Paper-Composite Porcelain:

Characterisation of Material Properties and Workability from a Ceramic Art and Design Perspective

Paper-Composite Porcelain:

Characterisation of Material Properties and Workability from a Ceramic Art and Design Perspective

Jeoung-Ah Kim

The School of Design and Crafts HDK (Högskolan för Design och Konsthantverk)
at the Göteborg University

Thesis for the degree of Doctor of Philosophy in Design
at School of Design and Crafts, Faculty of Fine and Applied Arts,
Göteborg University

ArtMonitor is a publication series from the Board for Artistic
Research (NKU) of the Faculty of Fine and Applied Arts,
Göteborg University
Publisher: Johan Öberg
Adress: Art Monitor, Göteborgs universitet
Konstnärliga fakultetskansliet
Box 141, SE-405 30 Göteborg, Sweden
www.konst.gu.se

Designed and typeset by Sara Lund, Anna Frisk and the Author
Swedish translation by Cecilia Häggström
Photographs by: Jeoung-Ah Kim

Cover:
Right above: Figure 1 of Paper I. Paper-composite porcelain (MCP 3)
fired at 1300°C. Mullite, α-quartz, anorthite and amorphous materials
are formed during batch composition.
Left above: Figure 5 of Paper I. The SEM image of paper-composite
porcelain (MHP1) fired at 1260°C. Fibrous structures display binding
and an interlocking of the fibres, and construction of fibrous bridging.
Below: Figure 1 (b) of Paper III. A model produced with MCP 3 by the
slip casting method and fired at 1300°C. A transparent glaze was
applied. The image was photographed by Jeoung-Ah Kim and the
layout designed by Cecilia Häggström.

Printed by Elanders, Mölnlycke 2006

ISBN: 91-975911-2-2

To my parents, and my son Peter

List of Papers

This doctoral thesis is based on the following four papers, which are referred to by the Roman numerals as shown below:

Paper I Jeoung-Ah, K. The characterisation of paper composite porcelain in a fired state by XRD and SEM. *Journal of the European Ceramic Society,* 2004, 24 (15–16), 3823–3831.

Paper II Jeoung-Ah, K. The characterisation of paper-composite porcelain in a green state. *Journal of the European Ceramic Society,* 2006, 26 (6), 1023–1034.

Paper III Kim, J. A. Paper-composite porcelain in practice: Artistic applicability and technical properties. Submitted for publication.

Paper IV Kim, J. A. A perspective on knowledge in ceramic art, craft and design: Examples of porcelain manufacture and paper-composite porcelain. Submitted for publication.

Papers I and II are published under the author name Kim Jeoung-Ah.

Abstract

Title: Paper-Composite Porcelain: Characterisation of Material Properties and Workability from a Ceramic Art and Design Perspective
Language: English
Year: 2006
Keywords: Ceramic art and design, Interdisciplinarity, Paper clay, Porcelain, Practice based
ISBN: 91-975911-2-2

Paper-composite porcelain is a type of paper clay which is made by combining any kind of porcelain with paper. Paper is added to clay to improve low green strength and plasticity, two of the main practical problems of working with porcelain. Despite widespread interest in the material, the characteristics of paper-composite porcelain have remained undetermined. The purpose of this research was to understand the artistic applicability of, and obtain reliable knowledge of the properties of paper-composite porcelain.

The research involved a combination of practical artistic experiments and laboratory experiments used within material science. The artistic experiments investigated the workability and applicability of paper-composite porcelain with different amounts of paper in various casting models. The technical studies qualitatively investigated the material characteristics and microstructures using X-ray diffraction and scanning electron microscopy. The qualitative physical properties tests involved different casting body recipes, production methods and firing temperatures. Quantitative studies were used to measure and analyse the properties of porcelain and paper-composite porcelain.

The artistic experiments involved the development of a slip casting method which recycled the excess water from the process. Slip casting of various tableware models showed that there was significantly less cracking, warping, bending and deformation of the paper-composite porcelain than of the mother porcelain. Furthermore, sharp angles and fine lines and surfaces were obtained even with the highest paper-fibre content used (90% in volume). Paper-composite porcelain had the same whiteness as ordinary porcelain, but it had a silkier lustre and was more translucent when glazed. Fibrous structures were identified in both green and fired states. It was proved that the presence of paper fibre, the paper type and the paper-fibre content were the factors behind the increased green strength of the paper-composite porcelain. In comparison, paper-composite porcelain has higher green strength, lower shrinkage, lower deformation degree and wider firing range.

The results provide new knowledge of paper-composite porcelain by identifying the reinforcement role of paper fibre in the formation and fabrication stages. They also demonstrate a practically tested and documented method for slip casting which shows some of the potential application of paper-composite porcelain in artistic practice.

Table of contents

Acknowledgements

I would like to express my sincere gratitude to my supervisor Dr. Cecilia Häggström at the School of Design and Crafts (HDK) at Göteborg University (GU) in Sweden, for her guidance, support and care, especially in regards to the theoretical development of this work. I am also grateful to my artistic co-supervisor Professor Elisa Helland-Hansen of the Department of Ceramic Art, HDK at GU for her useful suggestions and ideas for improvements. It has been my great pleasure to have Associate Professor Vratislav Langer from the Department of Environmental Inorganic Chemistry at Chalmers University of Technology (CTH) in Sweden as my technical co-supervisor. I especially thank him for his assistance with X-ray diffraction analysis (XRD) and his advice throughout the technical sections of the work. Without their help, this thesis would never have been completed.

I wish to express my thanks to, opponent at my closing seminar, Dr. Kevin Petrie at the School of Arts, Design, Media and Culture at the University of Sunderland in England, for his valuable comments on this thesis.

Special thanks go to the following people: Professor Nigel Wood at the Department of Ceramic art at the University Westminster in UK for his interest in my work and the sincere discussions during the months of research, as well as for sending me his extensive book on porcelain. Professor Roger Carlsson at the Swedish Ceramics

Institute for his challenges, comments and sensible advice, all of which have been of great importance to the development of my ideas since 1994. Professor Kim Yong-Bae at the Department of Chemistry of the Kon-Kuk University in Seoul in Korea, who believed in my hypothesis and encouraged me to embark upon research in the field. Professor Tapio Yli-Viikari at the Department of Ceramic and Glass Design at the University of Art and Design Helsinki (UIAH) in Finland for his encouragement and his guidance in ceramic design throughout the period of my previous doctoral studies at UIAH. Associate Professor Lena Falk at the Department of Experimental Physics at CTH/GU for helping me to work with the scanning electron microscope (SEM). Dr. Ulf Södervall at the Department of Microtechnology and Nanoscience at CTH/GU for introducing me to the world of material characterisation.

I also wish to thank the staff at HDK: Annett and Renata at the Department of Ceramic Art for their support and encouragement over the years, Roy for constructing the model, Ulla-Britt for assisting with the references and all other members of staff who assisted, even though I cannot mention all their names here.

I am also grateful to the staff of the Faculty of Fine and Applied Arts (KFN), especially Anna Frisk for her invaluable support and assistance with the layout of the document, Johan Öberg for careful readings of my manuscripts, as well as all the other people who have helped me in one way or another.

My thanks go to ceramic artist Marianne Hallberg and Sintra members for their support during my exhibition.

I am thankful to: Ove Thorsén and Bibbi Forsman, my former teachers at HDK, for their support since 1991. My former colleagues Heikki, Jari, Jyri, and Raija at UIAH for our interesting discussions. Anne-Charlotte Lotta Borberg at BodaNova Höganäs, Malin Bengtsson at IKEA of Sweden, Malene Bruun at the European Environment Agency (EEA), Marie-Louise Dunker Nielsen at The Royal Copenhagen, Lars Ericsson at Papyrus, Margareta Almberg at StoraEnso, Phil Wills at Imerys ECC International and Jan-Willy Gustafsson at North Cape Minerals for their information support.

I am indebted to my uncle and his family, especially Dan-Bee, for their care and prayers. I hope that this book will bring them strength and excuse my absence.

Finally, I wish to thank my parents and my brother, who have provided me with great support, understanding and endless love. With all my love, I thank my wonderful son Peter for his great patience in tolerating a phantom-like mother during these past years.

Financial support from GU is greatly acknowledged. Some of the practical experiments for the artistic purposes were made possible through financial support from the Estrid Ericson Foundation, the Kerstin Wijk-Broström Trust and the Wilhelm and Martina Lundgren Scientific Fund in Sweden.

Jeoung-Ah Kim
Gothenburg, Sweden
15 July 2006

CHAPTER 1

Introduction

This chapter describes the background of this thesis, its aims, outline and form and the contents of the appended papers I, II, III and IV.

1.1 Background

This research has emerged from creative practice. The following background and images of my works describe the important starting points and explain how this research started from a practitioner's perspective.

From the autumn of 1991 to the spring of 1992, I worked with large-scale ceramic art production (wall decoration tiles) using porcelain clay (Figures 1-3 show some of the works. These works have been part of the public collection of Kulturnämnden in Göteborg, Sweden since 1993.). The weight of the porcelain posed problems for the production and the transportation of the artwork, both during the working process and afterwards, during the display and installation processes. Moreover, the porcelain body tended to have more cracks and warping in the green and/or fired state than any other clay body.

Figure 1. Wall decoration tile work.
This piece was produced by the slip casting method with white porcelain and coloured porcelain. It was fired at a temperature of 1300°C in an oxidised environment in an electric kiln. A transparent glaze was applied.

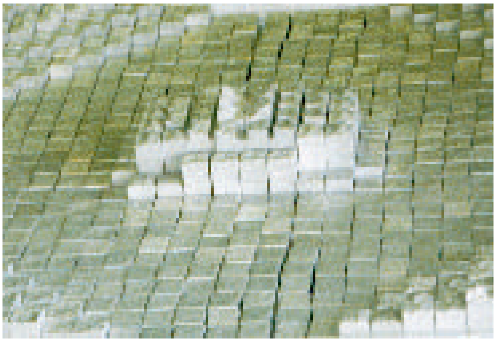


Figure 2. Wall decoration tile work.
This was produced by the slip casting method with white porcelain.

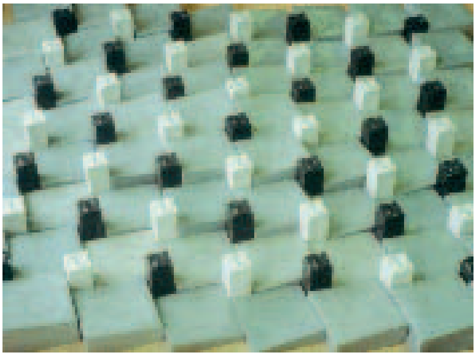


Figure 3. Wall decoration tile work.
This was produced by the slip casting method with white porcelain and coloured porcelain.

In the spring of 1992, I started to combine porcelain clay with other materials such as textile fibre, paper fibre, metal, small plastic balls and sawdust in order to achieve a lightweight porcelain body. The textile fibres could not be mixed as they destroyed the mixer, and the metal pieces hurt my hand. The small plastic balls and sawdust resulted in an excellent lightweight product. However, both made visible open pinholes on the surface. The best material was waste paper combined with porcelain: it was easy to mix, resulted in a lightweight material and had virtually the same appearance as ordinary porcelain.

In June 1992, I participated in a session on paper clay by Gault (1993b) at a ceramic conference held at UIAH (University of Art and Design in Helsinki, Finland). The information interested me as it was related to my experiments on combining porcelain clay materials with paper. According to Gault, the paper is burnt out during the firing process and leaves a porous structure in the paper clay body.

Until 1993, I worked mostly with paper combined with porcelain. I used decorative tiles as an artistic application (Figures 4 and 5), the results of which were shown at the Röhsska Museum in Sweden in 1993 (Kim, 1993).

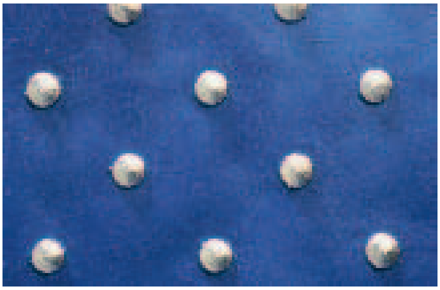


Figure 4. Paper-composite porcelain tile.
This work is produced by the double-casting method (first slip casting and then press casting). The method was invented during the study of the paper-composite porcelain. The highest paper fibre content (the amount of paper in a slip was 90% by volume as 39.8% in weight) was used. The coloured paper-composite porcelain was mixed with cobalt monooxide. No glaze was applied, however the ashes from the paper gave it a natural glaze effect.

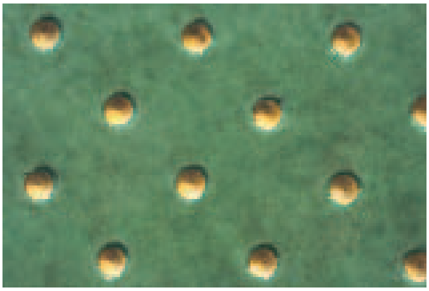


Figure 5. Paper-composite porcelain tile.
Produced by the double-casting method with the highest amount of paper fibre. It was fired at a temperature of 1300°C in an oxidation environment in an electric kiln. Celadon glaze was applied.

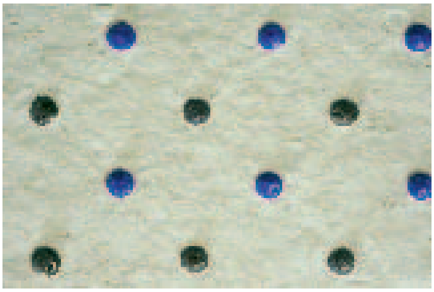


Figure 6. Paper-composite porcelain tile.
Produced by the hand-press casting method. MCP 3 was used. Fired at a temperature of 1300°C. No glaze was applied. Many fibre forms were seen on the surface of the tile.

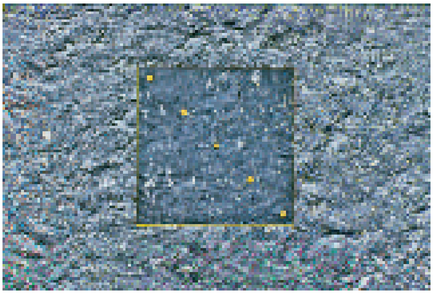


Figure 7. Paper-composite porcelain tile.

1.2. Research questions

During my work with tiles I received some unexpected results. The surface quality of the final tile products raised questions about the material. Many fibre forms were seen on the surface of every single tile which had been fired at 1300°C (Figures 6-9). This gave me the idea that the paper may not have just burnt away, but rather that the material might have changed from one form into another. Other questions that arose were:

- What is this fibrous form on the surface of the tiles?
- Why did it not burn away?
- What had happened to the structure during firing?
- Did the result change any original characteristics of the porcelain body?

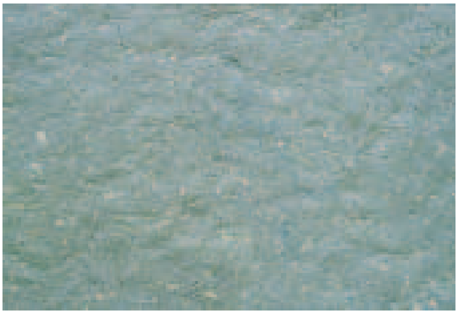


Figure 8. Paper-composite porcelain tile. *Produced by the hand-press casting method with MCP 3 and fired at a temperature of 1300°C. No glaze was applied. Many fibre forms were seen on the surface of the tile.*

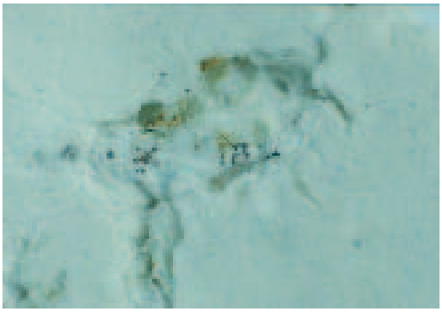


Figure 9. Paper-composite porcelain tile. *We can read printed text (X and Ta) from waste paper and fibre forms on the surface of the tile.*

1.3. Hypothesis

After observing the fibre forms on the surface of fired tiles, I formulated my hypothesis, which was that the organic materials would be burnt out during firing, but that the inorganic compounds would not be burnt out if any were present in the paper that had been mixed with the porcelain clay materials.

- My initial reasoning was that the ashes from the burnt paper might contain some minerals. It is a well-known fact that ashes from different natural fibres contain different minerals, and that potters have been using them for thousands of years to mix ash glazes. Bone china is an example of a ceramic body that is made from a mixture of bone ashes. In addition, several articles (e.g. Cardew, 1971; Hamilton,

1978; Li, 1985; Rhodes, 1971; Sutherland, 1987) have mentioned that some ashes contain traces of different oxides, silica, soda and potash.
- My second thought was that paper manufacturers use clay minerals when producing paper (Biermann, 1996; Bown, 1996; Conners and Banerjee, 1995).

Thus, my hypothesis was that the minerals in the paper were not burnt away during firing and might therefore influence the body characteristics when the paper is used as an additive in clay.

However, there was no scientific evidence to explain the hypothesis. In addition, no detailed studies have been reported in relation to my questions or hypothesis. This is how I identified that there was insufficient information about this material and how to use it in the field of ceramic art and design.

The lack of information concerned:
- The physical properties and structures of the material. Despite the broad interest shown in paper clay by numerous ceramic artists, the characteristics of this material were still poorly defined. Unfortunately, the lack of technical information on practical applications in the field of ceramic art and design has to be taken into consideration when using paper-mixed clay bodies.
- The chemical components and micro-structural interactions between the porcelain raw materials, paper filler and fibres which make up the combined paper-porcelain body in its fired state. Questions related to such aspects could only be answered by means of explicit research. According to Polanyi (1983), explicit knowledge is related to theoretical understanding and to scientific principles, so it has the characteristic of being fully codified. Thus an explicit form of knowledge is related to the scientific results of basic research and innovative activity composed of facts, information, principles and practical understanding of science. This explicit knowledge is the opposite of tacit knowledge, which is a personal property of knowledge. Tacit knowledge is linked to the abilities that individuals possess based on elements of knowledge that were acquired through practical experience. Thus, craft skills, routines and workmanship stem from tacit knowledge, particularly in the field of ceramic art/craft/design. Tacit knowledge includes all experiential knowledge that human beings have, even though it cannot be expressed by means of verbal concepts. It includes manual skills, as well as knowledge of the skill and thoughts, which characterise the traditional form of craftsmanship that potters have. I looked for answers by consulting many scientists in the fields of

> ceramics, chemistry, physics, mineralogy and material science. However my questions were regarded by people as an artist's problem or a nonsense theory without any scientific evidence.

My motivation was strengthened by the fact that these questions were not being asked by any scientists, even though these questions had been raised not only by me, but also by other ceramicists. According to Gault, it is possible that, at a microscopic level, ash from burnt paper contains trace minerals which melt or glaze the interior of the voids left by the fibre during the firing of the clay body. She encouraged future research as a way of shedding more light on this matter (Gault, 1993b).

This was the starting point for this interdisciplinary research project encompassing the fields of art and science.

1.4. Aims

The research project described in this thesis had the following aims:

- To characterise paper-composite porcelain (Papers I and II)
- To investigate the properties of the product (Papers II and III)
- To obtain knowledge on workability to guide ceramicists using this material in practical applications (Papers III)
- To contribute to the development an explicit knowledge base within the field of ceramic art and design (Papers I, II, III and IV).

This research differs from previous studies in that it attempts to solve the practical problems of working with paper-mixed porcelain that have been experienced by studio potters and ceramic artists. This is an issue which is usually neither addressed by scientists nor even by those working in artistic environments or art studios. Paper-composite porcelain is inexpensive to produce, readily available and easier to handle than traditional porcelain. Furthermore, it does not require special techniques or production instruments such as those required by the highly advanced ceramic bodies that are developed for intensive technical applications in certain industries. Thus this study not only aimed to identify the characteristics of the paper-composite porcelain through technical experiments, but also to provide practical information on possibilities artistic applications of this material. This knowledge can be used to create artistic and functional products in a small-scale production system such as a ceramic artist's studio, but may also be of value for development on an industrial scale in the future.

1.5. Outline of thesis

This thesis is divided into eight chapters and four separate papers. The first two are already published and the last two have been submitted for separate publication. The outline of the thesis is however ordered as if the four separate papers are all parts of one complete research project. Thus the questions, aims, literature review, methods, results and conclusions, as well as the contributions of this research to the field of ceramic art and design, are accounted for all together – that is, not in the form of a paper-by-paper report.

