared to a firing time of two days up to the same temperature. The rate of temperature rise during the last phase (approximately the last 150°C–200°C/300°F–400°F before the top temperature) is critical. Obviously the **top temperature** of the glaze firing is determined by the sintering and fusion range of the (sinter) engobes and glazes to be fired, but the vitrification point of the body determines the maximum firing temperature as well. If this point is exceeded, the piece itself will be more subject to distortion. Due to an increase of gases escaping from the body the chance of pin-holing and blistering of the glaze will increase considerably.

Cooling speed also determines the outcome. A very slow cooling, after the top temperature has been reached, will result in more fusion. The cooling speed between 850°C and 700°C (1562°F–1292°F) influences the extent of crystallisation of the glaze, especially semi-matt glazes; slow cooling will increase crystallisation. Natural cooling



Gusta Kullberg (The Netherlands), *Beest*, 1993. W: 275 cm (107 in.). A coiled piece glazed with a very thick layer of copper-saturated glaze. In addition to copper oxide, iron oxide was added to the glaze. Controlled cooling resulted in a shiny silvery glaze surface with blue and purple shades. (Photo: Peer van der Kruis)

in small size kilns will be fast, rendering a semi-matt glaze more shiny. The cooling speed below 700°C (1292°F) even down to 350°C (662°F) can have a clear influence on the surface quality of over-saturated copper glazes. A high gloss could turn into a matt surface if cooling is slow. Controlled fast cooling, as fast as the piece can bear, should be implemented if a high metallic gloss is aimed at, especially if fired in a gas kiln. A reduced cooling speed may be necessary to reduce firing tension due to quartz inversion around 575°C (1067°F), and if cristobalite is present around 225°C (437°F) in the case of large tiles and large rectangular and flat-shaped pieces.

Differences in contraction between glaze and body

During cooling both body and glaze will contract differently. As long as the glaze layer is in a fluid stage no tension build-up will take place, but during the last part of cooling (usually from 650°C/1202°F downwards), the glaze solidifies and it becomes more rigid. As cooling proceeds the difference in contraction between the glaze and body increases. Large differences can lead to crazing or shivering or, in extreme cases, cracking of the piece.

Variations of firing and cooling speed

Differences in speed of firing in sucessive firings may occur because the controller system works inaccurately and/or a different way of packing of the kiln is implemented. The position of the thermocouple in relation to the load is important: work or a kiln shelf placed near a pyrometer can influence temperature registration! The smaller the kiln used, and the narrower the fusion range of the glaze (often the case with low temperature glazes), the more these differences can lead to larger deviations in outcome. Also whether the damper, of an electric kiln, is left open or not during firing will be decisive.

In the case of automated firing, large differences arise if the power of the kiln is inadequate related to the load. Each time a different load is stacked the firing ramp during the last part of firing will change: heavy loads will cause a very slow temperature rise; slower than that programmed, resulting in more fusion. The same kiln fired with less or less heavy pieces, and/or less kiln shelves, will follow the programmed firing slope more easily.

The cooling speed of a kiln can vary a lot if it is allowed to cool naturally. The speed is determined by the weight of the total load (pieces plus kiln furniture) and the way it is packed (a different packing will lead to different cooling) as well as whether or not the damper is left open. As stated before, this will affect the rate of crystallisation of a semi-matt glaze, and the occurrence of cooling stress.

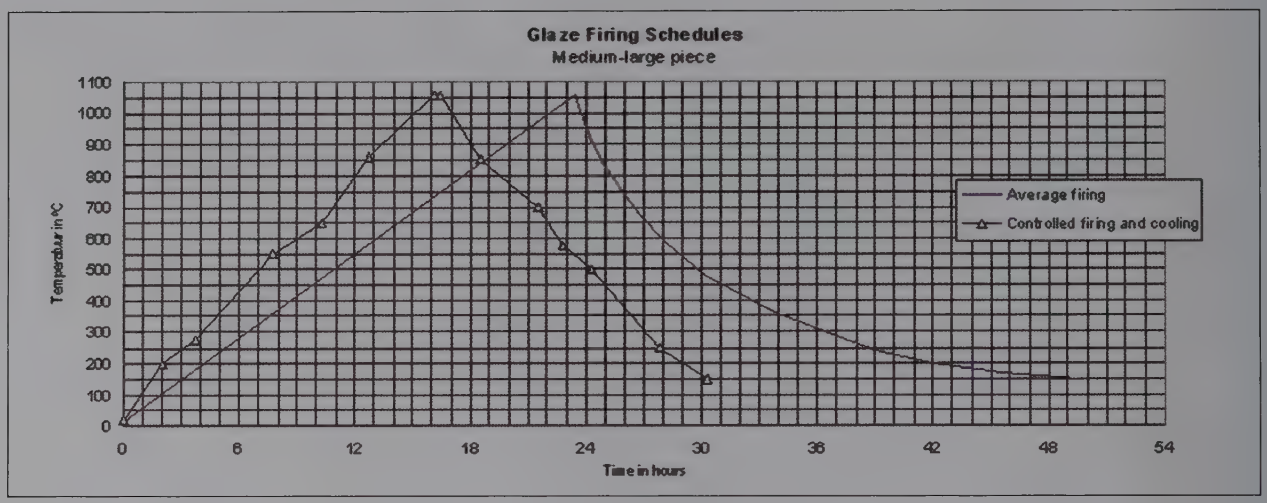


Diagram 11.1

11.2.2 Planning a glaze firing cycle

If the aspects discussed previously are taken into account several phases can be distinguished within the firing and cooling slope that require the speed of firing or cooling to slow down; other phases allow an increase of firing and cooling speed (*Table 11.2* provides an overview). *Diagram 11.1* shows a glaze firing of a medium large piece if these aspects are taken into account. *Tables 11.3* and *11.4* can be used as a starting point to compose one's own firing cycle. **NB:** These firing schedules are based on the assumption that after glazing the piece has been fully dried and no large tension build-up took place during biscuit firing. Wall thickness exceeding 3.5 cm (1⅜ in.) calls for extra slow firing and cooling.

NB: Indoor kilns should be well vented. During glaze firing all kinds of gases are released. Depending on the glaze applied, these gases can be more or less hazardous to health. It is important to ventilate a room in which firing takes place while the kiln is in operation.

11.2.3 Temperature registration

Measuring temperature during firing is usually done with a pyrometer. In the case of advanced controlling systems the pyrometer is connected to a controller and programmer. A pyrometer has some disadvantages in that it measures the temperature of the kiln's atmosphere only locally. Great differences may exist between the temperature of the atmosphere around the thermocouple and in the middle of the kiln. Moreover, over the course of time a pyrometer will show deviations to an increasing extent. On top of that, a pyrometer measures the temperature per moment. As has been pointed out, all sintering and fusion processes are determined by temperature and time. Faster firing to a certain temperature indicated on the pyrometer will lead to less fusion as compared to slow firing to or soaking at the same temperature. Slower cooling from the top temperature down to 960°C (1760°F) will increase fusion slightly. To avoid the disadvantages of a pyrometer, '**cones**' can be used as well. Cones are made of ceramic materials and during firing a cone will melt and subsequently bend. Firing speed, top temperature and soaking determine how much fusion will take place within a cone, and consequently how much the cone will bend: so the effect of temperature and time is registered. Another advantage of cones is that they can be placed on different levels and in the middle of the stack.

Table 11.2

Phases during glaze firing

Temperatures	*Reaction within the body and glaze*	*Firing and cooling speed*
20°C–200°C (70°F–400°F)	Removal of water absorbed from the glaze mixture out of the body.	Too fast firing during the first 100°C (212°F) will cause glaze defects if the piece has not been dried fully.
200°C–275°C (400°F–527°F)	Cristobalite inversion around 225°C (437°F). Due to the lagging effect this can take place at a higher temperature.	If cristobalite has been formed during the biscuit firing, the firing speed should be reduced.
275°C–550°C (527°F–1022°F)		Firing speed could be increased.
550°C–650°C (1022°F–1202°F)	Quartz inversion around 575°C (1067°F), depending on the lagging effect this can happen at higher temperatures.	This is a critical stage. Slowing down the firing speed will reduce tension and temperature lag within the piece. If a high proportion of free quartz is present in the body the firing speed should be extra slow.
650°C (1202°F) – 200°C (400°F) *below top temperature*	Sintering of the glaze and (sinter) engobe starts.	Firing speed could be increased.
200°C (400°F) *below top temperature*– top temperature.	Fusion of the glaze. The forming of the body-glaze layer takes place.	The last 200°C–150°C (500°F–300°F) before the top temperature the firing speed determines the rate of fusion to a large extent.
Soaking at top temperature.	Fusion of the glaze. The forming of the body-glaze layer continues.	Soaking could even out temperature differences in the kiln.
Top temperature–850°C (1562°F)	Due to the formation of a liquid melt, the body is somewhat flexible. Formation of gases in the glaze or body still possible and as such increase the chance of pin-holes forming. Crystallisation of matt glazes will start within this temperature range.	Fast cooling. This will also reduce the chance of pin-holes in the glaze.
850°C–700°C (1562°F–1292°F)	Crystallisation of matt glazes well under way.	In the case of satin matt glazes: no fast cooling to ensure sufficient time for crystallisation.
700°C–575°C (1292°F–1067°F)	Components that have been fused into a glassy state become rigid.	In the case of small pieces, natural cooling could be implemented. Medium-large, larger pieces, complex pieces and tiles will need controlled cooling.
575°C–500°C (1067°F–932°F)	Increased contraction takes place around 565°C (1049°F) due to inversion. This is a critical stage.	Slowing down the cooling speed will reduce temperature lag; as a result less tension within the piece will occur. This is especially important if the amount of quartz present in the body is high, and in the case of large and complex pieces and tiles.
500°C–250°C (932°F–482°F)		Cooling speed can be increased.
250°C–150°C (482°F–302°F)	If cristobalite is present in the body between 275°C and 170°C (527°F–338°F) cristobalite inversion takes place, usually around 225°C (437°F).	Slowing down the cooling speed will reduce temperature lag; as a result less tension within the piece will occur. This is especially important if the amount of cristobalite present in the body is high, and for large and complex pieces and tiles.
150°C–50°C (302°F–122°F)	A premature opening of the kiln door can cause tension in the work, especially if the body has a high expansion rate.	

Table 11.3

Glaze firing cycle of medium-sized pieces

Body: average expansion rate

Medium-sized pieces (For controllers with min. ramps.)		***Medium-sized pieces*** (For controllers with 9 ramps or more.)		***Medium-sized tiles*** (For controllers with 9 ramps or more.)	
Temperature	*Time[1] (hr:min)*	*Temperature*	*Time[1] (hr:min)*	*Temperature*	*Time[1] (hr:min)*
20°C–550°C (68°F–1022°F)	6:00	20°C–200°C (68°F–392°F)	1:30	20°C–200°C (68°F–392°F)	1:30
550°C–650°C (1022°F–1202°F)	0:45[2]	200°C–240°C (392°F–464°F)	0:40[2]	200°C–240°C (392°F–464°F)	1:00[2]
660°C (1202°F)–top temperature	60°C (140°F)/hour	240°C–550°C (464°F–1022°F)	3:00	240°C–550°C (464°F–1022°F)	4:00
Soaking	0–15 minutes	550°C–650°C (1022°F–1202°F)	0:45[2]	550°C–650°C (1022°F–1202°F)	1:30[2]
Natural cooling		650°C (1202°F)–200°C (400°F) below top temperature	100°C (212°F)/hour	650°C–200°C below top temperature	100°C (212°F)/hour
		Last 200°C (400°F) up to top temperature	60°C (140°F)/hour	Last 200°C (400°F) up to top temperature	60°C (140°F)/hour
		Soaking	0–15 minutes	Soaking	0–15 minutes
		Top temperature down to 850°C (1562°F)	200°C (400°F)/hour or faster	Top temperature down to 850°C (1562°F)	200°C (400°F)/hour or faster
		850°C–700°C (1562°F–1292°F)	3:00[3]	850°C–700°C (1562°F–1292°F)	3:00[3]
		Natural cooling		500°C (932°F)	1:45[2]
				Natural cooling	

Notes:
Open kiln preferably below 150°C (300°F).
Adjusted firing speeds:
[1] *In the case of* ***simple forms****, multiply time sections by 0.9* ***except sections indicated with darker shading****.*
[2] *If the body has a* ***high expansion rate****, multiply indicated time by 1.5: if it has a* ***low expansion rate****, multiply indicated time by 0.7.*
[3] *If only shiny glazes are to be fired multiply time by 0.5.*

Cones are produced by several manufacturers and are sold in extensive series with specific number codes. These code numbers represent different values for each manufacturer. This book refers to Orton Standard Pyrometric Large Cones (2½ in.). By using tables supplied by the manufacturer it is possible to find out for what peak temperature a certain cone is intended as each cone has a narrow temperature range of about 15°C–20°C (60°F–70°F). To cover a wider temperature range often three cones are used side by side in the same firing. The bottom part of the cone should be placed straight on to the kiln shelf to obtain the correct angle. This is important as the angle determines the rate of bending and around the cone is a thin coil of clay to provide the necessary stability, see *Figure 11.2*. A kiln provided with a spyhole allows monitoring of the bending of the cones

Table 11.4

Glaze firing cycle of medium-large to extra large pieces

Body: average expansion rate

Medium-large pieces		***Large pieces***		***Extra large pieces***	
Temperature	*Time*[1]	*Temperature*	*Time*[1]	*Temperature*	*Time*[1]
20°C–200°C (68°F–392°F)	2:00	20°C–200°C (68°F–392°F)	3:00	20°C–200°C (68°F–392°F)	4:00
200°C–250°C (392°F–482°F)	1:45[2]	200°C–265°C (392°F–509°F)	2:00[2]	200°C–280°C (392°F–536°F)	3:20[2]
250°C–550°C (482°F–1022°F)	4:00	265°C–550°C (482°F–1022°F)	4:00	280°C–550°C (482°F–1022°F)	4:00
550°C–650°C (1022°F–1202°F)	2:30[2]	550°C–650°C (1022°F–1202°F)	4:00[2]	550°C–650°C (1022°F–1202°F)	6:45[2]
650°C (1202°F)–200°C (400°F) below top temperature	100°C/212°F hour	650°C–200°C (400°F) below top temperature	100°C/212°F hour	650°C–200°C (400°F) below top temperature	100°C (212°F) hour
Last 200°C (400°F) up to top temperature	60°C (140°F)/ hour	Last 200°C (400°F) up to top temperature	60°C (140°F)/ hour	Last 200°C (392°F) up to top temperature	60°C (140°F)/ hour
Soaking	0–15 minutes	Soaking	0–15 minutes	Soaking	0–15 minutes
Top temperature down to 850°C (1562°F)	200°C (400°F)/ hour or faster	Top temperature down to 850°C (1562°F)	200°C (400°F)/ hour or faster	Top temperature down to 850°C (1562°F)	200°C (400°F)/ hour or faster
850°C–700°C (1562°F–1292°F)	3:00 [3]	850°C–700°C (1562°F–1292°F)	3:00[3]	850°C–700°C (1562°F–1292°F)	3:003
700°C–575°C (1292°F–1067°F)	1:15	700°C–575°C (1292°F–1067°F)	1:30	700°C–575°C (1292°F–1067°F)	2:00
575°C–500°C (1067°F–932°F)	1:30[2]	575°C–500°C (1067°F–932°F)	2:00[2]	575°C–500°C (1067°F–932°F)	3:30[2]
500°C–250°C (932°F–482°F)	3:30 Or natural cooling[4]	500°C–250°C (932°F–482°F)	6:00 Or natural cooling[4]	500°C–250°C (932°F–482°F)	10:00 Or natural cooling[4]
250°C–150°C (482°F–302°F)	2:30[2] Or natural cooling[4]	250°C–150°C (482°F–302°F)	4:00[2] Or natural cooling[4]	250°C–150°C (482°F–302°F)	6:45[2] Or natural cooling[4]
		150°C–100°C (302°F–212°F)	2:00 Or natural cooling[4]	150°C–50°C (302°F–122°F)	6:45 Or natural cooling[4]

Notes:

Adjusted firing speeds:

[1] *In the case of* ***simple forms****, multiply time in all sections by 0.9; in the case of* ***tiles and slabs****, multiply time in all sections by 1.25;* ***except sections indicated with darker shading****.*

[2] *If the body has a* ***high expansion rate****, multiply time by 1.5: if it has a* ***low expansion rate****, multiply indicated time by 0.7.*

[3] *If only shiny glazes are to be fired multiply time by 0.5.*

[4] *Natural cooling could be implemented if the cooling speed will be similar or less than that given and if temperature variations within the kiln are limited to 30°C–40°C (80°F–100°F).*

during firing. It is important to check that the cones are visible at the edge of the shelf , and aligned with the spyhole before firing commences.

NB: It is important to realise that cones are not really indicators of the final firing temperature. They simply register the effect of a specific firing on fusion; they are a

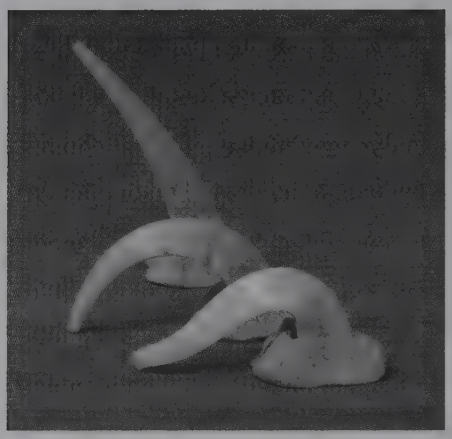


Figure 11.2
Different stages of bending of Pyrometric Large Cones. The rate of bending is used as a means of calibration: the extent of bending of a successful firing is used as a starting point for future firings.
(Photo: Anton Reijnders)

means of calibration. The extent of bending can be noted in relation to a successful outcome of a glaze and, as such, it will provide valuable information that can be used for successive firings.

Cones are indispensable if accurate results are needed, particularly in the following situations:

- A different way of packing than usual is applied.
- A different top temperature than usual is required.
- When an unfamiliar kiln is used.
- When the maximum available power of a kiln is used to reach the top temperature. Large temperature deviations can occur if the weight of the load changes (kiln furniture included). Only by using a cone can these deviations be registered.

NB: A new batch of cones can show variations. Before an old batch of cones is finished a new batch should be tested by firing an old and new cone simultaneously.

11.3 Once-firing

Once-firing has some great advantages. It shortens the ceramic process and it saves energy costs. Less tension is created within a once-fired piece due to the fact that the piece will be less often subjected to the quartz and cristobalite inversions and generally the intermediate layer between glaze and body develops better. But there are also some disadvantages. Glazing an unfired piece demands more attention because of its fragility, and the possibility of crawling and pin-holing also increases because all the gases generated in the body have to escape through the glaze layer.

11.3.1 Planning a once-firing cycle

The firing schedules provided in *Tables 7.2* and *7.3* up to 850°C (1562°F) and the firing schedules in *Tables 11.3* and *11.4* from 850°C onwards, including the cooling, could be implemented. If necessary a slower firing between 650°C and 850°C (1202°F–1562°F) and soaking at 850°C could be carried out to reduce the formation of pin-holing caused by the escape of gases from the body.

11.4 Reduction firing

Reduction is an atmospheric condition in the kiln characterised by a shortage of oxygen. Reduction firing is used to achieve a colour change in the body and glaze. It is linked to the use of solid fuel and occurs when there is not sufficient oxygen present to combust the fuel. The main element found in fuels like wood, oil and gas, is carbon. During combustion carbon combines with oxygen and is converted into carbon dioxide gas, provided sufficient oxygen is present in the atmosphere of the kiln. This gas escapes through the chimney. There are three kinds of atmospheres possible in a kiln during firing: oxidation (meaning a surplus of oxygen); neutral (exactly enough oxygen), and reduction (too little oxygen present to combust the fuel optimally). If full combustion does not take place an unstable **highly toxic carbon monoxide** gas is formed. Unstable means that the carbon monoxide is, as it were, constantly searching for oxygen to form a more stable **carbon**



Byron Temple (USA), untitled, 1994. Ht: max. 17 cm (6¾ in.). Porcelain pieces thrown on a wheel. The bottoms of the pots were altered using a cutting wire. They were partly glazed with a transparent shiny glaze. The faint bluish colour was caused by the reduction of iron oxide in the porcelain body. Due to variations in reduction throughout the kiln, the piece in front is cream-coloured in places.
(Photo: Peer van der Kruis)

dioxide gas. As a result all compounds present in a body or glaze that easily give up some of their oxygen will enter into a reduced state: their chemical composition is altered. This change in chemical composition can result in a change of colour of some colouring oxides.

A deficit of oxygen can be obtained by inserting a surplus of fuel (more than can be combusted by the available oxygen); by decreasing the draught by partly closing the damper, bungs or chimney in a conventional gas kiln (resulting in less air being brought into the kiln and as such a deficit of oxygen) or even an absence in draught as is the case with saggar firing, (see section *11.4.3 Saggar firing*); or by reducing the amount of air entering the kiln through the burner port(s) or burners.

11.4.1 Change of colour

The main colouring oxides that are subjected to a colour change during reduction are iron oxide and copper oxide. Other colouring oxides are not stable in their reduced form and they will easily re-oxidise (nickel oxide, cobalt oxide and manganese oxide). Several of the ceramic pigments will lose their colour or will show colour shifts in reduction (see section *8.3.5 Ceramic stains*). In practice, iron and copper oxide are the most important colorants where reduction is concerned.

Change of colour in the body

Iron oxide is the main oxide responsible for a colour change in a body during reduction. The amount of calcium oxide, magnesium oxide and especially titanium oxide present in the clay used to compose the clay body will have an effect on the colour change that takes place with the iron oxide. As has been pointed out, iron oxide is always present in clay as a natural component or can be added to a clay body. As a general indication of colour in a body with a low titanium oxide content (1%–1.5%): the presence of a small amount of iron oxide (less than 2%) can yield a grey or buff (low titanium oxide content); up to 3.5% can give a brown or orange (low titanium oxide content); and 5%–6% can give a metallic dark aubergine brown up to a rusty aubergine brown. Very small amounts of iron oxide, as in porcelain, can lead to a bluish tone, provided the titanium oxide content is extremely low (0.1%) though as the titanium oxide content increases the blue will shift more towards grey.

The change of colour is best maintained when reduction is continued until the clay body starts to vitrify and the reduced iron oxide will then be captured by fusion. The coloration all through the body, called **body reduction**, will only be possible if the body is porous enough. If reduction starts as vitrification is progressing only the surface



Marien Schouten (The Netherlands), *Vase*, 2003. Ht: 39 cm (15¾ in.). A press-moulded piece using a fine-grained sculpture body. An extremely thick layer of a Longquan type of celadon and a copper red glaze was applied on the surface. The glaze was heavily reduced from 1000°C (1832°F), causing the red colour to disappear in places. Barium carbonate in the recipe resulted in a dark red colour. (Photo: Marien Schouten)

will change in colour. A vitrified stoneware body will be very difficult to reduce, and a fully vitrified porcelain body, even more so.

Re-oxidation occurs on the surface of a piece, hence another change of colour could take place. Re-oxidation occurs at high temperatures when, after reduction, oxygen re-enters the atmosphere. It can happen either during the firing or during the cooling phase. Re-oxidation can be implemented deliberately, it also can happen unintentionally; oxygen enters the kiln easily through chinks and starts reacting with the reduced iron oxide. A change of colour will be more likely to occur if the surface is a little rough, allowing the oxygen to get a better grip on the iron oxide. Re-oxidation produces warmer colours compared with full oxidation. In general, porcelain does not re-oxidise due to its high vitrification, which fuses the reduced iron oxide into the clay body. If a patchy change in colour takes place it is most likely related to an uneven reduction atmosphere in the kiln or with a porcelain piece, to traces of glaze or salt that ended up on the surface.