- Chapter 1 introduces the background and starting points of this research and describes the aims, outline and form of the thesis, as well as the main issues of each of the separate papers.
- Chapter 2 gives an overview of porcelain, paper clay and composite material.
- Chapter 3 accounts for the methods used in this study.
- Chapter 4 describes some additional tests and results that are not included in the four appended papers.
- Chapter 5 presents the results and conclusions of the thesis.
- Chapter 6 presents the contributions of this research to the field of ceramic art and design.
- Chapter 7 outlines further research and recommendations.
- Chapter 8 gives a summary of the thesis in Swedish.
- Paper I characterises paper-composite porcelain in its fired state by XRD and SEM.
- Paper II traces the characteristics of paper-composite porcelain in its green state.
- Paper III describes the artistic applicability and technical properties of paper-composite porcelain in practice.
- Paper IV discusses a perspective on knowledge in ceramic art, craft and design through examples of porcelain manufacture and paper-composite porcelain.

1.6. Background and research questions for the separate four papers

This section serves to explain the background and main issues addressed in the separate four papers.

PAPER I.

The paper-composite porcelain clearly behaved differently from the traditional porcelain, and it appeared as if not all of the paper was burnt away. If some of the inorganic compounds from the paper had remained then it might have influenced the paper combined porcelain body. The first paper thus addresses the following initial questions:

- Is it likely that the paper is not burnt away, but rather that the material has changed from one form into another?
- What has happened to the structure during firing?
- Does the result change any of the original characteristics of the porcelain body?

These questions guided the investigations of my hypothesis, which was that inorganic compounds in the paper are not burnt out during firing.

In this study, the interaction between paper filler, paper fibre and the porcelain clay body in its fired state were investigated using

- X-ray diffraction (XRD) and
- Scanning electron microscopy (SEM) techniques.

A micro-structural investigation was conducted to determine whether the addition of the selected waste paper would change the physical characteristics, microstructure and chemical properties of the paper-composite porcelain in the fired state.

PAPER II.

The results obtained by SEM and presented in the Paper I, indicated that a fibrous structure was created in the paper-composite porcelain body in its fired state. The calcite from the recycled papers melted with the kaolinite during the firing process and transformed to anorthite identified in the microstructure of the paper-composite porcelain in the fired state. The XRD showed that the only major crystalline compounds present in the fired paper-composite porcelain bodies were mullite, α-quartz, anorthite and amorphous materials, despite the differences in the types of paper in the bodies. Anorthite is a material that is used in the construction of fibrous bridges and tunnels. The structures of fired paper-composite porcelain bodies had special fibre binders covered with anorthite, which changed the composition of the body. The development of anorthite in the fired paper-composite porcelain was caused by calcium carbonate from the waste paper, which increased the degree of heterogeneity in the formation of a porcelain body. The fibrous structures displayed strongly binding, interlocking fibres and fibrous bridging. These normally provide a supporting structure for ceramic objects. However, the microstructure and chemical compounds of the body in its green state had not yet been investigated, nor had the influences of different production methods and the paper fibre content of the body been studied. The second paper deals with these questions.

The studies outlined in the second paper had the following aims:

- To test samples produced by two different production methods, the free-hand press casting and the slip casting method.
- To characterise the material properties of paper-composite porcelain in its green (unfired) state through XRD, SEM and quantitative studies carried out to measure and analyse the properties of the porcelain and paper-composite porcelain: shrinkage, weight-loss, porosity, absorption, density and strength by using the international ceramic material standard methods.
- To investigate the role of paper fibre and its influence on the technical properties of the paper-composite porcelain in its green state by conducting qualitative studies to compare differences arising from different casting body recipes, production methods and firing temperatures, as well as to compare these results to those obtained in the quantitative studies.

PAPER III.

Through the studies described in the first and second papers, much of my initial research questions and my original hypothesis were answered. However, new questions were raised, not only by me but also in inquiries from many people through my home page, at exhibitions and in response to the published papers. I had a home page which contained a research presentation under the title "Recycling of paper in porcelain" from 2001 until March 2006 (www.hdk.gu.se/forskning/kim) which was widely read by ceramicists, scientists, researchers in paper recycling and students. In 2001, a conference proceeding (Jeoung-Ah, 2001) was published in both printed and electronic form. In 2002, I presented the application models in a solo exhibition (Appendix I) at a craft gallery, Sintra, in Gothenburg in Sweden. The exhibition and public articles in a newspaper (Appendix II), a design magazine (Appendix III) and electronic articles by the newspaper and the gallery (Appendix IV and V) on the exhibition quickly spread news of the work to other ceramicists and the Scandinavian public. In 2004 and 2005, two papers (Papers I and II in this thesis) were published by a journal in electronic form via the Elsevier Science Direct. These two papers were published in printed form in 2004 and 2006 by the Journal of the European Ceramic Society (Jeoung-Ah, 2004 and 2006). Some studio potters were concerned with the practical problems using this material in the slip casting method in their studios, while others requested more information about the fired properties of the material. Among many inquiries, some selected questions are accounted for in Appendix (Appendix VI).

These led to the investigations outlined in the third paper. This paper explores the workability of the paper-composite porcelain in relation to different amounts of paper fibre, fragility/handling problems in the green and fired states and the behaviour of the materials during the casting process. The aims were as follows:

- To strengthen the artistic applications of this material, especially in the production of functional wares.
- To identify useful information through practical experiments.
- To investigate the material properties of paper-composite porcelain in its fired state and relate these to the results from the second paper, in order to provide a more complete overview of this material.

PAPER IV.

The investigations described in the fourth paper were started after the publication of my Licentiate thesis (Kim, 2004). The background to this study came from my practical experiences and inquiries from other people through the years. I began studying ceramic art in 1978 in Korea and opened my own studio in 1984, continuing until 1986. Between 1987-1991 in Korea and 1992-1993 in Sweden, I shared a studio with other ceramicists. From 1983, I also worked as a journalist in Korea, and from 1996 as a freelancer reporter in the field of ceramic art and design in Scandinavian countries. All those years of professional experience gave me numerous opportunities to meet many ceramicists in many countries (selected articles from 1996-2006 are listed in Appendix VII). Most of the technical difficulties that were encountered in practice became problems to which we, the studio potters, were not particularly eager to seek solutions through more complicated tests. I believe this is partly due to a lack of knowledge about how to conduct such tests. Many of us kept our own clay and glaze recipes a secret, even though we knew that we could help each other more if we shared our recipes and experiences. As a reporter, getting a proper answer about materials and technical questions could be quite problematic in interviews. Among the e-mail inquiries from other people, and personal discussions with ceramicists, researchers and colleagues, I have also found a lack of understanding of why it is necessary to combine technical and artistic methods and what this could contribute to the field of ceramic art.

This led me to questions about the importance of conducting interdisciplinary research as well as about methods by which this explicit study could contribute to the field of ceramics, for which individual know-how has traditionally been an important part of knowledge.

Therefore this study focused on the relation between tacit and explicit knowledge by using historical examples to illustrate the importance of developing both forms of knowledge in the field of ceramics field in parallel.

The aim of this study was to establish the importance of balanced knowledge in practice and in research within the field of ceramic art, craft and design.

CHAPTER 2

Literature Review

This chapter gives an overview of pottery, porcelain history and practice, paper clay, composite material, tacit and explicit knowledge in pottery and its importance in the field of ceramic art and design. The aim is to outline the field and context which this thesis relates to. In order to avoid repetition, some parts which are more thoroughly reported in the separate papers are only briefly mentioned in this chapter.

2.1. Pottery

Pottery first appeared around 15000-10000 B.C. during the Neolithic age in the form of clay figurines, which were used for magical or religious purposes. Later, practical and functional needs were probably most in the minds of the makers when producing necessary goods which are characteristic of the settled life (Cooper, 1981; Morly-Fletcher, 1987; Rado, 1969). Nowadays, pottery is not only functional but is also of artistic value.

> Pots not only reflect technological development at particular times but they are often beautiful objects in their own right, over and above the demands of function. Changes in style and type of pottery occurred in

> response to social, economic and technical demands, and for this reason pottery is closely integrated with the development of different civilizations from the earliest times to the present day. (Cooper, 1981, p. 7)

The recipes for clay bodies have developed through the passage of time, depending on their uses in different techniques, with different characters and values. The clay bodies used in pottery by ceramicists are divided in three broad categories: earthenware, stoneware and porcelain, depending on properties, firing temperatures, etc. Among the pottery clay bodies, porcelain generally has the highest firing temperature, highest density and strength, and the lowest porosity (see additional information in Papers I-IV).

2.2. Historical overview of porcelain

Porcelains are vitreous ceramic whiteware that are currently used extensively in ceramic art, decorative ware, tableware, sanitary ware, electrical insulators and dental prosthetics. Composed primarily of kaolin, feldspar and quartz, porcelains are heat-treated to form a mixture of glass and crystalline phases (William and Udayan, 1998). Porcelain was discovered in China during the Hou-Han Dynasty (A.D. 25-220). It was gradually refined over many years into the hard-paste porcelain that developed during the Tang Dynasty (A.D. 618-906) (Lane, 1980). According to an extensive study about the Chinese porcelain and technology by Kerr and Wood (2004), the world's first high temperature hard-paste porcelains (hard-paste porcelain is also called true porcelain) were made in Hopei province in China in the 6th century. The hard-paste porcelain called Hsing ware had a firing temperature of about 1360°C. An essential ingredient for the body of these high-fired porcelains was the plastic white-burning clay 'petuntse'. Kaolin became the main source of porcelain since 1004. The finding made Jingdezhen, in the southern china, world famous as an imperial porcelain kiln. The name kaolin comes from a village "Kao-Ling (it means, high hill in Chinese)" near Jingdezhen in China, where the clay was first found by an unknown Chinese potter. It has been used to produce the highest quality kaolin for the Jingdezhen porcelain. The name survived in English as kaolin, or china clay. According to Gray (1952), Chinese porcelain was introduced to the Western parts of the world in A.D. 851 through a document entitled "The story of China and India" written by Sulieman, an Arab traveller. The porcelain was introduced in Europe in 1295 by Marco Polo, who was also the first to apply the name porcelain (Rado, 1969). In 1298, Marco Polo wrote a book entitled 'Travels' in which he described porcelain and porcelain-making in China. This first report introduced Chinese porcelain to Europe. However, according to Kerr and Wood (2004), prior to the 16th century, porcelain products had only reached Western Europe in small numbers, and individual items were highly prized. At the time when physical Chinese porcelain objects and Marco Polo's book appeared in Europe, the European society was ready to appreciate porcelain. A massive amount of porcelain was imported into Europe through the East India Company at the beginning of the 1600s, much of it from China. The arrival of Chinese porcelain in Europe heralded a major artistic revolution and stimulated the search for porcelain recipes and ingredients (Lane, 1980). It fascinated the Europeans and became highly valuable as collectible items for the aristocracy. However, Europeans did not have enough knowledge to produce the unique quality of porcelain, and the imported Chinese porcelain was so expensive that only those in high society could afford it. Towards the end of the seventeenth century, royal and aristocratic collectors began to arrange special rooms, called "porcelain cabinets" to display their porcelain. It was no wonder that the enormous European market for porcelain encouraged efforts to discover the secret of how to make it. At the beginning of the sixteenth century, a Venetian glass worker, Leonardo Peringer, tried make porcelain with frosted glass which was whitened by addition of tin oxide. In 1568, the first proto-porcelain, called Medici porcelain, was made in Europe. At the turn of the eighteenth century the secret of how to make true porcelain was still a mystery in Europe, until Böttger discovered white and translucent European porcelain bodies in Meissen on the 15th of January 1708 (Hlavac, 1983). This was more than 1,000 years after the first hard-paste porcelain appearance in north China in 575 (Kerr and Wood, 2004). This serious research and dedication to study established the European porcelain and china industry as the foundation for the production of porcelain. This successful research also became the basis of ceramic industrial product design in Europe.

The long tradition, advanced technology, well-trained labour and demands from society, including the understanding of the people and the economic and political influences contributed strongly to the discovery of porcelain. The conditions for porcelain manufacture in Europe were different from those in China, as its cultural base was different and Europe did not have the same raw materials or technology as China. For this reason, Europeans needed to develop forms of porcelain that were different from those which were being produced in the regions where it originated. European porcelain compounds contain more silica and alumina which give the porcelain body a more translucent quality than ordinary Chinese porcelain. This is why Europeans are more concerned with translucency. The other important factor in categorising porcelain material is the type of kaolin used. China and Korea have two types of kaolin, a pink type (secondary kaolin) and a white type (primary kaolin). In Europe, only the white type or a similar material is present, therefore Europeans prefer the colour of their porcelain to be white. Kerr and Wood (2004) reported that chemical analysis of Jingdezhen (Ching-te-chen by Kerr and Wood) kaolin show rather high iron contents compared with European kaolin, and occasionally high alkali ($K_2O + Na_2O$) levels from residual mica and feldspar. Kaolin is used in different ways in China and Korea, depending on the type of porcelain that is produced. White kaolin is used to produce Chinese Celadon and white porcelain. Pink kaolin is used for glazes, Korean Celadon colour-glazed porcelain and black crystal-glazed porcelain. Porcelain also found common ground among the wealthy, and was produced for the royal and aristocratic members of society in China, Korea and Western countries. The irony is that the porcelain makers belonged to the lowest class in their society. Society and culture changed the upper classes' perception of porcelain items, from products for ordinary people to desirable objects to be produced especially for them. This continued until the twentieth century, when porcelain industries began to build mass production systems. European porcelain developed throughout history and the historical porcelain documentation became one of the most important bases of modern European ceramic material research. Today, clay manufacturers throughout the world produce a variety of porcelain products.

In spite of its unique properties of hardness and high density, the lack of plasticity and heavy weight of porcelain traditionally give limited artistic options in the development of porcelain products. The problems of traditional porcelain bodies are described in Paper III.

2.3. General overview of paper clay

Clay has been used in combination with natural fibres to make unfired bricks as building material since the beginning of the Neolithic period, 10,000 years ago. Adobe is one of the examples, a primary building material of mixed clay and straw that is sun-dried or fired at a low temperature. On the northern coast of Peru, the Moche pyramids, dating from A.D. 100-700, provide visible evidence of adobe (Peterson, 1995). Traditional adobe mixtures also encompass a sun-dried mixture of clay, sand and fibre as unfired clay used in primary construction (Griffith, 1998). This can be seen in Africa, Oceania, Melanesia, Indonesia, Far East, parts of Central and Eastern Asia, South-western part of the USA, Mexico and Central and South America. The most common use of adobe is to mix it with straw, bamboo, paper and/or other fibres to prevent shrinkage cracks (Hornbostel, 1991). Traditional Korean and Chinese sun-dried and unfired bricks were inexpensive architectural material with which the local people could build houses. The unique advantages of this material are its low cost and its high dry strength; the porous quality of these bricks absorb the moisture and protect the interior of the houses from hot, dry or cold weather (Hamilton, 1978).

In the ceramic art field, "individuals have added a variety of tempers to clay bodies to improve working qualities and dry strength. In the 1960s, a number of ceramic artists worked slip into fibre-glass cloth and draped the slip-laden material over a variety of forms to create thin veils of clay. In the 1970s and '80s, nylon fibre was added to allow artists to develop thin but tough clay sculptures" (Baker, 1998, p. 46). In the 1970s, the artist Rauschenberg mixed adobe clay with seeds, powdered gum and paper pulp to get dry strength for artistic purposes (Lightwood, 2000). In the 1970s and 1980s, nylon fibre was added to allow artists to develop thin but tough clay sculptures (Lowell, 1998). In the 1990s, cellulose fibre was added to get a translucent effect (Kähkönen, 1993), and paper pulp was added to increase its dry strength and to achieve a lightweight clay body. Paper clay was introduced to the field of ceramic art by several potters and material chemists in the 1990s (e.g. Baker, 1998; Gault, 1993a and 1993b; Hay, 1996; Juvonen, 1995; Peterson, 1995; Soong and Ling, 1995). Peterson (1995) described an adobe body with added paper to increase its workability; fibre could be embedded to strengthen the ancient sun-dried earth bricks and to adobe bodies to enhance their artistic qualities. Juvonen (1995) has tested clay with different fibre additives to produce a large bowl as an artistic model. The merits and problems of paper-composite porcelain are more thoroughly described in Paper III.

2.4. Composite material

The term "Composite material" implies a combination of two or more materials differing in form or composition to achieve a particular function (Composite, 1987) One of the important properties of the composite material is that it can obtain the value of a given physical property which is not obtainable by either of the combined components on their own (Chou, 1993). As the term indicates, a composite material is one which is different from common homogeneous materials. The composite material obtained is instead heterogeneous.

The earliest evidence of ceramic composites was sun-dried brick such as adobe, which mixed clay and straw. In the 1900s, composite products were associated with inorganic materials that included clay, and organic materials that included cellulose products. Ceramic products were mainly derived from clay. Ceramic materials used alone are brittle and hence produce fragile components which could easily be broken. However, they can resist cracking if they contain fibres (Kelly, 1994). The natural fibre-based ceramic composites are mostly mixed clay with other additives as a binder (Richerson, 1992) to control the shrinkage, improve the green strength (Onoda, 1976) and to provide better handling while forming the shape of the product (Delmonte, 1989). The bonding between fibres and matrix is created during the manufacturing phase of the composite material. This has a fundamental influence on the mechanical properties of the composite material (Gay, 2002).

2.5. Knowledge in pottery

According to Polanyi (1983), tacit knowledge includes all experiential knowledge. Explicit knowledge or scientific knowledge is related to the theoretical understanding and to scientific principles, so it has the characteristic of being fully codified. The codification refers to knowledge which has an explicit form and is related to scientific results of basic research and innovative activity composed of facts, information, principles and practical understanding of science. This explicit knowledge is the opposite of tacit knowledge, which is a personal property of knowledge. Tacit knowledge is linked to the abilities that individuals possess based on elements of knowledge that were acquired through practical experience. Thus, craft skills, routines and workmanships stem from tacit knowledge, particularly in the field of ceramic art/craft/design. Knowledge in pottery has traditionally been deeply rooted in tacit knowledge, which has existed in the form of art and craft long before scientists like Polanyi identified it. The ability to work with ceramic materials includes knowledge of the properties of the clay raw materials, techniques and the nature of the tools. This knowledge may be acquired through tacit observation and practice or systematically, through various forms of explicit instruction. Rowley (1997) stated that skill involves an understanding of materials and an ability to work with them to create something. It is not necessary that all practitioners should be able to describe their knowledge explicitly. However, as Shortland and Gregory (2002) also mentioned, there are many economic and social benefits to be gained from wider scientific knowledge. As Fraser (1986) stated, the faults that arise in clay ware are by no means surprising, given the variable nature of the raw materials and the numerous stages involved before the final product is completed. Thus, many problems encountered in the making of ceramic objects are involved in a complex procedure, which in many cases can be solved explicitly. This would reduce the trial and error, make more effective use of time and increase production. A more detailed account of tacit and explicit knowledge in pottery is given in Paper IV.

CHAPTER 3

Research methods

This chapter describes the methods used in this research. It gives an introduction to, and brief descriptions of each technique in order to provide basic knowledge to the ceramic artists and researchers in this field. The descriptions are therefore rather more general than technical. Detailed descriptions of the experimental materials and procedures are given in the appended papers (Papers I, II and III).

3.1. Interdisciplinary methods

This research used an interdisciplinary method to scientifically investigate the material characteristics and properties of the paper-composite porcelain in combination with artistic experiments. It was necessary to apply scientific methods to the study in order to obtain deeper knowledge of the technical topics under investigation. This required the development of a method that crosses disciplinary boundaries.

Friedman (2003) described design research, approaches, theory and method.

> *Design involves solving problems, creating something new, or transforming less desirable situations to preferred situations. To do this, designers must*

> *know how things work and why. Understanding how things work and why requires us to analyse and explain. This is the purpose of theory (p. 507).*
>
> One model of the design field represents six general domains. These domains are (1) natural sciences, (2) humanities and liberal arts, (3) social and behavioural sciences, (4) human professions and services, (5) creative and applied arts, and (6) technology and engineering. Design may involve any or all of these domains, in differing aspects and proportions. These depend on the nature of the project at hand or the problem to be solved. With this as a background, we are prepared to examine how and why (p. 508).

Ceramicists in every day practice work with various minerals, chemicals and small or big machines, manually handling materials, techniques and equipment that require combined knowledge from different fields. Thus, academic research in our field requires a combination of methods from different fields of research to form an interdisciplinary approach.

Bunnell (1998) submitted her Ph.D. thesis on CD-ROM, without a printed format. In her thesis, she examined the integration of new technology into ceramic designer-maker practice. She has pioneered new practice based research methodologies and demonstrated how electronic media can be used to communicate craft based research. A study on the monitoring and control of specialist ceramic kiln atmospheres and missions by Malin (1993) thoroughly explored a technical approach. In his study, Malin used scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS) experiments as the main tools of investigation, in combination with the production of artistic models. An experimental work by Dawes (1999) on the manufacturing processes of Hellenistic and Roman glass illustrates a combination of theory, model application and scientific study, which concentrates almost entirely on the chemical and structural analysis of ancient glass. The water-based ceramic transfer printing research by Petrie (1999) focuses on on-glaze screen-printed transfers of decorating industrial ceramics. His research focuses on three aspects which are practice, literature studies and examples of transfer printed ceramics, by using technical experimental methods and testing models. This was done in cooperation with another scientist who was responsible for the technical part of work. Kerr and Wood (2004) conducted an in-depth study of Chinese porcelain using an approach that combines history, archaeology and chemistry. All of the above studies are important as forerunners of this research, as they began to transcend the traditional boundaries of ceramic art/craft/design to develop research that combined other sciences or research fields.

In my research, I combined SEM, X-ray diffraction (XRD) and various physical properties tests, as well as experimental methods used in the fields of material science, inorganic chemistry and micro-physics, together with artistic experiments. I was involved in or carried out all technical experiments and tests in this research in order to make direct observations and conduct the analysis. The reason for choosing to be personally involved in the technical experiments was that I had seen researchers who had been unable to explain or give accurate answers when asked about parts of their experiments, the results of which had been ordered from laboratories.

The technical experiments in this research were selected since my initial research questions and major aims required material research into the micro-structure and analysis of the mineral compositions of paper-composite porcelain. It has therefore been important to establish an approach which was relevant to the nature of the questions and aims as well as to develop a suitable methodology for research within this field. For this reason the study was conducted through a combination of technical and artistic experiments. The technical experiments were carried out in different laboratories where the chosen equipment was accessible. However, all specimens were prepared in a studio environment to be representative of the production in a ceramicist's artistic practice. The artistic experiments were carried out as usual ceramic art studio work. The procedures, experience of practical handling and direct effects are described, and the results discussed.

3.2. Technical experimental methods

Scanning electron microscopy (SEM) is a powerful tool which can be used to look at the microstructure of porcelain products. It was used in conjunction with X-ray diffraction (XRD) and the physical properties tests. The aim of the technical experiment in this study was to obtain a better understanding of paper-composite porcelain, to identify the mineral compounds and relationships in the crystal structure and to study the properties of this material. These methods have been used by many other ceramic researchers, such as Richerson (1992), Hamers (2004) and Rado (1969). Kingery (with Vandiver, 1986; and 1993) used the same methods when he investigated the internal structure and visual effects of porcelain art pieces.

The technical experimental methods were used to analyse the material characters, structures and properties of the following materials used in the study: porcelain raw materials, waste papers, porcelain and paper-composite porcelain both in green and in fired state. XRD and SEM were used to perform the qualitative tests. Both XRD and SEM are common tools used in non-destructive tests to examine ceramic materials. The physical properties were characterised according to the international standard test methods (ASTM). In the physical properties tests, qualitative studies concerned different casting body recipes, production methods and firing temperatures. Furthermore, quantitative studies, in destructive tests, were carried out to measure and analyse the properties of the porcelain and paper-composite porcelain: shrinkage, weight-loss, porosity, absorption, density, strength and deformation (Jeoung-Ah, 2004 and 2006).

3.2.1. X-ray diffraction (XRD)

XRD was used to qualitatively determine the crystalline phases of the materials used in this study: kaolin, feldspar, quartz, copy/print waste paper (CP), other mixed waste papers (HP), mother porcelain (M) and paper-composite porcelain bodies (MCP 1, 2, 3 and MHP 1, 2, 3) both in green and fired states. The X-ray intensities were recorded using a computer system and the commercial software Diffract AT. Crystalline phases were identified by comparison with standard reference patterns from the Powder Diffraction File PDF-2 database sets 1–52, maintained by the International Centre for Diffraction Data (ICDD) (Jeoung-Ah, 2004 and 2006).

XRD is a routine technique used for the identification of minerals in ceramic samples and is therefore a standard experimental tool for analysing crystal structures. It can also be used to determine the crystalline structure of a new material, or the known structure of a common material. It is often used in chemical identification. A beam of X-rays of known wavelength strikes a sample and is diffracted at different angles, depending on the structure of the material. The output is a diffraction pattern showing a series of peaks. Each pure mineral or compound has a specific X-ray diffraction pattern which is called a “fingerprint”. A diffractometer gives compounds or minerals names by matching against a database or, as in this case, against the Powder Diffraction File (PDF) (Langer, 2002).

Since every crystalline material gives a unique X-ray diffraction pattern, the study of diffraction patterns from unknown phases offers a powerful means of qualitative identification (Glusker et. al, 1994). The XRD method has historically contributed more than any other diffraction method to the understanding and determination of the composition of ceramic samples. There are a few other techniques that can be used to characterise the ceramic compound. However, compared to these, the XRD has several merits, which are: it is non-destructive, less expensive than other methods and needs only small amounts of samples (around 0.5g as a powdered sample or small solid). Furthermore, it has a simple sample preparation method, is convenient and may be used in the laboratory. Its diffraction patterns are also easy to interpret.

A qualitative analysis is a convenient method of identifying the mineral compounds in mixtures of more than three compounds, such as multi-complex ceramic materials (e.g. porcelain and paper-composite porcelain). Qualitative analysis involves matching the diffraction pattern from the unknown material with patterns from a single-phase reference material. The PDF is a collection of single-phase XRD patterns. For the qualitative analysis of ceramic materials, PDF uses many thousands of patterns (about 400,000 structures are identified) which have been recorded and published in the ICDD.

A quantitative analysis is used for a two-component mixture, comparing one component to another. The problem with quantitative analysis by X-ray is that it is sensitive to preferential orientation of crystals. It was therefore almost impossible to apply this analysis to the study of porcelain and paper-composite porcelain, since both materials have multi-complex compounds. Furthermore, it is a time consuming analysis; in general, the quantitative analysis of a new phase system requires a minimum of a few days and often up to a week of set-up time.

3.2.2. Scanning electron microscopy (SEM)

The microstructures of the materials which were used in this study were observed by using SEM. This technique was used to reveal their microstructures and to observe topographical contrast in the secondary electron imaging (SEI) mode. The specimens were coated with gold using an electron beam evaporation system.

The SEM is used to create images of objects such as minerals and ceramic samples and is often used in combination with the XRD to identify and characterise minerals. It is especially useful for examining the surface details of ceramics. The SEM provides an image of the surface and allows images to be viewed at a magnification of up to 100,000 times that of an optical light microscope. The SEM can provide both high magnification and good image depth at the same time, so that sharp images of very fine details are produced. Unlike an ordinary microscope, the SEM uses a beam of electrons instead of light to view a specimen. However, an electronic charge builds up on the surface of non-conductors and repels the electrons. For this reason, a fine conductive coating of gold or carbon must be applied to ceramics so that they can be examined. The coated specimen is placed in a vacuum so that the electron beam can move without interference. The electrons are generated from a thin tungsten wire in a "gun" of the SEM. Electricity is passed through the wire and then focused by magnets onto the specimen. When the electrons from the gun strike the surface coating of gold, electrons are reflected from the specimen to a detector and transmitted to a television screen, where an image is viewed and photographed. The SEM is especially useful for inspections of the microstructure of ceramic materials on which the irregular surface also can reveal information about the nature of the mechanism of the material (Shackelford, 2000).

3.2.3. Characterisation of physical properties

The physical properties of a material determine how it can be used. When ceramic artists set about planning an art object, one of our first decisions is which material to use. We usually seek a material that has certain properties and characteristics that are suitable for the planned object. Therefore, ceramicists need to understand the properties of the used materials. This understanding enables us to move more directly towards our goal when creating an item, and to experiment with factors that really are less predictable.

In this study, qualitative and quantitative analyses were conducted to measure and evaluate the properties of the porcelain and paper-composite porcelain. The physical properties were characterised according to the international standard test methods with respect to linear drying shrinkage (according to ASTM C326), and weight-loss (ASTM C373). An Instron universal testing machine was used to determine mechanical strength in a three-point bend mode, which was tested according to ASTM C689. In the physical properties tests, qualitative studies concerned different casting body recipes, production methods and firing temperatures. Furthermore, quantitative studies were carried out in the form of destructive tests to measure and analyse the properties of the porcelain and paper-composite porcelain: shrinkage, weight-loss, porosity, absorption, density, strength and deformation. Detailed test methods are described in the appended Papers II and III.

3.3. Artistic experiment for practical application purposes

In accordance with the research questions (see Section 1.2) and hypothesis (Section 1.3), the physical properties tests in technical experiments were carried out before performing the artistic experiments in order to study the characteristics and properties of paper-composite porcelain. This enabled me to plan the procedure of the practical work. From 2001 to 2006, open discussions about my research have taken place through my research home page. This has brought me a wider range of feedback from other parts of the world. The choice of specific models in the artistic experiment is partly related to such inquiries from colleagues and other ceramists. SEM and XRD experiments were carried out in parallel with artistic modelling, which helped me to figure out what I experienced and observed during the artistic experiment procedure. Before writing the reflection on artistic practice, all models were shown in public at a solo exhibition in 2002 to collect public reactions, opinions and comments. This proved helpful in the latter stages, when describing and reflecting on the artistic experiment segment of the work. The public solo exhibition was necessary in order to make this research accessible. It was also important that the actual pieces produced were the ones which were presented, as photographic images do not fully exhibit the subtle visual and tactile qualities apparent in the actual objects. Details of all practical methods used and images of most of the ceramic artwork models are presented in Paper III. (A more detailed background of this study is given in Section 1.6 and additional pictures in Appendices I-VI).

There have been previous examples of combining technical study with the production of artistic model works in ceramic art and design research. A study on ceramics with viscose silica clothing by Kähkönen (1993) describes the addition of cellulose fibre to obtain a translucent effect in ceramics. Juvonen (1995) reports using paper fibre as a substitute in ceramic clays. Juvonen has tested clay with paper fibre additives of 2-20% in weight percentages and fired at 1100-1250°C and produced large bowls as artistic models. Hortling and Siren (1993) studied the effect of Finnish earthenware clay and calcium oxide on the colour changes in stoneware glazes using laboratory experimental methods and demonstrating a few models. All of those previous studies used direct observations to describe the ceramic artwork models.

In this research, the purpose and methods of the artistic experiments were as follows:

- To understand the underlying factors and test the artistic applicability of paper-composite porcelain in ceramic art and design practice, in comparison to traditional porcelain.
- To understand the workability of paper-composite porcelain with different amounts of paper fibre, the fragility/handling problems in the green and fired states and the behaviour of the materials during the entire process.

- To provide practical information on firing at a high temperature of 1300°C.
- To highlight the artistic applicability of this material with a 50-90% paper fibre volume (as 6.8-39.8% in weight).
- To develop and use a new method of slip preparation for paper-composite porcelain.
- To use only waste paper throughout the course of the study.

The following artistic qualities were observed in this study:

- The surface and texture of the final paper-composite porcelain product.
- The possibility of casting products with fine lines and complex shapes with sharp angles.
- The colour and translucency of the paper-composite porcelain, both body and glaze, especially effects related to extra calcium carbonate and extra anorthite in the fired state.

In this study, the artistic application produced prototype tableware. The models were primarily designed to test the applicability of the paper-composite porcelain clay body. The details of the procedures are described in Paper III.

CHAPTER 4

Additional tests and results

Some additional tests were carried out which were not directly related to the main focus of each paper and were therefore not included in the separate papers. Although they were only performed out of personal curiosity, some of the results are reported and analysed here for readers who may derive some benefit from them.

The leading questions for these additional tests where:

- How do the properties of paper-composite porcelain with CP differ from those of paper-composite porcelain with HP and from M?
- How does paper-composite porcelain withstand higher firing temperature compared to M?
- How does extra $CaCO_3$ from waste paper affect paper-composite porcelain, in comparison to ordinary porcelain?

The answers to these questions contribute to a deeper understanding of the paper-composite porcelain as an artistic material.

4.1. MHP properties fired at 1300°C

CP was selected for the artistic experiment because the paper quality of CP was the same as that of HP, which is a mix of various waste papers (MultiCopy produced from Papyrus StoraEnso. See Papers I and II for a more detailed description of the papers). However, there were differences in the physical properties of MHP in the fired state in comparison to M and MCP in fired state.

Slip 1300°C	Linear shrinkage from wet to dry (%)	Total linear shrinkage From wet to fired (%)	Weight-loss from wet to dry (%)	Weight-loss from wet to fired (%)	Fired apparent porosity by volume (%)	Water absorption by weight (%)	Fired bulk density (g cm^{-3})	Green strength (Mpa, N/mm_2)	Standard deviation of dry strength	Fired strength (Mpa, N/mm_2)	Standard deviation of fired strength
M	4.80	15.73	16.04	24.82	0	0	2.46	5.80	0.26	56	7
MCP 1	4.13	15.67	25.93	33.58	0.25	0.11	2.39	7.60	0.47	47	8
MCP 2	4.53	16.13	30.06	37.23	0.98	0.42	2.37	9.40	0.43	43	5
MCP 3	4.67	16.53	37.67	44.22	1.19	0.50	2.36	9.70	0.41	43	3
MHP 1	3.53	15.27	25.15	31.16	0	0	2.42	9.00	0.32	49	8
MHP 2	3.67	15.53	25.37	31.28	1.14	0.47	2.36	10.00	0.33	43	7
MHP 3	4.33	16.13	25.40	31.81	2.20	0.97	2.27	11.40	0.48	36	3

Table 1. Linear shrinkage, weight-loss, porosity, absorption, density and strength of M, MCP, and MHP slip bodies fired at 1300°C (compare to Table 5 in Paper III)

From the above test results, the following remarks can be made:

- All MHP bodies have less wet to dry shrinkage than M or MCP bodies.
- MHP 1 and MHP 2 bodies have less total shrinkage than M or MCP bodies.
- MHP 3 has higher total shrinkage than M, however it has less than MCP 3 which has same amount of CP.

- All MHP bodies have higher weight loss than M, but less than MCP bodies.
- MHP 1 absorption became 0 as M while MHP 3 has the highest absorption of all studied bodies.
- MHP 1 has the highest density among all MCP/MHP bodies and near to M, while MHP 3 has the lowest density.
- All MCP/MHP bodies have higher green strength than M.
- Green strength of MHP 3 is the highest among all studied bodies and it is nearly twice as high as that of M.
- The fired strength of MHP 1 is the highest among MCP/MHP bodies while MHP 3 has the lowest fired strength.

Slip bodies	950°C	1000°C	1050°C	1100°C	1150°C	1200°C	1250°C	1300°C
M	0	0.8	0.8	0.8	1.3	2.0	4.8	7.3
MCP 1	0	0	0	0	0.7	1.7	4.0	6.0
MCP 2	0	0	0	0.1	1.7	2.2	4.5	6.5
MCP 3	0	0	0.2	0.5	3.2	3.2	6.0	6.7
MHP 1	0	0	0	0	0.3	2.0	3.2	3.8
MHP 2	0	0	0	0.5	1.2	2.5	3.7	4.8
MHP 3	0	0	0.5	0.8	1.8	3.0	4.0	5.7

Table 2. Degree of deformation (average/mm) of M, MCP, and MHP slip bodies in fired states (compare to Table 5 in Paper III)

From the above results, the following statements can be made:

- It is clear that paper-composite porcelain bodies undergo a sudden structural transformation in the interval 1100-1200°C, and again between 1200-1250°C (see Section 6.2 of Paper III for more details).
- Paper-composite porcelain bodies have firing temperature that are about 50-150°C higher than M (see Section 6.2 of Paper III).
- All MHP bodies have less deformation than M or MCP bodies at 1250°C and 1300°C.

4.2. The fired state above 1300°C

In the artistic experiments, the gloss firing temperature was selected at 1300°C because studio potters rarely use firing temperatures above 1300°C. However, I was curious about the physical properties above 1300°C, since hard-paste porcelain can be fired at higher temperatures than 1300°C. The following result show the degree of deformation of M, MCP and MHP bodies at a firing temperatures of 1350°C. Table 3, the results for bodies fired at 1350°C have been inserted into Table 2 to show the changes.

Slip bodies	950°C	1000°C	1050°C	1100°C	1150°C	1200°C	1250°C	1300°C	1350°C
M	0	0.8	0.8	0.8	1.3	2.0	4.8	7.3	7.5
MCP 1	0	0	0	0	0.7	1.7	4.0	6.0	6.0
MCP 2	0	0	0	0.1	1.7	2.2	4.5	6.5	6.5
MCP 3	0	0	0.2	0.5	3.2	3.2	6.0	6.7	7.0
MHP 1	0	0	0	0	0.3	2.0	3.2	3.8	4.5
MHP 2	0	0	0	0.5	1.2	2.5	3.7	4.8	5.0
MHP 3	0	0	0.5	0.8	1.8	3.0	4.0	5.7	6.2

Table 3. Degree of deformation (average/mm) of M, MCP, and MHP slip bodies in fired states (compare to Table 2 in 4.1)

From these results, the following statements can be made:

- MCP and MHP bodies have lower deformation than M above 1300°C.
- There are no changes in the degree of deformation for MCP 1 and MCP 2 when the firing temperature is increased from 1300°C to 1350°C.
- The biggest difference is between MHP 1 (4.5 mm) and M (7.5 mm) at 1350°C.
- Deformation of all MCP and MHP bodies occurs between 1050°C and 1150°C, but at 1000°C for M, which suggests that the MCP and MHP bodies can withstand firing temperatures that are 50-150°C higher than M, although MCP 2 and 3, and MHP 2 and 3 show a higher degree of deformation in the intervals 1150-1250°C and 1150-1200°C respectively.

4.3. Effects of extra $CaCO_3$ in the fired state

In the artistic experiment, it was clearly shown that extra calcium carbonate ($CaCO_3$) from the paper and extra anorthite in the fired state directly influenced the visual characteristics of the paper-composite porcelain in both body and glaze (see Sections 5.3 and 6.2 of Paper III). However, to discover the effect that extra $CaCO_3$ from waste paper have on paper-composite porcelain, I wanted to compare them with the effect of adding extra $CaCO_3$ minerals to M. The differences between the two body types were studied through a deformation test. For better accuracy, I chose to recalculate the MCP composition to three comparable MCa (M porcelain combined with extra $CaCO_3$) bodies (MCa 1, 2, and 3).

CP has 20% $CaCO_3$ in weight in its composition (see Section 2.1 of Paper I). MCP bodies were prepared with three different paper ratios: 6.8%, 14.6% and 39.8% in weight. Recalculating 20% $CaCO_3$ in weight from each MCP paper ratio indicated that 1.36%, 2.92% and 7.96% more $CaCO_3$ should be added to each body respectively. Danish $CaCO_3$ was used as extra $CaCO_3$ for the MCa bodies. The formulations of M, MCP and MCa bodies are shown in Table 4.

	M	MCP 1	MCP 2	MCP 3	MCa 1	MCa 2	MCa 3
Kaolin	50	46.60	42.70	30.10	49.32	48.54	46.02
Feldspar	25	23.30	21.35	15.05	24.66	24.27	23.01
Quartz	25	23.30	21.35	15.05	24.66	24.27	23.01
CP ($CaCO_3$ in CP)		6.80 (1.36)	14.60 (2.92)	39.80 (7.96)			
Extra $CaCO_3$					1.36	2.92	7.96

Table 4. M, MCP and MCa body formulations (wt.%)

Slip bodies	950°C	1000°C	1050°C	1100°C	1150°C	1200°C	1250°C	1300°C	1350°C
M	0	0.8	0.8	0.8	1.3	2.0	4.8	7.3	7.5
MCP 1	0	0	0	0	0.7	1.7	4.0	6.0	6.0
MCP 2	0	0	0	0.1	1.7	2.2	4.5	6.5	6.5
MCP 3	0	0	0.2	0.5	3.2	3.2	6.0	6.7	7.0
MCa 1	0.5	0.8	1.0	1.3	1.8	3.5	7.3	13.3	x
MCa 2	0.7	0.8	1.3	1.5	1.8	4.0	7.8	14.0	x
MCa 3	0.8	1.0	1.3	1.5	1.8	4.0	9.0	17.0	x

Table 5. Degree of deformation (average/mm) of M, MCP, and MCa bodies in fired states (compare to Table 3 in 4.2)

The results are as follows:

- All MCa bodies started to deform from as early as 950°C. Compared to any of the

MCa bodies, MCP 1 had a 200°C higher resistance against deformation.
- At 1000°C, the degree of deformation of the MCa bodies and the M body were similar.
- At 1300°C, MCa 3 deformation was nearly three times larger than that of MCP 1.
- At 1350°C, all MCa bodies were collapsed. MCa 3 looked like melted frozen glass while MCa 1 and 2 had stuck to the kiln shelf.