Re-oxidation can be avoided if cooling takes place in a reduction atmosphere, in principle down to at least 950°C (1742°F). Also a very rapid cooling down to 950°C could prevent re-oxidation, because the iron oxide is not allowed sufficient time to re-oxidise.

Change of colour in the glaze

In this chapter, Cone 9 reduction firing (1260°C–1280°C/2300°F–2336°F firing speed: 100°C/212°F per hour) is central. A variety of colour changes in iron- and copper-containing glazes can be achieved during reduction. There are many factors that will influence the final colour: the amount of iron or copper oxide; the purity of these ingredients; the composition of the glaze and the body underneath; the moment reduction starts; the duration and intensity of the reduction; the top temperature; and the way of cooling.

Copper oxide is added to a glaze or (sinter) engobe in the form of black copper oxide (CuO) or copper carbonate ($CuCo_3$). **Iron oxide** can be added through a variety of ingredients like red iron oxide (Fe_2O_3), black iron oxide (FeO) or ochre ($2Fe_2O_3.3H_2O$–Fe_2O_3). The addition of T-MTR-clay and even the small amounts present in a white burning clay or traces in other ingredients can also lead to colour changes in a glaze.

As soon as a glaze enters fusion the colour of the body underneath will be sealed off, largely preventing any further reduction or re-oxidation of the body. If reduction started at that stage the body will look oxidised under glazed areas and a colour change might only become visible on the unglazed parts of the piece.

11.4.2 The amount and moment of reduction

The amount of reduction needed to attain the best results is a subject of discussion. Some ceramicists continue heavy reduction from 850°C (1562°F) up to the top temperature. It is questioned whether this is effective, as after colour change caused by reduction has taken place in the body or glaze, and the body becomes vitrified or the glaze is starting to melt, continuation of heavy reduction is probably not very effective

because the oxides are taken into a glassy state. Apart from whether a heavy reduction is effective in obtaining the desired aesthetic effects, continued heavy reduction requires an unnecessarily excessive amount of fuel and will cause extra air pollution. Extremely heavy reduction at an early stage (below 900°C/1652°F) can lead to captured carbon, visible as black lines in the glaze so the moment to start the reduction is of great importance and is mainly determined by the temperature at which the glaze starts to fuse and the body starts to vitrify. Small changes in composition can affect the outcome. In general, starting reduction between 900C and 950°C (1652°F and 1742°F) will yield good results. As soon as the reduction starts oxidation should be avoided as it can tend to affect the coloration, this is especially important up to 1100°C (2012°F). The glazes as discussed in *High temperature glazes for reduction* under section *8.4.2 Glaze recipes* have been fired according to the schedule provided in *Table 11.5* in a fibre blanket-insulated kiln equipped with a high-velocity burner system.

Table 11.5

Reduction schedule

Temperature	*Slope average*	*Reduction*
930°C–1000°C (1706°F–1532°F) (Cone 09–06)	60°C (140°F)/ hour (duration 1:10)	Medium to heavy reduction
1000°C–1100°C (1832°F–2012°F) (Cone 06–03)	100°C (212°F)/ hour (duration 1:00)	Medium reduction
1100°C–1270°C (2012°F–2318°F) (Cone 03–9)	100°C (212°F)/ hour (duration: 2:50)	Medium to light reduction
1270°C–950°C (2318°F–1742°F)	600°C (1112°F)/ hour (duration 0:50)	Forced cooling*

*Note: * A slower cooling can be implemented if other than copper red glazes are fired.*

Measuring reduction

Measuring the amount of reduction by detecting the amount of carbon dioxide, carbon monoxide and oxygen can require costly special equipment. In practice, this information is usually gained by the observation of the flame that runs through the chimney, peepholes or at the vent (in the case of an updraught kiln or a gas kiln equipped with high-velocity burners). This requires experience and will be different from kiln to kiln. Observing the force of the flame (length and width) will yield valuable information: a long and wide flame shows a heavy reduction; a flame disappearing from time to time indicates a neutral to a slight reduction atmosphere.

NB: The flame will only be shown if the combusted air leaving the chimney, peepholes or vent is hot enough. Only then will the carbon monoxide present in the combusted air start to catch fire as soon as it comes into contact with oxygen outside the kiln. The moment the flame becomes visible is very much determined by the kiln system and the type of kiln insulation used. Even the way of packing can influence the moment the flame will be visible (a piece close to the vent, for instance). The colour of the flame could give some clue but the colour is influenced by the kiln system (fire bricks, insulation bricks or fibre blanket, natural draught, wood, oil or gas fuelled, a forced air burner or high-velocity burner system); the temperature of the kiln atmosphere during reduction; the presence of copper oxide (in the glazes but also collected in the kiln walls or furniture due to captured copper oxide fumes of previous firings); and the influence of ambient light (i.e. a flame will seem brighter at night).

NB: The kiln room should be well ventilated as during reduction very toxic carbon monoxide gas (no smell and colourless) will end up in the kiln space.

11.4.3 Saggar firing

To achieve a black or mottled finish, partly independent of the colour of the body, a saggar firing can be implemented. The black shading is caused by the lodging of carbon in the ultra-fine pores at the surface of a piece. Carbon is stable up to approximately



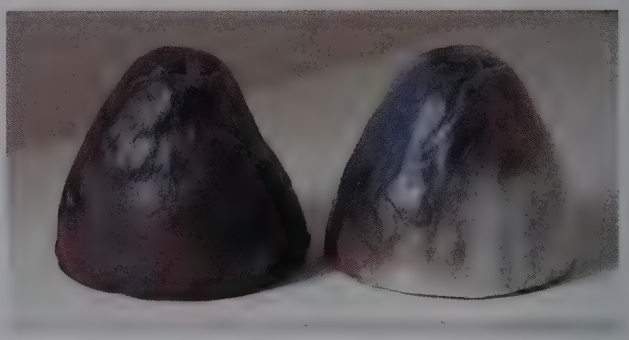


Figure 11.3
Terra sigillata and saggar firing. Left – a terra sigillata made of a T-MTR clay; right – made of an HTR-clay. Due to oxygen entering the saggar, the colour of the body underneath is visible.
(Photo: Anton Reijnders)

600°C (1112°F). At higher temperatures, provided sufficient oxygen is present, it will ignite and be transformed into carbon dioxide gas. Saggar firing makes use of the fact that carbon remains stable in an environment that lacks oxygen. A deficit of oxygen is created by putting a piece in a saggar (a ceramic container fitted with a lid, or a box constructed out of kiln shelves) and filling the space between the piece and the saggar with a combustible material.[1] To prevent oxygen entering the saggar, the seams between the box and lid or the seams between the kiln shelves are sealed with clay. Using chunks of charcoal as combustible material works very well; it creates less smoke or smell compared with, for instance, sawdust. The piece should preferably be unfired.

Above:
Steve Heinemann (Canada), untitled, 1992. Ceramics and steel. L: 77 cm (30 in.). Two sections, made of a white and of a mixture of white and terracotta sculpture clay, were press-moulded into the metal form. The clay parts were fired positioned in the metal form. The piece was smoke-fired by placing it in a saggar made of kiln shelves and filled with sawdust.
Collection: Museum voor Hedendaagse Kunst, 's-Hertogenbosch, The Netherlands
(Photo: Peer van der Kruis)



Right:
Jan van den Dobbelsteen (The Netherlands), *Bridge*, 1996. Installation overview. Ceramics, video and sound recordings. Extruded coarse-grained terracotta sculpture clay, partly altered. A base glaze containing ceramic colouring pigments was applied at the dry stage.
(Photo: Peer van der Kruis)

Low-fired biscuit pieces could be used as well provided sufficient open pores are present that will allow the lodging of carbon. As the temperature rises the risk of oxygen entering the saggar increases. By limiting the top temperature (use 1060°C /1940°F as a starting point) and/or carrying out fast firing and cooling beyond 600°C (1112°F), the chance of oxygen entering is reduced. If oxygen does enter, the charcoal will burn away. A part burning away will result in different shades of grey brown and black and in places the original colour of the body might become visible. If the charcoal burns away totally, hardly any or no traces of carbon will remain visible.
NB: Combining terra sigillata and saggar firing yields interesting results provided once-firing is implemented, see *Figure 10.3*. Provide good ventilation of the space the kiln is located in as toxic fumes like carbon monoxide will be formed.

11.5 Analysing faults apparent after the glaze firing

During glaze firing cracks within the piece as well as glaze faults can occur. Faults can be related to the way of firing, to the body composition, to how body and glaze interact and solely to the glaze itself. In this section the causes of a piece cracking during glaze firing will be addressed, then glaze faults will be covered. Some of these glaze 'errors' may be intentionally applied to achieve a specific effect.

11.5.1 Cracking of the piece

Cracks occurring during the glaze firing can be related to either an inadequate biscuit firing or to repeatedly re-firing a work. Every time a work is re-fired a build-up of tension takes place. If remedies discussed below are followed, but cracks still appear, it is advisable to alter the clay body, see section 2.*4.1 Sculpture bodies*. Cracking can occur during firing and/or cooling.

Firing crack

A firing crack can be distinguished by rounded edges along the crack. Possible causes: conflicting expansion within the piece during quartz inversion and/or possible cristobalite inversion.
Remedy:
• Reduce the firing speed between 550°C and 650°C (1022°F and 1202°F); and if cristobalite could be present reduce the firing speed between 175°C and 275°C (347°F and 527°F) as well.

Cooling crack

A sharp edge along the crack indicates a cooling crack.
Remedy:
• Reduce the cooling speed during the quartz and/or cristobalite inversion; between 600°C and 500°C (1112°F and 932°F) and between 275°C and 150°C (527°F and 302°F).

Hairline cracks after the work has been taken out of the kiln

Such a crack may occur immediately after the work has been taken out of the kiln or some days after the firing.
Possible causes:
• Cooling too fast during the cristobalite inversion.
• The work has been taken out of the kiln too soon.



Maarten Vanden Eynde (Belgium), *My Great-Grandmother*, 2002. Ht: 2 m (78 in.). A hollow-built sculpture using the coiling method. The ceramic figure was covered with a thick clay slip. Bentonite was added to increase drying shrinkage, intentionally promoting the development of surface cracks. Collection: International Ceramics Festival, Mino, Japan.
(Photo: Corné Bastiaansen)

- The work was stuck to the kiln shelf due to the presence of glaze between the work and the kiln shelf.
- Too much tension between glaze and clay body, see below under *Dunting or Bulging*.

Remedies:

- The kiln should be opened at a lower temperature.
- Reduce cooling speed during quartz and cristobalite inversion.
- Use clean kiln shelves. Wipe off the glaze from the bottom of the piece before it is directly put on a kiln shelf. If the glaze tends to flow, apply a thinner layer, alter the glaze recipe or lower the top temperature. If the flowing is used intentionally take precautions as discussed in section *11.1.1 Protecting kiln shelves*.

Surface cracks

A glaze applied on a dry unfired piece can cause surface cracks due to the fact that water is sucked into the surface causing this to expand. The chance of this happening increases if layers of clay are not well joined during the making and if a highly plastic clay body is used that has an open structure.

Remedies:

- The transitional phase from leatherhard/brittle to the dark stage is preferred for applying a glaze on an unfired piece, see *Ideal condition of the body for applying a glaze* under section *8.8.4 Applying glazes*.
- Take more care when joining layers of clay during making.
- Use a clay body with no more plasticity than strictly needed.

11.5.2 Faults related to divergent expansion rates

Each glaze, engobe, sinter engobe, and body will expand if heated, and contract during cooling. The differences in contraction during cooling will lead to a build-up of tension between body and glaze or (sinter) engobe layer and can be the cause of a range of different faults. Although these faults are related to differences in contraction during cooling it is common practice to explain these differences by referring to divergence in expansion rates.

In general, the expansion rate of conventional clay bodies and casting clay bodies designed for functional ware is higher compared to the expansion rate of sculpture bodies. The expansion rate of clay bodies specially designed for large and complex pieces, as described in section *2.4.1 Sculpture bodies*, is low. A method of obtaining an indication about the expansion rate of a fired body is provided in section *13.2.7 Determining the expansion rate*. The expansion rate of most common glazes is higher than that of an average body. This is especially true for low temperature range glazes. The expansion rate of middle, and high temperature glazes can be more moderate as more ingredients can be used having a low expansion rate. The expansion rate of engobes is very similar to an average body, sinter engobes tend to be about halfway between a glaze and an engobe. In general, the expansion rate of a body increases if fired at a higher temperature, up to a certain temperature, depending on the rate of fusion of quartz and cristobalite, the expansion rate will decrease.

Crazing

A higher rate of expansion of the glaze or sinter engobe compared to the fired body causes the glaze or sinter engobe to shrink more than the body. This will lead to small hairline cracks in the glaze or sinter engobe: so-called 'crazing'. Crazing is often more clearly visible on transparent glazes and less visible on an opaque matt glaze or sinter



Bruce Gernand (USA/England), untitled, 2001. W: 78 cm (30½ in.) These forms were designed by computer and fit into each other. The pieces were press-moulded using a fine-grained sculpture clay and the embossing method. The lines on the edge were drawn by using an underglaze pencil. A clear glaze was applied on top. The crackle lines followed the forces linked to the way the piece was press-moulded. Ink was used to enhance the crackle. (Photo: Corné Bastiaansen)

engobe. If used intentionally the term crackle is used. Crazing often occurs during the last part of cooling or shortly after the piece has been taken from the kiln. If crazing only starts after a few days or weeks, the expansion rates of the glaze and body are fairly similar. Due to the **absorption of moisture** into the body or to **repeated heating and cooling** of functional ware the piece expands slightly.

This slight expansion can disturb the balance.

Remedies (general advice):

- Apply the glaze or sinter engobe more thinly, as layer thickness increases, so does the possibility of crazing.

Altering the biscuit temperature

- In the case of low temperature glazes, increase the biscuit temperature up to the point where the body starts to get vitrified but still has some porosity, this will increase the expansion rate of the body. Due to the fact that this will lower the moisture expansion of the body the chance of crazing over time will be reduced as well.
- Encourage the formation of a body-glaze layer. The better this intermediate layer is formed, the lower the chance of crazing. This layer forms with a higher top temperature, a slower firing, soaking and a slow cooling of the first part from the top temperature downwards.

See section *14.2.4 Determining tendency of crazing* for a method to determine whether a glaze will craze.

Alterations to the glaze or sinter engobe

- Ingredients causing an increase in thermal expansion (see *Table 8.3*) must be reduced.
- If the glaze is on the verge of crazing; enhance the elasticity. Adding lead bisilicate (suitable for low temperature glazes), a tiny amount of lithium carbonate (up to 1%), and calcium borate frit (up to a maximum of 5%), will make the glaze slightly more elastic. Tension caused by higher shrinkage of the glaze compared to the body is better absorbed this way but this will only work if the glaze does not already contain these ingredients.
- Replace some of the nepheline syenite with petalite.

Alterations to the clay body

- The expansion rate of the fired body should be increased to minimise the chance of crazing. As has been indicated before, the expansion rates of low-fired bodies and sculpture bodies in general are low, and the expansion rate of low temperature glazes tends to be high. Adding ingredients like quartz, whiting, wollastonite or talc to an earthenware clay body will increase the expansion rate, but this is not advisable for earthenware sculpture bodies as the firing and cooling tension will increase.

Warping or crazing

Very thin-walled work may warp if a glaze or (sinter) engobe is applied on only one side. Due to a difference in thermal expansion the flat planes of a piece warp and tend to pull concave on the side to which the glaze or engobe has been applied (the opposite effect – bulging – will be discussed later). The shape of the piece determines if this will actually happen. Very thin tiles or slabs will easily warp. Most other forms and average thick tiles tend to resist warping, hence the glaze or sinter engobe will craze instead.

Remedies:

- Apply the glaze or (sinter) engobe on both sides of the body.
- Apply a less thick coat of glaze or (sinter) engobe.
- Increase the wall thickness of the piece.

Shivering

A fired body with a significantly higher expansion rate than that of the glaze or sinter engobe will shrink much more than the glaze, as a result of which slivers of glaze or sinter engobe may shear away on edges and rims. Glaze shivering from the rims of cast pieces may be caused by excessive sponging (removing irregularities from the surface with a damp sponge). This may wash away the clay minerals from the surface resulting in a higher concentration of quartz at the rim and as a consequence a localised higher expansion rate occurs causing the glaze to shiver.

Remedies:

- Increase the proportion of ingredients with a low expansion rate in the glaze or sinter engobe (see *Table 8.3*).
- Decrease layer thickness of the glaze or sinter engobe.
- Sponge the edges of cast pieces less intensely.

Shelling

Shelling (also referred to as flaking or peeling) of glaze, sinter engobe or engobe, along with a cover glaze, can be caused by large differences of expansion rate combined with a **weak bond** between the layer and body.

Glaze shelling

A combination of a low temperature glaze containing **lithium carbonate** applied onto a piece of biscuit fired to less than 1150°C (2102°F) and made of a clay body containing mainly HTR-clay and/or kaolin, will increase the chance of shelling.[2] Another cause could be lithium carbonate penetrating the body during application of the glaze, as lithium carbonate is slightly soluble in water. During drying of the glaze layer the dissolved lithium carbonate migrates to the surface of the body, hence a thin layer, with a greatly different expansion rate, is formed between the body and the glaze.

Remedies:

- Increase the biscuit temperature considerably in the case of a body with a high vitrification point. This will also reduce the chance of lithium carbonate penetrating the body.
- Limit the amount of lithium carbonate (maximum 5%) or rearrange the glaze ingredients by introducing lithium oxide (partly) through petalite.

Sinter engobe shelling

A sinter engobe fired to the point before apparent fusion starts, in combination with the presence of lithium carbonate, could be subject to shelling.

Remedies:

- Lower the fusion range of the sinter engobe by adding nepheline syenite.
- Limit the amount of lithium carbonate.

Engobe shelling

A thickly-applied refractory **engobe**, in combination with a thickly-applied low temperature cover glaze, could shell due to the lack of a strong bond between the engobe and the body underneath, especially if the body was fired way below its vitrification point.

Remedies:

- Decrease layer thickness of the engobe.
- Lower the fusion range by adding nepheline syenite.
- Remove soluble compounds, dust or grease (see next section).



Anne Wenzel (Germany/The Netherlands), *Meisje met hert (Girl with Deer)*, 2003. Ht: 20 cm (8 in.). A solid modelled piece treated with a terra sigillata (HTR-clay), satin gloss glaze and platinum lustre. Due to a thickly applied layer and differences in the rate of expansion the terra sigillata partially flaked. (Photo: Anton Reijnders)

Terra sigillata shelling

Flaking off of the terra sigillata layer is often related to too thick a coat. If terra sigillata has not been applied too thickly then one or more of the following aspects could be the cause:

- Dust, grease or soluble compounds could hinder good adhesion.
- The extent of vitrification of body and terra sigillata varies too much. For instance, a terra sigillata made from a terracotta clay applied to a porcelain body and fired way below vitrification of the body will be very prone to flaking.

Remedies:

- Dust can be blown away.
- Grease can be removed by using methylated spirit.
- Soluble compounds, that usually appear as a white layer on the edges and the most protruding parts of the work, can be removed with a hard brush. If a clay body with a lot of soluble materials is used it is advisable first to biscuit fire the piece (biscuit temperature should be to a maximum of 1000°C (1832°F) to prevent these soluble materials from vitrifying), the unwanted compounds can then be removed more easily after firing. Regularly changing the position of the piece during drying can prevent an accumulation of soluble compounds. However, doing this could also lead to fingerprint traces becoming visible after firing due to handling the piece from the plastic-stiff up to the dark stage. Wrapping the piece in newsprint or using gloves during repositioning will prevent this from happening.

If no improvement is achieved another kind of clay body for making the piece should be considered.

Dunting or bulging of the work

If a good interlayer has formed between a glaze and the body (the body has been fired to its vitrification point), stress caused by different expansion rates could cause bulging; flat planes of a piece warp and tend to pull convex. **Bulging** occurs if a thin-walled work is glazed on only one side or if two different glazes or sinter engobes are applied on either side, one having a high expansion rate, the other a low one. If the stress between body and glaze or sinter engobe develops to such an extent that it exceeds the strength of the body, or the form of the piece withstands bulging, the piece will crack, often referred to as **dunting**. Dunting occurs during cooling (the edges of the crack in the glaze are sharp). The likelihood of dunting will increase if a thick glaze or sinter engobe layer was applied. A thick pool of glaze, at the bottom, inside a piece can also cause dunting.

Remedies:

- Apply a thinner glaze or sinter engobe layer.
- Apply an even layer to both sides (inside and outside) of the work using glazes or sinter engobes with similar expansion rates.
- Slow down the cooling between 600°C and 100°C (1112°F–212°F).
- Prevent a thick layer of glaze or sinter engobe forming, at the bottom, inside a piece. With a runny glaze: reduce layer thickness, increase the amount of ingredients that increase the expansion rate and increase viscosity, see *Table 8.3*.
- Use ingredients that enhance thermal expansion of the glaze or sinter engobe, see *Table 8.3*. In the case of a matt glaze with a high aluminium oxide ratio and lithium oxide content: reduce the proportion of lithium carbonate.

11.5.3 Glaze faults related to viscosity and surface tension

Too high or too low viscosity and too high surface tension of a glaze or sinter engobe may lead to a range of faults such as blistering, pin-holing, orange peel, running, and crawling.

Blistering, pin-holes, orange peel

Gases are formed during sintering and fusion of the sinter engobe and glaze. These gases will be trapped as ultra-fine bubbles as fusion evolves and they can merge together to form larger bubbles and become visible to the naked eye. Eventually, as fusion progresses the bubbles will rise to the surface. The extent to which this happens depends on the composition and viscosity of the glaze or sinter engobe: high viscosity tends to keep the bubbles trapped, low viscosity increases the possibility of the bubbles reaching the surface. Once on the surface, blisters are formed and as they burst they make craters, mostly with rounded edges. Small craters that are spread over the entire surface are referred to as orange peel. Pin-holes are larger craters and spread more randomly over the surface. To what extent the craters remain is determined by the surface tension of a glaze or sinter engobe: a high surface tension will prevent the craters being filled and smoothed out.

The following conditions will **increase the chances of pin-holes or orange peel** arising:

- A thickly applied layer. In a thick layer more gases are formed and it takes more time

for the bubbles to reach the surface, so pin-holes will be formed over a longer period of time.
- A glaze layer containing grains of larger size or lumps. The fusion of these grains or lumps will take more time, giving rise to the formation of gases during the entire melting process and the first stage of the cooling process.
- Volatile components in the sinter engobe or glaze, (especially sodium oxide (NaO), manganese oxide (Mn_2O), chromium oxide (Cr_2O_3) and cadmium oxide (CdO), and particularly if the glaze or sinter engobe is overfired.
- High amounts of tin oxide or zirconium silicate in a white glaze. They cause a considerable increase of surface tension.
- Air is trapped between the body and applied glaze layer, due to a very porous (biscuit) body, the surface being rough with small holes on the surface of the body.
- Air is included in the glaze layer due to improper application.
- Gases escaping from the body during the fusion of the glaze. Formation of gas may occur due to components, (like organic materials) and calcium oxide compounds (like whiting), not being fully oxidised during biscuit firing, or due to decomposition of manganese oxide in black-firing clay and when the body is overfired.
- An improperly fabricated mould, see *Quality and strength of the mould* under section *5.2.1 Plaster*.
- Once-firing.
- A core of combustible materials, used for modelling purposes, was not removed before firing, creating gases.
- Carborundum in the pores of the body. If a biscuit fired piece has been sanded with an abrasive or sandpaper containing carborundum (as most modern abrasives and sand papers do) in combination with a glaze having a high surface tension (especially glazes with zirconium silicate or tin oxide), then pin-holes can form during firing.