From these results the following has clearly been proved.
- The material characteristics, physical properties and visual effects of paper-composite porcelain are not only influenced by the extra $CaCO_3$ from CP which changes to anorthite in the fired state, but also by the paper fibre in the structure, which influences the body.
- In MCa bodies with extra $CaCO_3$ but without paper fibre, $CaCO_3$ works as a strong flux, increasing deformation and decreasing the firing temperature in comparison to M.
- MCP bodies with extra $CaCO_3$ from the added paper fibre and with anorthite in fired state have higher firing resistances and higher firing temperatures than M.

CHAPTER 5

Results and Conclusions

This chapter presents the results from both the technical and artistic experiments, as well as the conclusions of the thesis. In order to avoid repetition, the results presented in the four separate papers are only presented as a short summary in this chapter.

The initial research questions (see Section 1.2) were:

- What are the fibrous forms that are seen at the surface of fired paper-composite porcelain?
- Why is that these fibres do not appear to burn away?
- What happened to the structure of paper-composite porcelain during firing?
- Did the adding of paper change any of the original characteristics of the porcelain body?

My hypothesis was (see Section 1.3):

- Minerals in added paper are not burnt away during the firing process and may therefore influence the body characteristics when paper is used as an additive in the production of paper-composite porcelain.

The main aim of this research project was to obtain a better understanding of paper-composite porcelain and its workability in ceramic art and design practice (see Section 1.4). The following sub aims were therefore outlined:

- To characterise paper-composite porcelain (Papers I and II)
- To investigate its properties (Papers II and III)
- To investigate the feasibility of using this material for practical ceramic art and design purposes (Paper III)
- To contribute to the development of explicit knowledge within the field of ceramic art and design (Paper I, II, III and IV).

The following findings and conclusions can be presented.

- From the SEM examinations we can see that a fibrous structure is present in the paper-composite porcelain body in both its green and fired states. The calcite from the recycled papers melted with the kaolinite during the firing process and transformed to anorthite. This was identified in the microstructure of the paper-composite porcelain in the fired state. The XRD showed that the only major crystalline phases present in the fired paper-composite porcelain bodies were mullite, α-quartz, anorthite and amorphous materials, despite the presence of different types of paper in the bodies. The development of anorthite in the fired paper-composite porcelain is caused by calcium carbonate from the waste paper, which increases the degree of heterogeneity in the formation of a porcelain body. The conclusion is thus that the fibres seen at the surface of fired paper-composite porcelain are transformed residues from the paper. The paper does not burn away completely since the calcite in the paper melts during firing and is transformed to anorthite (Paper I).
- The structures of fired paper-composite porcelain bodies had special fibre binders covered with anorthite. This is a material which is involved in the construction of fibrous bridges and tunnels and which therefore changes the body composition. The fibrous structures displayed binding, interlocking fibres and fibrous bridging. The conclusion is thus that the residual mineral calcite and paper fibre which are transformed into anorthite during firing form a supporting complex structure of interlocking fibres and fibrous bridging, changing the body composition in the process (Paper I).
- The microstructure of paper-composite porcelain bodies showed different body structures compared to the ordinary porcelain bodies. The changed body composition has a fundamental influence on the technical properties of the paper-com-

posite porcelain in both the green and fired states. The conclusion is thus that the added paper in paper-composite porcelain changes the original characteristics of the porcelain body. Paper-composite porcelain has a higher green strength, lower shrinkage, lower degree of deformation and wider firing range than traditional porcelain at firing temperatures of 1300°C and 1350°C (Papers I, II and III).

- A higher paper fibre content in a slip cast body resulted in a lighter weight, higher porosity and absorption, lower density and lower strength in the fired state. A higher fibre content improved the green strength; however the effect was the opposite in the fired state (see Paper II).
- The free-hand press casting method resulted in a lower shrinkage ratio and a higher green strength than the samples which were produced by the slip casting method. The conclusion is that factors influencing the technical properties of paper-composite porcelain are not only caused by the paper fibre itself, but also the amount of paper fibre in the body composition, the type of paper fibre added and the production method (see Papers II and III).
- There was less cracking, warping, bending and deformation of the paper-composite porcelain than of the M body. The strong fibre bonding structure supported the plastic stage during the casting process, especially in the case of the complicated shapes. The results showed that the behaviour of paper-composite porcelain varied according to the paper fibre content of the clay body. It was most convenient to use the paper-composite porcelain bodies with the lowest paper content in the casting process, as this produced the finest surface and texture in the final product. However, even the final paper-composite porcelain product with the highest paper fibre content produced fine lines and sharp angles. The paper-composite porcelain thus showed a high potential for artistic utility and could be used to expand the field of ceramic art and design, a field which can benefit from the characteristics of this material (see Paper III).
- No difference in whiteness was observed between the M and MCP bodies, however MCP bodies had a more silky lustre when compared to M. In glazed MCP bodies, the glaze showed a deeper and more translucent effect than M (see Section 5.3 in Paper III).
- Interdisciplinary research methods were applied in this study to understand the structure and behaviour of the material. The combination of artistic and scientific studies enabled the application of personal experience of practical craftwork, thus maintaining the artistic perspective, while the scientific perspective reduced the requirement for trial and error in practice. This method enabled me to understand

the materials in use, predict how it would react and explain the characteristics to others. Ceramic material research needs to be linked to actual ceramic art and design practice in order to promote a relevant, fundamental knowledge of materials. Ceramic practitioners would therefore be able to more accurately select the optimal material for the particular purpose of their practical work (Paper IV).

CHAPTER 6

Contributions of this research to the field of ceramic art and design

This research made the following contributions to the field of ceramic art and design.

- Characterisation of microstructure. The studies revealed that a fibrous structure was created in the paper-composite porcelain body in both its green and fired states. The microstructure of paper-composite porcelain bodies was different from that of ordinary porcelain bodies. The structures of fired paper-composite porcelain bodies had special fibre binders covered with anorthite. This is a material that is involved in the construction of fibrous bridges and tunnels and which changes the composition of the porcelain body. The fibrous structures displayed strongly binding, interlocking fibres and fibrous bridging, forming a support structure for the ceramic objects.
- New information on the residual minerals in paper-composite porcelain bodies: In stark opposition to the common belief that the paper is burnt away and leaves a

porous structure in the fired state of the paper clay body (Gault, 1993b; Juvonen, 1995: Stevens, 2002), this research found that mineral compounds in the added paper are transformed during firing and make an essential contribution to the special properties of the paper-composite porcelain. The calcite from the recycled papers melted with the kaolinite during the firing process and transformed to anorthite, which was identified in the microstructure of the paper-composite porcelain in the fired state.

- Waste paper was used to produce the studied paper-composite porcelain. Thus ethical and economic concerns were both addressed, since waste paper is an additive that can easily be obtained, and at little or no cost. The use of paper-composite porcelain can therefore contribute to the reduction of waste and help to turn ceramic work into an even more sustainable product (see Papers I, II and III).
- Comparison of effects of different production methods on physical properties: The free-hand press casting method resulted in a lower shrinkage ratio and a higher green strength than were obtained in the samples which were produced by the slip casting method (see Paper II).
- New slip preparation of paper-composite porcelain: The excess water was recycled as additional water when mixed with porcelain powders and paper pulps (see Papers I, II and III). No ready-made paper pulp was used. All of the excess water was recycled so as not to lose any minerals or chemical compounds from the paper. Thus, this clay body preparation method clearly differs from others used for paper clay making (Gault, 1992 and 1993; Goldgate, 2001; Juvonen, 1995), in which the excess water is discarded. The artistic experiments also proved that is was possible to slip cast fine lines and sharp angles with paper-composite porcelain, even when using the slip with the highest paper-fibre content.
- The highest amounts of paper fibre were mixed: In this research, the paper-fibre contents were 50%, 70% and 90% in volume (as 6.8%, 14.6% and 39.8% in weight) which are the highest amounts of paper fibre previously reported. Prior to this, the highest ratios reported were the 50% paper pulp by volume tested by Gault (1993), Goldate (2001) and Lightwood (2000) tested 50% paper pulp in volume and the 20% in weight tested by Juvonen (1995) (see Papers I, II and III).
- All raw materials used in this study were produced within European countries. This could be beneficial to European ceramicists (see Papers I, II and III).
- Detailed physical properties from test results both in green and fired states are reported (see Papers II and III).
- The biscuit firing temperature of paper-composite porcelain was identified as be-

ing 50-150°C higher than for M bodies (see Section 4.2).

- Higher firing temperatures were tested. It is assumed that paper-composite bodies can be fired up to at least 1500°C since its mother recipe, a hard-paste porcelain clay body, can normally be fired up to 1450°C. Tests of the physical properties and deformation tests indicate that paper-composite bodies have an even higher firing temperature, roughly 50-150°C higher than the M body (see Section 6.2 of Paper III).
- The effects of extra calcium carbonate and anorthite were identified. In the fired state, the extra calcium carbonate has a directly observable influence on the visual characteristics of the paper-composite porcelain, in both body and glaze (see Sections 5.3 and 6.2 in Paper III).
- The role of paper fibre in providing reinforcement in the initial stages of forming and fabricating clay composites was identified and explained. The relation between extra minerals and paper fibre in paper-composite porcelain in the fired state was discovered. It was demonstrated that the material characteristics, physical properties and visual effects of paper-composite porcelain are not only influenced by the extra $CaCO_3$ from CP which changes into anorthite in the fired state, but also that paper fibre influences the structure of the porcelain body. In MCa bodies with extra $CaCO_3$ and without paper fibre, $CaCO_3$ works as a strong flux, causing higher deformation than seen in the M body and lowering the firing temperature; MCP bodies with extra $CaCO_3$ from paper fibre and anorthite in the fired state have higher firing resistance and higher firing temperature than the M body (see Section 4.3, Papers I, II and III).
- An interdisciplinary methodology for practice-based research was applied to this research with the aim of contributing to the development of an explicit knowledge base within the field of ceramic art and design.

CHAPTER 7

Further research and recommendations

- One of the priorities among my interests many for further study one to investigate whether the paper fibres are carbonised in the microstructure of paper-composite porcelain bodies or whether they remain in their original form. One of my initial hypotheses was that the fibres are perhaps carbonised. However, due to the unavailability of the relevant technical instruments it was not studied in this research. Carbon fibre composites are of major interest as a multifunctional material, especially for construction uses (Chen and Chung, 1996; Chung, 2000) in the nanocomposite field. Further investigation of the microstructure and properties may open opportunities for the development of paper-composite porcelain for many other purposes.
- The transformation of calcium carbonate and anorthite in the microstructure of paper-composite porcelain, and how these influence the aesthetic appearance of the final product is another aspect which could be the subject of future research. In the fired state, these compounds directly influence the characteristics of the

paper-composite porcelain, i.e., both the body and the glazed form (see Sections 5.3 and 6.2 of Paper III). A deeper investigation of the degree of whiteness and translucency of paper-composite porcelain in comparison to porcelain would benefit both industry and art ceramicists. The use of quantitative methods such as a visual assessment on a match scale would give a more accurate description of the aesthetic qualities.

- It would be useful for porcelain industry and studio potters using high-fired porcelain if a more thorough investigation of the physical properties of paper-composite porcelain above 1350°C were conducted to establish its exact biscuit and gloss firing temperatures and changes in strength, etc. Hard-paste porcelain is a body that has been fired at high temperature. The results of this research indicated that paper-composite porcelain can be fired at higher temperatures than its mother porcelain.
- Paper-composite porcelain and the knowledge of it ought to be used as a base upon which to develop alternative designs, i.e., sustainable eco-design products and architectural material which would benefit both society and researchers in the future.

CHAPTER 8

Svensk sammanfattning

Denna avhandling omfattar åtta kapitel, som redogör för forskningsprojektet i sin helhet, samt fyra separata artiklar, varav de två första är publicerade och de två senare inskickade för publicering.

Papperskompositporslin är pappersblandad lera som kombinerar vilken som helst slags porslinslera med papper. Papper blandas vanligen med lera för att förbättra låg hållfasthet och plasticitet - två av de största praktiska problemen med porslinslera. Problemen med det traditionella porslinet är allmänt kända. Trots sin unika hårdhet och höga densitet har porslinet tydliga konstnärliga begränsningar som material. De allvarligaste problemen beror av porslinsmassans låga plasticitet, höga vikt, skörhet i grönt tillstånd, höga deformationsgrad och korta temperaturintervall för bränning.

Tidigare prövade inblandningar i porslinsmassan förbättrar dess gröna styrka och plasticitet, men har andra nackdelar, som t ex att det reducerar transparens och vithet, eller förstärker andra negativa beteenden, t ex genom att öka krympningen och tendensen till skevning/förvrängning under torkning och bränning.

Papperskompositporslin har en tydligt positiv effekt för porslinsmassans gröna styrka, men är ett relativt nytt och outforskat material, och de få studier som genomförts ger fragmentariska inblickar. Förutom att det saknas kunskap om materialets tekniska egenskaper och sammansättning, har praktiska konstnärliga problem också identifierats i tidigare studier. Papperskompositporslin sägs vara svårt att få skarpa kanter, komplexa former och fina ytor med, vara svår att gjuta och ha tendens att fastna i gipsformen vid gjutning – särskilt när andelen inblandat papper är hög.

Trots ett utbrett intresse inom keramikkonsten för att använda papperskompositporslin har dess egenskaper ännu ej beskrivits. Syftet med detta forskningsarbete har varit att förstå den konstnärliga användbarheten hos papperskompositporslin och få tillförlitlig kunskap om materialets egenskaper.

Praktiska konstnärliga experiment kombineras i detta forskningsarbete med laboratorieexperiment som används inom materialvetenskaperna. De konstnärliga experimenten undersöker hanterlighet och användbarhet hos papperskompositporslin med olika volymprocent iblandat papper (50, 70 och 90 %) i gjutning av formmässigt olika modeller. De tekniska studierna undersöker kvalitativt materialegenskaper och mikrostruktur med hjälp av röntgendiffraktionsmätning och svepelektronmikroskop. Kvalitativa test av fysiska egenskaper användes för att undersöka betydelsen av olika recept för gjutmassan, olika produktionsmetoder och olika temperaturer vid bränning. I kvantitativa studier, i enlighet med internationell standard test (ASTM) metoder, mättes och analyserades egenskaperna hos papperskompositporslin med olika volymprocent iblandat papper, och hos moderporslinet.

De konstnärliga experimenten omfattar utveckling av en fungerande gjutmetod där överskottsvattnet återanvänds. Processen och erfarenheterna från arbetet med olika andelar pappersinblandning redogörs för i alla väsentliga detaljer, från beredningen av pappersmassan till den slutliga bränningen, inräknat observationer av yta och textur hos de slutliga produkterna. Gjutningen av modeller för olika delar i en matservis visade att sprickbildning, skevning, buktning och deformation var betydligt mindre hos papperskompositporslinet än hos moderporslinet, och skarpa vinklar liksom fina linjer och ytor erhölls också med den högsta volymprocenten iblandat papper (90 %). Vitheten hos slutprodukten var, jämfört med moderporslinet, densamma, men papperskompositporslinet hade en mer silkig lyster och, när det glaserats, större genomskinlighet.

Fibriga strukturer identifierades hos papperskompositporslin i både grönt och bränt tillstånd. Kalkspat, från papperstillsatserna i det återvunna av pappert, smälter med kaolinit under bränningen och omvandlas till fiberaktig anortit som observerats i mikrostrukturen hos det brända papperskompositporslinet. Pappersfiberns närvaro, liksom papperstypen och volymen tillsatt papper bevisas vara viktiga faktorer för den förbättrade gröna hållfastheten hos papperskompositporslin, som i jämförelse med moderporslinet har högre grön hållfasthet, lägre krympning, lägre deformationsgrad och större temperaturintervall för bränning.

Papperskompositporslin visade sig inte bara ha kvalitéer som löser de ursprungliga problemen med traditionellt porslin. Den här utvecklade metoden för gjutning visar också att de identifierade problemen med papperskompositporslin är möjliga att lösa, och med sina speciella egenskaper har materialet stor potential för utveckling inom en konstnärlig kontext.

Resultaten ger oss ny kunskap om papperskompositporslin genom att identifiera pappersfiberns förstärkande roll och materialets uppförande i den normala konst- och konsthantverksproduktionens olika stadier, och förmedlar dessutom en praktiskt prövad och dokumenterad metod för gjutning med upp till 90 volymprocent iblandat papper, vilket tillsammans tydliggör papperskompositporslinets potential som konstnärligt material.

Translation: Cecilia Häggström

References

ASTM C 326-82 (1997). *Standard test method for drying and firing shrinkage of ceramic whiteware clays.* ASTM International, Ohio.

ASTM C 373-88 (1999). *Standard test method for water absorption, bulk density, apparent porosity, and apparent specific gravity of fired whiteware products.* ASTM International, Ohio.

ASTM C 689-80 (1999). *Standard test method for modulus of rupture of unfired clays.* ASTM International, Ohio.

Baker, W. L. (1998) Spraying paper-reinforced clay. *Ceramic Monthly,* 46 (9), 46-49.

Biermann C. J. (1996) *Handbook of pulping and papermaking. 2nd ed.,* Academic press, London.

Bown. R. (1996) Physical and chemical aspects of the use of fillers in paper. In: Roberts. J. C. (ed.) *Paper chemistry, 2nd ed.,* Blackie academic & professional, London, pp194-228.

Brown, N. C. M. (1997) Theorising the crafts: new tricks of trades. In *Craft & contemporary theory,* Rowley, S. (ed.), Allen & Unwin, Sydney, pp 3-17.

Bunnell, K. (1998) *Re:presenting Making, The Integration of New Technology into Ceramic Designer-Maker Practice.* PhD thesis on CD-ROM, The Robert Gordon University, Aberdeen.

Cardew, Michael. (1971) *Pioneer pottery,* Longman, London.

Carty, W. M. and Senapti, U. (1998) Porcelain-raw materials, processing, phase evolution, and mechanical behaviour. *J. Am. Ceram. Soc.,* 81 (1), 5-20.

Chen, P. W. and Chung, D. D. L. (1996) Low-drying-shrinkage concrete containing carbon fibres. *Composites part B.,* 27 (3-4), 267-274.

Chou, T. W. (1992) *Microstructural design of fibre composites.* Cambridge University Press, Cambridge.

Chung, D. D. L. (2000) Cement reinforced with short carbon fibres: a multifunctional material. *Composites part B.,* 31 511-526.

Cochrane, G. (1997) Keeping content: craft, history and curatorship. In *Craft & contemporary theory,* Rowley, S. (ed.), Allen & Unwin, Sydney, pp 53-62.

Composite. (1987) *Engineered materials handbook.* Vol. 1, ASM International, Ohio.

Conrad, W. J. (1980) *Contemporary ceramic formulas.* Macmillan publishing Co., Inc. New York.

Cooper, E. and Royle, D. (1978) *Glazes for the studio potter.* B. T. Batsford Ltd, London.

Cooper, E. (1981) *A history of world pottery.* B. T. Batsford Ltd., London.

Cooper, E. (2002) *Ten thousand years of pottery.* The British museum press, London.

Dawes, S. (1999) *The manufacturing processes of Hellenistic and Roman glass, 300 BC to 200 AD: A new theory of production.* Unpublished PhD thesis, University of Central England, Birmingham.

Dawson, S. (1993) *The art and craft of papermaking.* Aurum Press, London.

Delmonte, J. (1989) *History of composites.* Reference book for composites technology, vol. 1, Lee, M. S. (ed.) Technomic publishing company, Inc., Lancaster.

Dormer, P. (1997) Craft and the Turing test for practical thinking. In *The culture of craft,* Dormer, P. (ed.), Manchester University Press, Manchester, pp 137-157.

Fournier, R. (1973) *Illustrated dictionary of practical pottery.* Van Nostrand Reinhold Company Ltd, London.

Fraser, H. (1986) *Ceramic faults and their remedies.* A & C Black, London.

Friedman, K. (2003) Theory construction in design research: criteria: approaches, and methods. *Design Studies,* 24, 507-522.

French, N. (1972) *Industrial ceramics: Tableware.* Oxford University press, London.

Fyleverken Industrimineralberednings IMB AB (2003). *Technical data.* Fyleverken Industrimineralberednings IMB AB, Eriksdal, Sjöbo.

Gartside, B. (1993) Paper clay. *New Zealand Potter,* 35 (3), 32-33.

Gault, R. (1992) Amazing paperclay. *Ceramic monthly,* June/July/August, 96-100.

Gault, R. (1993a) *Paper clay for ceramic sculptors: A studio companion.* Clear light pub., WA.

Gault, R. (1993b) Second generation ceramic sculpture: technical and aesthetic potential of paperclay. Valkonen, A. (ed.), In: *Interaction in ceramics,* UIAH, Helsinki, pp 72-79.

Gault, R. (1998) *Paper clay.* A & C Black, London.

Gay, D. (2002) *Composite materials.* Hoa, S. V. and Tsai, S. W. (eds.) Materiaux Composites. 4th ed., CRC Press LLC, Florida.

Glusker, J. P., Lewis, M. and Rossi, M. (1994) *Crystal structure analysis for chemists and biolo gists.* Wiley-VCH, Philadelphia.

Goldate, S. (2001) Working with paperslip. *Ceramics technical,* 13, 78-80.

Gray, B. (1952) *Early Chinese pottery and porcelain.* Faber and Faber, London.

Griffith, R. (1998) The Adobe series. *Ceramics technical,* 6, 30-33.

Hamer, F. and Hamer, J. (2004) *The potter's dictionary of materials and techniques. 5th ed.,* A & C Black, London.

Hamilton, D. (1978) *Architectural ceramics.* Thames and Hudson, London.

Hay, G. (1996) More on paperclay. *Ceramics technical,* 3, 22-28.

Heller, J. (1978) *Papermaking.* Watson-Guptill Publications, New York.

Hlavác, J. (1983) *The technology of glass and ceramics.* Glass science and technology, Vol 4, Nemeck, K. (ed.), Elsevier, Amsterdam.

Hornbostel, C. (1991) *Construction materials: types, uses and applications.* John Wiley & Sons, Inc., Chichester.

Hortling, A. and Siren, K. M. (1993) The effect of Finnish earthenware clay and calcium oxide on the colour changes in stoneware glazes. In: *Interaction in ceramics,* Valkonen, A. (ed.), UIAH, Helsinki, pp 113-118.

Imerys mineral Ltd (2000). *Typical data.* Imerys mineral Ltd, Paris.

Jeoung-Ah, K. (2001) Recycling of paper in porcelain as an ecological design. In *Proceeding of the 5th ADC Design Congress 2001,* Seoul.

Jeoung-Ah, K. (2004) The characterisation of paper composite porcelain in a fired state by XRD and SEM. *Journal of the European Ceramic Society,* 24 (15-16), 3823-3831.

Jeoung-Ah, K. (2006) The characterisation of paper-composite porcelain in a green state. *Journal of the European Ceramic Society,* 26 (6), 1023-1034.

Juvonen, L. (1995) Using paper fibre as a substitute in ceramic clays. In *Proceeding of the 8th CIMTEC World Ceramics Congress 1994,* Vincenzini, P. (ed.), Faenza, pp 193-200.

Kelly, A. (1994) *Concise Encyclopedia of composite materials.* Elsevier science Ltd., Amster dam.

Kerr, R. and Wood, N. (2004) *Science and civilisation in China.* Chemistry and chemical technology Vol. 5, Ceramic technology Part XII, Kerr, R. (ed.), Cambridge University press. Cambridge.

Kim, J. A. (1993) To construct by repetition to reflect time and space for subject interpretation through the ceramic works by the use of paper clay. In: *An exhibition catalogue of MA examination,* Göteborg University (ed.), Tryckeri AB Framåt, Gothenburg.

Kim, J. A. (2004) *The characterisation of paper-composite porcelain: Material properties and workability from ceramic art and design perspective.* Unpublished thesis for the degree of Licentiate of Philosophy, Göteborg University, Gothenburg.

Kingery, W. D. and Vandiver, P. (1983) Song Dynasty Jun (Chun) ware glaze. *Ceramic Bullen tin,* 62 (11) 1269-1279.

Kingery, W. D. and Vandiver, P. (1986) *Ceramic masterpieces.* Macmillan Publishing Co., New York.

Kingery, W. D. (1990) *The changing roles of ceramics in society.* American Ceramic Society, Westerville.

Kingery, W. D. (1993) Internal structure and visual effects of ceramics. In: *Interaction in ceramics,* Valkonen, A. (ed.), UIAH, Helsinki, pp 87-98.

Kobayashi, Y. and Kato, E. (1994) Low temperature fabrication of anorthite ceramics. *J. Am. Ceram. Soc.,* 77 (3), 833-834.

Kähkönen, R. (1993) Ceramics by viscose silica clothing. In: *Interaction in ceramics,* Valkonen, A. (ed.), UIAH, Helsinki, pp 67-71.

Lane, P. (1980) *Studio porcelain.* Pitman house, London.

Langer, V. (2002) Lecture Notes: Crystallography, x-ray diffraction and their use in material science. Compendium: *Material science; Characterisation.* Graduate school of Materials science, Chalmers University of Technology, Gothenburg.

Lee, W. E. and Iqbal, Y. (1999) Fired porcelain microstructure revisited. *J. Am. Ceram. Soc.,* 82 (12), 3584-3590.

Lee, W. E. and Iqbal, Y. (2001) Influence of mixing on mullite formation in porcelain. J. *Eur. Ceram. Soc.,* 21, 2583-2586.

Li, J. Z. (1985) The evolution of Chinese pottery and porcelain technology. In: *Ancient technology to modern science,* Kingery, W. D. (ed.), The American ceramic society, Inc., p 148.

Lightwood, A. (2000) *Working with paper clay and other additives.* The Crowood Press, Wiltshire.

Longworth, C. (2005) Buckley ceramics in the seventeenth century. *Interpreting ceramics,* Issue 6, Electronic journal http://www.interpretingceramics.com.

Malin, J. (1993) *The monitoring and control of specialised ceramic kiln atmospheres and emissions.* Unpublished PhD thesis, The Robert Gordon University, Aberdeen.

Matson, R. F. (1965) *Ceramics and man.* Aldine publishing company, Chicago.

Morley-Fletcher, H. (1987) *Techniques of the world's great masters of pottery and ceramics.* Phaidon Christies, Oxford.

Norsker, H. (1987) *Clay materials for the self-reliant potter.* Vieweg, Frankfurt.

North Cape mineral AS (2003). *Technical data.* North Cape mineral AS, Rud.

Norton, F. N. (1956) *Ceramics for the artist potter.* Addison-Wesley Publishing Company, Reading.

Oh, Y. T., Yoshihara, K., Takebe, H. and Morinaga, K. (1997) Phase transformations of alkalineearth aluminosilicate glasses during isothermal heat treatment. *J. Ceram. Soc. Jpn.,* 105 (12), 1199-1204.

Onoda, J. Y. (1976) Theoretical strength of dried green bodies with organic binders. *J. Am. Ceram. Soc.,* 59 (5-6), 236-239.

Peterson, S. (1995) *The craft and art of clay. 2nd ed.,* The overlook press, New York.

Petrie, K. (1999) *Water-based ceramic transfer printing: The development and creative use of a new on-glaze screenprinting system.* Unpublished PhD thesis, University of the West of England, Bristol.

Polanyi, M. (1964) *Science, faith and society.* The University of Chicago Press, Chicago.

Polanyi, M. (1983) *The tacit dimension.* Peter Smith, Gloucester, Massachusetts.

Polanyi, M. (2002) *Personal knowledge: Towards a post-critical philosophy.* Routledge & Kegan Paul Ltd, London.

Prasad, P. (2005) *Crafting qualitative research.* M. E. Shape, Inc., London.

Rado, P. (1969) *An introduction to the technology of pottery.* Pergamon press, London.

Rawson, P. (1971) *Ceramics.* Oxford University Press, Oxford.

Rhodes, D. (1964) *Clay and glazes for the potter.* Sir Isaac Pitman & Sons Ltd, London.

Rhodes, D. (1971) *Stoneware & porcelain.* Pitman publishing, London.

Richerson, D. W. (1992) *Modern ceramic engineering. 2nd ed.,* Marcel Dekker Inc., New York.

Rowley, S. (1997) *Craft and contemporary theory.* Allen & Unwin, Sydney.

Santacruz, I., Nieto, M. I., Moreno, R., Ferrandino, P., Salomoni, A. and Stamenkovic, I. (2003) Aqueous injection moulding of porcelains. *J. Eur. Ceram. Soc.,* 23 (12), 2053-2060.

Shackelford, J. F. (2000) *Introduction to materials science for engineers. 5th ed.,* Prentice-Hall, Inc., New Jersey.

Sheaf, C. (1987) Chinese blue and white. In *Techniques of the world's great masters of pottery and ceramics,* Morley-Fletcher, H. (ed.), Phaidon Christie's Limited, Oxford, pp 68-77.

Shortland, M. and Gregory, J. (2002) *Communicating science.* Addition Wesley Longman Limited, Essex.

Silveira, G., Forsberg, P. and Conners, T. E. (1995) Scanning Electron microscopy: A tool for the analysis of wood pulp fibres and paper. In *Surface analysis of paper,* Conners, T. E. and Banerjee, S. (eds.), CRC Press, New York, pp 41-71.

Smith, T. (1997) Craft, modernity and postmodernity. In *Craft & contemporary theory,* Row ley, S. (ed.), Allen & Unwin, Sydney, pp. 18-28.

Soong, D. K. and Ling, Y. C. (1995) Determination of PCDD/DFs in paper clay samples. *Chemosphere,* 30 (9), 1799-1803.

Stevens, G. (2002) An investigation into the properties of porcelain paperclay. *Ceramics Tech nical,* 14, 72-77.

Sutherland, B. (1987) *Glazes from natural sources.* Batsford Ltd., London.

Trilly, W. (1989) Japanese blue and white. In *Techniques of the world's great masters of pottery and ceramics,* Morley-Fletcher, H. (ed.), Phaidon Christie's Limited, Oxford, pp 78-83.

Turner, S. (1991) *White paper.* BSA Printers Ltd., New York.

Whitney, R. P. (1979) Chemistry of Paper. In *Paper-Art & Technology,* Long, P. (ed.), World Print Council, San Francisco, pp 36-44.

William, M. C. and Udayan, S. (1998) Porcelain-Raw materials, processing, phase evolution, and mechanical behaviour. *J. Am. Ceram. Soc.,* 81 (1), 3-20.

Paper I

The characterisation of paper composite porcelain in a fired state by XRD and SEM

Jeoung-Ah, K. The characterisation of paper composite porcelain in a fired state by XRD and SEM. *Journal of the European Ceramic Society,* 2004, 24 (15–16), 3823–3831.

Table of contents

Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Journal of the European Ceramic Society 24 (2004) 3823–3831

www.elsevier.com/locate/jeurceramsoc

The characterisation of paper composite porcelain in a fired state by XRD and SEM

Kim Jeoung-Ah*

School of Design and Crafts HDK, Göteborg University, Box 131, 405 30 Göteborg, Sweden

Received 3 October 2003; received in revised form 1 March 2004; accepted 6 March 2004

Abstract

Paper composite porcelain is widely used to produce artistic objects in ceramic art. The aim of this study is to characterise the microstructure and chemical compositions of paper composite porcelain since they determine the material properties. Interaction between paper filler, paper fibre, and the porcelain clay body in its fired state were investigated using X-ray diffraction (XRD) and scanning electron microscopy (SEM) techniques. The starting materials were kaolin, feldspar, quartz, hybrid copy/print waste paper, and other waste papers. XRD clearly shows that the paper composite porcelain bodies in the fired state mainly consist of α-quartz, mullite, anorthite and amorphous materials in a complex matrix. In the fired state, calcite from the waste paper's mineral interface to kaolinite from porcelain. A transformation to anorthite in the microstructure of paper composite porcelain was indicated. In the microstructure, anorthite glass were observed as fibrous structures in their fired state.

Keywords: Waste paper; Calcite; Anorthite; Microstructure; Chemical analysis; Porcelain

1. Introduction

Porcelains are vitreous ceramic whitewares used extensively in tableware, sanitary ware, decorative ware, electrical insulators and dental prosthetics. Porcelains typically have a triaxial formulation comprised of 50% clay, 25% flux and 25% filler.[1] Firing bodies containing these three components results in a grain and bond microstructure consisting of coarse aggregate (filler) particles held together by a finer matrix or bond system that is almost fully dense.[2] Porcelain represents the foundation of the ceramics discipline and is one of the most complex ceramic materials. Composed primarily of kaolin, feldspar, and quartz, porcelains are heat-treated to form a mixture of glass and crystalline phases.[3]

The term "paper composite porcelain" stands for any kind of porcelain that is combined with paper. Paper composite porcelain is a type of paper clay[4] that mainly consists of plant-based fibre pulp and mineral additives. They are widely used to produce artistic objects in ceramic art. As a ceramic material, paper composite porcelain is a specialised product and is the basis for the most attractive and inexpensive types of ceramic art products, mainly due to its light weight, workability and its high strength in its green state.[5] Despite the wide use of paper composite porcelain by numerous ceramists over many years, the character of this material is still poorly determined. No detailed studies have been reported for the chemical components and microstructural interactions between the porcelain raw materials, paper filler, and fibres, which make up the paper composite porcelain body in its fired state. In spite of the commercial interest in developing paper composite porcelain, very little research has been conducted in this field. This leaves significant opportunities for investigation and study, particularly in the two topic areas of phase and microstructural evolution and mechanical performances, the main topics to be addressed here. According to Gault,[6] Juvonen,[7] and Lightwood[4] the paper fibre is burnt away and leaves the porous structure in the fired state of paper composite porcelain body that gives a lighter weight than ordinary porcelain bodies. The organic paper fibre cellulosics act as a binder in the paper composite porcelain body. However, the inorganic mineral additives as a filler from paper may not just burn away, but could change

---

* Corresponding author. Tel.: +46-31-7734721; fax: +46-31-7734838.
E-mail addresses: [illegible] (K. Jeoung-Ah).

0955-2219/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jeurceramsoc.2004.03.002

form while interacting with other porcelain raw minerals. As a result, a controversy about the formation and chemistry of constituent phases in a paper composite porcelain body, particularly the glass matrix phase in a fired body, remains.

The main goal of this paper is to investigate the microstructural formation and chemical analysis in paper composite porcelain bodies, highlighting the importance of mixing of the paper fillers and fibres formed in the porcelain bond system. Additionally, some comparisons have been made to porcelain body formations to purify the porcelain system. This study involves the characterisation of the interactions between paper filler, paper fibre and the porcelain clay body during the production process in the fired state using XRD and SEM techniques. The aim is to obtain detailed and systematic information about the morphological and chemical characteristics of the resulting phases formed at the interfaces. This paper focuses on the complexities of the microstructure and the phase development in paper composite porcelain in a fired state.

2. Experimental procedure

2.1. *Raw materials of porcelain*

Porcelain has been studied as a mother body. The most relevant characteristics of porcelain are the following: it is composed of 50% kaolin, 25% feldspar and 25% quartz. The starting raw materials were kaolin (ECC International Standard Porcelain, Imerys Minerals Ltd., UK), the mineralogical composition is 84% kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) of 100% weight, whose chemical analysis approximates 48% silica (SiO_2), 36.5% alumina (Al_2O_3), and 12.5% H_2O. Particle size distribution is 70% <2 μm of weight %. FFF Finnish flotation feldspar (Partek Industry Mineral Ltd., Finland) of ceramic grade 200 mesh; the typical minerals are 47% potash feldspar ($K_2O \cdot Al_2O_3 \cdot 6SiO_2$) and 42% soda feldspar ($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$), whose chemical analysis is 67.2% silica, 18.3% alumina, 7.7% potash (K_2O) and 5.0% soda (Na_2O). The typical mineral composition of Finnish flotation quartz (Partek Industry Mineral Ltd.) of ceramic grade 200 mesh is 95.5% quartz and 4.5% feldspar whose chemical analysis approximates 98.5% SiO_2 of high purity. Silica stone consisted of almost pure quartz, which is hereafter designated as quartz. The recalculated oxides of the raw materials are shown in Table 1.

Table 2
Composition of copy paper (wt.%)

Product: Multi Copy Original	
Short fibre pulp (birch)	56
Long fibre pulp (pine and spruce)	16
Precipitated calcium carbonate (PCC)	20
Starch	3.1
Optical brightening agent	0.5
Polymer	0.1
Neutral size agent	0.1
Retention agent (silicon dioxide, PMAC)	0.1
Water	4.1

Source: technical data of office paper of Stora Enso, Nymölla AB (2004).

2.2. *Waste paper as additional raw material of paper composite porcelain*

Starting waste materials were chosen among the numerous varieties in paper production. Two different hybrid waste papers were selected due to easy availability. The first is a hybrid copy/print paper waste (CP), and the second is other hybrid paper waste (HP) that mixes all types of paper. Both included coated and uncoated papers. Table 2 shows the chemical compositions of the copy paper used in this study. The mineralogical constituents of the two papers are approximately the same with the exception of kaolinite and talc which are included in HP. The mineral additives of the paper used in this study are kaolin (kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), calcium carbonate (calcite, $CaCO_3$) and talc ($3MgO \cdot 4SiO_2 \cdot H_2O$). The mineral additives of paper, as fillers and coatings, are added to papermaking stock to improve properties such as opacity and smoothness, and often to reduce costs in paper production.[7] Kaolin and calcium carbonate are the most common mineral fillers of paper. Talc or titanium dioxides (TiO_2) are also used.

2.3. *Sample preparation*

Both hybrid waste papers (CP and HP) were reduced to pulp before being mixed with the porcelain powders. The waste paper was first soaked in hot water and beaten to disintegrate the fibres. Using a large mesh screen to get a pulp with 20% water, the porcelain powders were then added, and squeezed to get rid of excess water. The excess water was recycled as additional water when mixed with porcelain powders and paper pulp. The starting powders were mixed with various ratios in a planetary mixer for 3 h. The content of added water was 30 wt.%. Test samples were made of each test batch by free-hand pressing into a one sided plaster

Table 1
Chemical compositions of the raw materials (wt.%)

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	P_2O_5	Rb_2O	MgO	Na_2O	K_2O	Loss of ignition	Total
Kaolin	48	36.5	0.68	0.02	0.07	–	–	0.30	0.10	1.65	12.5	99.82
Feldspar	67.2	18.3	0.10	–	0.5	0.04	0.02	<0.005	5.0	7.7	0.59	<99.45
Quartz	98.5	0.6	0.025		0.1			0.01	0.2	0.15	0.70	100.285

Table 3
Composition of the mother porcelain body (M)

Raw materials	Percentage (%)
Kaolin	50
Feldspar	25
Quartz	25

mould, and the open surface was smoothed with a splint. Test samples were dried for 48 h at room temperature. After air-drying at room temperature for 48 h, they were further dried in an oven for 24 h at 110 °C. Firing was carried out in an electric kiln (Nabertherm, Germany), heated with Kanthal A1 elements. The samples were fired once at peak temperatures of 1220, 1240, 1260, 1280 and 1300 °C. The firing temperature is fixed at 1300 °C because studio potters rarely use firing temperatures above 1300 °C and commercial paper porcelains are mainly produced for studio potters. The samples were heated up to 350 °C (90 °C/h), and the heating continued up to 600 °C (150 °C/h), and then the firing proceeded at full rate to a final temperature, with a dwell time of 5 min.

The mineralogical composition of the mother porcelain powders used is shown in Table 3. The ratio of dried fibre varies from 6.8, 14.6 and 39.8% in relation to the dry weight of porcelain powders.

The test batches were mixed with two different paper types (CP and HP) with three different paper ratios (50, 70 and 90% by volume; 6.8, 14.6 and 39.8% in weight), five different firing temperatures, a base porcelain body (mother porcelain, M) with no paper fibre added, and two different raw paper types. The formulations of paper composite porcelain bodies are shown in Table 4. The characterisation quality assurance was adapted according to ISO-8402.

It should be noted that one practical difficulty with the XRD work was to prepare representative specimens of the relevant interfaces. The paper fibres were not uniformly distributed in the samples. The unevenness of the surface and different depths of penetration made the assessment of the diffractogram a difficult task.