Dinie Besems (The Netherlands), untitled, 2002. Ht: 17 cm (6½ in.). Two layers were applied to this ready-made teapot. The first layer, an engobe containing manganese oxide, released gases that caused large craters in the second layer, a white opaque low-temperature range glaze. (Photo: Anton Reijnders)

Remedies:

Pin-holes or orange peel are persistent problems, often caused by a combination of the above factors.

First, all factors that increase the forming of gases should be minimised as follows.

General remedies to reduce the forming of gases:

- Prevent larger grains in the glaze layer by sieving the prepared glaze, see section *8.8.3 Preparing glazes*.
- Reduce layer thickness.
- Reduce the chance of inclusion of air during application see under section *Reducing the chance of glaze faults* under section *8.8.4 Applying glazes*.
- Prevent the formation of pin-holes at the surface of the piece (or of air bubbles during casting), see section *13.3.1 Casting body:water:deflocculant ratio*.
- Use carborundum-free sand paper when sanding the work.
- Biscuit fire first.
- Alter the way of biscuit firing: slow down firing rate between 650°C and 850°C (1202°F–1562°F) and/or soak at 850°C.

- Remove all combustible materials inside a piece before firing.

Altering the glaze firing:

- Maintain top temperature, implement soaking, or increase soaking time in the case of a glaze or sinter engobe with a high surface tension (large amounts of zirconium silicate and tin oxide); this will reduce surface tension.
- Reduce the top temperature and/or soaking time if the glaze or sinter engobe tend to be overfired.
- Implement fast cooling down to 950°C (1742°F): this will reduce the formation of gases in the glaze or body and so reduce the chance of pin-holes forming during cooling.

If using these measures did not bring improvement then the clay body and/or glaze recipe has to be adjusted.

Altering the clay body:

- Avoid ingredients in a clay body that will enhance the formation of gases, see *Release of gases* under section *7.3.1 What determines the way of biscuit firing?*
- Increase the vitrification point of the body.

Altering the glaze recipe:

- Limit the addition of ingredients that become volatile easily: (colouring oxides such as manganese oxide and chromium oxide, and colour pigments containing cadmium (red and orange colour pigments).
- Reduce the amount of nepheline syenite or partly replace it by petalite.
- Add ingredients that lower surface tension, see *Table 8.3*.
- In the case of a white glaze or sinter engobe, reduce the zirconium silicate or tin oxide content.
- In cases of orange peel, where no high surface tension is involved, the viscosity should be attuned by either increasing or reducing the amount of quartz; small alterations could be enough.

Runny glazes or sinter engobes

A high content of strong fluxing agents and a low ratio of silica, and especially aluminium oxide, will lead to a very runny glaze.[3] (If running of the glaze is a desired effect however, precautions must be taken to prevent the piece from sticking to the kiln shelf, for more information see section *11.1.1 Protecting kiln shelves*.)

Remedies:

- Limit the layer thickness of the glaze.
- Lower the top temperature, or decrease soaking time, thus increasing the viscosity of the glaze or sinter engobe.
- Add ingredients that increase viscosity, see *Table 8.3*, kaolin will be very effective.
- Reduce the amount of colouring oxides that will decrease viscosity sharply like cobalt oxide but especially copper oxide and manganese oxide.

Crawling

Crawling is the partial rolling back of a glaze or sinter engobe layer during fusion leaving a bald patch of body. Crawling occurs if insufficient adhesion of the layer to

the body took place, or due to the formation of cracks in the layer during drying of the applied layer. High surface tension in combination with low viscosity will considerably increase the chance of crawling.

Shrinkage cracks of the applied layer and poor adhesion can be caused in several ways.

- The probability of cracks forming in the glaze or (sinter) engobe layer during drying will increase with large amounts of plastic components and if the layer is applied to a dried or biscuit body.
- Applying a glaze or sinter engobe layer containing hardly any plastic components, or none at all, to a piece still at the plastic or leatherhard stage will result in poor adhesion. The piece will shrink more than the applied layer which will be pushed off the piece in places.
- No proper adhesion has taken place between glaze layer and body because of grease or dust.
- The piece was not sufficiently dried when placed in the kiln. Due to fast firing in the first stage, steam from the body could lift and loosen the glaze layer.
- A glaze or sinter engobe applied to a sintered body. Such a body gives poor adhesion due to low absorption.



Jun Kaneko (Japan/USA), *Haiku*, 1996. Ht: 110 cm (43 in.). A piece consisting of three separate elements. They were fired in a high biscuit, low glaze firing. The glazes were applied in a thick layer using a brush. The white glaze contains zirconium silicate causing a high amount of surface tension. This intentionally resulted in a slight crawling in several places on the white piece. Collection: Museum Jun Kaneko, Omaha, NE, USA.
(Photo: Takashi Hatakeyama)

Remedies:

- Keep the surface grease and dust free.
- Improve adhesion of the glaze by using glaze additives and adjust the way of applying, see section *8.8 Preparing and applying glazes and (sinter) engobes*.
- Do not force-dry the applied layer: using a hairdryer or placing wet pieces in a kiln could cause extra shrinkage of the layer and, as such, increase the chance of crawling.
- Limit layer thickness. Whatever the cause of poor adhesion, thick layers will increase the chance of crawling.
- When a thick layer of glaze is desired in order to obtain a specific result, the glazed piece can be fired to a temperature 300°C–400°C (572°F–752°F) below its intended top temperature and then glazed with an extra coat; the glazed surface will still be porous enough. Finally the piece is fired to its eventual top temperature.[4]
- Slow down the firing speed in the first part of the firing.
- In the case of high biscuit firing and low glaze firing, lower biscuit temperature to a point where the body still absorbs to a small extent; this will improve adhesion of the glaze layer to the body.
- Attune shrinkage of glaze or (sinter) engobe and the piece to each other.
- Too high a shrinkage (which may be visible as surface cracks in the glaze layer): reduce the proportion of plastic components (use Molochite 200 or calcined kaolin instead).
- Too low a shrinkage (which may be visible as the glaze layer being pushed off the surface): increase the proportion of plastic components either by increasing the amount of kaolin, clay or plasticiser, see section *8.8 Preparing and applying glazes and (sinter) engobes*.
- Reduce the proportion of ingredients with a high surface tension and high viscosity, see *Table 8.3*.



Johanna Decalf (Belgium), untitled, 2002. Ht: 38 cm (15 in.). A coiled piece using an off-white sculpture body. A very thick layer of a celadon glaze was applied on the surface in order to exploit the crawling effect. Re-oxidation caused the warm colour of the unglazed surfaces.
(Photo: Corné Bastiaansen)

- Do not use raw zinc oxide. Reduce the total amount of zinc oxide.
- In the case of white glazes: reduce the proportion of zirconium silicate or tin oxide, this will reduce surface tension.

11.5.4 Other faults

Lime blows, unwanted matt results and rough glaze surfaces can be partially linked to the viscosity of the glaze. Flashing, if unwanted, can be very annoying, but it is sometimes deliberately encouraged.

Lime blows

Two types of lime blows can be identified. Shearing of small flakes of glaze caused by lumps of whiting in the fused glaze layer; and lumps of whiting or plaster in the body causing shearing of flakes of glaze and body. In both cases the whiting or plaster lumps did not fuse with the other components; as a result these lumps will hydrate (absorbing humidity out of the surrounding air) and expand as soon as the piece is taken out of the kiln. Lime blows in a glaze or sinter engobe will occur only if very high viscosity is involved: as a result the lumps will not dissolve during fusion. It can happen more frequently in engobes or clay bodies as no apparent fusion takes place. Because it takes time before the moisture can penetrate into the fired glaze, or sinter engobe layer and finally through the cover glaze into the engobe or body, lime blows can occur weeks or months after the piece has been taken out of the kiln.

Remedies:

Lime blows in the glaze or (sinter) engobe:

- The glaze or (sinter) engobe should be sieved: use a 60's sieve or finer.

Lumps of whiting or plaster in the body:

- Sieving and thorough mixing is needed to ensure whiting is dispersed evenly.
- Separate a clay body used for mould making or model making from a clay body used for casting to avoid contamination with plaster.
- If using a pre-packed clay body, switch over to another clay body.

Unwanted matt results and rough glaze surface

Some glazes get a rough and somewhat matt surface when fired in a gas kiln, but fired in an electric kiln at the same temperature the glaze will be shiny. Sometimes this problem is considered to be linked to an insufficiently dried glaze layer, but research has not confirmed this. Another explanation offered is the fact that burners may carry in more components that volatise during fusion of the glaze.

The incidence is highest with low temperature lead-free glazes having a high viscosity/surface tension with a low proportion of alkaline ingredients and a high proportion of ingredients containing aluminium oxide.

Remedies:

- Increase top temperature by 10°C–20°C (50°F–70°F).
- Use lead bisilicate frit as the main flux. **NB:** not suited for functional ware.
- Apply a coperta (a thinly-applied transparent high-gloss lead glaze) over the glaze, see section *9.1.3 Using a coperta*. **NB:** not suited for functional ware.
- Protect the piece by placing it in a saggar. Treating the sides and lid inside the saggar with a glaze will reduce the absorption of volatilised components.
- Use an electric kiln instead of a gas kiln.

If only a rough glaze surface occurs it can be sanded lightly until it feels smoother.

Flashing

Flashing is a partial coloration of the piece caused by volatilisation of certain colouring oxides. Sometimes used deliberately to achieve colour shading. Some glazes, especially copper and chrome glazes tend to influence the colour of neighbouring pieces due to volatilisation. Stains containing chromium oxide, copper oxide and, to a lesser extent, cobalt oxide and manganese oxide can also cause flashing. Copper oxide can result in green flashes in oxidation and rose or red flashes in reduction. Chromium oxide can cause pink coloration on white glazes containing tin oxide, or dull green on high lead glazes.

Remedies:

- Keep copper and chrome glazes away from other type of glazes. Fire them separately.
- Do not combine white, tin glazed pieces with chrome glazed pieces.



Patricia Rieger (USA), *A Cloud Passing*, 2002. Ht: 109 cm (42½ in.). Stoneware clay with added cellulose fibres. High temperature biscuit, then a low temperature glaze firing with a matt off-white glaze. The final firing was with blue lustre. The combination of a thick lustre layer and insufficient oxygen in the densely-packed lustre firing caused areas of the lustre to separate on the surface, revealing the glaze underneath. (Photo: Peer van der Kruis)

Notes:

1 A saggar is normally used to protect a piece from direct contact with flames in a fuel kiln.

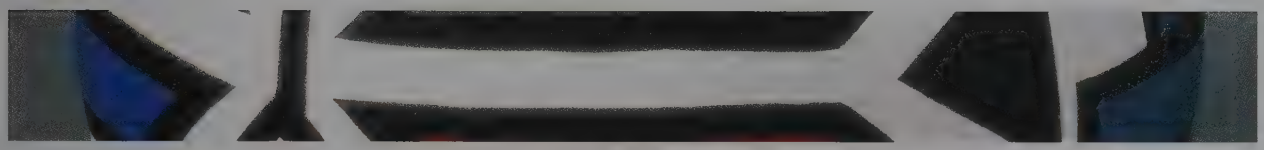
2 A clay body with an MTR-clay as its main ingredient and fired to a biscuit temperature of 1060°C (1940°F) tends not to be subject to this, possibly because of the presence of illite.

3 Due to the fact that sinter engobes have a high aluminium oxide content they will only be runny if greatly overfired.

4 This procedure was used by the Chinese potters for their very thickly glazed Longquan celadon pieces.



12 Non-ceramic treatment



Obviously, the process of making does not need to stop after the piece has been taken out of the kiln. Further non-ceramic treatments can be carried out. In this chapter only a very few methods will be discussed in a brief way: etching, sandblasting, painting and gluing.

12.1 Etching

As has been pointed out, matt glazes tend to be less transparent and yield less bright colours. A way to overcome these limitations is to treat a fired shiny glaze with an etching agent. A **glass etching agent** can be used successfully. Its main component is fluorine.[1] For application with a brush, a solution with a viscous paste-like consistency is the most convenient to work with. Depending on the durability of the glaze, it might take only a few minutes (most low temperature glazes) or up to an hour (high temperature glazes) before sufficient etching has been achieved. Interesting contrasts between shiny and matt surfaces can be achieved by using masking tape or latex to mask parts of the surface. After sufficient etching time the etching agent is washed off.

NB: For your safety: use gloves, a respirator and eye protection. Do not allow the etching agent to go directly into the drain system. Collect it in a basin with water to which whiting has been added. The whiting will neutralise the fluorine resulting in non-toxic calcium fluoride. A handful of whiting per litre of water will be sufficient.

12.2 Sandblasting

A fired piece can be sandblasted to alter its surface quality. This calls for acquiring a sandblasting booth and the necessary equipment, or using a company that specialises in sandblasting steel or glass. A glass sandblaster is preferred for detailed work and more subtle surface alterations. For stronger surface alterations steel sandblasting is the best choice. Because a more powerful abrasive force is used in this type of sndblasting, a substantial part of the surface of a piece can be removed, even holes can be created. The fired strength of the piece will be a determining factor. Steel sandblasting companies are often capable of dealing with large-scale pieces.

OPPOSITE:
Xavier Toubes (Spain/USA), *Exquisite Nomads*, 1999. Ht: 67 cm. (26 in.). A coil-built piece made from coarse terracotta sculpture clay. Fired in reduction and afterwards low-temperature glaze fired. A sandblaster was used as a tool to partially remove the glaze and remodel the form and the surface. (Photo: Anton Reijnders)



12.3 Painting

Unglazed ceramics, especially porous or slightly porous pieces, form an excellent base for paint. All sorts of paint can be used ranging from oil, to acrylic or polyurethane. Painting has some obvious advantages and disadvantages: no extra firing is needed and the colours change only slightly after application compared to glazes and (sinter) engobes. On the other hand, paint will not last as long as glazes, sinter engobes and engobes. Also, it does not create as strong a surface compared to a well-balanced glaze or sinter engobe.

12.4 Gluing

Gluing separate parts to create larger pieces is another option to continue the making process after the piece (or pieces) has been taken from the kiln. In general, four major types of glue are suited for gluing ceramic: silicon, epoxy, polyurethane glue and a thermoplastic glue. In the case of polyurethane, the two-component version is to be preferred as it creates the strongest joints. The choice of the best glue for the situation depends on the type of surface to be glued and on whether the joints are to be temporary or permanent. In general, a **silicon based glue** is preferred for gluing elements that are glazed and also for semi-permanent adhesion (if one can reach the glued spot the silicone glue can be cut loose). An **epoxy resin glue** is best applied on unglazed pieces that fit tightly. If unglazed pieces make poor contact or do not fit at all, **polyurethane glue** is the best choice. One of the big advantages of polyurethane glue over epoxy is that it also expands slightly filling the space between the joints and moreover it remains flexible to a small extent after setting. This slight flexibility results in very good shock resistance. Other advantages are that it is weather resistant and that good adhesion can be achieved joining ceramics with wood or metal. If a glazed piece has to be glued and polyurethane is preferred, grinding the points of contact will be necessary to achieve a good grip. An epoxy or polyurethane glue can also be used to fill cracks. Epoxy is best used for small cracks, polyurethane for wide cracks. In the case of very wide cracks a mixture

Franzina and Angelina Ndimande (Ndebele tribe, South Africa), untitled, 1994. Ht: 95 cm (37 in.). A wheel-thrown piece. A fine-grained sculpture body was used. A traditional pattern, typical of the Ndebele tribe, was painted on using acrylic paint.
(Photo: Peer van der Kruis)



José Maria Secilia (Spain), *Pillow*, 1998. W: 44 cm (17 in.). An Egyptian blue glaze, over-saturated with pigment causing uneven dark shades of colour. The glaze has been treated with an etching agent to obtain a matt finish.
Collection: Frans Hals Museum, Haarlem, The Netherlands
(Photo: Peer van der Kruis)

of polyurethane and fine grog (2:1) could be used first. Adding stains to these glues can help to make a crack less visible, epoxy is especially suited for this. Painting on top of both glues is possible. Sanding might be necessary for a better adhesion.

Polyurethane glue can also be used for mending broken plaster moulds that are used for press-moulding or plemping. It is less suitable for moulds used for casting as it hampers the water absorption at the points where joining has taken place.

Thermoplastic glue, a glue that becomes viscous through heating, can be used for temporary adhesion. A **hot glue gun** that heats up a glue cartridge of thermoplastic glue is a very practical tool. Preheating the ceramic parts using an electric paint stripper will improve the strength of the joint. The disadvantage of this glue is its limited gripping strength, making it unsuitable for joints that support weight.

Notes:

1 Fluorine is also present to some extent in gases that escape from the kiln and cause the etching of glass windows in the studio.



13 Advanced section: Clay



In this chapter the nature of clay, its geological origin and the mineral structure of clay minerals will be discussed. This will help to give an understanding of why clay is not a clearly definable material with a strict set of properties, but that these properties can vary a lot from one clay to the other. Some practical methods of analysis will be addressed that can provide valuable information about whether a particular clay body fits the intended requirements. Finally, finding the very delicate equilibrium between clay body composition, deflocculant and water of a casting clay will be discussed in more detail.

13.1 What is clay?

Working with clay sooner or later poses the questions: what is clay? what is the reason for so many variations? Why do differences in properties and qualities exist? Clay, mineralogically speaking, is a product of the weathering process of specific minerals in rocks. It's a 'conglomerate' of a large number of different and varying components. Eleven main groups of components can be identified, which can be divided into fifty or more subgroups. It is beyond the scope of this book to go into all these components, here only the most important ones are mentioned:

- Clay minerals
- Quartz
- Mica
- Feldspar
- Calcium- and magnesium-containing associate minerals
- Iron-containing associate minerals
- Titanium oxide-containing associate minerals
- Organic materials.

The clay minerals and other components in a clay are either by-products of the weathering process or are picked up along the way as the clay is carried by water or wind from the original eroded rock. The term clay minerals is most commonly used to denote a family of hydrous alumino-silicates. In this book three major groups of clay minerals are focused on: kaolinite, illite and montmorillonite and two sub-types: disordered kaolinite and mixed layer minerals. It is more accurate to talk about clay mineral groups because there are many known variables in mineral structure that are allocated to one of the three major groups, but for the sake of simplicity in this book a reference is made simply to kaolinite, illite and montmorillonite. There is no uniform conclusion

OPPOSITE:
Anne Ausloos (Belgium), *A Journey*, 2002–2003. Bottle rack, bottles, earth. Ht: 101 cm (39 ¼ in.). A variety of earth and clay specimens from different parts of the world. The specimens were put in the glass bottles and mixed with water. After a long period of sedimentation and the evaporation of the water the bottles were fired up to the point when the glass started to slump.
(Photo: Sahra Blee)

in 'studio ceramic literature' as to which minerals make up the true clay substance. Not that long ago only kaolinite was considered to be the true clay substance, whereas now, more and more, montmorillonite is seen as part of the true clay content as well. In some literature the role of illite is neglected and it is still not considered to be part of the clay minerals despite its profound impact on the properties of the majority of the available clays. Because of its less specified nature and its readiness to interlock with montmorillonite (mixed layer minerals), illite is more difficult to identify, although present in almost all clays in ratios varying from very small to large. It was first identified as a separate group of clay minerals in clay deposits located in Illinois, USA (giving it its name).

13.1.1 Clay minerals and size

The size of clay minerals can vary a lot and this plays a decisive role in plasticity. Kaolinite can vary considerably in size. As found in kaolin, kaolinite often occurs in stacked units of relatively large size (see *Figure 10.2*), surpassing 2 µm (0.002 mm), as such they do not add to plasticity (2 µm is considered to be the borderline of plastic components). Kaolinite, and especially disordered kaolinite, present in a secondary clay is of a much smaller size. The weathered form of mica is called hydromica or hydrous mica. If weathered to a very fine size it is rated among the illite group of clay minerals. Illite can be as small as 0.2 µm or less. Montmorillonite minerals have an extremely small size: 0.06 µm and smaller. As the size reduces the **surface area** increases. A comparison of the surface area of one gram of clay minerals will clearly show the huge differences:

- Kaolinite and disordered kaolinite: 10–60m^2 per gram.
- Illite: 80–150m^2 per gram.
- Mixed-layer minerals: 175–200m^2 per gram.
- Montmorillonite: 500–800m^2 per gram.

13.1.2 The geological origin of clay

The following process is usually considered to be the geological origin of clay. Potassium feldspar weathers down, resulting in kaolin: the primary clay. When this is moved away from its weathering origin by erosion, the more plastic secondary clay is formed.However, this does not explain the variety of clay minerals that can be found in most clays. The reason so many different clay minerals exist is related to the fact that, besides potassium feldspar, many other minerals can also be formed or transformed into clay minerals. It is therefore necessary to go more deeply into the geological processes.

The earth as we know it today has been formed over a period of millions of years. As a result of a very slow cooling process the earth's crust (about 10 kilometres or 6 miles thick) developed. During cooling down of the liquid magma, at specific temperatures certain minerals have been and still are being formed due to crystallisation (a process similar to the crystallisation of a glaze, only the timespan and pressure is of a vastly different order). Other minerals solidify at lower temperatures and some minerals have migrated higher up in the still partly liquid magma resulting in different strata of minerals. At higher levels the minerals contain more silica and potassium, and lower down the minerals contain more sodium, calcium, magnesium, iron and titanium oxide. Depending on the speed of cooling, rocks are formed containing minerals consisting of large, small or very small crystals.

The surface of the earth as we know it is partly the result of expanding forces from within, causing folding, faulting, intrusion (magma that got trapped) and volcanic

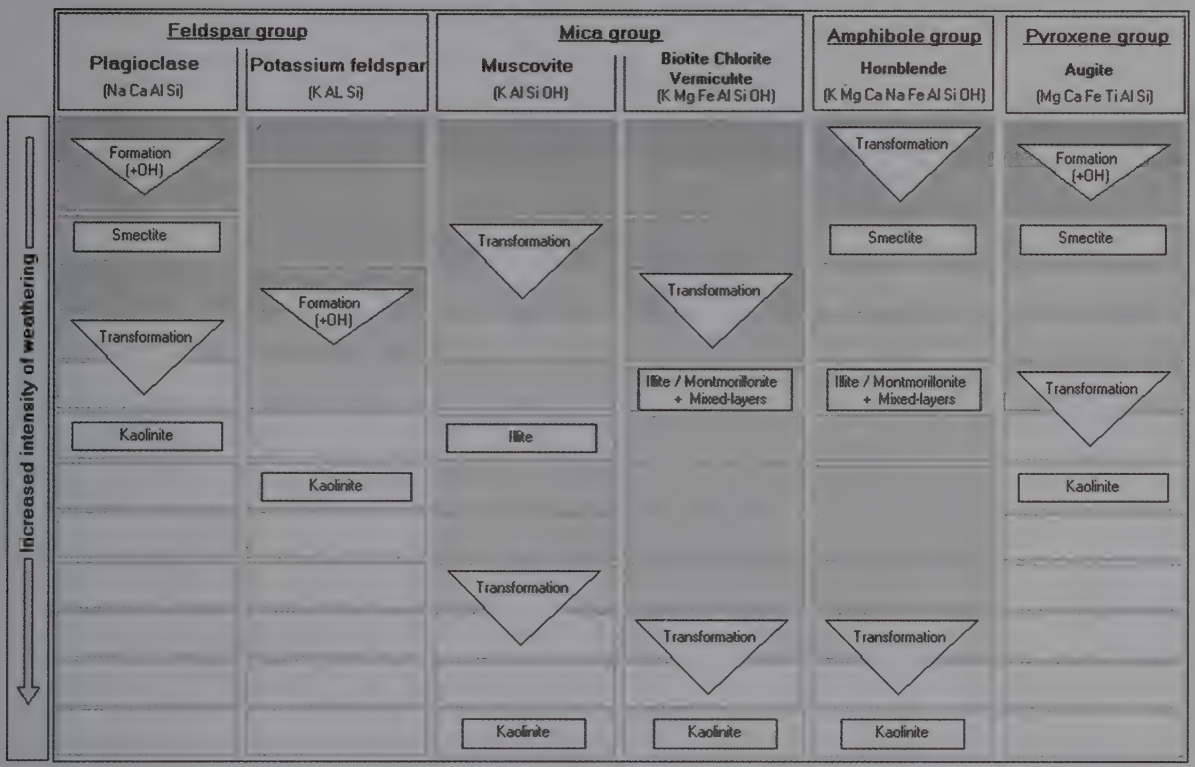


Figure 13.1
A simplified representation of the decomposition process of six main minerals into clay minerals. Formation: change from non-plastic to plastic material through hypogenic action (OH locks into the mineral structure) and leaching (removal of Na, Ca, K and Mg). Transformation: change from non-plastic material into plastic material by leaching. Adapted from J.H. Krumb (*Keramische Zeitschrift 50* [12] 1998).

eruptions. The forming of the atmosphere, the oceans and weathering processes all contributed to the earth we now have today. As a result of these different rates of cooling, moving, folding, volcanic eruptions, weathering and sedimentation, rocks can be found at the surface of the earth made up of a variety of minerals containing crystals of different dimensions. Fast cooling, that happens as a result of volcanic eruption, will lead to small crystals (as can be found in basalt). Slow cooling, as happens in trapped magma close to the surface of the earth, will lead to large crystals (as can be found in granite). The most frequently found minerals in rocks are quartz and the minerals of the feldspar group. Minerals of the mica, amphibole, and pyroxene groups can also be found in vast quantities. Apart from quartz a large variety of minerals belonging to each of these groups can be (trans)formed into clay minerals. *Figure 13.1* provides an overview of the most important minerals.

Granite, or granite types of rock, cooled down very slowly and therefore consist of large crystals. Potassium feldspar is the main mineral in granite (recognisable as large crystals mostly of a light rose colour). Various amounts of plagioclase (soda/calcium type of feldspar) can be present in granite but in smaller amounts than potassium feldspar. Also mica minerals are present, they have a sheet-like structure that is either light (muscovite) or dark (biotite) in colour and are often recognisable as sparkling flecks. Minerals of the amphibole group can be found less frequently in granite, but quartz is always present. **Basalt** or basalt-like rocks, originating from volcanic eruptions and **volcanic ash**, often contain large amounts of minerals of the amphibole and pyroxene group; minerals that contain more magnesium and iron oxide. Basalt contains feldspar (mostly calcium and sodium feldspars), as well as mica and biotite minerals. Due to fast cooling these minerals often cannot be seen with the naked eye.

The forming and transformation of clay minerals

As a result of weathering processes clay minerals are being formed. This can take place in the rock itself or after the basic minerals are eroded from the parent rock. The extent to which this (trans)formation happens, and the speed, is determined by geological conditions. In whichever way it happens, water plays an important role, especially with its ability to penetrate into the structure of the minerals and to take into solution specific compounds that will be leached out.

Decomposition of parent rock

Under specific geological circumstances the parent rock can decompose without changing its volume or form. *Figure 13.1* shows in a simplified way the different (trans)formation stages of the most important minerals present in parent rock. **Formation** takes place as water enters and creates a hydroxyl bond (OH) in the mineral structure; the so-called hypogenic action. Soda (Na), calcium (Ca), potassium (K), or magnesium (Mg) compounds and a part of the silica (SiO_2) are taken into solution and leached out. **Transformation** is linked to those minerals that already contain a hydroxyl bond by nature. Water enters the structure of these minerals and takes potassium, soda, calcium, magnesium, iron (Fe) compounds, and partially silica, into solution after which they are leached out as well. As *Figure 13.1* shows, there are different transformation stages. Besides illite, montmorillonite and kaolinite, mixed layer minerals and smectite can also be formed. **Smectite**[1] is a mineral group sometimes also referred to as the montmorillonite group as montmorillonite is its major representative. The minerals of the smectite group have a similar mineral structure to montmorillonite, but they differ from montmorillonite because they consist of high amounts of magnesium atoms instead of aluminium atoms and they often contain 'exotic' compounds like lithium compounds. Mixed-layer minerals consist of interlocked illite and montmorillonite. If the decomposition of the parent rock did not progress fully, as is often the case, non-transformed minerals like feldspar and muscovite (mica) will still be present. As has been pointed out quartz will always be present in both partly and fully decomposed rock.

Decomposition of parent rock can take place in two ways:

- Rocks can decompose due to hot and humid gases of volcanic origin that penetrate the rock from below. Where the contact of these gases is most intense mainly kaolinite will be formed. Less intense contact will lead to the formation of illite, montmorillonite and mixed-layer minerals. Higher up in the rock, smectite will be formed.
- Under tropical and humid conditions, the parent rock can be decomposed by water and dissolved acid from plants (humus) found in water. As water penetrates the rock from above gradual decomposition takes place. In the highest parts where the leaching process is more intense, kaolinite will be formed, while at the lower end more illite, montmorillonite and mixed-layer minerals will be formed.

Erosion, transportation and sedimentation

Parent decomposed rocks are relatively scarce. Often rocks, in different stages of decomposition have been eroded by wind, rain and frost and gradually crumble down. All the previously mentioned minerals, either (trans)formed or in their initial state, are washed away. Under the right circumstances the eroded non-clay minerals can be transformed into clay minerals and if these minerals and/or the clay minerals settle close to

where the weathering has taken place a clay deposit will be formed consisting of little or no alien materials.

Most of the time the transportation of eroded rock, and especially clay minerals, takes place over large distances. Clay minerals can more easily cover long distances due to their (ultra) small size. The transport can take place either by water (rivers), glaciers or wind. Water, particularly, acts as a separation device, dividing lighter particles from heavy particles, and as clay minerals, ultra-fine quartz and mica are very light, these will be transported furthest away. The finest particles will be deposited only when the river moves very slowly, and the ultra-fine particles will only settle when water is still, hence deposits of various composition are formed. As the (clay) minerals are washed away by rivers they become mixed with clay minerals from other sources and with non-plastic minerals like iron oxide, quartz (sand), calcium-containing compounds (like chalk) and organic matter. During transport the clay minerals will weather down further, reduce in size (due to de-lamination) and become more plastic.

When the weathered clay minerals are transported by wind, ultra-fine particles can be carried far away and can also form highly plastic clay formations.

Formation and weathering down of sedimentary rocks

Deposits of clay can become compressed if covered by layers of other material and, due to high pressure, sedimentary rocks like shale or slate can be formed. As these rocks become re-exposed they will be weathered down and washed away again. This results in deposits containing clay minerals of ultra-fine size and high plasticity.

It has become clear that the forming of clay minerals and clay deposits is no simple linear process. It is a complex action that varies according to the geological circumstances. As a consequence large differences will occur – even in one clay deposit there can be great variations between different layers – because most clay deposits have been formed over a very long period of time.

13.1.3 Types of clay

It is common practice among ceramicists to divide clay into primary clays and secondary clays. **Primary clay** is a clay found in its place of origin. The term is mostly reserved for kaolin being mined from decomposed parent granite and granite-like rocks. The decomposed rock is processed using water and deflocculant in order to separate the clay minerals from the coarser non-plastic components that are still present in the rock. The major clay mineral that will be present in kaolin is kaolinite, but as previously mentioned other clay minerals like illite, montmorillonite and/or mixed-layer minerals can also be present. The plasticity of kaolin will be low if it consists mainly of 'large' stacks of kaolinite (see *Figure 10.2*). As the amounts of other types of clay minerals increase, plasticity increases.

Decomposed basalt rocks will contain large amounts of montmorillonite or other clay minerals from the smectite family. Bentonite, consisting mainly of montmorillonite, is considered to originate from decomposed basalt or volcanic ash.

Clay that has been transported away from its place of origin is called **secondary clay**. Kaolin can also be of a secondary clay type, although such deposits are rare. The transport of this kaolin from the parent will have taken place over a relatively short distance, hence it will have hardly picked up any alien materials. However, this type of kaolin often has somewhat more plasticity due to the presence of finer kaolinite, and can be even more plastic if sufficient other clay minerals are also present. Most other clays are transported over larger distances and become mixed with clay minerals from various

origins and non-plastic minerals. The actual plasticity and other properties of these clays can vary a lot according to the presence of fine to very fine kaolinite, disordered kaolinite, illite, montmorillonite and mixed layer minerals as well as different amounts of non-plastic components and organic components. The colour of secondary clays widely varies, depending on their origin (granite or more basalt-like rocks) and the amount of iron oxide and calcium compounds picked up along the way. In contrast to what is sometimes stated feldspar will only very rarely be present in secondary clay. As has been pointed out, quartz can be weathered down to ultra-fine particles and, as such, it will accompany clay minerals on their journey. HTR-clay, MTR-clay and T-MTR-clay are all secondary clays.

13.1.4 The crystal structure of clay minerals

In general, clay minerals have a crystal structure containing at least silica (Si), aluminium (Al), oxygen (O) and hydroxyl (OH) compounds. Besides these compounds, the different clay minerals can be identified, having potassium (K), magnesium (Mg), and iron (Fe) in their mineral structure. The way the atoms are linked in the mineral lattice is different for each clay mineral. These differences provide the minerals with their specific characteristics. Most clay minerals also have calcium (Ca) and sodium (Na) cations (atoms with a mostly positive electric charge) 'attached' to the outside of the mineral structure.

Kaolinite has a crystal structure that is built up out of a repetition of 'twin layers'. One layer is formed by silicon atoms linked to oxygen atoms, the next layer is formed by aluminium atoms linked to hydroxyl. This is why kaolinite is called a double layer mineral. The oxygen from the first layer links with the hydroxyl in the next layer and this is called the hydroxyl bond (see *Figure 13.2*). This bond is fairly strong resulting in 'large' crystals. The individual kaolinite minerals have a sheet-like irregular (hexagonal) shape (see *Figure 10.2*). Although the bond between the mineral layers is fairly strong, it can split under certain weathering conditions resulting in smaller fractions, as will be the case in a secondary clay. Because the mineral structure is composed of silica and aluminium hydroxyl molecules (hardly any alien compounds like potassium, magnesium, or iron are present), kaolinite minerals have a weak electrical charge compared to other clay minerals.

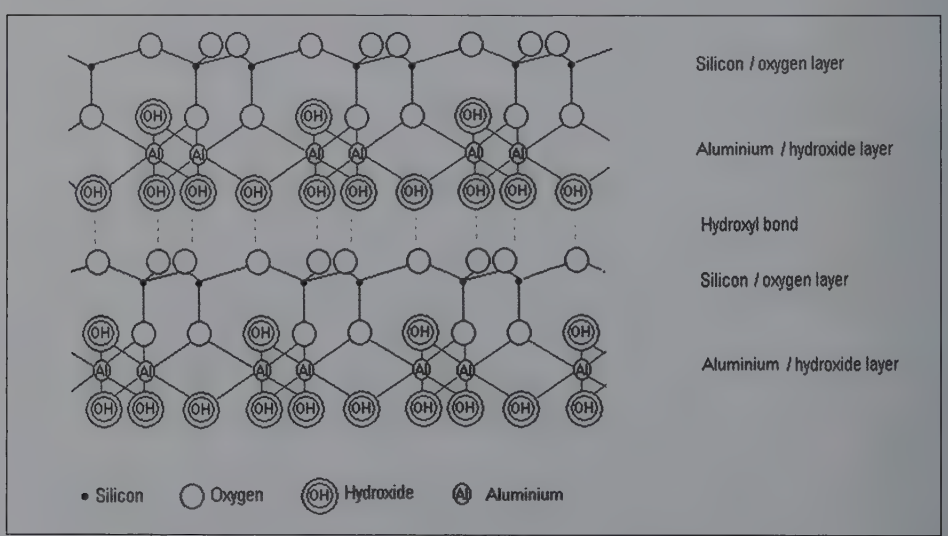


Figure 13.2
The kaolinite structure
Adapted from Salmang H, Scholze H, *Die Physikalischen und Chemichen Grundlagen der Keramik.*

Disordered kaolinite (sometimes also referred to as fireclay minerals), has a similar structure to kaolinite but it contains within its mineral structure some magnesium, and occasionally iron, compounds. This results in a stronger electrical charge compared to kaolinite. Disordered kaolinite minerals are also of a much smaller size than kaolinite and they are often found in secondary clays like ball clays and fire clays. Compared to kaolinite, disordered kaolinite minerals contribute to a higher plasticity, are slightly less refractory and less white burning. The lessening of refractoriness is due to their smaller size, the presence of some magnesium and possibly iron atoms within the mineral structure, and the presence of Ca and/or Na cations at the outside of the minerals, see section *13.1.5 Water/clay mineral relation.*

The crystal structure of **illite** is made up of 'triple layers'. One layer of aluminium atoms, oxygen atoms and hydroxyl molecules is sandwiched between two layers of silicon and oxygen atoms. This is why illite is called a triple-layer mineral. The triple layers are held strongly together by potassium atoms. A type of illite commonly found has a mineral structure that comes close to the structure of muscovite (see *Figure 13.3*) although it contains less potassium. The potassium in the mineral structure of illite causes a stronger electrical charge compared to disordered kaolinite. Depending on its source, varying amounts of magnesium and iron atoms can also be present in the mineral structure.[2] An increase of magnesium and possibly iron atoms will lead to an even stronger electrical charge. The very small size, the presence of potassium and magnesium atoms within the mineral structure and the presence of Ca and/or Na cations at the outside of the minerals, makes illite less refractory as compared to kaolinite. If iron compounds are present illite will yield a less white body after firing.

The crystal structure of **montmorillonite** is, like illite, made up of triple layers. The mineral structure always includes magnesium atoms, and often iron atoms are present as well. This causes a large electrical charge compared to

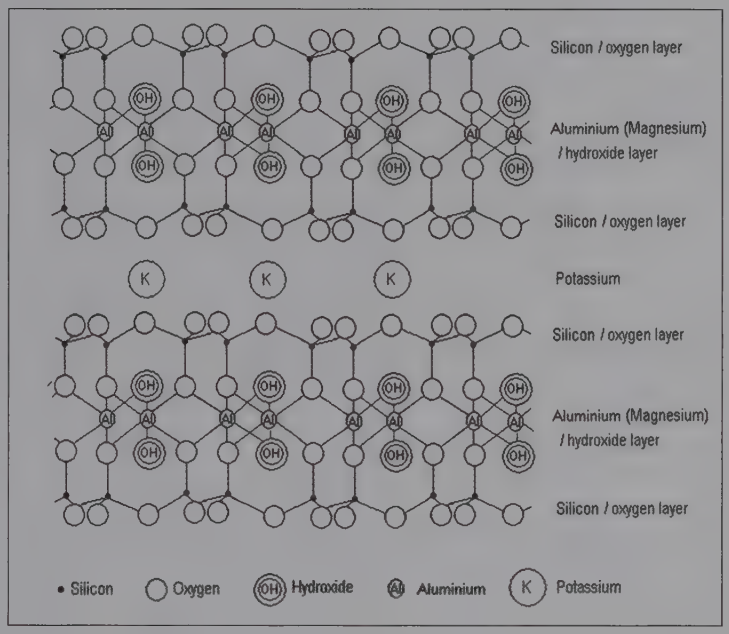


Figure 13.3
The Muskovite structure. This structure supposedly comes close to illite, although less potassium atoms are present between the triple layers.
Adapted from Salmang H, Scholze H, *Die Physikalischen und Chemichen Grundlagen der Keramik.*

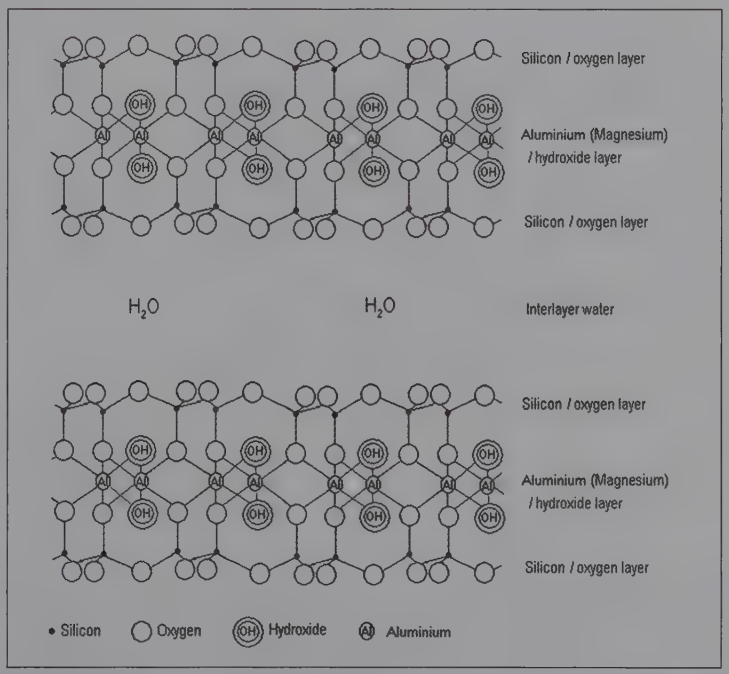


Figure 13.4
The structure of montmorillonite.
Adapted from Salmang H, Scholze H, *Die Physikalischen und Chemichen Grundlagen der Keramik.*

previous clay minerals. Very typical of montmorillonite is that the triple layers are not linked by potassium atoms (as with illite) but by water molecules, the so-called interlayer water (see *Figure 13.4*), but this is only a very weak bond. More water can easily enter between the mineral structure, and as a result montmorillonite will swell (up to six times its volume). As a result a very flexible molecular structure is formed because the triple layers can slide past each other. Due to the weak bond between the layers, montmorillonite, as compared to kaolinite, has no clear plate-like shape and is of extremely small size. The fact that the triple layers can slide along past each other gives montmorillonite extremely high plasticity. The magnesium and possibly iron atoms in the mineral structure, the relatively large amount of Ca and/or Na cations and its ultra-small size makes it even less refractory than illite.

In the **mixed layer minerals** the minerals illite and montmorillonite triple layers are interlocked. Mixed-layer clay minerals also have a strong bond of water on the outside of the mineral due to a large electrical charge, are of small size and very plastic.

13.1.5 Water/Clay mineral relation

The electric charge determines the capacity of the clay mineral to bind a layer of water to its outside: called the **double water layer**. This layer is made up of hydroxyl molecules linked to the outside of the clay minerals and a second layer of water molecules. Both make up the amount of **held water**. The hydroxyl molecules are fairly strongly linked to the outside of the clay minerals and will only be fully removed if heated up to 110°C (230°F). As more water is held at the outside of the clay minerals the plastic properties of the clay increase. Kaolinite binds the least and montmorillonite the most, held water. As pointed out montmorillonite and mixed layer minerals also contain **interlayer water**. This water is even more strongly linked in-between the mineral structure as compared to held water and it will only be fully removed if heated up to 250°C (482°F) although some literature refers to 300°C (572°F) and higher.

The hydroxyl molecules linked in the mineral structure of the clay minerals are strongly linked and will form water molecules if fired at a much higher temperature than the previously indicated water. These hydroxyl molecules are also referred to as **structural water** (or chemically-combined water). Kaolinite and disordered kaolinite contain a large amount of hydroxyl and so a lot of structural water will be released. This will happen between 450°C and 650°C (842°F and 1202°F). The structural water of illite will be released within the same temperature range, but the amount is much less, as much less hydroxyl is present in the mineral structure. The same is true for montmorillonite but, contrary to the other types of clay minerals, the release will take place at a later stage: between 600°C and 800°C (1112°F and 1472°F).

The extent of electric charge also determines the ability of clay minerals to be deflocculated if suspended in water: kaolinite as well as disordered kaolinite easily deflocculates. Illite and, especially, mixed layer minerals and montmorillonite are difficult to defflocculate.

13.2 Testing a clay body

Often the clay body's qualities and suitability are being evaluated during the process of making, drying, firing and beyond. By implementing some practical methods of analysis, valuable information can be obtained in advance as to whether a particular clay body fits the intended requirements.

Apart from accurate weighing scales, the methods of analysis and testing described here do not require expensive equipment. They can be carried out in the studio, workplace or the art classroom. In addition to instructions on how to carry out tests, evaluations will be given to help analyse the outcomes. **NB:** The outcome of the tests should not be understood as absolute values but as relative ones; if executed under controlled conditions it makes comparison possible.

In the following sections methods for determining plasticity, (the workability range of a clay body) will be discussed. Next, methods to determine linear drying shrinkage, firing shrinkage, porosity, frost resistance and expansion rate of a body will be provided. To this end a test tile has to be made. Also methods of determining dry crack resistance, optimal packing and grain size structure will be discussed. For a complete series of tests approximately 1.5 kg (3.3 lb) of a prepared clay body will be required.

13.2.1 The right consistency

The consistency of a clay body determines its workability range and the amount of shrinkage that will occur during drying. Therefore a verifiable indication of the right consistency is essential to this. The 'sticking margin': the stage at which the clay body sticks only slightly to the hands, will be used as a reference and will allow the following series of tests to be executed with a fair degree of uniformity.

Determining the sticking margin consistency

Determining the right consistency should be done 24 hours after the clay body has been prepared (and not before). This is the minimum amount of time required for the water to achieve a bond with the clay minerals. Requirements:

- Plasterboard.
- Plywood.



Figure 13.5
Indication of the sticking margin: only a thin layer sticks to the hands.
(Photo: Anton Reijnders)

Before determining the sticking margin, the clay body should be shortly kneaded (see section *2.7.6 Kneading*), after which the hands should be rinsed with water and dried thoroughly (hands that are completely dry from the start will give a slightly different result). Approximately 200 g of the clay body is rolled into a roll between the hands, to a length of approximately 15 cm (6 in.). The roll is folded and rolled again between the hands. This is repeated five times. If after the first time a lot of clay is already sticking to the hands too much water is present. If, after four or five times, a thin layer of clay sticks to the hands (see *Figure 13.5*) and the surface of the roll is fairly smooth, the consistency of the clay is within the sticking margin. If after the fifth time hardly any or no clay is sticking to the hands, too little water is present. An excess of water can be removed through kneading and this is preferably done on a firm wooden board as this allows a more gradual removal of water. Plasterboard is only used if the clay is very sticky. If the clay does not stick at all, water should be added. To do this, the clay body is cut into 1 cm (½ in.) slices with a cutting wire. These are moistened on both sides and put back together. The clay is then left for 5 or 10 minutes, wrapped in plastic, before kneading. **NB:** To achieve repeatable results it is important that the water is kneaded thoroughly through the clay body and that the hands are rinsed and dried well prior to each new test.

To prevent the clay body from drying during testing, it should be wrapped in two

layers of plastic and kept in a covered plastic bucket. When the clay reaches sticking margin consistency, the following series of tests can start.

13.2.2 Determining plasticity

As plasticity involves many aspects (see *Plasticity* under section section *2.1.1 Workability*), it is a complicated matter to determine plasticity in an accurate way. A simple method can be implemented based on the notion that plasticity is linked to the ability of clay to retain water before rupture occurs. By rolling a clay body on a plaster board water will be extracted. At a certain point too little water will be present, causing an insufficient adhesion within the roll during rolling; the so-called rolling out limit has been reached. As the plasticity increases more water will be held and it will take more time before it becomes insufficiently adhesive.

Quite a number of clays cannot be used directly, as their plasticity makes them too sticky and therefore unmanageable. To solve this problem the clay is mixed 1:1 with a 30's mesh (0.5 mm) grog or Molochite. A clay body should be tested as it is. Requirements:

- Dry plaster board.
- A scale with an accuracy to 0.1g.
- Clay:Molochite 30 (or 0.5 mm non-absorbent grog) 1:1, or clay body both with sticking margin consistency.