2.4. Experimental techniques

2.4.1. X-ray diffraction (XRD)

XRD was used for the qualitative determination of the crystalline phases present in the 1300 °C fired paper composite porcelain bodies, 1300 °C fired porcelain body, CP hybrid paper, and HP hybrid paper. This was performed using a Siemens D 5000 diffractometer operating at 45 kV and 45 mA. Monochromatic Cu Kα radiation, $\lambda = 0.154060$ nm, was employed. The X-ray scan was made over a range of 2θ values of 15–60° with data acquisition for 3.0 s at intervals of 0.05°. The X-ray line traces were recorded using a computer system and commercial software Diffrac AT. Crystalline phases were identified by comparison with standard reference patterns from the Powder Diffraction File PDF-2 database sets 1–52, maintained by the International Centre for Diffraction Data (ICDD).

Table 4
Paper composite porcelain formulations (wt.%)

	MCP1	MCP2	MCP3	MHP1	MHP2	MHP3
Kaolin	46.60	42.70	30.10	46.60	42.70	30.10
Feldspar	23.30	21.35	15.05	23.30	21.35	15.05
Quartz	23.30	21.35	15.05	23.30	21.35	15.05
CP	6.80	14.60	39.80	–	–	–
HP				6.80	14.60	39.80

2.4.2. Scanning electron microscopy (SEM)

This study examined the microstructures of samples fired at different temperatures in order to understand developments and how cellulose from the waste paper changes the porcelain structure to the [illegible] structure. The MCP and MHP samples were fired once at temperatures of 1220, 1240, 1260, 1280 and 1300 °C. The M sample was fired once at a chosen temperature of 1300 °C. The CP sample was prepared raw. Microstructural examination of the interfaces in surfaces were carried out using a CamScan S4-80DV analytical SEM equipped with Oxford Instruments EXL Link microanalysis system. This technique was used for a fired porcelain body, as well as fired paper composite porcelain bodies, to reveal their microstructures and to observe topographical contrast in the secondary electron imaging (SEI) mode. Gold coating of the specimens was carried out using an electron beam evaporation system (Model: S150B, Edwards High Vacuum Ltd., UK).

3. Results and discussion

3.1. X-ray diffraction (XRD)

XRD phase analysis of the components detected from the samples is shown Table 5.

Raw material compositions consisted of equal amounts of kaolin, feldspar and quartz in MCP1 and MHP1, MCP2 and MHP2, MCP3 and MHP3, respectively, with a variation in

Table 5
XRD analyses of the detected components from samples

Samples	Phase
CP raw	Calcite, cellulose, [illegible], sodium calcium silicate
HP raw	Calcite, cellulose, talc, kaolinite
M 1300 °C fired	α-quartz, mullite, [illegible]
MCP1 1300 °C fired	Anorthite, α-quartz, mullite
MCP2 1300 °C fired	Anorthite, α-quartz, mullite, albite, [illegible]
MCP3 1300 °C fired	Anorthite, α-quartz, mullite, albite, [illegible], [illegible]
MHP1 1300 °C fired	Anorthite, α-quartz, mullite, albite
MHP2 1300 °C fired	Anorthite, α-quartz, mullite, albite
MHP3 1300 °C fired	Anorthite, α-quartz, mullite, albite, [illegible]

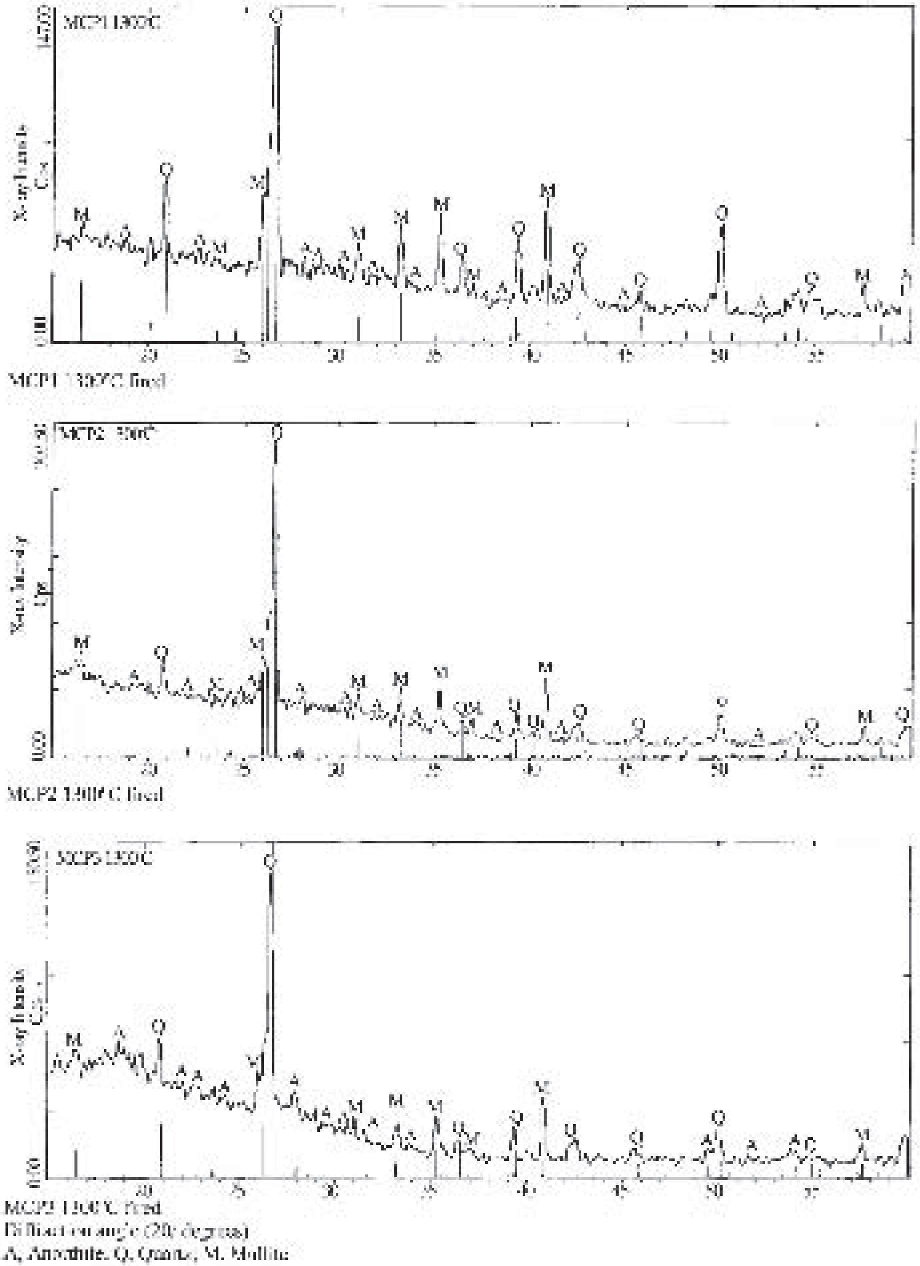


Fig. 1. X-ray diffraction patterns with various compositions in 1300 °C fired MCP bodies.

the CP and HP contents. Compositions fired at 1300 °C consisted almost totally of mullite ($3Al_2O_3 \cdot 2SiO_2$), α-quartz (SiO_2), anorthite ($CaO \cdot Al_2O_3 \cdot 2SiO_2$) and an amorphous silica-rich phase. The increased amounts of CP or HP in sample batches are attributed to the increasing Ca content as anorthite, wollastonite ($CaO \cdot SiO_2$) and portlandite ($Ca(OH)_2$) in samples. Representative XRD diffractograms of the samples are illustrated in Figs. 1–4. Examination of the peaks leads to the conclusion that the only major crystalline phases present in the fired paper composite porcelain

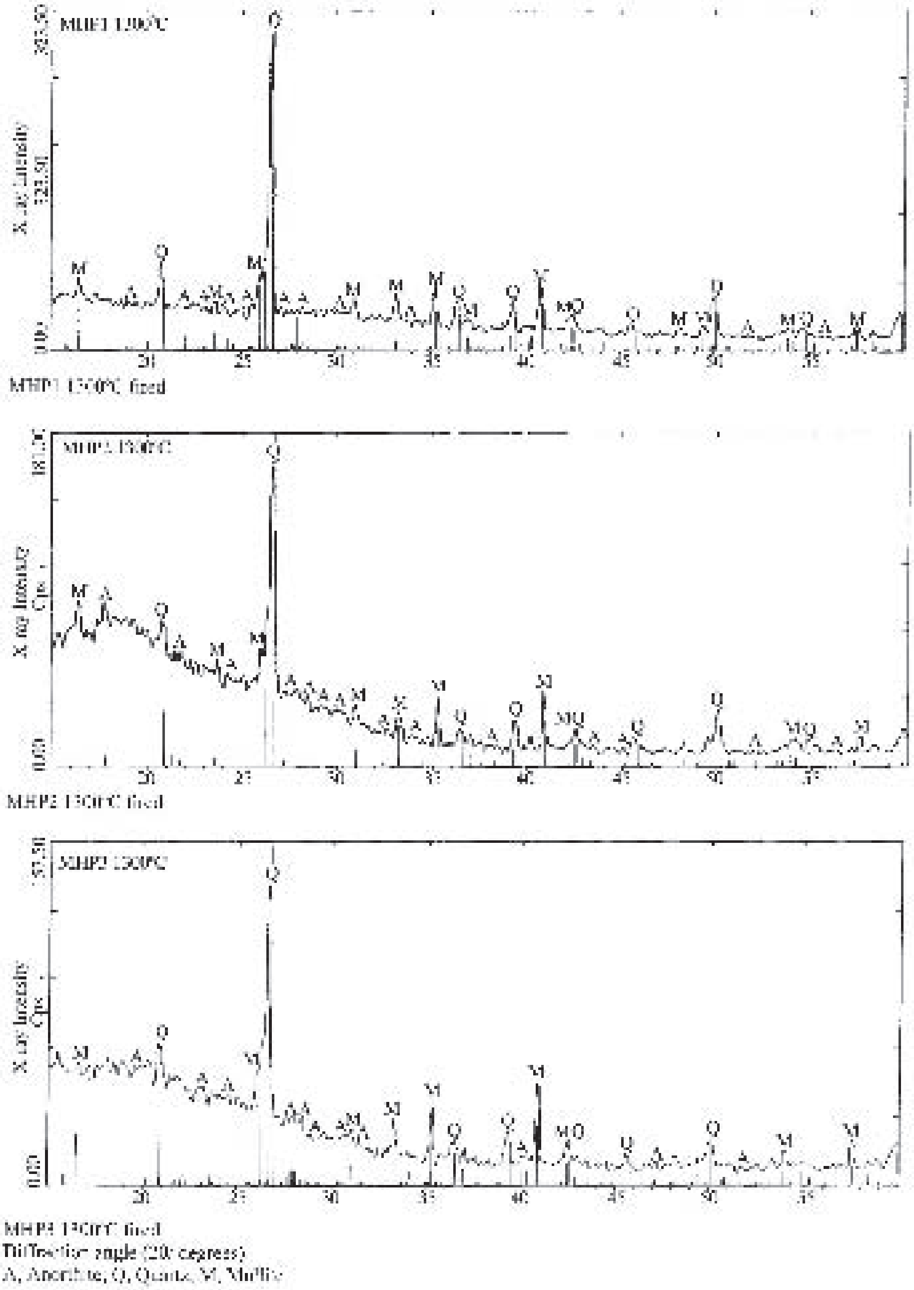


Fig. 2. X-ray diffraction patterns with various compositions in 1300 °C fired MHP bodies.

bodies are mullite, α-quartz and anorthite (marked as M, Q and A, respectively, in the diffractogram) despite the different amounts of the different types of paper contents in the bodies.

In Figs. 1–4, the major phases show the distinct peaks marked in the XRD patterns. The traces are also determined by XRD but the peaks are not marked in the patterns.

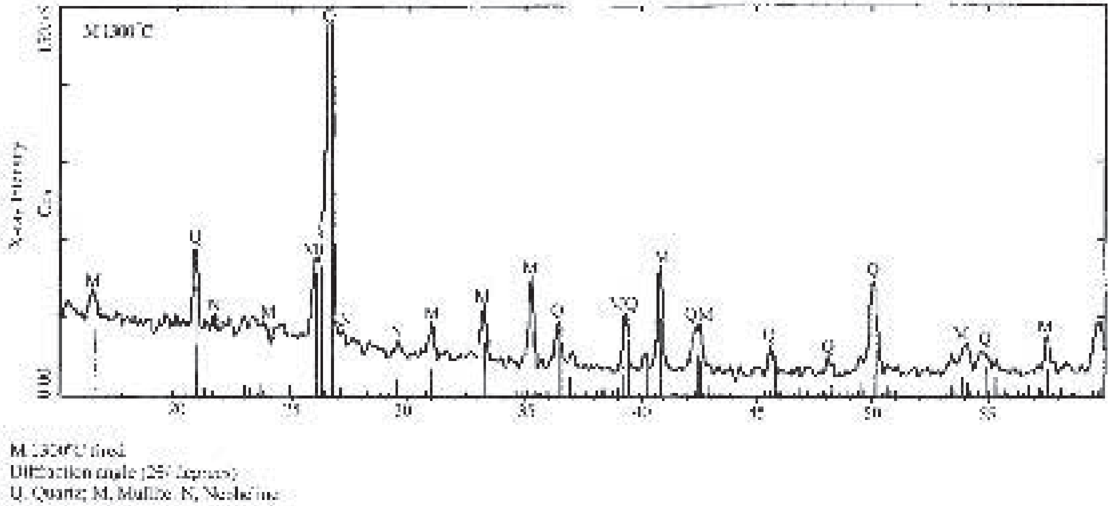


Fig. 3. X-ray diffraction pattern of 1300 °C fired M body.

Fig. 1 shows XRD patterns as a function of the composition in the fired MCP bodies heated at 1300 °C. The XRD patterns show that mullite, α-quartz, anorthite and amorphous materials are formed at all the MCP batch compositions. Wollastonite and albite ($Na_2O·Al_2O_3·6SiO_2$) are formed in MCP2 and MCP3 with larger amounts of CP than MCP1. Hematite (Fe_2O_3) is formed only in the MCP3 fired body with the largest amount of CP.

The increasing anorthite peak is directly proportional to the increasing amount of CP in the porcelain body. This is because more calcite is relict from CP, as shown in Fig. 4. The anorthite is formed by crystallization from the glassy phase produced from the calcite, feldspar, quartz and kaolin. Anorthite was also synthesized from kaolin and $CaCO_3$[10] and SiO_2, $CaCO_3$ and Al_2O_3.[11] α-quartz and mullite decreased inversely in proportion to increasing CP in a porcelain body. Major components of the MCP1 sample fired at 1300 °C are anorthite, α-quartz and mullite. Major components of the MCP2 sample fired at 1300 °C are anorthite, α-quartz and mullite, and its traces are wollastonite and albite. Major components in the MCP3 sample fired at 1300 °C, anorthite, α-quartz and mullite were identified with traces of hematite, wollastonite and albite. It is presumed that hematite is relict from print ink in CP. Compared with these profiles, no differences were observed except the intensity of diffraction peaks and some traces indicating changes in the relative amounts of these compounds. All MCP1, MCP2 and MCP3 samples fired at 1300 °C show anorthite, α-quartz and mullite as major phases.

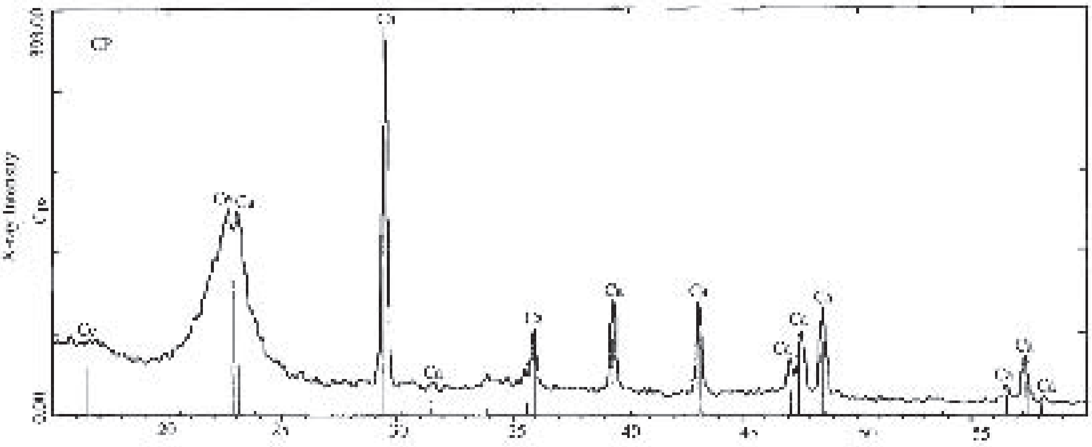
Fig. 2 shows the features of the MHP 1300 °C bodies with XRD patterns very close to those of MCP 1300 °C fired bodies, in which the major components anorthite, α-quartz and mullite are formed. The addition of HP as a substitute for clay forms anorthite in all the MHP fired bodies. Albite as a trace it is formed in all the MHP fired bodies. Portlandite, a trace, is formed only in the MHP3 fired body with the highest HP content. α-Quartz and mullite are a decreasing inversely in proportion to a larger amount of HP in a porcelain body. However, the anorthite increases directly proportional to the increases the amount of HP in a porcelain body because of the fact that more calcite is relict from paper. No portlandite is detected from MHP1 and MHP2.

The XRD analysis (Fig. 3) shows that M body fired at 1300 °C contains mostly α-quartz and mullite as major components. A trace is nepheline ($Na_2O·Al_2O_3·2SiO_2$). Anorthite is not formed in the M body that clearly differs from the MCP and MHP bodies.

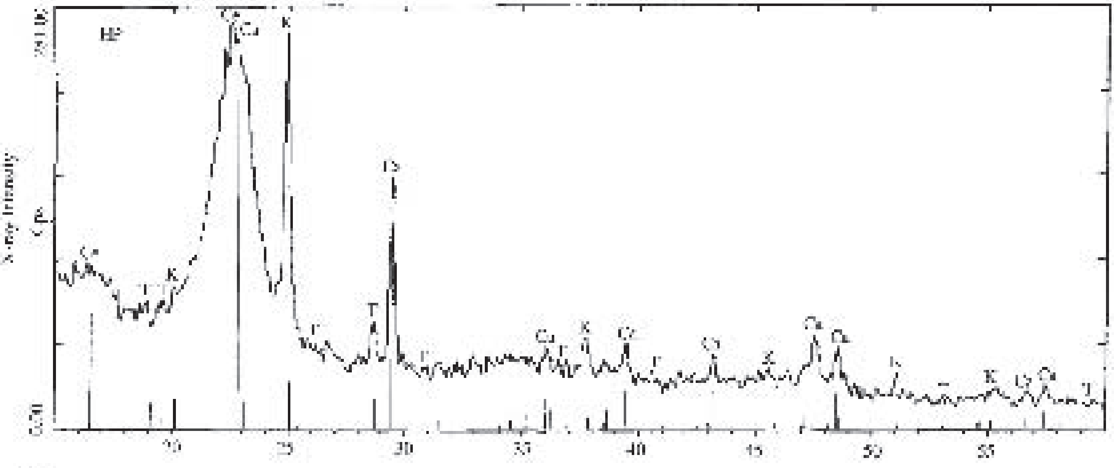
Fig. 4 shows the XRD patterns of the CP and HP raw samples. Major components of the CP raw sample are calcite and cellulose ($(C_6H_{10}O_5)_n$). Traces are maghemite (Fe_2O_3) and sodium calcium silicate ($Na_2O·CaO·SiO_2$). It is assumed that maghemite is relict from CP used as a pigment of print ink. This remains on MCP bodies even after 1300 °C fired as a trace. Sodium calcium silicate is an impurity from calcite. Major components of the HP raw sample are calcite and cellulose. Traces are talc and kaolinite.