To ensure a successful test, the following should be observed:

- The test is executed 24 hours after the clay body or clay grog mixture was prepared.
- It is important that the plaster board is made out of pottery plaster,[3] following the water:plaster powder ratio indicated by the manufacturer, for more information see section *5.2.1 Plaster*.
- The plaster board should be clean and equally dry at the start of each new test.
- Make a mark of 15 cm (6 in.) on the plaster board (this will be the ultimate length while rolling).
- The sticking margin should be observed accurately at the start, as it will affect the outcome of the test considerably.
- The clay body should have been stored at normal room temperature, cold clay will reach the rolling out limit earlier.
- For each test 12 g of clay is used. This amount should be followed exactly using more or less will reduce or increase the amount of time before the rolling out limit will be reached.
- The clay is rolled into a little ball in the palms of the hands. This ball is rolled into a roll 15 cm (6 in.) long on the plaster board. Rolling should be done reasonably fast with equal (not heavy) pressure and the length of the roll should be close to 15 cm each time.[4]
- After each rolling session the roll is folded, pushed together, folded, pushed again with reasonable force between the fingers becoming a wad before it is rolled into a ball in the palms of the hands.
- These actions are repeated until the roll loses cohesion: a hollow core is formed and it starts to open up at the surface (see *Figure 13.6*): the rolling out limit has been reached.

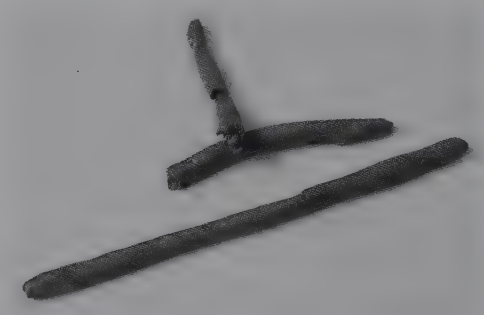


Figure 13.6
The rolling out limit has been reached when the roll loses cohesion inside: a hollow core is formed and it starts to open up at the surface. If rolling is continued the roll starts to crumble. (Photo: Anton Reijnders)

Table 13.1

Indication of plasticity of clay (1:1 clay:Molochite 30's) and clay bodies

Plasticity	*Number of times rolled out without reaching rolling out limit*
Low	1–4
Moderate	around 6
Average	around 9
Fairly high	around 12
High	15 and more

Note:
These figures are related to testing 24 hours after mixing of the clay body.

Table 13.2

Preferred workability range of a clay body

Type of clay body	*Number of times rolled out without reaching rolling out limit*	
	Large to extra large pieces	Medium-large and smaller pieces
Tile body	4–5[1]	6–8[1]
Sculpture body	Around 6-7[1]	8–10
Throwing clay	Around 8	9–12

Note:
[1] *Clay body includes cellulose fibres.*

- Each test should be done without interruption.
- Execute the test three times and take the average.

Table 13.1 can be used for reading the results.

13.2.3 Determining workability range

The test for plasticity can also be used to determine the workability range of a specific type of clay body. *Table 13.2* can be used for reading the results. With this test one can also find out the influence storage has on the workability range; storing the clay for several weeks could increase the number of times of rolling out before the limit is reached by up to two (see also section *2.8 Storing*).

13.2.4 Determining shrinkage

With the aid of a test tile the linear drying and firing shrinkage of a clay body can be determined. Also, the vitrification, the porosity, and an indication of frost resistance and the expansion rate of the body can be achieved.

Figure 13.7
A test tile in different stages of completion.
(Photo: Anton Reijnders)



Making a test tile

To make a test tile the following requirements are needed:

- A piece of (newsprint) paper measuring 7 × 15 cm (3 × 6 in.)
- A piece of plywood measuring at least 7 × 19 cm (3 × 7½ in.).
- 140 g (4.9 oz) of a clay body with 'sticking margin consistency' rolled in a roll of 13 cm (5 in.). The clay body is allowed to rest for at least 24 hours after preparation. For calculation reasons the weight should be fairly exact.

Figure 13.7 shows how a test tile is made. The piece of paper is positioned on the plywood. The 13 cm (5 in.) roll is placed in the middle of the paper. Then the roll is flattened with the thumbs from the centre outward towards each end. The roll is then flattened evenly from the centre to the sides. The tile will

eventually measure approximately 7 × 15 cm (3 × 6 in.). During making, unwanted spreading of the tile is prevented by holding a finger (with the fingernail pointing downward) at the paper's edge, and irregularities in thickness can be levelled with the fingertips. Edges and corners will be somewhat rounded, which is preferable as it will prevent pieces from breaking off during tests making the test results more accurate and reliable (especially when determining porosity). Experience shows that smoothing the surface increases the chance of warping. So, for this reason, one should refrain from this. **NB:** The way the test tile is made has a big influence on the final drying shrinkage, therefore the tiles should be made each time in a similar way.

Linear drying and firing shrinkage

To determine the shrinkage the following requirements are needed:

- A tape measure, or flexible steel ruler. This allows the measuring of the inside of the curve of a warped tile.
- Newsprint and sheet plastic.
- A kiln, for determining drying shrinkage, preferably one that can be kept at a steady 45°C (113°F).
- A hygrometer.

To determine linear shrinkage, the test tile is marked immediately after being made. A diagonal line is made in the tile with the aid of a ruler. This line is marked at a right angle in two places 15 cm (6 in.) apart: this is the initial length. Make sure the marks are as sharp as possible, allowing accurate measuring. For optimal accuracy the distance between the marks should be as great as possible, so 15 cm (6 in.) is preferable to 10 cm (4 in.). Also, a code should be scored into the tile to be able to tell the different tiles apart.

Determining the **linear drying shrinkage** is basically a simple matter but establishing it in an accurate and reliable way is surprisingly demanding. This is because many variables contribute to the ultimate amount of shrinkage. The following aspects are particularly important:

- Careful observation of the sticking margin.
- Allowing the same amount of time between preparation of the clay body and making the test tile.
- The same method of making and drying the tiles should be used each time.
- The moment of measuring the tile is decisive: some clay bodies show a certain re-expansion, as a result of which shrinkage could reduce at the last stage. The distance between the marks is best measured when the tile is not cold to the touch any more.
- The average of several shrinkage tests provides a more reliable outcome.

Drying can be done in two ways: leaving the tile in a room with a relatively stable temperature and humidity, or placing it in a kiln. The latter means a considerable saving of time, as in the kiln, drying time is 6 to 10 hours; outside, it could take 4 to 8 days. This duration is partly dependent on the plasticity of the clay body, and in regard to using a kiln, on the number of tiles dried simultaneously.

Drying outside the kiln is preferably done in a place where the temperature is reasonably steady (i.e. not directly in the sun or near a heat source). The outcome is most accurate if the environmental temperature does not fluctuate too much (no more than

±2°C (4°F) at an average of 21°C/70°F)) and if the tiles are dried in the same place each time. To achieve a more constant drying speed the tiles are covered. The way of covering is determined by the humid conditions. For example: if the relative humidity is 85% or above, the tile need not be covered; if it is between 75% and 85%, a layer of newsprint will do; if it is between 50% and 75%, the tile should be covered with two layers of newsprint; if it is 50% or less, a sheet of thin plastic is put over one layer of newsprint. These layers should cover the tile generously. The distance between the marks is best measured at the moment the tile has become light in colour and is no longer cold to the touch.

If **drying** is carried out **inside a kiln**, dry the same number of test tiles each time, and preferably use the same kiln. The tiles are placed in the upper part of the kiln and the temperature is kept at a steady 45°C (113°F) for at least 6 hours.[5] The distance between the marks is best measured at the moment the tile has become light in colour and is no longer cold or damp to the touch.

The following calculation yields the drying shrinkage:

$$\frac{\text{initial length} - \text{length after drying}}{\text{initial length}} \times 100 = \text{drying shrinkage}$$

For example:
The initial length was 15 cm; length after drying is 14.3 cm.

$$\frac{15\text{ cm} - 14.3\text{ cm}}{15\text{ cm}} \times 100 = 4.67\%\text{ linear drying shrinkage}$$

Table 13.3 can be used for reading the results. As mentioned before, the sticking margin consistency of the clay body, the way of making and the drying method all affect the outcome.

The test tile can also be used to determine the **linear firing shrinkage**. Before the tiles are fired, record the distance between the marks as described before. It is important that the tiles are fired in the same way as the final work, i.e. with the same firing speed and if applicable a similar soaking time at maximum temperature. After the tiles have been fired, the distance between the marks is measured again. If a tile is warped, it is best to measure the inside of the curve with a tape measure.

The following calculation yields the firing shrinkage:

Table 13.3

Linear drying shrinkage of plastic clay bodies

Type of clay body	*Total drying shrinkage*	*Proper application of the clay body*
Throwing clay	4.5–6.5%	For small pieces a shrinkage up to 6.5% is ok, for medium-large pieces the shrinkage should preferably be less than 5.5%.
Sculpture body	3.5–5.5%	For small pieces a shrinkage up to 5.5% is ok, for large pieces the shrinkage should preferably be less than 4.5%.
Tile body	Not more than 4%	For small tiles a shrinkage up to 4% is ok, for large tiles the shrinkage should preferably be less than 3.5%.

$$\frac{\text{distance before firing} - \text{distance after firing}}{\text{distance before firing}} \times 100 = \text{firing shrinkage}$$

For example:
The distance before firing was 14.3 cm, after firing it is 13.5 cm.

$$\frac{14.3\text{ cm} - 13.5\text{ cm}}{14.3\text{ cm}} \times 100 = 5.59\%\text{ linear firing shrinkage}$$

The **total shrinkage** cannot be determined by simply adding drying shrinkage and firing shrinkage! The following calculation yields the firing shrinkage:

$$\frac{\text{Initial length} - \text{length after firing}}{\text{Initial length}} \times 100 = \text{total linear shrinkage}$$

For example:
The initial length of the tile was 15 cm, after firing it is 13.5 cm.

$$\frac{15\text{ cm} - 13.5\text{ cm}}{15\text{ cm}} \times 100 = 10\%\text{ total linear shrinkage}$$

13.2.5 Vitrification point

The **vitrification point** can be determined by firing a set of test tiles to a range of different temperatures. Placing the test tiles in the hottest and coldest part of the kiln and also placing one test tile in a saggar at the coldest part could be used as a start. Pyrometric cones should be set near to the test tiles to determine the firing temperatures. The firing temperature is then marked on the test tile. When firing shrinkage within the series stops, this indicates that the vitrification point is reached. An increase in size indicates that at the given temperature the vitrification point has been passed.

13.2.6 Vitrification, porosity and frost resistance

With the aid of the test tile, vitrification can be determined. This provides an indication as to the porosity of the body, and whether it is waterproof and possibly frost resistant. **NB:** For a reliable outcome it is important that the tile is fired the same way as the final work, i.e. at the same firing speed and if applicable the same amount of soaking at the maximum temperature.

Requirements:

- Demineralised water at ± 20°C (70°F) (for instance water used for a car battery)
- A saucepan approximately 16 cm (7 in.) in diameter
- A grid
- A scale with an accuracy to 0.1 g
- A sponge.

In order to be able to determine an indication about vitrification, porosity and frost resistance the fired test tile is weighed under three conditions:

A. Determine weight after the test tile has been kept in a kiln at 110°C (230°F) until it maintains a constant weight. Usually this will take at least 1.5–2 hours.

B. Determine weight after submerging in water for 24 hours. The tile must be submerged in demineralised water at ±20°C (70°F). Place a grid or something similar in

Table 13.4
Vitrification/readily absorbed water

Percentage readily absorbed water: ***D***	*Property of fired body*
More than 6.5%	Low vitrification
4.5–6.5%	Moderate vitrification
2–4.5%	Vitrification well under way
2% or less	Vitrified

Table 13.5
Porosity

Percentage absorbed water: ***E***	*Property of fired body*
6.5–10%	High porosity
4.5–6.5%	Moderate porosity
2–4.5%	Low porosity, body is possibly waterproof
2% or less	Non porous: the body is waterproof

the pan, to prevent direct contact with the bottom. The test tile must be submerged by at least 2 cm (¾ in.). If more than one tile is tested simultaneously, they should not be placed directly on top of each other; placing a (metal) spoon or something similar between them will create sufficient room. Before determining the weight, the tile is cleared of any excess water by patting it with a slightly moist sponge.

C. If porosity and frost resistance are to be determined the test tiles should be weighed after submerging for two hours in demineralised boiling water. The tiles should be positioned in the same way as described under B. Place a lid on the pan to limit evaporation, and add boiling water from time to time to avoid the water level becoming too low. Then allow the sample to cool down by submerging it in water at a temperature of 20°C (70°F) for two hours. Pat it dry with a slightly damp sponge, then weigh.
A = Dry weight **B** = Wet weight **C** = Boiled weight

In order to find out the degree of **vitrification** the following calculation has to be used:

$$\frac{\mathbf{B} - \mathbf{A}}{\mathbf{A}} \times 100 = \mathbf{D} \text{ (readily absorbed water)}$$

For example:
The weight of a test tile as determined under A (dry weight) is 120.2 g. The weight as determined under B (wet weight) is 128.5 g. The percentage of readily absorbed water is:

$$\frac{\mathbf{B} - \mathbf{A}}{\mathbf{A}} \times 100 = \mathbf{D} \qquad \frac{126.4 - 120.2}{120.2} \times 100 = 5.2\%$$

See *Table 13.4* for reading the results.

To determine the **porosity** of the body the following calculation has to be used:

$$\frac{\mathbf{C} - \mathbf{A}}{\mathbf{A}} \times 100 = \mathbf{E} \text{ (absorption)}$$

For example:
The weight of a test tile as determined under A (dry weight) is 120.2 g. The weight as determined under C (boiled weight) is 129.2 g. The percentage of water absorbed is:

$$\frac{\mathbf{C} - \mathbf{A}}{\mathbf{A}} \times 100 = \mathbf{E} \qquad \frac{129.2 - 120.2}{120.2} \times 100 = 7.5\%$$

See *Table 13.5* for reading the results.

Table 13.6

Calculated frost resistance

D	*X*	*Conclusions*
< 4.5%	< 0.78	The ratio of fine pores is low, and the body contains a sufficient number of large pores: there is little risk of frost damage.
4.5–6.5%	< 0.78	The test tile contains a sufficient number of large pores. Despite the high ratio of fine pores there is little risk of frost damage.
> 6.5%	< 0.78	The test tile absorbs water too easily: it contains many very fine pores, increasing the risk of frost damage. Raising the maximum temperature could be a solution.
	> 0.78	There is a high risk of frost damage.

Note: this test only gives an indication of the frost resistance. It is a useful method for comparing different clay bodies fired at different temperatures, before the ultimate test is executed in a laboratory of ceramic building materials.

A coarse-grained sculpture body fired to its vitrification point often shows a percentage of readily absorbed water between 4.5% and 2% but a percentage of absorbed water between 6.5% and 4.5%. The percentages of readily absorbed and absorbed water of a fine-grained body show much less difference.

To determine whether a body could possibly be **frost resistant** the following calculation has to be implemented.

$$\frac{C - A}{A} \times 100 = E \qquad \frac{D}{E} = X \text{ (ratio figure)}$$

For example:
The weight of a test tile as determined under A (dry weight) is 120.2 g. The weight of a test tile as determined under C (boiled weight) is 128.6 g. The percentage of water absorbed (D) is: 5.2%. The ratio figure is:

$$\frac{C - A}{A} \times 100 = E \qquad \frac{128.6 - 120.2}{120.2} \times 100 = 6.9\%$$

$$\frac{D}{E} = X \qquad \frac{5.2\%}{6.9\%} = 0.74$$

See *Table 13.6* for reading the results.

13.2.7 Determining the expansion rate

A test tile can also be used to obtain a rough indication of whether a clay body has a low, average or high expansion rate. The tile should be biscuit fired first to Cone 6 (1200°C/2192°F, firing speed: 60°C (140°F)/hour) after which it is glazed with a lead bisilicate glaze frit, see *Table 13.7*, in four partly-overlapping layers. The fourth layer should be approximately 0.5 mm thick in the unfired state, the first layer should result in a glaze layer after firing that still shows the structure of the body. Use the flat (back) side of the tile. The glazed tile is fired to Cone 04 (1050°C/1922°F), firing speed: 60°C (140°F)/hour, no soaking). **NB:** the firing

Table 13.7

Lead bisilicate frit for expansion test

P2950 (Potterycrafts)	1 PbO	0.086 Al_2O_3	1.86 SiO_2

Note: If not available, use a frit coming as close as possible to this unity formula, especially the aluminium oxide:silica ratio. Adding 0.5% quartz and 1% aluminium oxide to lead bisilicate frit 3647 will yield a similar result.

Table 13.8

Rough indication of the expansion rate of a fired body

Crazing	*Indication of expansion*	*Suitability of the clay body*
Crazing when taken from the kiln	Low expansion rate	Very suited for making large tiles and sculptures
Crazing after being refired to 140°C (284°F) and submerged in water	Average expansion rate	Suited for making up to medium-large sized work
No crazing after being refired to 140°C (284°F) and submerged in water	High expansion rate	Suited for functional work

temperatures should be followed within ± 15°C (60°F). The test tile is taken from the kiln at a temperature below 150°C (300°F). After the test tile has cooled down, it is refired to 140°C (284°F), soaked for 10 minutes and then submerged in water. *Table 13.8* provides an indication of the expansion rate.

13.2.8 Drying crack resistance

Drying crack resistance is a term used in the EKWC. It is the ability of a clay body to resist tensile stress during drying. Tensile stress may occur as a result of uneven drying; as a result of unevenly divided tension in certain forms (in most cases complex or rectangular forms and tiles); and as a result of pressure exerted on the bottom of large work, preventing shrinkage in that area. The greater a clay's ability to resist tensile stress the better suited it is for the construction of large and/or complex work. This testing method, which was developed by the author, simulates tensile stress in a work during drying.

To test the drying crack resistance of a clay body, a mould is made as shown in *Figures 13.8* and *13.9*.[6] The length of the plaster mould is 52 cm (20½ in.)and the dimensions of the inner form are 1.9 cm × 1.9 cm (¾ in. × ¾ in.). The angle at the ends is 12°. Prior to usage the new mould must be completely dry (this will normally take three to four days) and each time the mould should be similarly dry (weighing and marking the weight on top of the mould will give an indication of the state of dryness).

To fill the mould, 600 g–700 g (1¼ lb–1½ lb) of a clay body (with sticking margin consistency) is used. A roll of clay 50 cm (20 in.) long is rolled out. The roll should be slightly thicker towards the ends than in the middle, and flattened somewhat (to just under 2 cm/¾ in.), to make it fit into the mould. The roll is pressed into the mould with

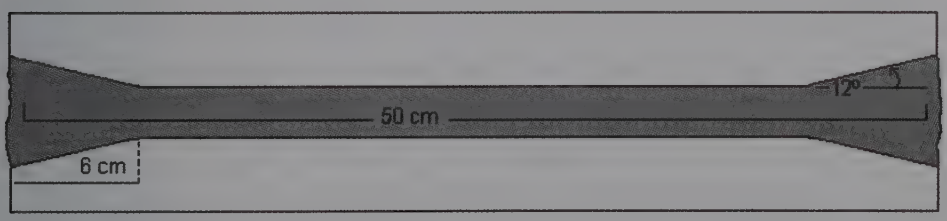
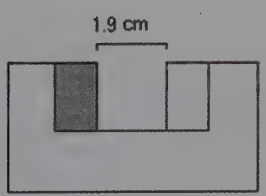
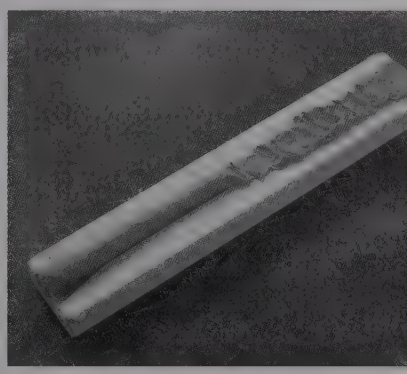


Figure 13.8
Dimensions of a drying crack resistance mould.
(Figure: Anton Reijnders)





Right:
Figure 13.9
The filling of the drying crack resistance mould.
(Photo: Anton Reijnders)

the thumb by exerting a slight downward pressure. The pressing is done from the middle outward, one side at a time (see *Figure 13.9*), holding it lightly at the opposite end to keep it from sliding. The method of filling the mould affects shrinkage, so it should be done the same way each time.

The drying must be gradual and even, i.e. the mould should not be in a draught, or be dried near a heat source or in direct sunlight. Quick and uneven shrinkage will greatly affect the outcome. The following measures can be taken to ensure an even drying speed:

- Measurements are most accurate if the environmental temperature does not fluctuate too much (no more or less than 2°C (4°F) from an average of 21°C (70°F).
- Humidity also affects drying speed. If the humidity (indicated by a hygrometer) is 85% or more, the form can be dried in the open. If the humidity is between 85% and 70%, the form should be covered with one layer of newsprint. Between 70% and 50% the form is best covered with two layers of newsprint. In the case of less than 50% humidity, one layer of newsprint and a thin sheet of plastic should be applied. The layers should amply cover the form to prevent air from entering in through gaps.
- Drying a test body should preferably be done in the same place each time.
- Draughts can be prevented by putting the mould into a shallow cardboard box (left open at the top).

Table 13.9

Drying crack resistance in a 12°[1] mould

Cracks through and through	Clay body is not suitable for large and complex work if it has a dense structure.[2] A clay body with an open and coarse grain size structure can be used if even drying conditions are provided.
Surface cracks	Clay body is suitable for large work. For complex work, creating even drying conditions is important.
No cracks	Clay body is very suitable for making large and complex work. The work will be less sensitive to uneven drying conditions.

Note: 1 See Figure 13.8.
2 See section 13.2.10 Determining the structure of a clay body.

For reference: in the case of a sculpture body with an average plasticity it takes 5 or 6 days before the clay body visibly changes in colour shade (see section *13.2.2 Determining plasticity*). Cracks usually occur at the moment the body is at the leatherhard-brittle stage (when a visible impression can be made with the fingernail only if a lot of pressure is exerted; a line drawn with the fingernail is sharp), or at the dark stage (a line drawn with the fingernail is crumbly at the edges and clay dust occurs). *Table 13.9* can be used to interpret the outcome.

The drying crack resistance can be improved considerably if the grain size structure is optimally packed and especially by adding cellulose fibres.

13.2.9 Grain size analysis

Smaller grains filling the spaces between the larger ones will result in a higher density of the clay body: as the packing becomes more optimal, drying and firing shrinkage will decrease. In addition, the surface will allow smooth finishing (see also *Figure 2.2*) Testing of the optimal packing of the clay body can be done through a grain analysis and comparing this with the Litzow curve. A grain size analysis can also be used for determining the structure of a clay body.

The Litzow curve

The German researcher Litzow has shown that optimal packing is determined by a specific ratio between the various grain diameters. *Table 13.10* shows the relation between specific grain sizes, with 1 indicating the largest diameter. *Table 13.11* shows an example of ideal grain size structure if 0.5mm is taken as the maximum grain size.

Table 13.10

Ideal grain size ratio according to Litzow

100%	smaller than 1
89%	smaller than ⅛
78%	smaller than ¾
67%	smaller than ⅔
56%	smaller than ½
45%	smaller than 1/10
33%	smaller than 1/20

Table 13.11

Ideal grain size distribution if the largest grains are not larger than 0.5 mm

0.5 mm	100%
0.4 mm	89%
0.3 mm	78%
0.2 mm	67%
0.1 mm	56%
0.05 mm	45%
0.025 mm	33%

In *Diagram 13.1* the series of *Table 13.11* is shown in a curve: **Litzow curve**, 0.5 mm. In practice the Litzow curve cannot be followed strictly, as this would not leave any space for plastic components. Research at the EKWC has shown that following the ratio of grains more or less down to 0.1 mm will represent a packing that yields a very reliable clay body.

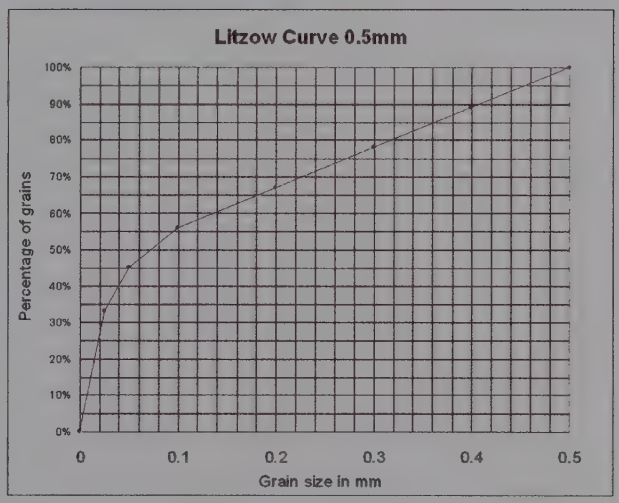


Diagram 13.1

Executing a grain size analysis

A grain size analysis can be carried out on an existing clay body, or on the ingredients, especially grog or Molochite, that will make up the intended clay body. In the method described below grain size can only be determined roughly. Inaccuracy of the sieves and a slightly different way of sieving will lead to variations in results. However, this method does provide adequate information.

To be able to determine the grain size distribution, a series of sieves with gradually decreasing mesh sizes is required. *Table 13.12* shows a possible series of sieves and a comparison of three different sieve codes.

To determine the grain size structure of a clay body, first the fine clay particles are separated from the non-plastic components and then the remainder is dried and sieved. (Dry sieving is needed; wet sieving will lead to a totally different outcome.)

Requirements:

- A dried and ground clay body (at room temperature), with lumps not exceeding 3 mm (pulverising should be done carefully, see below).
- A series of clean and dry sieves with decreasing mesh sizes (see *Table 13.12* for comparative values of various sieve types). The largest grain present in the clay body will determine the number of sieves required

Table 13.12

Types of sieve

	Types of Sieve		
Mesh size in mm	*Great Britain Mesh#*	*USA (ASTM)*	*DIN*
2.0 mm	8's	10	2
1.18 mm	14's	16	1,18
0.71 mm	22's	25	710
0.5 mm	30's	35	
0.425 mm	36's	40	425
0.25 mm	60's	60	250
0.125 mm	120's	120	125
0.075 mm	200's	200	75

for the test: if the maximum grain size is 0.5 mm, the 0.5 mm sieve and smaller mesh size should be used. Sieves with a metal or plastic frame are preferred. Ideally, laboratory sieves that fit into each other.
- A scale with a minimum accuracy of 0.1 g.
- A 500 ml graduated cylinder.
- Water.
- Sodium silicate 140° TW[7] (water-glass).
- A power drill fitted with a screw propeller (not a hand blender, as this would make the particles smaller, thus affecting the outcome), see *Figure 13.10*.
- A kiln shelf (without coating, or use the un-coated side).
- A kiln which can be kept at a constant 45°C (113°F).
- A fine-dust respirator.
- Newsprint.
- Scraper.
- A stiff brush.

Separating plastic and non-plastic components

To separate the fine particles from the grains, first add 1 g sodium silicate to the graduated cylinder followed by 400 ml of water. (Putting in the sodium silicate first allows for adjustment if too much is added by accident.) Mix thoroughly. The dried and ground clay body is then added. However, if the clay body has been heated in order to dry it, it must first cool down to room temperature. It may be necessary to expose it to the air for several hours until as much water has been absorbed as is usually present in the clay body at room temperature. The clay body should not be added in lumps larger than 3 mm, as this may result in an inappropriate separation of the fine and coarse particles, therefore grinding should be done carefully. If a mortar and pestle is used, the lumps should be gently ground by pressing and not by vigorous pulverising: as this would make the particles smaller, affecting the outcome.

The mixture is stirred for one minute (with a power drill fitted with a screw propeller) and left for ten minutes, thoroughly mixed again for one minute, then left for 2 hours. These actions allow the sodium silicate to interact with the clay and help the separation of non-plastic components. Before continuing, the mixture is thoroughly mixed again for one minute. After this the liquid part is poured off carefully, and if during pouring the bottom layer begins to come close to the rim of the measuring jug the pouring should be stopped. The settled part still contains plastic components, so to separate these components 400 ml of water and 1 g of sodium silicate is added to this sediment. After thoroughly mixing for one minute and allowing the mixture to settle for one minute the liquid part is poured off. The sediment is then poured onto the uncoated side of a kiln shelf. The residue in the cylinder is scraped out as thoroughly as possible and added to this. Kiln shelf, graduated cylinder and scraper are dried for at least two hours in a kiln at 45°C (113°F) (the residue should be dry and powdery). The dried parts are scraped from the scraper over a sheet of newsprint. The measuring jug is brushed clean with a stiff brush, after which the brush is stripped of clay dust also over the piece of newsprint. These residues are all combined with the dried sediment from the kiln shelf. All actions should be carried out carefully to ensure that all residues are collected with minimum loss. The whole is weighed and the outcome is recorded.

NB: It is necessary to wear a dust mask during scraping, weighing and sieving, as inhaling the released dust is hazardous to the health.

Sieving

The sieves used should be dry and clean and the sieve with the largest mesh size is used first. Using a stiff brush the grains are sieved over a layer of newsprint. For each sieve, the sieving should take approximately six minutes. Sieving is finished when only very few grains still fall on the pages. (To observe whether substantial amounts of grains are still passing through the sieve the page should be emptied over another sheet of newsprint.) All grains are collected on this sheet of newsprint, and both sieve and brush can be shaken out over it as well. Everything must be done with utmost care to limit any loss. Watch for grain residue in the sieve. Tapping the handle of the brush against the side of the sieve will loosen any grains that are stuck.

The weight of the contents of the sieve and the size of the sieve are recorded. Alternatively, it is possible to weigh the sieve and the brush in advance, and weigh all again after sieving with the residue remaining in the sieve. By subtracting the first weight from the second, the weight of the residue alone can be determined. This method is repeated with the dry material being taken through ever-finer sieves. Each time the contents and the size of the sieve are recorded. Finally the weight of the grains that go through the 0.075 mm sieve is recorded. All components are now put in a percentage ratio.

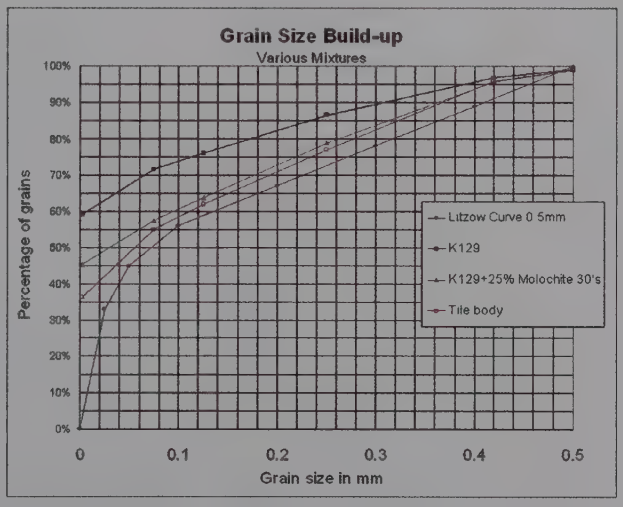
For example:
A grain analysis has been made of a ready-to-use sculpture clay body K129 with a reported grain size of 0–0.5 mm. The outcome after sieving is:

In sieve 0.71mm	0.0 g remains	
In sieve 0.425mm	0.7 g remains	
In sieve 0.25mm	10.5 g remains	
In sieve 0.125mm	10.5 g remains	
In sieve 0.075mm	4.3 g remains	
Pass through sieve 0.075		14.6 g
Total:		40.6 g
Calculated remains 100 – 40.6	=	59.4 g

Next the percentage ratio can be calculated:

100% – 0%	=	100%	0.71mm
100% – 0.7%	=	99.3%	0.425mm
99.3% – 10.5%	=	88.8%	0.25mm
88.8% – 10.5%	=	78.3%	0.125mm
78.3% – 4.3%	=	74.0%	0.075mm
74.0% – 14.6%	=	59.4%	0.002mm*
59.4% – 59.4%	=	0%	0mm

* 0.002mm or 2µm is the theoretical upper limit for plastic components.



If put in a diagram this makes a comparison with the Litzow curve possible, see *Diagram 13.2*. Diagram 13.2

The Litzow curve and the development of a recipe

The Litzow curve can be used as a base for determining which grog or Molochite grain sizes should be added, and in what amount. *Diagram 13.2* shows that the K129 clay body deviates far from the optimal packing. This indicates that this body is not very

Table 13.13

Grain analyses of Molochite

Aperture size of the sieves	*Molochite 30*	*Molochite 80*	*Molochite 120*
0.5 mm	98%		
0.425 mm	92%		
0.25 mm	54%	100%	
0.125 mm	24%	56%	95%
0.075 mm	11%	25%	86%

suited for making large tiles. Having a grain size analysis of different grades of Molochite and other possible fillers helps to determine how much, and possibly which combination of different grades, could be added to come close to an optimal packing. *Table 13.13* shows the grain size analyses provided by the manufacturer. To calculate and to visualise the effect of additions a computer spreadsheet program can be used. *Diagram 13.2* shows a comparison of K129, K129 with an addition of 25% Molochite, and a tile body mixture (40% MTR-clay, 50% Molochite 30, 5% of Molochite 120 and 5% nepheline syenite). By implementing a grain size analysis in conjunction with the determination of plasticity and drying shrinkage, as described above, a reliable tile body can be developed.

13.2.10 Determining the structure of a clay body

The structure of a clay body largely governs its possible applications, and how the work should be dried and fired. In *Table 13.14* the various structures are compared. Comparing the outcome obtained from determining the plasticity and grain size analysis to this table can provide insight into which category the clay body will fit. **NB:** A clay body with a grain size build-up fitting a dense structure should be considered to have a very dense structure if its plasticity exceeds the indicated maximum.

Table 13.14

Structure of a clay body

	Open structure		
	Fine grained	*Medium fine grained*	*Coarse grained*
Grain size build-up	30% or more between 0.125 mm and 0.075 mm (120's–200's)	30% or more between 0.425 mm and 0.125 mm (36's–120's)	15% or more larger than 0.425 mm (36's) and 10% or more between 0.425 mm and 0.125 mm (36's–120's)
Plasticity[1]	4–6	max. 8	max. 9

	Dense structure			
	Very fine grained	*Fine grained*	*Medium fine grained*	*Coarse grained*
Grain size build-up	All less than 0.075 mm (200's)	15–20% between 0.125 mm and 0.075 mm (120's–200's)	15–20% between 0.425 mm and 0.125 mm (36's–120's)	9–12% larger than 0.425 mm (36's) and 5–10% between 0.425 mm and 0.125 mm (36's–120's)
Plasticity[1/2]	max. 4	max. 6	max. 8	max. 9

Notes:

[1] See section 13.2.2 Determining plasticity.

[2] If plasticity exceeds the indicated maximum the structure is considered to be very dense.

13.3 Testing a casting slip

Because a casting slip requires a very delicate equilibrium between clay body composition, deflocculant and water, to determine the optimal ratio is essential to find the best balance. The following methods to determine viscosity, thixotropy and slop weight will help to find this optimal balance. These methods can also be used to adjust a casting slip if casting faults occur. **NB:** Paper fibres are not added when determining the optimal ratio between the clay body, water and deflocculant.

13.3.1 Casting body:water:deflocculant ratio

The following requirements and ingredients are needed to determine the optimal ratio of casting body:water:deflocculant.

- A scale with an accuracy of 0.1 g, or preferably 0.01 g. The scale preferably being equipped with a tare to be able to compensate for the weight of the container.
- A 3 litre (5.3 pints) container with lid.
- A power drill with a mixing blade, see *Figure 13.10*.
- A spoon.
- 1100 g (38.7 oz) of powdered casting clay.
- Water at 20°C (70°F) (± 1°C/2°F).
- Sodium silicate 140°TW (water-glass).
- Sodium carbonate (soda ash) diluted in the water mixture: 10 g (0.4 oz) of sodium carbonate mixed with 30 ml (1.1 fl.oz) of hot water.
- Fine dust respirator.
- Paper and pencil.

The amount of water as well as the type and amount of deflocculant to be added is largely determined by the specific ingredients used. A casting slip consisting mainly of kaolin will need more water, and generally only sodium silicate is needed to obtain the necessary deflocculation. A mixture containing other types of clay, like HTR-clay or T-MTR-clay, will also need sodium carbonate to be added. Sodium carbonate is especially useful if a clay contains organic materials; it increases the density of the cast.[8]

Preparing a casting slip test

First add the amount of deflocculant(s) (as indicated in *Table 13.15* under *Starting amounts*) to a 3 litre (5.3 pints) container. Adding the deflocculant first allows for adjustment if too much is put in by mistake. Next add the starting amount of water, followed by the casting clay body then stir the mixture well. (**NB:** Wear a respirator!) Stirring is done with the aid of the power drill mixer. Next the sodium silicate is added in additions of ±0.5 g. After each addition the mixture should be thoroughly stirred and each addition is recorded. The change in consistency of the mixture should be closely observed: it will go from a thick creamy phase, to a more fluid stage. As soon as the surface of the mixture becomes smooth its fluidity should be checked regularly by observing the way the slip runs from a spoon that is being held at an angle of 45°. If the slip runs off with difficulty and a lot is still gathered at the tip of the spoon, more sodium silicate can be added. The additions should now be limited to 0.15 g each time. As soon as the slip begins to run off the spoon, the addition of sodium silicate should stop. If, in the case of **porcelain** or **vitreous china**, the slip has not reached this stage after the indicated maximum addition of sodium silicate, water should be added in steps of

Table 13.15

Casting slip test

Starting amounts		*Max. addition*		
		Sodium silicate	*Sodium carbonate/ water mix*	*Water*
1000 g Porcelain	0.6 g Sodium silicate 401 g Water	2.4 g	–	86 g
1000 g Vitreous china	0.5 g Sodium silicate 0.75 g Sodium carbonate/ water mix 382 g Water	2 g	–	19 g
1000 g Earthenware/ Stoneware[1]	0.5 g Sodium silicate 0.5 g Sodium carbonate/ water mix 355 g Water	1 g	1 g	46 g

Note:
1 Very little or no kaolin present in the body.

10 g (0.4 oz) each time up to the indicated maximum. After each addition and thorough stirring the fluidity is checked and the addition is recorded. In the case of **stoneware** or **earthenware** first the sodium carbonate/water mixture is added in steps of 0.25 g. If after adding the maximum indicated amount the slip is still not fluid enough, water is added in steps of 10 ml (0.3 fl. oz) each time. After reaching sufficient fluidity or when the maximum additions have been added, the slip should be allowed to stand for 24 hours before the viscosity, thixotropy and, ultimately, the slop weight are checked. This standing time is necessary for the interaction of the clay minerals, water and deflocculant.

Determining viscosity and thixotropy

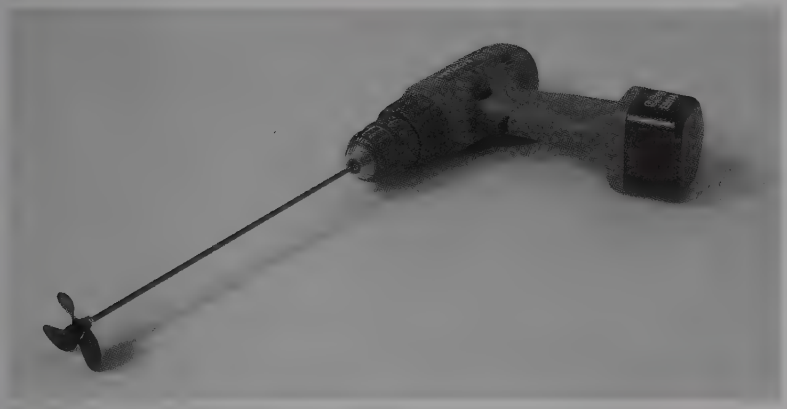
Testing the viscosity and thixotropy of the slip provides information about how much the casting clay:water:deflocculant ratio has to be altered to achieve optimal casting properties. Once the 24-hour resting period is complete the viscosity and thixotropy can be determined. The following items will be needed:

- A funnel that holds 250 ml of liquid and has a hole of 6 mm (¼ in.). The top part of a plastic bottle can be used for this, See *Figure 13.11*. The volume level of 250 ml should be marked all around.
- A bucket.
- A power drill with a mixing blade, see *Figure 13.10*.
- A stopwatch.
- Paper and pencil.

Viscosity is determined by measuring the time it takes for the slip to pass through the funnel. Thixotropy is determined by relating that first timespan with the time it takes for the slip to pass through the funnel again after a 5 minute delay.

The following principles are important while testing the viscosity and thixotropy of a slip:

- The slip should be 20°C (70°C) (±1°C/2°F).





LEFT:
Figure 13.10
A power drill with a mixing blade: a propeller used for ship models is very useful as a mixing blade for mixing small quantities. (Photo: Anton Reijnders)

RIGHT:
Figure 13.11
Example of a funnel used to determine viscosity and thixotropy. A 6 mm (¼ in.) hole is drilled in the cap. (Photo: Anton Reijnders)

- Stirring should be done in the same way each time; the data provided in *Table 13.16* are based on stirring for one minute at moderate speed. While mixing, air inclusion should be avoided: immerse the mixing blade deeply and adjust the mixing speed.

After stirring, the casting slip is poured into the funnel up to the 250 ml mark while one finger blocks the opening. The funnel should be held over the bucket to catch the slip. The time it takes for the slip to drain from the funnel should be recorded and is noted down as **Viscosity 1**. The stopwatch should be kept running as the slip has to pass through the funnel again after exactly 5 minutes. In the meantime the bucket should be covered to avoid the evaporation of water and the funnel should be cleaned and dried. About 3 minutes before the second draining is due to start the slip is poured gently into the funnel once again. Filling earlier or later, and more or less agitation will influence the result. After exactly 5 minutes the finger is pulled away from the hole in the cap. The time it takes for the slip to run through the funnel is recorded. **Viscosity 2** is calculated by subtracting 5 minutes from the last recorded time.

Thixotropy is calculated as follows:

$$\frac{\text{Viscosity 2} - \text{Viscosity 1}}{\text{Viscosity 2}} \times 100 = \textit{Thixotropy}$$

Table 13.16

Correction of the casting slip

Viscosity	*Calculated Thixotropy*	*Corrections*
Too high: more than 40 seconds	Too high: more than 25	Add sodium silicate
	Average: 15–25	Add water
	Too low: less than 15	Add clay powder and extra water
Average: between 25 and 40 seconds	Too high: more than 25	Add sodium silicate and clay body
	Average: 15–25	–
	Too low: less than 15	Add clay powder and water
Too low: less than 25 seconds	Too high: more than 25	Add sodium silicate and clay body
	Average: 15–25	Add clay body
	Too low: less than 15	Add clay powder and water

Note: Determining the necessary corrections is only done 24 hours after the slip was prepared. It is also advisable to perform a test cast to achieve the right casting properties.

Example:
It took 34 seconds for the slip to run through the funnel the first time. The second recorded time is 6 minutes and 17 seconds. However, this also includes the 5 minutes of preparation.
Viscosity 2: 6 minutes and 17 seconds – 5 minutes = 1 minute and 17 seconds = 77 seconds.

$$\frac{77 - 34}{77} \times 100 = 55.8$$

Table 13.16 can be used to correct the viscosity and thixotropy. **NB:** Only small additions should be done at a time. Each addition should be recorded and the mixture stirred as indicated previously. By adding up all additions the first indication of a recipe can be established.

Casting test

To fine tune viscosity and thixotropy in order to achieve the right casting properties, a test cast should be carried out. A small-sized (max. volume 200 ml) good quality casting mould (see section *5.5.1 Optimal water-absorbing properties*) can be used provided that it is completely dry, or a specially made two-sectioned casting mould can be used, see *Figure 13.12*. Before testing, the mould should be dried (a newly-made mould should be allowed to dry fully, see also section *5.7 Drying moulds*). After the mould is dry the mould sections are weighed. With a marker the weight is recorded on each mould section. Each time the mould is used the weight of the mould should be close to the original weight (clean off traces of casting clay before weighing). The slip at 20°C/70°F (±1°C/2°F) should be stirred for one minute with a power drill equipped with a mixing blade; avoid creating and blending in air bubbles. The following time intervals should be observed:

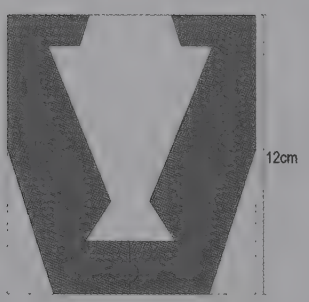


Figure 13.12
A cross-section of a test mould.
(Figure: Anton Reijnders)

Porcelain
After 5 minutes the slip should be drained
After 10 minutes the mould is reversed
After 10 minutes de-moulding takes place.

Vitreous china
After 15 minutes the slip should be drained
After 30 minutes the mould is reversed
After 30 minutes de-moulding takes place.

Earthenware/Stoneware (very little or no kaolin present in the body)
After 30 minutes the slip should be drained
After 30 minutes the mould is reversed
After 30 minutes de-moulding takes place.

The information provided in *Table 13.17* will provide extra clues for adjusting the casting slip. **NB:** The additions of deflocculant at this stage should be very small to avoid 'over doping' (a quantity of deflocculant beyond the optimal causing the slip to become viscous again).

When an HTR-clay or T-MTR-clay are the main clay ingredients, small amounts of a polyacrylate type of deflocculant (like Dolapix PC 67, Darvan 811 or Darvan 7) could be added to effectively reduce the thixotropy of this type of casting slip.

Table 13.17

Casting faults related to an improper balance of slip

Viscosity	*Casting faults*	*Thixotropy*	*Casting faults*
Too high (low fluidity of slip)	No visible casting faults, possibly details show less clearly, build-up of wall takes more time.	Too high (fast firming up of slip)	Fast build-up of wall, draining is more difficult. Roping (uneven surface on the inside of the cast). Cast deforms during de-moulding, and drying of the cast takes more time.
Too low (high fluidity of slip)	In the case of multi-sectioned moulds: slip could seep through. Pin-holes on the surface.	Too low (it takes a long time before the slip firms up)	Slow build-up of wall, brittle cast: cutting off the spare is more difficult. Fast drying of the cast.

Slop weight

The slop weight[9] is the weight of a specific volume of slip. Because the weight of 1000 ml (35.2 fl. oz) of water is 1000 g (35.3 oz) and the weight of 1000 ml increases accordingly as clay is added, the slop weight provides a practical indication of the water/clay relationship and as such indicates the **density** of a casting slip. Each casting slip has an optimal water:clay powder ratio that will lead to the best possible result.

Determining slop weight

The following requirements are needed to determine the slop weight:

- A scale (preferably with an accuracy within 0.1g).
- 500ml (17.6 fl. oz) graduated measuring cylinder.
- If the scale is not equipped with a tare (the ability to compensate for the weight of the cylinder by resetting at zero), the weight of this graduated cylinder should be determined and recorded on the cylinder with a marker. The cylinder should be clean and dry before the actual weighing.
- To determine the slop weight the slip should be 20°C (70°F) (±1°C/2°F). It should be sieved (sieve size 0.25 mm/60's) and thoroughly stirred for one minute. The slop weight, viscosity and thixotropy should be determined 24 hours after the slip has been prepared.
- The slip should have a similar temperature each time. Stirring should also be done in the same way each time.