3.2. *Scanning electron microscopy (SEM)*

SEM micrographs of the surfaces of the MCP and MHP samples containing different fibrous structures compared with M 1300 °C fired body, are shown in Fig. 5. The fibrous structures display strongly binding fibres, an interlocking of the fibres and construction of fibrous bridging. The surface morphologies of fired samples (M, MCP, MHP fired samples) and a fibrous raw sample (CP raw) are examined



CP
Ca: Calcite, Ce: Cellulose

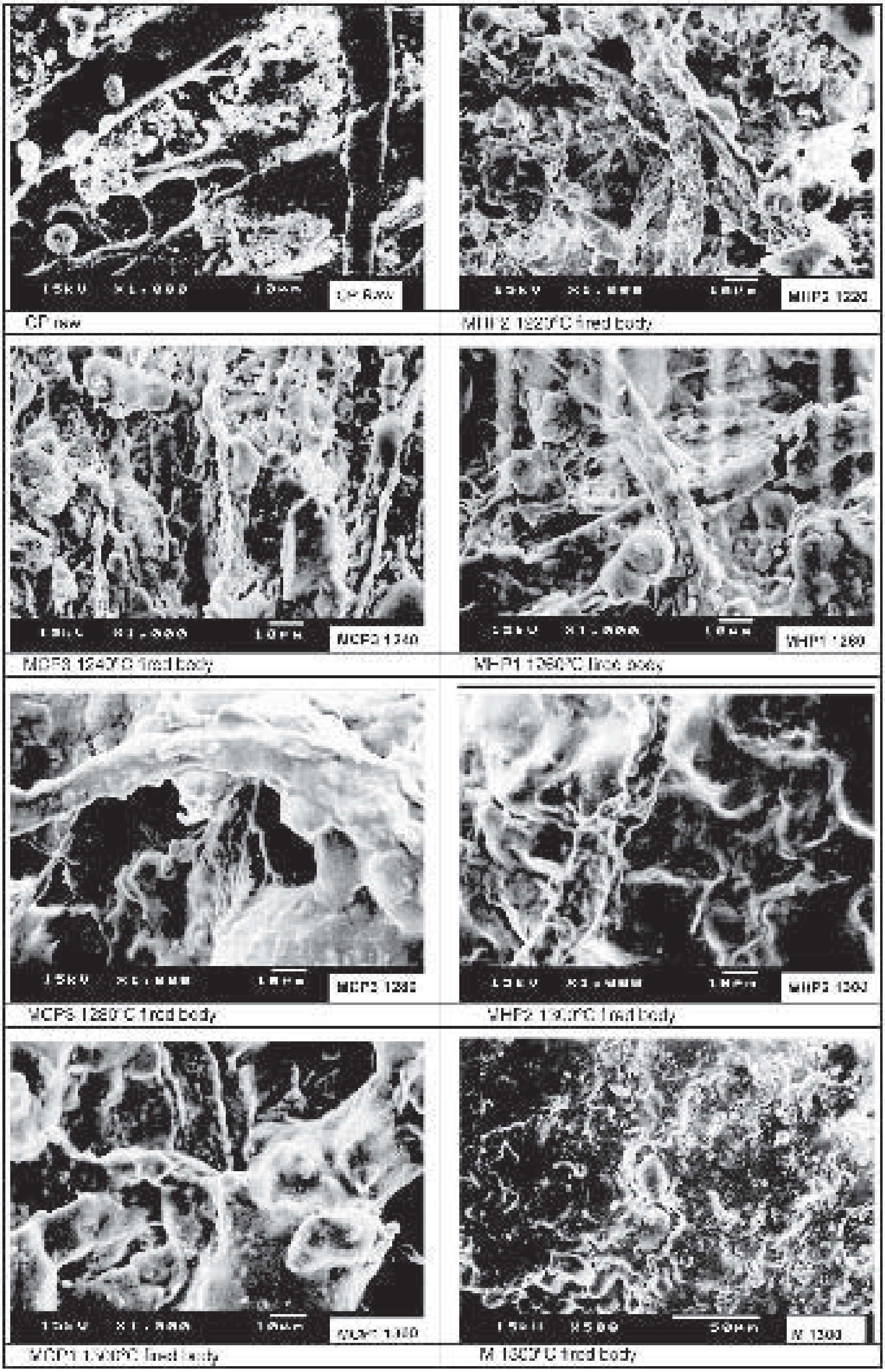


HP
Diffraction angle (2θ degrees)
Ca: Calcite, Ce: Cellulose, T: Talc, K: Kaolinite

Fig. 4. X-ray diffraction patterns of CP and HP raw samples.

by SEM techniques. SEM examinations revealed that the fibrous structure decreases with increasing firing temperature. As shown in Fig. 5, the orientation of the fibrous structure is random in the composites. It is also observed that the fibrous structure distribution in the composites is not very homogeneous. Fig. 5 shows SEM photomicrographs of the base samples surfaces that were fired at 1220, 1240, 1260, 1280 and 1300 °C as an elevated temperature.

The micrographs, taken at different firing temperatures, show how the typical surface structure changes with increasing temperature, which are characteristic of all the compositions used in this work. The high porosity fibrous structure is clearly visible in the structure of 1220 °C fired MHP2 body fired at the lowest temperatures. At higher temperatures, the pores start to coalesce to form a closed porosity that is reduced between 1220 to 1240 °C in the MCP1 body. At the highest temperature of MCP1 and MHP2 bodies fired at 1400 °C, the surface structures of the dense glassy matrix is formed and vitrified. However, the fibrous structures are still displayed at 1300 °C in MCP1 and MHP2 fired bodies, which illustrates the degree of the inhomogeneity in its microstructure. The individual crystalline phases are rather unevenly dispersed in a glassy matrix. It is difficult to locate



CP raw

MHP2 1220°C fired body

MCP3 1240°C fired body

MHP1 1260°C fired body

MCP3 1280°C fired body

MHP2 1300°C fired body

MCP1 1300°C fired body

M 1300°C fired body

Fig. 5. SEM photomicrographs of the base sample surfaces that fired at 1220, 1240, 1260, 1280 and 1300 °C as an elevated temperature.

the anorthite crystals in the fired MCP and MHP microstructure. On the other hand, the anorthite crystals are formed into anorthite tubes in the fibrous structures. The anorthite originates from the calcite component of waste paper, and the anorthite tubes are shaped from the cellulose fibrous structure from the CP and HP. In addition, it is believed that there may be some dissolution of anorthite crystals in the glassy phase at high temperatures. The M 1300 °C fired body shows the surface of the mother porcelain body without CP or HP. The microstructure of the 1300 °C fired M body has no fibrous structure, and clearly differs from the MCP and MHP bodies.

4. Conclusions

A microstructural investigation was conducted to determine if the addition of the selected waste paper would change the microstructure and chemical properties of paper composite porcelain in the fired state. After firing, the microstructure of paper composite porcelain bodies mainly consists of α-quartz, mullite, anorthite and amorphous materials, the grains held in a complex matrix. The chemical composition of raw recycled hybrid copy/print papers mainly consists of calcite, cellulose, and small amounts of maghemite and sodium calcium silicate. The chemical composition of other raw recycled hybrid papers mainly consists of calcite, cellulose, talc and kaolinite. Calcite as paper filler from the recycled papers melts with the kaolinite during the firing process. Their compositions transformed to anorthite in the microstructure of paper composite porcelain in a fired state. In paper composite porcelain, anorthite tubes as a fibrous structure are observed in fired bodies by SEM. The fibrous structures display strongly binding fibres, strong locking of the fibres and construction in the fibrous bridging.

It is shown by the XRD that the only major crystalline phases present in the fired paper composite porcelain bodies are mullite, α-quartz, anorthite, and amorphous materials despite the different amounts or the different types of paper contents in bodies. The development of anorthite in the fired paper composite porcelain is caused by calcium carbonate from the waste paper that increases the heterogeneity in the formation of a porcelain body.

Acknowledgements

Access to XRD facility provided by Dr. Vratislav Langer, Department of Environmental Inorganic Chemistry, Chalmers University of Technology in Sweden, and helpful discussions are gratefully acknowledged. The author would also like to thank Dr. [illegible], HDK, Gothenburg University in Sweden, for helpful discussions.

References

1. Lee, W. E. and Iqbal, Y., Influence of mixing on mullite formation in porcelain. *J. Eur. Ceram. Soc.*, 2001, 21, 2583–2586.
2. Iqbal, Y. and Lee, W. E., Fired porcelain microstructures revisited. *J. Am. Ceram. Soc.*, 1999, 82(12), 3584–3590.
3. Carty, W. M. and Senapati, U., Porcelain—raw materials, processing, phase evolution, and mechanical behavior. *J. Am. Ceram. Soc.*, 1998, 81(1), 3–20.
4. Gault, R., *Paper Clay*. A & C Black, London, 1998, p. [illegible].
5. Gault, R., Second generation ceramic sculpture. In *Innovation in Ceramics*, ed. Anne Välikangas. UIAH, Helsinki, Finland, 1999, pp. 73–80.
6. Gault, R., *Paper Clay for Ceramic Sculptors*. Studio Ceramics, Seattle, WA, USA, 1993, p. [illegible].
7. [illegible], Long paper fibre as a substitute in ceramic clays. In *Proceedings of the 9th CIMTEC World Ceramics Congress 1998*, ed. P. Vincenzini, Faenza, Italy, 1999.
8. Lightwood, A., *Working with Paperclay and Other Additives*. The Crowood Press, United Kingdom, 2000, p. [illegible].
9. Turner, S., *Which Paper*. E&S Printers Limited, 1991, pp. 124–125.
10. Kobayashi, Y. and Kato, E., Low-temperature fabrication of anorthite ceramics. *J. Am. Ceram. Soc.*, 1994, 77(3), 833–834.
11. [illegible], Yoshihara, K., Takebe, H. and Morinaga, K., Phase transformations of alkaline-earth aluminosilicate phases during solid-state treatment. *J. Ceram. Soc. Jpn.*, 1997, 105(12), 1[illegible]–[illegible].

Paper II

The characterisation of paper-composite porcelain in a green state

Jeoung-Ah, K. The characterisation of paper-composite porcelain in a green state. *Journal of the European Ceramic Society*, 2006, 26 (6), 1023–1034.

Table of contents

Available online at www.sciencedirect.com
SCIENCE @ DIRECT®

ELSEVIER

Journal of the European Ceramic Society 26 (2006) 1023–1034

ECERS
www.elsevier.com/locate/jeurceramsoc

The characterisation of paper-composite porcelain in a green state

Kim Jeoung-Ah[*]

School of Design and Crafts (HDK), Göteborg University, Box 131, 405 30 Göteborg, Sweden

Received 2 October 2004; received in revised form 7 December 2004; accepted 8 December 2004
Available online 26 February 2005

Abstract

A porcelain body traditionally used to produce ceramic art and design products was reformulated using additional waste paper. The aim of this study was to develop knowledge into the fundamental properties of paper-composite porcelain in its green state for use within the traditional processes of ceramic art and design production.

Characterisation was made by X-ray diffraction (XRD) and scanning electron microscopy (SEM). Two different production methods used by potters, slip casting and free-hand pressing, were used.

The presence of the paper fibre, the paper type and the content amount are the important factors in strength-bearing development. Significant differences were found in relation to the content amount of paper fibre, between the mother porcelain body and the different content amount of paper fibre in the mixed composite porcelain body.

Keywords: Fibres; Microstructure-prefiring; Porcelain; X-ray methods; Waste materials; Paper

1. Introduction

Porcelain is vitrified and fine-grained whiteware produced from natural raw materials comprised of clays (mostly of the kaolinite group), quartz and feldspar.[1] It is dense and vitreous, and one of the strongest of all clay bodies, and is an important material in the ceramics field. It can be used for both technical and artistic purposes. However, it can be more difficult to work with than many other types of clay.[2] The purest clays are the least flexible and therefore the hardest to work with during production. A porcelain body is not only difficult to work with in its green state, but also cracks and deforms easily and requires time-consuming precautions during production. For many years, numerous ceramic artists attempted to improve the handling properties of porcelain in a green state by adding different binders.[3] In this process, different types of fibres were mixed as binding media to obtain a new product with improved physical properties. Today, different types of paper fibres are widely used as substances for artistic purposes. For ceramic artists especially, this results in better control over their artistic process in the green state. Paper-composite porcelain, as a kind of *Paper-clay*,[4] fills in these limitations. Unfortunately, the lack of technical information has to be taken into consideration for practical application work when using this material. This especially concerns the different properties obtained by different production methods.

The deficiencies of porcelain in its green state are its low mechanical strength, its fragility, its high shrinkage, and its heavy weight. In practice, all clay materials and clay bodies show a decrease of size in the drying process. The amount of shrinkage depends on many factors; water content, composition of the clay, and the method of producing goods. For this reason, substances are added to the plastic raw materials to prevent drying shrinkage. The shrinkage rate is an important factor in ceramics because the reduction in size that invariably occurs during the drying and firing of pieces of pottery causes problems. Thus, high shrinkage is a serious problem for the industrial potter/ceramic designer and for the ceramic artist, who must produce finished pieces to a pre-determined size. Drying shrinkage is also an important property that causes cracks, warping, and distortion of the ware. Consequently, knowledge on drying shrinkage is

---

[*] Tel.: +46 31 7734771; fax: +46 31 7734888.
E-mail address: kimjeoung-ah@hdk.gu.se

0955-2219/$ – see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jeurceramsoc.2004.12.008

very important to get the right shape and size of finished goods.

The heavy weight is another problem in porcelain clay: light-weight clay bodies give better workability and more freedom to the artists to produce their ceramic art/design work. Besides, the lighter weight ceramics are easier to handle especially for transportation, installation and finally to the consumers.

2. Aim and methods

The aim of this study is to contribute to better understanding of paper-composite porcelain. We also want to find out how the paper fibre affects the technical properties such as linear drying shrinkage, weight loss from its wet to its dry state and its mechanical dry strength, and to compare the differences when using two different production methods.

This study is part of an extended study partly presented in a previous paper in which the characterisation of paper-composite porcelain body in a fired state was made by X-ray diffraction (XRD) and scanning electron microscopy (SEM).[5]

In the present paper, the final characteristics of the paper-composite porcelain and a mother porcelain body in their green state are characterised and are compared. The raw materials in the green state are analysed and characterised with respect to their mineralogical composition using XRD and microstructural SEM analysis. The technological properties observed are: linear drying shrinkage, weight loss ratio and mechanical strength in the green state.

Using SEM techniques, this study carried the investigation of the microstructure of a paper composite porcelain body, and the mineral composition was analysed by XRD.

The basic raw materials are kaolin, feldspar, quartz, copy/print waste paper, and other mixed waste papers. The raw materials, paper fibre and porcelain clay materials are mixed together in different proportions. In this study, two common production methods, slip casting and free-hand pressing were used to get information on the differences in the properties. XRD test samples are prepared only by the free hand press method. The production methods of this study are carried out as similarly as possible to the traditional practices of ceramic artists to ensure technological transfer. Functional ware and various artistic objects with asymmetrical and complicated thin walled shapes are often produced by the use of the slip forming method. The problem of slip casting is that it uses intensive labour, thus making it more difficult to implement in large-scale production or by fine shaping of artistic objects. The free-hand pressing method is a type of plastic forming, implying a simple manual method. This method is nowadays mainly used to produce artistic objects or in small scale industrial production.[6] In this study, a free-hand pressing method is used to produce the test bars from the plastic mass and is closer to the normal artistic production method of plastic forming than machine pressing.

3. Experimental procedure

3.1. *Porcelain raw materials*

Porcelain has been studied as a mother body. The starting raw materials were kaolin (ECC International Standard Porcelain, Imerys Minerals Ltd., UK), FFF Finnish flotation feldspar (Partek Industry Mineral Ltd., Finland) and Finnish flotation quartz (Partek Industry Mineral Ltd.).

3.2. *Waste paper as additional raw material of paper-composite porcelain*

In this study, only waste paper was used in combination with a porcelain body. Two different types of waste papers were selected due to easy availability. The first is a copy/print paper waste (CP), and the second is other paper waste (HP) that mixes all sorts of paper.

3.3. *Sample preparation*

The mineralogical composition of the mother porcelain powders used is composed of 50% kaolin, 25% feldspar, and 25% quartz.

The test batches were mixed with two different paper types (CP and HP) with three different paper ratios (50, 70, and 90% by volume; and 6.8, 14.6, and 39.8% in weight), and a base porcelain body (mother porcelain, M) with no paper fibre added. The formulations of paper-composite porcelain batches are shown in Table 1.

Both CP and HP were reduced to pulp before being mixed with the porcelain powders. The waste paper was first soaked in hot water and beaten to disintegrate the fibres. Using a large mesh screen to get a pulp with 20% water, the porcelain powders were then added and squeezed to get rid of excess water. The excess water was recycled. The starting powders were mixed with various ratios in a mixer for 3 h. The content of added water was 30 wt.% to produce samples by free hand pressing. The content of added water was 45 wt.% to produce the samples by the slip casting method. In order to enhance slip stability a commercial organic deflocculant, Dolapix PC 67 (Zschimmer&Schwarz GmbH and Co., Germany) was introduced in amounts of 0.25 wt.%, based on the weight of the powder. Test bars from each test batch for hand pressing were made with dimensions 25 mm × 25 mm × 115 mm according to the international standard test method (ASTM C326-03).[7] The clay batch was made in a one-sided plaster mould and

Table 1
Paper-composite porcelain formulations (wt.%)

	MCP1	MCP2	MCP3	MHP1	MHP2	MHP3
Kaolin	46.60	42.70	30.10	46.60	42.70	30.10
Feldspar	23.30	21.35	15.05	23.30	21.35	15.05
Quartz	23.30	21.35	15.05	23.30	21.35	15.05
CP	6.80	14.60	39.80			
HP				6.80	14.60	39.80

the open surface was smoothed using a splint. Just after demoulding, the samples were measured for their weight and length. Test bars were dried for 24 h at normal room temperature. After air drying at room temperature for 24 h, they were further dried in an oven for 24 h at 110 °C. The weight and length of the wholly dried samples were then measured. The characterisation quality assurance was adopted according to ISO-8402.

3.4. *Experimental techniques*

3.4.1. *X-ray diffraction (XRD)*

X-ray diffraction was used for the qualitative determination of the crystalline phases present in CP and HP paper, the porcelain raw materials (kaolin, feldspar and quartz), and the green paper composite porcelain bodies MCP2, MCP3, MHP2 and MHP3. This was performed using a Siemens D 5000 diffractometer operating at 45 kV and 45 mA. Using monochromatic CuK$_\alpha$ radiation, $\lambda = 0.154060$ nm. The X-ray scan was made over a range of 2θ values of 15–60° with data acquisition for 2.0 s at intervals of 0.05°. The X-ray intensities were recorded using a computer system and commercial software Diffrac AT. Crystalline phases were identified by comparison with standard reference patterns from the Powder Diffraction File PDF-2 database sets 1–52, maintained by the International Centre for Diffraction Data (ICDD).

3.4.2. *Scanning electron microscopy (SEM)*

Microstructural examination of surfaces were carried out using a CamScan S4 80DV analytical scanning electron microscope equipped with an Oxford Instruments EXL Link microanalysis system. This technique was used for a porcelain green body, as well as paper composite porcelain green bodies, to reveal microstructures and observe topographical contrast in the secondary electron imaging (SEI) mode. Gold coating of the specimens was carried out using an electron beam evaporation system (Model S150B, Edwards High Vacuum Ltd., UK).

3.4.3. *Linear drying shrinkage, weight loss and mechanical strength*

The physical properties in its green state were characterised according to the international standard test methods with respect to linear drying shrinkage (according to ASTM C326), and weight loss as the weight change (ASTM C573).[7] An Instron universal testing machine was used to determine mechanical strength in a three-point bend mode, which was tested according to ASTM C689.[12] Test bars were obtained in a plaster mould. Just de-moulded as well as wholly dried test bars were measured for their weight to 0.001 g and length. The linear drying shrinkage was determined by the difference in the length of the test bar before and after drying. The thickness and length were measured using a vernier caliper to 0.01 mm.

All tests were performed at normal room temperature. The test results were recorded using an average value (mean value) of five measurements (one measurement on each of the five specimens). In this paper, the standard deviation of the mechanical strength is reported. Every experimental step in this study kept the test conditions as similar as possible so that a fair comparison could be made.

4. Observations and results

4.1. *X-ray diffraction*

The results from XRD phase analysis (see Table 2) confirmed that the phases present were within the expected range.