Next the graduated cylinder is filled up to the 500 ml mark plus ±1mm to compensate for the curved surface of the slip. The weight of the empty graduated cylinder subtracted from the weight of the filled cylinder is the slop weight. In principle the slop weight should be within the figures provided in *Table 13.18*. A lower or higher slop weight than indicated will generally result in an increased risk of casting faults occurring. A casting slip suited for medium-sized pieces should preferably have a higher density, meaning a litre weight of 1760–1800 for porcelain, 1810–1820 for vitreous china and 1830–1850 for stoneware and earthenware.

Table 13.18

Slop weight ranges of casting slip

Type of casting slip	*Weight in grams of 500 ml*	*Litre weight*
Porcelain	860–900	1720–1800
Vitreous china stoneware	900–910	1800–1820
Stoneware and earthenware *	900–925	1800–1850

*Note: * Main clay ingredients HTR-clay and/or T-MTR-clay*

13.3.2 Overview on casting faults

A whole range of casting faults can occur. Besides a less than optimal ratio between all ingredients, these faults could also be linked to the mould's inadequate absorption and/or the way the slip has been mixed, poured and drained. Storing the casting slip for too long can also lead to casting faults. *Table 13.19* provides an overview as well as some advice on how to overcome these faults.

Table 13.19

Possible causes and remedies of casting faults

Faults	*Possible causes*	*Visible effects*	*Remedies*
The settling of heavy particles	Viscosity is too low	High fluidity of slip	Increase clay content
	In the case of porcelain; too low plasticity		Add HTR-clay (5%)
The build-up of sufficient wall thickness takes a long time	Viscosity is too low	High fluidity of slip	Increase clay content
	Thixotropy is too low	It takes a long time before the slip firms up	Reduce sodium silicate content
Livering (jelly-like as well as viscous slip)	Contamination with plaster due to excessive recycling of casting scraps	Jelly-like as well as viscous slip	Do not add more than 20% of casting scraps
The casting slip cannot be drained easily from the mould (especially noticeable in the case of moulds with small pouring holes)	Thixotropy is too high	Slip firms up readily	Increase sodium silicate content
Roping	Thixotropy is too low	It takes a long time before the slip firms up and there is an uneven surface on the inside of the cast	Reduce sodium silicate content and increase sodium carbonate content to avoid high viscosity
	Insufficient stirring of casting slip	Uneven surface on the inside of the cast	Stir well before casting
	Viscosity is too high	Low fluidity of slip and uneven surface on the inside of the cast	Increase water content
	Premature turning of the mould after draining	Uneven surface on the inside of the cast	The mould should remain upside down for a longer period of time after draining
	Long storage of casting slip or too much recycled casting slip.	Low fluidity of slip	Prepare new batch of casting slip
Cast releases while draining the slip	Viscosity is too low	High fluidity of slip	Increase clay content
	Viscosity is too high due to long storage of casting slip	Low fluidity of slip	Prepare new batch of casting slip
	Vacuum is created during draining	Cast deforms while still in the mould	Slower draining
Cracks develop in areas where sections meet	Thixotropy is high	Slip firms up readily	Increase sodium silicate content
	Thixotropy is low	Slip does not firm up readily	Reduce sodium silicate content
	In case of porcelain; too low plasticity		Add HTR-clay (5%) or Bentone EW (0.2%)

Table 13.19 continued

Faults	*Possible causes*	*Visible effects*	*Remedies*
Cast deforms during handling	Thixotropy is too high	Slip firms up readily	Increase sodium silicate content
	Over doping	Slip firms up readily and viscosity is high	Increase clay and water content
	Casting slip has been stored over a long period of time		Prepare new batch of casting slip
	Mould too wet		Dry the mould
	Mould absorbs water insufficiently		Replace the mould
Pin-holes on the surface and/or on the inside of the cast	Improper mixing causing air bubbles to become mixed in	Pin-holes in the cast that could result in pin-holing in the glaze or the formation of pockets in a vitrified body	Slow down last part of mixing. Stir more slowly over a longer period of time (up to 24 hours)
	Viscosity is too high	Low fluidity of slip	Increase water content
	Too fast pouring in combination with a low viscosity	Small pin-holes are formed on the surface	Slow down pouring, increase water content, use less deflocculant
	Wet mould	Larger pin-holes are formed on the surface	Dry mould sufficiently
Lines on the mould side of the cast	Viscosity is too high and thixotropy is too low	Low fluidity of slip, firming up of slip is slow and lines follow the flow of the slip	Increase water content. Reduce sodium silicate content and increase sodium carbonate content to avoid high viscosity
	The slip has been poured too slowly or with a pause	Horizontal lines on the cast	Continuous but steady pouring
Cast is very brittle	Thixotropy is too low	It takes a long time before the slip firms up and the cast is difficult to cut or fettle	Reduce sodium silicate content
Flashing or casting spot (noticeable during glazing where the body does not absorb)	Thixotropy is too low	It takes a long time before the slip firms up	Reduce sodium silicate content
Casting spot (noticeable during glazing where the body does not absorb)	Where the slip hits the mould a deviation in slip composition occurred	Where the slip hits the mould the body is more vitrified resulting in discoloration in the biscuit and/or less absorption in areas during glazing	Reduce pressure in the spot where the slip hits the mould. The mould should spin during pouring

13.3.3 Shrinkage, vitrification and porosity

To determine the shrinkage during drying and firing and the absorption of the body after firing, a test tile has to be cast. *Figure 13.13* shows an example of a plaster mould that could be used.

A mark made in the mould allows the shrinkage to be measured. **After de-moulding** a code should be scratched into the tile to identify it. Calculating the drying and firing shrinkage, vitrification, porosity and expansion rate is done in a similar way, as discussed in previous sections under *13.2 Testing a clay body*.

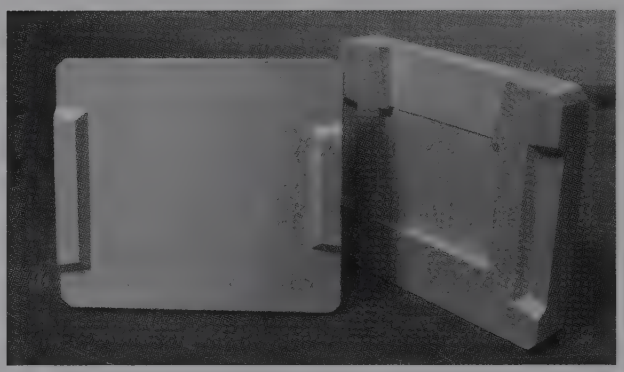


Figure 13.13
Mould for determining shrinkage and water absorption.
(Photo: Anton Reijnders)

13.4 Testing a plemp body

Determining the right ratio of clay body:water:deflocculant is also essential for a plemp body. Only by doing this will the plemp body be easy to spread and the fine detail in the mould show on the surface of the piece. Also a good adhesion between the added layers will be achieved and premature separation from the mould will be avoided. Extra drying shrinkage will also be prevented and it will take less time before the piece can be removed from the mould. To determine the right plemp body:water:deflocculant ratio use a similar procedure to that described in *Preparing a casting slip test* in section *13.3.1 Casting body:water:deflocculant ratio*. However, the addition of the deflocculant(s) should stop as soon as a very thick creamy phase has been achieved. Because the optimal consistency depends in part on the absorption of the mould, the final attuning should be done by spreading the plemp body in the mould to be used. A highly absorbent plaster mould should be made damp first. Step-by-step, deflocculant is added until the desired quality of impression is achieved and the plemp body can be spread easily. Each time the consistency is judged, another part of the mould should be used.

Notes:

1 An example of such a mineral is hectorite. Plasticisers like Bentone EW contains hectorite. VeegumT also contains minerals of the smectite group.

2 Illite transformed from muscovite will have less magnesium and iron atoms in its mineral structure, as compared to illite transformed from biotite.

3 Do not use plaster meant for master and case moulds as the absorption will be insufficient.

4 Getting some practice first in rolling is recommended. It should take approximately 9 times of rolling before the length of 15 cm (6 in.) is reached.

5 Some kilns show a large deviation in temperature; placing test tiles at different positions will result in a range of temperatures.

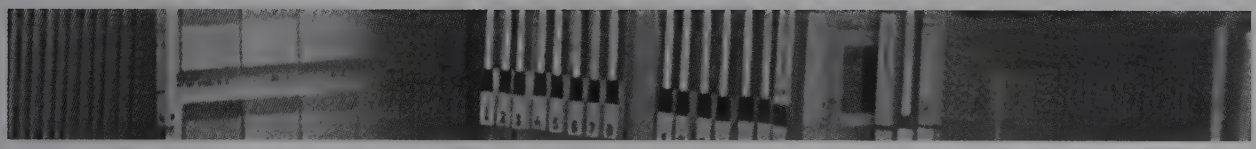
6 See section *5.2.1 Plaster* for directions on how to achieve the best water-absorbing properties in combination with strength.

7 140°TW (Twaddle) indicates the relative density of the sodium silicate.

8 Glasson, N.P. and Forbes, N.R., *Clay systems for improved performance* (CFI, DKG, No.3, 2001).

9 Also referred to as litre weight: the weight of one litre of slip.

14 Advanced section: Glaze



In this chapter the molecular structure of glazes will be discussed in more detail. This will help in understanding the make-up of a glaze and its behaviour during fusion. If a studio-made glaze is formulated some testing will be inevitable. A method of testing will be discussed in more detail as well as a way to determine viscosity, surface tension and glaze fit.

14.1 What is a glaze?

In order to understand the properties of a glaze one has to get a closer look at the process of breaking down the molecular structures of the ingredients used and the formation of new molecular structures during firing.

Ceramic materials have a lattice structure: they are composed of a regular structure of molecules also referred to as a crystalline structure. Fired to a high enough temperature the regular lattice structure gradually breaks down and becomes less regular due to the intermolecular vibration.[1] Parts of the molecules connected to the structure break loose and react with other molecules, some volatise and turn into a gas that will escape. At a certain temperature the liquid state is entered and no clear molecular structure exists. As the liquid is allowed to cool down the intermolecular vibration slows down again, but the newly formed molten material does not return to a regular crystalline state again as would be expected. Due to the presence of quartz (SiO_2), the liquid melt reacts differently; after cooling, an amorphous structure will be preserved. To understand this we have to take a closer look at the behaviour of quartz during melting and cooling. As



Tony Cragg (England/Germany), *Cathedral, Meteor, Chair*, 1996. Ht: (ceramic part) 110 cm (43 in.). This piece was modelled solid using a coarse sculpture clay and hollowed out at the leatherhard stage. A chrome red glaze was applied containing mainly red lead and chromium oxide. It was fired to a low temperature (800°C/1472°F). Due to its high toxicity red lead is no longer available as a base glaze material in most countries.
Collection: Local council, 's-Hertogenbosch, The Netherlands.
(Photo: Peer van der Kruis)

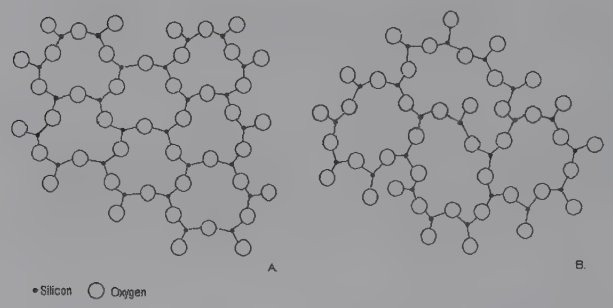


Figure 14.1
Diagram of (A) quartz = lattice structure (crystalline state), (B) silica glass = amorphous structure. In this image the actual spatial structure has not been taken into account. Adapted from W.G. Lawrence, R.R.West, *Ceramic Science for the Potter*, 2001.

quartz melts, its crystalline structure (*Figure 14.1A*) changes into an amorphous structure (*Figure 14.1B*) with a very high viscosity; it does not flow easily. During cooling viscosity keeps increasing, preventing the formation of a regular lattice structure and silica enters the 'supercooled liquid' state: quartz glass (glass is a solid material with the structure of a liquid). Quartz is therefore called a **glass-former** and is the essential component in a glaze. But quartz melts only at a very high temperature; above 1700°C (3092°F). This temperature is too high for a conventional kiln and a conventional clay body. Therefore, alongside quartz, a flux is always present in a glaze. During fusion a **flux** will 'break open' the amorphous viscous structure of silica (*Figure 14.2B*). As a result the viscosity of glass will decrease considerably; it becomes fluid (hence the use of the name 'flux') at a much lower temperature. Some examples of fluxes are: sodium oxide (Na_2O), potassium oxide (K_2O), lithium oxide (Li_2O) (the strong alkalis). Lead oxide (PbO), calcium oxide (CaO), and barium oxide (BaO) also belong to the fluxes.

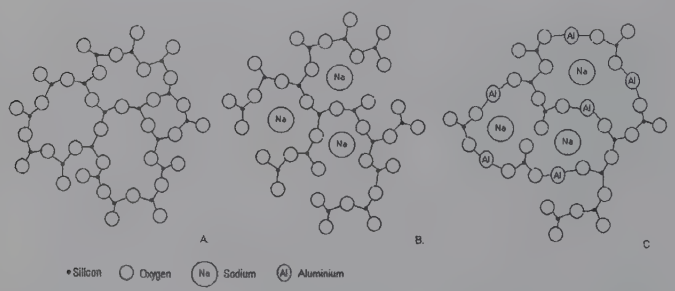


Figure 14.2
A diagram showing the role of the glass-former silica (A), flux sodium oxide (B), and stabiliser aluminium oxide (C). In this image the actual spatial structure has not been taken into account. Adapted from W.G. Lawrence, R.R.West, *Ceramic Science for the Potter*, 2001.

A mixture consisting solely of fluxes and silica will tend to be very fluid and runny within a short temperature range. Certain oxides are capable of stabilising the structure, because they fill up parts of the structure that have been broken open, as a result the melt will be less runny and much more stable within a longer temperature range. Aluminium oxide (Al_2O_3) plays an important role as a **stabiliser**, see *Figure 14.2C*. In the right proportion it ensures better interaction among all components of the glaze. There are also oxides that are considered to assume the role of a flux as well as a stabiliser, for example zinc oxide (ZnO).

Boron oxide (B_2O_3) is also considered to have a combination of functions: acting as a glass-former, it is supposed to assume the role of stabiliser as well. Although it is formally not a flux, boron oxide also contributes to the lowering of viscosity, due to its very low melting point.

So a glaze will be composed of materials that introduce the oxides as mentioned above in such a proportion that the right balance between glass-formers, fluxes and stabilisers will yield the desired melting behaviour at the intended firing temperature.

14.2 Testing glazes and (sinter) engobes

To obtain a glaze or (sinter) engobe with the desired properties, such as surface quality or colour at a certain temperature, one of the recipes provided in the previous chapters or from another source can be taken as a starting point. Often a recipe does not give the desired result from the beginning. One of the most important reasons why differences occur is because materials with the same name from different suppliers can have variations in composition. The following is a list of ingredients divided into three groups according to the degree of composition variations.

- The first group consists of fairly purified materials that generally show only small variations; hence differences in the final result will often be hardly noticeable.

Lithium carbonate, quartz, industrially-prepared zinc oxide, whiting, barium carbonate and Molochite belong to this category. Also colouring oxides belong to this group.

- The second group of materials like kaolin, clay, nepheline syenite, Cornish stone, petalite and wollastonite tend to have dissimilarities. Due to geological conditions these materials can show variations in molecular composition that could lead to noticeable differences in the final result. Also less-purified zinc oxide and colouring oxides could also lead to noticeable differences in the final result.
- The third group is made up of glaze frits and ceramic pigments. Obtained from the same manufacturer these materials will usually be of a constant quality, but using an alternative frit or pigment from different manufacturers could lead to unpredictable results.

14.2.1 Glaze calculation

Glaze calculations can be carried out before mixing and testing a recipe. Glaze calculation will make it possible to achieve fairly similar results despite using materials from another source, provided the chemical makeup of their ingredients is known. One gains information on how to alter the glaze recipe to produce a similar molecular composition as the initial recipe. As such, glaze calculation will potentially reduce the number of tests needed. To be able to calculate the ultimate analysis or unity formula of the ingredients at hand, especially for the ingredients of the second and third group, the percentage analysis or unity formula has to be known as well as the percentage analysis or unity formula of the initial glaze recipe. The percentage analysis of the ingredients can be obtained from the manufacturer or supplier.[2] **NB:** Ask for current information. For ingredients of the first group available data is generally sufficient. The percentage analysis and unity molecular formula of the ingredients used in this book are given in *Appendix 1, Tables A1* and *A2*.

There are certain restrictions to glaze calculation one should be aware of from the beginning. In glaze calculations, oxides are viewed separately and it is necessary to know the source ingredient of each oxide; for example the amount of K_2O, Na_2O, Al_2O_3 and SiO_2 in a specific glaze. The use of potash, soda ash, aluminium oxide and quartz will not yield similar results if nepheline syenite is used although according to the calculations the ratio of oxides match.[3] The same is true for CaO and SiO_2. Wollastonite replaced by whiting and quartz will yield different results. If a recipe is to be recalculated, first of all, it is advisable to use similar ingredients to those in the original glaze recipe, or greater differences should be expected. Of course, the accuracy of the percentage analysis will determine the usefulness of the calculation as well.

Calculation can be tedious. A computer with either a spreadsheet program or glaze calculation software is a very useful tool.[4] A lot of ceramic handbooks discuss the theory of glaze calculation. See *Appendix 3 Glaze calculation software* and *Appendix 2 Further reading* for some examples of computer software, and handbooks related to glaze calculation. After calculation, testing is still needed to find out how the glaze actually behaves.

14.2.2 Line blend

If a recalculated recipe does not yield the required result, testing (small) variations of the ingredients could be the next step. The 'line blend' method can be used to establish the best variations of a recipe. A line blend is a proportionate blending of two mixtures in several steps. An important advantage of this type of testing is that it saves work. It is not necessary to weigh out all the ingredients (including pigments and glaze additives)

each time, this is only necessary for the two original mixtures (A and B). Besides finding the best way to reconstruct a recipe, line blends are of special interest to a more systematic research on materials. A line blend can be used for research in four different ways:

1. Research on the effect one specific ingredient will have on the properties of a glaze: in this case, all ingredients in A and B are similar, except one specific ingredient in mixture B which is present in a higher amount.
2. Researching the effect on the properties by exchanging two ingredients: in this case, A and B contain the same ingredients in similar proportions except two ingredients.
3. Researching the effect on the properties by adding an ingredient that is not yet present in either recipe: in this case, A and B are similar except one ingredient.
4. Finding out how the blending of two random glaze recipes A and B will behave. 1 and 2 are the most useful to reconstruct an existing glaze recipe with the materials at hand.

A line blend should involve four or more mixings of A and B (including pure samples of each unblended). In general, a line blend of four to six steps will generate sufficient information. The differences between the recipes of A and B can be small or large. Small differences are implemented if a specific glaze recipe is to be tested, large differences are used to develop a new recipe.

An example of a line blend of four mixtures (see *Table 14.1*) will be discussed below. In this example, for a test tile with a surface area of approximately 9 cm^2, 6 g of glaze is needed (including inevitable leftovers in container and brush). It is recommended to perform at least a double series of tests to obtain valuable information on how the glaze will react to variations in temperature in the kiln. Therefore 24 g of mixture A and 24 g of mixture B have to be weighed. **NB:** A scale should be used with an accuracy of 0.01 g. If this is not available, the figures should be increased (see *Table 8.27* for an indication on the accuracy of the scale). As a lot of repeated calculation is involved a computer spreadsheet program will be very useful.

Table 14.1

Example of a four-step line blend

	A			B	
	1	2	3	4	
A	100%	66.6%	33.4%	0%	
B	0%	33.4%	66.6%	100%	
A	12 g	8 g	4 g	0 g	total 24 g **A**
B	0 g	4 g	8 g	12 g	total 24 g **B**

	A			B	
	1	2	3	4	
Calcium borate frit 3221	10%	11%	12%	13%	Calcium borate frit 3221
Nepheline syenite	50%	52%	54%	56%	Nepheline syenite
Quartz	24%	24%	24%	24%	Quartz
Wollastonite	16%	13%	10%	7%	Wollastonite
Total	100%	100%	100%	100%	
+ 0.5% Copper oxide				+ 0.5% Copper oxide	
+1% Tin oxide				+1% Tin oxide	
+ Addition of glaze additives				+ Addition of glaze additives	

After the line blend tests are prepared, each mixture is added in three partially overlapping layers on a test tile. In this way the relation of glaze layer thickness and its effect on colour, opacity, pin-holing and running will be seen on the fired test tile. *Figure 14.3* shows an example of the line blend as shown above.

Because colouring oxides and pigments do have an impact on certain glaze characteristics, for example fusion and viscosity, stains should be included from the beginning when developing a new recipe. To limit the amount of testing during the investigation of a base glaze or (sinter) engobe, a specific range of pigments and colouring oxides could be used that will have a clear influence on the properties: red pigments (of the Zr–Si–Cd–S–Se or the bright red type) will show the tendency of pin-holing, Prussian blue (of the Co–Al–Zn type) will show the tendency of a glaze to turn more

matt, and aubergine pigments (of the Cr–Sn–Ca–Si type) will show whether a tendency of colour changes will occur if zinc oxide is present. Copper oxide will reduce viscosity and shows clearly the influence of the fluxing and matting agents on coloration. Obviously, the development of a special glaze requires the use of a particular colouring oxide from the beginning.

NB: Because the way of firing and cooling determines the outcome, the most reliable results are obtained if the firing cycle of the test tiles is the same as the final firing. This advice is more important to keep in mind if the test tile and final firing are done in different kilns. As stated before, a double series test – one placed at the coldest part, the other at the hottest part– will yield valuable information about the temperature tolerance of the glaze. In the case of large temperature differences in the kiln (more than 20°C/70°F) a third series, placed at the spot having the average temperature, could be considered as an option. If one is interested to repeat the results, it is important to use cones, see section *11.2.3 Temperature registration*. For easy study after firing, the test tiles can be glued to a board, see *Figure 14.4*.





Top:
Figure 14.3
A four-step line blend applied on one test tile.
(Photo: Anton Reijnders)

Above:
Figure 14.4
Test tiles glued to a board provide a clear overview.
(Photo: Peer van der Kruis)

14.2.3 Testing surface tension and viscosity

A combination of high surface tension and high viscosity could lead to several glaze faults like crawling and pin-holing. For determining the surface tension and viscosity and their relationship with the glaze layer thickness, the following method can be used. Mix the glaze using the same glaze additives and amount of water to be used for the final piece. Apply the glaze in three different partially overlapping layers on a test tile (same body and biscuit temperature as will be used for the final piece). Use a soft brush. The thickest layer should be 1mm thick, measured when the layer is dry. After the glaze has been allowed to dry, make a fine groove straight down to the body with a sharp thin-bladed knife (not into the body). The test tile is then fired in the same way it would normally be fired. The extent to which the groove is still visible after firing provides the desired information.

Indication of viscosity

Very high viscosity: all three layers are clearly visible as well as the brush marks.
High viscosity: all three layers are clearly visible, in the place where the layers overlap a rounding but no flowing occurred.
Fair amount of viscosity: all three layers are still visible and a slight flowing occurred on the third layer.
Moderate viscosity: all three layers are somewhat visible and flowing occurred on the third layer.
Low viscosity: flowing occurred in all three layers.

Indication of surface tension

High surface tension: at the bottom of the groove the body is visible and the glaze layer at either side of the groove thickened.
Fair amount of surface tension: the groove has closed but is still visible.

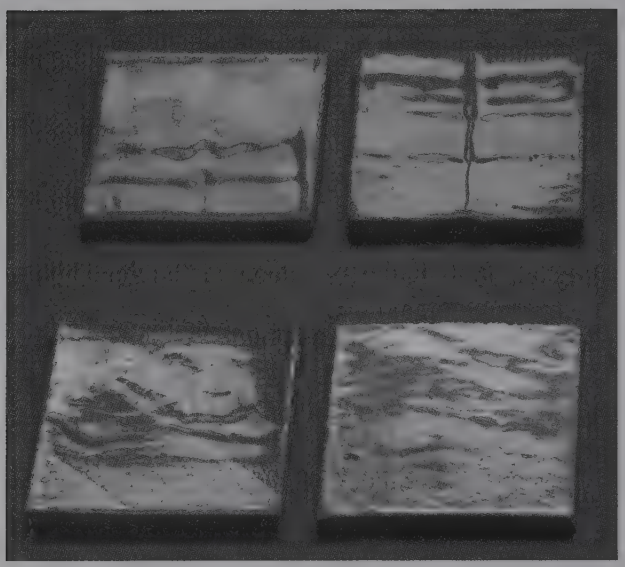


Figure 14.5
Test tiles showing the degree of surface tension and viscosity. The top row shows a lead-free glaze pure (top left) and with zirconium silicate (top right) and the bottom row shows a high-lead glaze pure (bottom left) and with zirconium silicate (bottom right). The lead glaze shows a very low viscosity and surface tension even with zirconium silicate.
(Photo: Anton Reijnders)

Moderate surface tension: the groove has disappeared; a mark can be seen only on the surface of the thinnest layer. **Low surface tension:** no trace of the groove is visible.

A combination of high viscosity and high surface tension would call for measures as discussed in *Crawling* under *11.5.3 Glaze faults related to viscosity and surface tension*. A glaze showing indications of moderate to low viscosity and surface tension will not be subject to crawling. However, if there is grease or dust on the surface the glaze could still crawl.

14.2.4 Determining tendency of crazing

Due to **absorption of moisture** into the fired body or due to re-heating of the piece a slight expansion occurs. If the expansion rate of glaze and body are fairly similar, even this slight expansion could disturb the balance and the glaze could start to craze. It could take days, months or even years before crazing occurs. To find out whether a glaze has a tendency to craze on a specific body the **Hartkort Test** can be carried out.

A test tile is made in the same manner as the final piece: it is made of the same body, biscuit fired in a similar way, applied with the same glaze layer thickness on one side and glaze fired and cooled in the same way. This test tile is then heated to successively higher temperatures: 140°C, 160°C, 180°C, 200°C and 220°C (284°F, 320°F, 356°F, 392°F, 428°F). The tile should be held at each temperature for 15 minutes and then submerged in water. **NB:** Use tongs!

Each firing and submerging provides an indication of how long it will take before the glaze will begin to craze: if crazing occurs after firing to 140°C (284°F), crazing is likely to occur after one week under normal conditions; if it crazes after being fired to 220°C (428°F) it will take more than three years (if at all) for crazing to occur naturally. If no crazing occurs after the fifth cycle of firing and submerging, the chance of crazing is low: the expansion rate of the glaze is lower compared to the body and the glaze has sufficient elasticity. This test could reveal that a temperature increase of 50°C (125°F) during the biscuit firing and/or an increase of 20°C (70°F) at the top temperature during glaze firing could make a difference. Therefore placing a test tile on the lowest and highest positioned kiln shelves during biscuit and glaze firing will provide valuable information.

Notes:

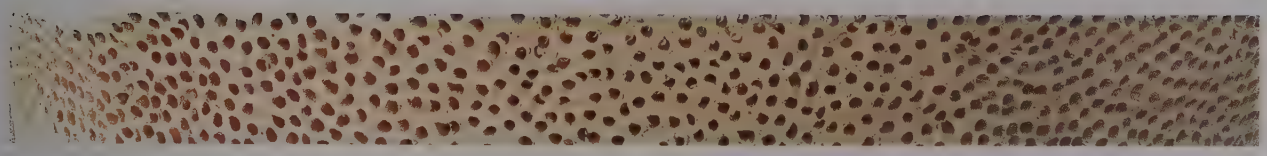
1 Molecules of solids, liquids and gases are subjected to intermolecular vibration. This vibration is different in each material; the intermolecular vibration of a solid is relatively low and of a gas very high.

2 Some frit manufacturers do not provide this kind of information, therefore the use of their frits is not recommended. However, with these data a reconstruction of the recipe is possible.

3 In practice, the Na_2O and K_2O content of nepheline syenite can be considered as one group during calculation; the final result in a fired glaze will show fairly similar results. This will make matching of different kinds of nepheline syenite much easier.

4 Make sure that the glaze calculation software allows entering of data of materials being used.

15 Advanced section: Terra sigillata



In chapter 10, it was pointed out that the right water:clay: deflocculant ratio is essential to obtain a good terra sigillata, and also that no general recipe can be given to obtain this. However, it is possible to determine the right ratio for each type of clay or clay body, and in this chapter a method of determining a recipe will be discussed in more detail.

15.1 Determining a terra sigillata recipe

The following requirements are needed to determine the right water:clay:deflocculant ratio:

- A 100 ml (3½ fl.oz) and a 250 ml (8⅘ fl.oz) graduated cylinder. **NB:** Household measuring cups can be very inaccurate. Filling them with 100 g or 250 g of water respectively and marking the water level, will overcome this inaccuracy (remember to allow for your container when measuring out water in grams).
- Two glass jam jars (with straight sides, as in *Figure 15.1*, and a minimum height of 9 cm/3½ in.) including lid.
- 100 g (3½ oz) of clay powder or pulverised clay body.
- A polyacrylate type of deflocculant. If not available sodium silicate (water-glass) could be used.
- A scale with an accuracy to 0.1 g.

For calculation reasons each empty graduated cylinder (dry and clean) is weighed and the outcome is noted down.[1] Choose one of the most appropriate recipes provided in *Table 10.1* but divide all figures by ten. If no polyacrylate is available sodium silicate can be used instead.

A plastic clay body should be divided into small pieces, dried and ground first, no lumps larger than 3 mm (⅛ in.) should be present. Sieving is not necessary; once prepared with water the heavy particles like grog or quartz will settle to the bottom.

First the deflocculant is added to a 250 ml graduated cylinder (this allows for correction if too much has been added), then water is added and both are stirred well. Next 100 g of dried clay (body) is added. All is stirred well and after five minutes stirred again in order to remove all lumps. The volume of the mixture should be noted down (this is needed for calculation reasons). The mixture is allowed to settle.

15.1.1 Determining the right deflocculant ratio

Observing the sedimentation process will give important information on whether the water:deflocculant ratio is correct. Using a fully transparent graduated cylinder makes



Leiko Ikamura (Japan/Germany), *Die Braut*, 1995. Ht: 197 cm (77 in.). A coiled piece perforated at the plastic-leatherhard stage. Terra sigillata made from HTR-clay was applied by brush on the biscuit-fired piece and fired to the low temperature range. In places where the terra sigillata was applied very thin the colour of the body can be seen underneath. (Photo: Jochen Littkemann, Berlin)

it possible to observe the sedimentation well. If such a cylinder is not available the mixture can be poured into a glass jar (using a glass jar with a lid makes it possible to shake well to ensure all lumps are removed). The amount of deflocculant to be added is determined by the occurrence of a distinct settled layer. If after 20 minutes no clear settled **layer at the bottom** is visible then 0.5 g of extra deflocculant should be added. The mixture is stirred well and left to settle again. If no clear layer becomes visible within 20 minutes the procedure is repeated. No more than 4 g (4%) of a polyacrylate type of deflocculant and 3.5 g (3.5%) of sodium silicate should be used as any higher amounts could tend to counteract settling; the division of the settled layer and the liquid part becomes even less clear. If after the maximum addition no clear layer is visible the clay or clay body is not suited for making terra sigillata. If settling was successful the right water:clay ratio can be determined.

15.1.2 Determining the right water:clay ratio

The mixture is left untouched for a total time of two hours (including the 20 minutes of the possible last addition of deflocculant) and the liquid part is poured off slowly into the glass jar. When, during this operation, the settled part becomes exposed, agitation should be avoided: pouring should be very slow. Sometimes the settled part starts to slide. As it reaches 0.5 cm (¼ in.) from the rim of the glass jar pouring should stop. An absence of a clear division between the liquid part and the settled part could indicate that more deflocculant is needed or that the clay is less suitable. To determine the right water:clay ratio the **slop weight** of the liquid part has to be determined (see *Slop weight* under section *13.3.1 Casting body:water:deflocculant ratio*). Experience shows that the slop weight after settling for two hours should ideally be around 115 per 100 ml. This density will guarantee an optimal separation of the clay particles and non-plastic components. A slop weight higher than 115 indicates that the water content in the initial recipe should be increased. A slop weight lower than 115 indicates that either more clay should be added or the water content should be decreased.

Too high a slop weight

The extra amount of water needed to achieve the ideal slop weight is calculated as follows:

(slop weight of 100 ml terra sigillata – the ideal slop weight) × 6.25* = extra water needed

$$\frac{\text{Volume in ml of initial test blend}}{\text{Volume of blend after syphoning off}} = \text{multiplying factor}$$

Extra water × multiplying factor = the extra water that needs to be added to the initial recipe. For example:
A test blend based on a recipe of 100g dry clay, 180g water and 2g of Dolapix PC 67, results in a volume of ±230 ml. After 2 hours of sedimentation the liquid part is syphoned off and its slop weight turns out to be 122 g.
122 – 115 = 7 then 7 × 6.25 = 43.8 g

$$\frac{230}{100} = 2.3 \qquad \text{and} \quad 2.3 \times 43.8 \text{ g} = 100.7$$

180 + 100.7 = 280.7

The right percentage of water to be added to the clay is: 180 + 100.7 = 280.7%

Too low a slop weight

The amount of clay that has to be added (or to put it differently) the amount of water that has to be decreased to achieve the ideal slop weight can be calculated as follows:

(ideal slop weight – weight of 100 ml terra sigillata) × 1.8* = extra clay needed

$$\frac{\text{Volume in ml of initial test blend}}{100\ (\text{Volume of blend after syphoning off})} = 2.35$$

Extra clay needed multiplying factor = the extra clay that needs to be added to the initial recipe. As stated before, in all terra sigillata recipes the clay content is put at 100% to make comparison possible. This is calculated as follows:

$$\frac{\text{amount of water in initial recipe}}{\text{calculated amount of extra clay + initial amount of clay}} \times 100 = \begin{matrix}\%\text{ of water in} \\ \text{relation to clay}\end{matrix}$$

For example: A test blend based on a recipe of 100 g dry clay, 180 g water and 1 g of Dolapix PC 67 has a volume of ±235 ml. After 2 hours of sedimentation the liquid part is syphoned off and its slop weight is determined; this turns out to be 108 g.

$155 - 108 = 7$ and $7 \times 1.8 = 12.6$

$\frac{235}{100} = 2.35$ and $12.6 \times 2.35 = 29.6$

$\frac{180\text{ g}}{29.6 + 100} = 1.39 \times 100 = 139\%$ = right percentage of water to be added to the clay.

15.1.3 Determining sedimentation time and suitability of clay

A new batch is prepared according to the calculated recipe. If the right water: clay:deflocculant ratio has been achieved, often within ten minutes stripes will become visible (see *Figure 15.1*) showing the coarse grains are separating from the fine particles and forming a sediment. A settling time of three hours is observed (this will ensure that most non-plastic components are settled). The liquid part is then syphoned off and applied on an unfired test tile. The terra sigillata should be applied in three coats using a soft brush. After drying, the gloss can be evaluated. If a moderate gloss can be seen the clay or clay body is very suitable. If no gloss has formed the liquid part should be allowed to stand for between 12 and 24 hours. Then the liquid is syphoned off once more and again three coats are applied on an unfired and dry test tile. If a gloss is obtained the clay or clay body is suitable provided a prolonged sedimentation time is implemented. If still no gloss appears the clay or clay body is not suitable. NB: If sodium silicate is used the first sedimentation time should be extended up to 6 hours. If not enough gloss has developed then the second sedimentation time should be 24 hours.



Figure 15.1
The formation of stripes as heavy particles are settling.
(Photo: Anton Reijnders)

Notes:

1 This will not be necessary if a professional scale is used that compensates for the weight of the graduated cylinder.

* This figure is linked to Brongniart's formula, see section *10.3.1 Determining the dry weight content.*

Appendices



• Appendix 1 •

Unity Formulas and Percentage analyses

Table A1 Unity Formulas

Ingredients	K_2O	Na_2O	Li_2O	CaO	MgO	BaO	ZnO	PbO	B_2O_3	Fe_2O_3	Al_2O_3	SiO_2	TiO_2	*Mol. Weight*
Aluminous ball clay (EOBBY)	0.05	0.01		0.01	0.02					0.03	1.00	2.65	0.04	311.80
Barium carbonate						1.00								197.40
Calcium borate frit 3221 (JM)				1.00					1.00					125.70
Cornish stone P3419*	0.28	0.45		0.26	0.01					0.01	1.02	8.46	0.01	696.90
Kaolin RM 255	0.05	0.01			0.01					0.01	1.00	2.11	0.01	270.80
Kaolin Grolleg	0.06				0.02					0.01	1.00	2.31		285.40
Lead bisilicate Frit 3647 (JM) (10.05)*								1.00			0.05	1.92		343.60
Lithium carbonate			1.00											73.90
Molochite	0.05				0.02					0.02	1.00	2.20	0.01	242.80
Nepheline syenite RM 094 (Canada)	0.22	0.72		0.05	0.01						0.98	4.32		427.90
Nepheline syenite (North Cape)	0.40	0.53		0.07							0.98	3.91		421.40
Petalite	0.03	0.06	0.85								1.00	8.28		638.20
Quartz												1.00		60.10
Whiting				1.00										100.10
Wollastonite	0.01			0.92	0.07						0.01	0.87		109.30
Zinc oxide							1.00							81.40

Note:
** (Old code.)*

Table A2 Ultimate analyses

	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	B_2O_3	CaO	MgO	BaO	ZnO	PbO	Li_2O	Na_2O	K_2O	Igneous loss
Aluminous ball clay (EOBBY)	51.00	32.70	1.00	1.30		0.20	0.30					0.20	1.50	11.80
Barium carbonate								77.70						22.30
Calcium borate frit 3221 (JM)					55.40	44.60								
Cornish stone P3419*	72.95	14.89	0.02	0.13		2.06	0.05					4.02	3.83	2.05
Kaolin RM 255	46.88	37.65	0.09	0.88		0.03	0.13					0.21	1.60	12.53
Kaolin Grolleg	49.00	36.00	0.05	0.75		0.06	0.30					0.10	1.85	12
Lead bisilicate frit 3647 (JM) (10.05) *	33.56	1.48								64.96				
Lithium carbonate											40.44			59.56
Molochite	54.50	42.00	0.07	1.00		0.06	0.31					0.10	2.00	
Nepheline syenite RM 094 (Canada)	60.60	23.30				0.70	0.10					10.40	4.80	0.70
Nepheline syenite (North Cape)	55.70	23.70				0.90						7.80	9.00	2.90
Petalite	78.00	16.00				0.30	0.10				4.00	0.60	0.50	0.50
Quartz	100.00													
Whiting						56.02								43.98
Wollastonite	47.81	0.65	0.20	0.03		47.15	2.66					0.28	0.05	1.17
Zinc oxide									100.00					

*Note: * (Old code.)*

Table A3 Alternative frits

Lead bisilicate frit	K_2O	Na_2O	CaO	PbO	B_2O_3	Al_2O_3	SiO_2	Mol. weight
3647 Johnson Matthey (NL)				1.00		0.05	1.92	343.60
P2950 Potterycrafts (GB)				1.00		0.086	1.86	343.70
2261 Potclays (GB)				1.00		0.086	1.86	343.70
Ceraflux Hammond (USA)				1.00		0.03	1.95	343.4
353/768 Mondré & Manz (Germany)				1.00		0.10	1.50	328.5
Calcium borate frit	K_2O	Na_2O	CaO	PbO	B_2O_3	Al_2O_3	SiO_2	Mol. weight
3221 Johnson Matthey (NL)			1.00		1.00			125.31
P2268 Potclays (GB)			1.00		1.50	0.097	0.609	207.10
P2960 Potterycrafts (GB)			1.00		1.50	0.097	0.609	207.10
3134 Ferro (USA)		0.317	0.683		0.63		1.475	190.6
M9152 Mondré & Manz (Germany)			1.00		1.00	0.11	0.15	145.90

Appendix 2 • Further reading

Suggested further reading

Bailey, Micheal, *Glazes Cone 6 - 1240°C/2264°F* (A&C Black, London, 2001)

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Consulted Writings

Besides the above-mentioned books the following Books and Articles have been consulted:

Books

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Articles

Carty, William, M., *Glass phase composition in porcelains and correlation with pyroplastic deformation* (Whitewares and Materials, Ceramic Engineering and Science Proceedings, Vol. 24, Issue 2, 2002, p.108, The American Ceramic Society)

Cizer, S., Terra sigillata: A sintered slip in use since antiquity (*Tile & Brick Int.*, No 4, 1994, Volume 15)

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Wolber, J., Keramische Technologie für Meister, *Einfürung in die*

Appendix 3 • Glaze calculation software

- Insight: www.digitalfire.com
- Matrix: www.matrix2000.co.nz

Appendix 4 • Suppliers list

Specialist Materials, Producers and Suppliers

Bentone EW Elementis Specialties, UK (producer/distributor); Johnson Matthey, The Netherlands (importer)
Calcium borate frit 3221 Johnson Matthey, The Netherlands (producer)
Cornish stone P3419 Potclays, UK (distributor)
Darvan 811 and *Darvan 7* R.T. Vanderbilt, Co. Inc., USA (producer)
Dolapix PC 67 Zschimmer & Schwarz, Germany (producer); WBB Fuchs, Germany (distributor); Pemco Corp., USA (importer)
Extruded batts and extruded supports Dyson Ceramic Systems (Kiln furniture), UK (producer)
Flax fibres (min. amount 1 kg) Keramikos, The Netherlands (distributor)
Flax fibres (min. amount 100 kg) Devalin NV, Belgium (producer)
Grolleg Imerys UK (producer, formerly ECC); Imerys Minerals, Belgium (importer); Imerys, USA (importer)
High alumina oxide containing bars Gimex (distributor)
High velocity burner computerised gas kilns Blaauw Products BV, The Netherlands (producer)
Intense orange and red pigment Johnson Matthey, UK and USA, The Netherlands (producer)
Lead bisilicate frit 3647 Johnson Matthey, The Netherlands (producer)
Molochite 30/80/120/200 Imerys, UK (producer, formerly ECC); Imerys Minerals, Belgium (importer); Imerys, USA (importer)
Mulcoa® 47: 35/100 mesh C-E Minerals, USA (producer)
Optapix KG 25 Zschimmer & Schwarz, Germany (producer); WBB Fuchs, Germany (distributor); Pemco Corp. USA (importer)
Plastic keys Wolbring, Germany (distributor)
Porous hose for mould air pressure system WBB Fuchs, Germany (distributor)
Precious metal lustres Johnson Matthey, The Netherlands (producer)
SISiC bars Gimex, The Netherlands (distributor)
SiC bars (Silit® SK) Saint-Gobain Ceramics, USA (producer)
Stellmittel ZS Zschimmer & Schwarz, Germany (producer); WBB Fuchs, Germany (distributor)
Veegum T R.T. Vanderbilt, Co. Inc., USA (producer)

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info@hammondlead.com

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info@wbbfuchs.com

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Nel Linssen The Netherlands
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Andrew Lord Great Britain/USA
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Rachel Lucas Great Britain
Hieke Luik The Netherlands
Sander Luske The Netherlands
Catharine Mägel USA
Sheila Makhijani India
Herman Makkink The Netherlands
Mark Manders The Netherlands
Andar Manik Indonesia
Raul Marroquin Columbia/The Netherlands
Mireya Masó Mas Spain
John Maters The Netherlands
Danae Mattes USA
Walter McConnell USA
Kathleen McFarlane Great Britain
Vincent McGourty Great Britain/The Netherlands
Bruce McLean Great Britain
Pascal Meccariello Dominican Republic
Marika Meershoek The Netherlands
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Jim Melchert USA
Monica de Miguel Rubio Spain/The Netherlands
Victor Mira Spain/Germany
Lee Mitchell Great Britain
Trees De Mits Belgium
Sachiko Mizoguchi Japan/Italy
Hanna Mobach The Netherlands
Ulrike Möntmann Germany/The Netherlands
Tatiana Montoya Colombia
Mrinalini Mukherjee India
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*NB: Numbers in bold refer to extensive text on a subject, while numbers listed with a * means it may also appear in a table or chart.*

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Class No.	738 REI
Acc. No.	5403000215419
Date Rec	4/06
Invoice No.	

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THE EUROPEAN CERAMIC WORK CENTRE (EKWC)

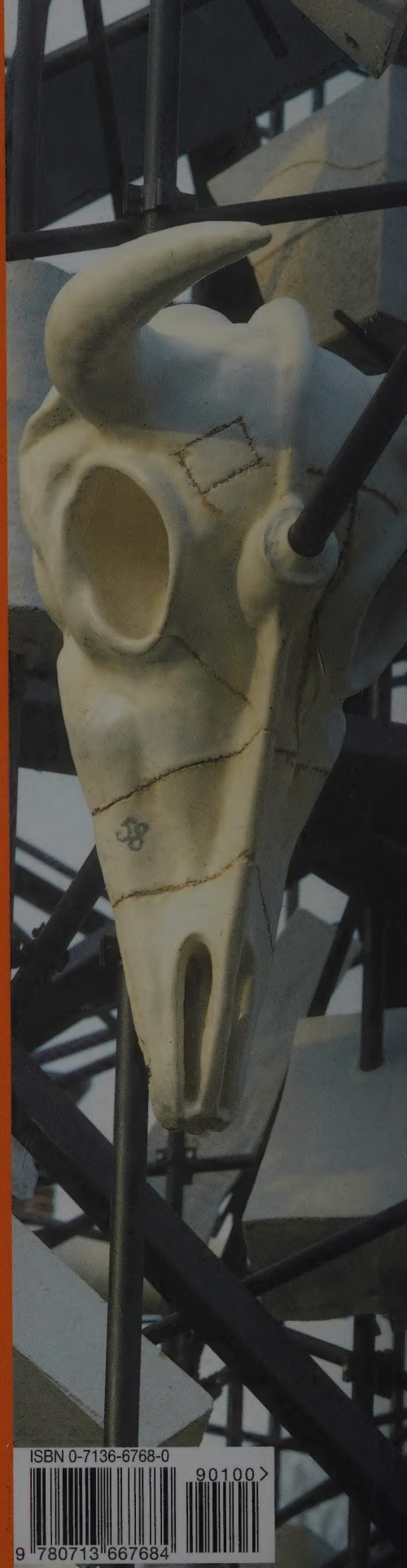
The European Ceramic Work Centre (**EKWC**) is an international workshop specialising in ceramics. The aim of the centre is to promote development in ceramics and to this end it combines its artist-in-residence function with that of a centre-of-excellence.

The residency programme means that, on an annual basis, the centre offers approximately 50 visual artists, designers, ceramicists and architects the opportunity of experimenting with ceramics during a continuous or phased residency of three months. To facilitate this, it not only makes studios, specialised workshops, the most modern equipment and living space available, but also an extensive staff of specialist technicians and tutors. They enable the participants, most of whom have no experience of ceramics, to develop their ideas in a relatively short time. The centre-of-excellence function implies that both participants and staff members carry out artistic and technical research. Experiments are regularly performed to find new ways of presenting ceramics. The knowledge and experience thus acquired is disseminated as much as possible by means of publications, lectures, exhibitions, congresses and master classes. In addition to this, there is close cooperation, often in the form of projects, with art academies, museums and galleries, as well as the ceramics industry.

The **EKWC** is subsidised to some extent by the Dutch Ministry of Education, Culture and Science, otherwise the centre has to rely on its own income, funds and sponsoring.

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ISBN 0-7136-6768-0

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