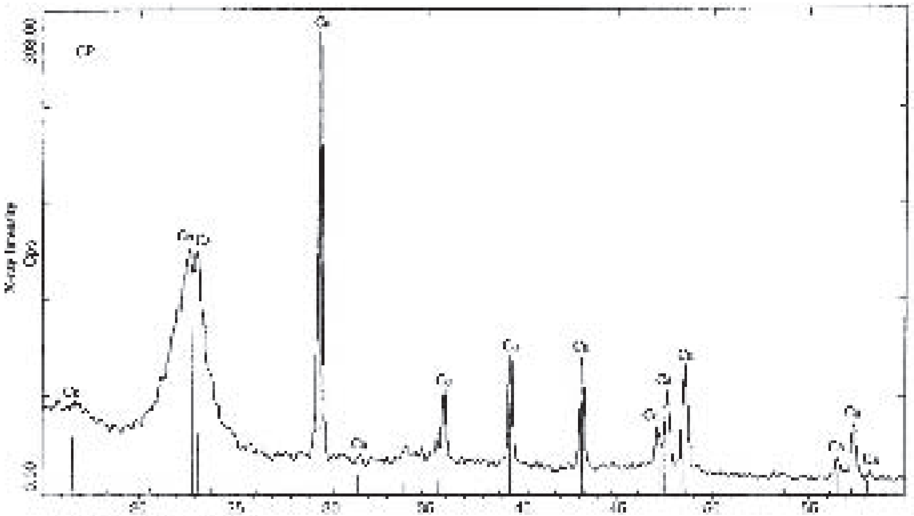
Representative XRD diffractograms of the samples are illustrated in Figs. 1–3. In Figs. 1–3, the major phases show the distinct peaks marked in the XRD patterns.

Fig. 1 shows the XRD patterns of the CP and HP raw samples. Major crystalline phases are marked as Ca (calcite), Ce (cellulose), K (kaolinite) and T (talc), respectively in the diffractogram. The mineralogical constituents of the two papers were approximately the same with the exception of kaolinite, and talc, which were present in HP. The mineral additives of the paper used in this study were kaolin (kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), calcium carbonate (calcite, $CaCO_3$) and talc ($3MgO \cdot 4SiO_2 \cdot H_2O$). Certain additives, such as calcium carbonate, kaolin, talc and titanium dioxide (TiO_2), are used to improve the opacity and brightness of paper. They usually come in a fine powder form; like pigments, they become entrapped between the fibres and improve the surface smoothness of a sheet for printing, or to reduce shrinkage to [illegible] and paper techniques.[11] Major components of the CP raw sample were calcite and cellulose ($(C_6H_{10}O_5)_n$). Traces were magnesioferrite ($MgO \cdot Fe_2O_3$) and sodium calcium silicate ($Na_2O \cdot CaO \cdot SiO_2$). It is assumed that magnesioferrite is from a pigment of print ink. However, in any case it did not show any significant peak in dried green MCP samples. Major components of the HP raw sample were calcite, cellulose, talc and kaolinite as CP. The XRD analyses of waste paper showed pure calcite mineral in every sample.

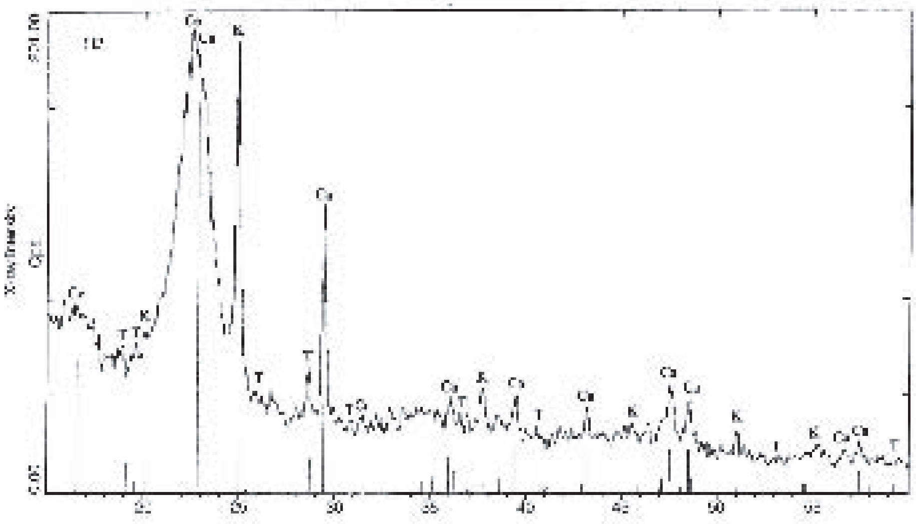
The mineralogical composition of the porcelain raw materials, such as kaolin, feldspar and quartz, were characterised

Table 2
XRD analysis of the mineral components of various samples

Samples	Phase
CP raw	Calcite, cellulose, magnesioferrite, sodium calcium silicate
HP raw	Calcite, cellulose, kaolinite, talc
Kaolin raw	Kaolinite, quartz, albite, hematite, muscovite
Feldspar raw	Albite, quartz, muscovite
Quartz raw	Quartz, albite, hematite, anorthoclase
MCP2 green	Kaolinite, quartz, calcite, cellulose, muscovite
MCP3 green	Kaolinite, quartz, calcite, cellulose, muscovite, hematite
MHP2 green	Kaolinite, quartz, calcite, talc, cellulose, muscovite, albite
MHP3 green	Kaolinite, quartz, calcite, talc, cellulose, muscovite, albite



CP raw (Computer paper)
(a) Ca: Calcite; Ce: Cellulose



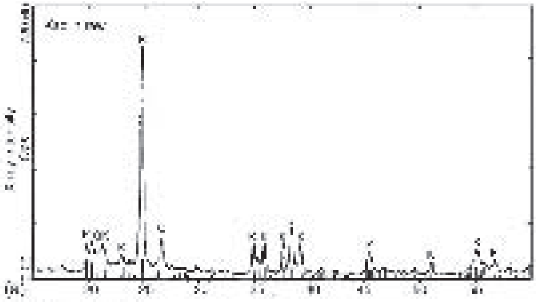
[illegible]
Diffraction angle (2θ, degree)
(b) Ca: Calcite; Ce: Cellulose; K: Kaolinite; T: Talc

Fig. 1. X-ray diffraction patterns of CP and HP raw samples.

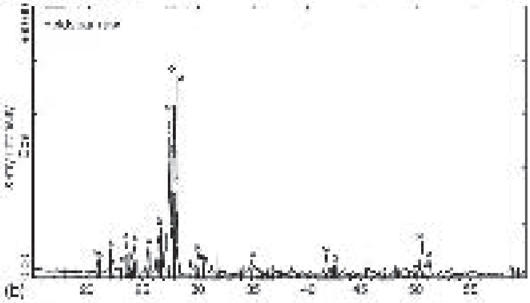
by XRD, as well as chemical composition. Fig. 2 shows the XRD patterns of kaolin, feldspar and quartz raw samples.

The XRD analysis shows that the kaolin raw sample consists mainly kaolinite and minor quartz (SiO_2). Other traces were rutile (TiO_2), hematite (Fe_2O_3) and muscovite ($KAl_2(AlSi_3O_{10})(OH)_2$). From the analysis of kaolin, the precise nature of iron minerals could not be determined. Feldspar raw sample contained albite, quartz and microcline ($K_2O·Al_2O_3·6SiO_2$) as its major components. The quartz raw sample showed definitely clear quartz peaks as its major component. The traces were albite ($Na_2O·Al_2O_3·6SiO_2$), larnite (Ca_2SiO_4) and anorthoclase ($(Na,K)AlSi_3O_8$).

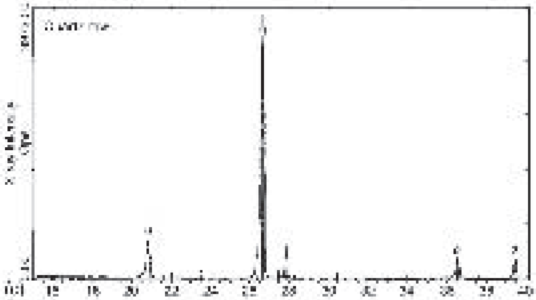
Fig. 3a and b shows XRD patterns as a function of the composition of the paper-composite porcelain bodies. The analysis showed that the compositions of all NBP and MHP samples consisted of kaolinite, quartz, calcite, orthoclase ($K_2O·Al_2O_3·6SiO_2$) and muscovite (mica-smectite: $NaKAl_2(Si,Al)_4O_{10}(OH)_2·2H_2O$) as the major components



Kaolin
K, Kaolinite; Q, Quartz



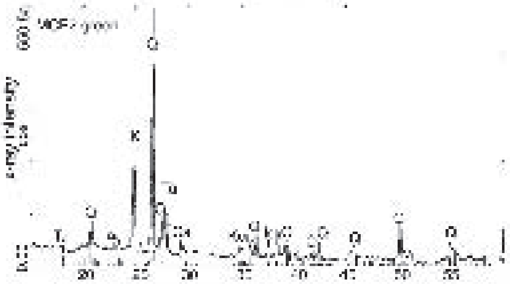
Feldspar
A, Albite; Q, Quartz; M, Microcline



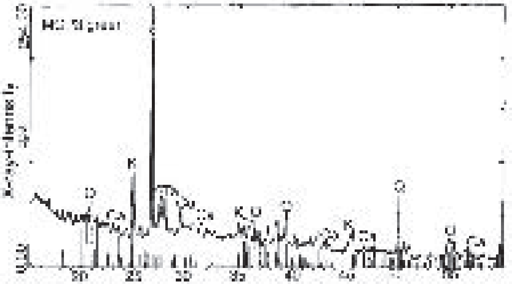
Quartz
Diffraction angle (2θ, degrees)
Q, Quartz

Fig. 2. X-ray diffraction patterns in the porcelain raw materials in a green state.

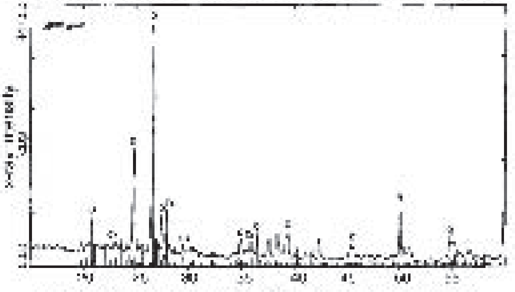
in their green state. Raw material compositions consisted of equal amounts of kaolin, feldspar and quartz in MCP2 and MHP2, MCP3 and MHP3, respectively, with a variation in the CP and HP contents. The increased content amounts of CP or HP in the paper-composite porcelain sample bodies showed a significant chemical influence in increasing calcite peaks in the composition of both MCP and MHP green samples. MCP3 and MHP3 green samples showed stronger calcite peaks than MCP2 green and MHP2 green samples. However, the MCP3 green sample showed stronger calcite peaks than the MHP3 green sample. It is clearly displayed that the increasing calcite peak was directly proportional to increasing CP or HP in a porcelain body.



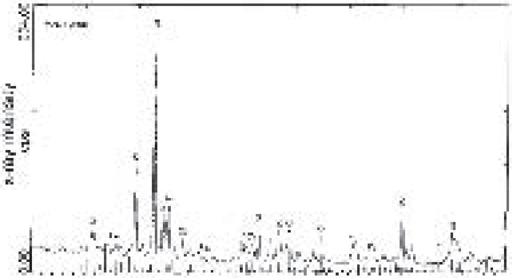
MCP2 green (kaolin 42.70, feldspar 21.05, quartz 21.05, CP 14.60 wt.%)



MCP3 green (kaolin 30.10, feldspar 15.05, quartz 15.05, CP 38.90 wt.%)
Diffraction angle (2θ, degrees)
(a) K, Kaolinite; Q, Quartz; Ca, Calcite; O, Orthoclase; Ta, [illegible]

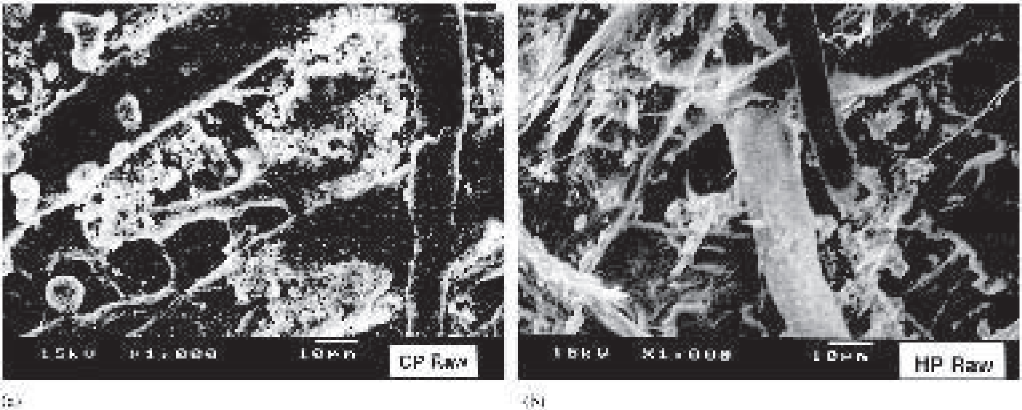


MHP2 green (kaolin 42.70, feldspar 21.05, quartz 21.05, HP 14.60 wt.%)



MHP3 green (kaolin 30.10, feldspar 15.05, quartz 15.05, HP 38.90 wt.%)
Diffraction angle (2θ, degrees)
(b) K, Kaolinite; Q, Quartz; Ca, Calcite; O, Orthoclase; Ta, [illegible]

Fig. 3. (a) X-ray diffraction patterns in MCP paper composite porcelain dried samples in a green state and (b) X-ray diffraction patterns in MHP paper composite porcelain dried samples in a green state.



(a) (b)

Fig. 4. SEM photomicrographs of the surfaces on the CP and HP raw samples: (a) CP raw and (b) HP raw.

Examination of the peaks leads to the conclusion that the major crystalline phases presented in the green paper-composite porcelain samples were kaolinite, quartz, calcite, orthoclase and tarnesvite (marked as K, Q, Ca, O and Ta, respectively, in the diffractogram) despite the different amounts or different types of paper contents in the bodies. However, nacrite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), and dickite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) were found only in the MCP3 green sample as traces that did not show in any other paper-composite porcelain green samples. Albite ($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$) was found in MHP2 and MHP3 as a trace that did not show any significant peaks in the MCP green samples. The features of the MHP2 and MHP3 green samples with XRD patterns were very close to each other; and all the major components and traces were the same.

4.2. Scanning electron microscopy

This study examined the microstructures of samples in the green state in order to understand the elements on how cellulose from the waste paper influences the paper-composite porcelain structure. The surface morphologies of samples were carefully examined by SEM techniques on the two kinds of fresh paper raw samples (CP and HP), porcelain raw materials (kaolin, feldspar and quartz) and green surfaces of M, MCP and MHP samples.

The characteristic green surface microstructures of the CP and HP raw samples are shown in Fig. 4a and b. Fig. 4a is a scanning electron micrograph of a CP raw sample. The fibres are long, and the widest fibre is approximately <80 µm. The morphology shows a part of the transverse side, near the bottom and left side. The cell walls of CP fibres are thin, and the lumens large, thus, these fibres have mostly hollow cores.[12] Fig. 4b shows that the HP paper fibres have been trodden. In general, it is believed[8] that trodden paper fibre increases the mechanical strength and increases the inter-fibre bonded area between fibres by making them more flexible. The strength of paper depends on the total number of bonds between the interfaced surfaces of the fibres. The trodden fibres form a more compact structure with less empty space. Trodden fibres bond together much better and produce a stronger structure than non-trodden fibres. The morphology of the HP raw sample also shows many inter-fibres bonds.

The morphologies of the porcelain raw materials are shown in Fig. 5a–c. Particle size distribution of kaolin is

(a) (b) (c)

Fig. 5. SEM photomicrographs of the porcelain raw materials: (a) Kaolin, (b) feldspar and (c) quartz.

20% <2 µm of wt.% (CCC International Standard Porcelain, Imerys Minerals Ltd.). Feldspar is 40% <10 µm, 20% <20 µm, and 30% <40 µm of wt.%. Particle size distribution of quartz is 50% <20 µm, 30% <5 µm, and 10% <45 µm of wt.%. Both feldspar and quartz are ceramic grade 200mesh (Parrot Industry Mineral Ltd.). The paper cellulose fibre is a hollow tube like structure and can siphon moisture into itself, acting like a sponge.[14] Since the clay particles are greatly smaller than paper fibre, small clay particles are easily siphoned into the fibre tubes, clay minerals and paper fibre are mixed together. Clay particles also cover the paper fibres, as shown in Figs. 6 and 7.

The microstructures of M, MCP and MHP green samples are shown in Figs. 6 and 7. Fig. 6a shows the surface of the M without CP or HP. The microstructure of the M green sample is fibre-free. The morphologies of the paper-composite porcelain bodies in the green state are shown in Fig. 6b–i. The fibrous structures display strongly binding fibres, an interlocking of the fibres and formation of fibre bridges.[15] The inter fibre bonding in the structures of MCP3 samples is shown in Fig. 6f, while Fig. 6d shows a fibrous tunnel in the structure of MCP2 sample body.

SEM examinations revealed that the fibrous structure increases proportionally to increasing amount of paper in the composites. Fig. 6e shows MHP2 sample, which has a much more increased fibrous structure than MHP1 shown in Fig. 6c. Fig. 6f–i show that the highest amount of paper-containing bodies, MCP3 and MHP3, displayed a more fibrous structure than MCP1 and MHP1, or MCP2 and MHP2 green samples (Fig. 6b–e).

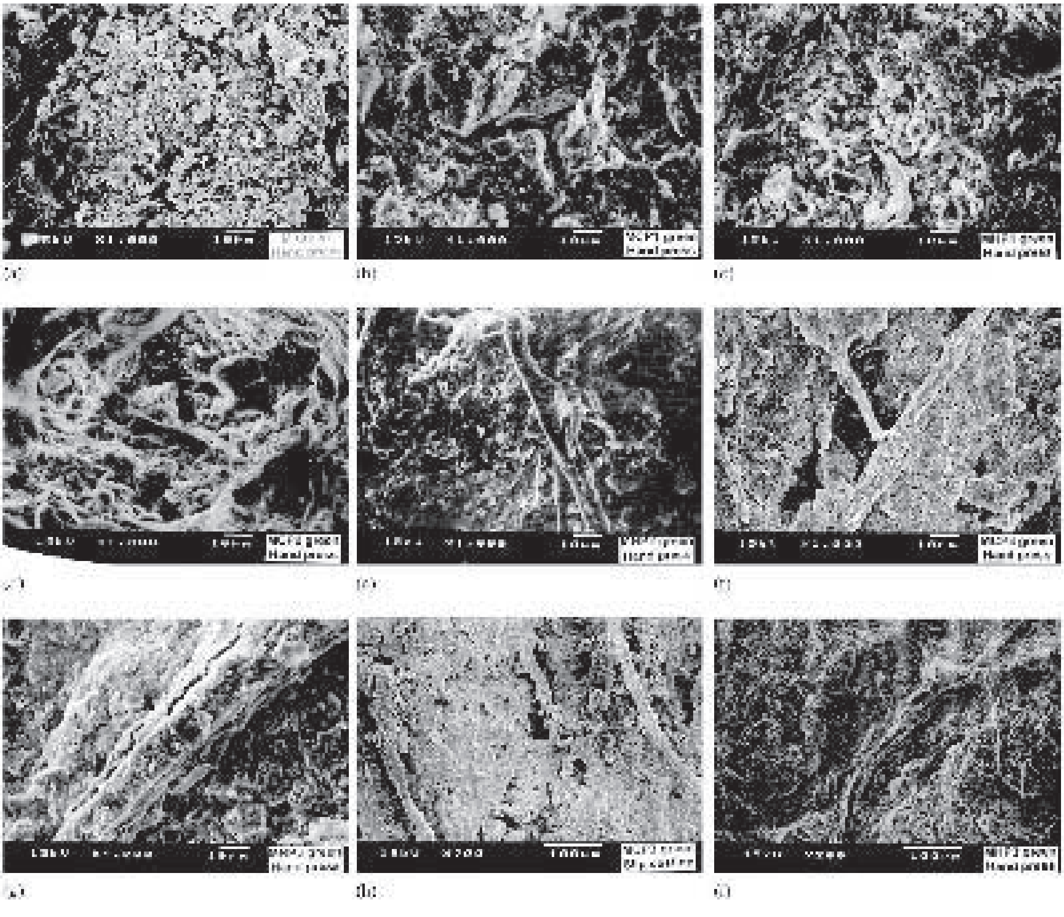


Fig. 6. SEM photomicrographs of the M matrix porcelain and paper-composite porcelain green samples: (a) M green free-hand press magnified 1000×; (b) MCP1 green free hand press, magnified 1000×; (c) MHP1 green free hand press, magnified 1000×; (d) MCP2 green free hand press magnified 1000×; (e) MHP2 green free hand press, magnified 1000×; (f) MCP3 green free hand press, magnified 1000×; (g) MHP3 green free hand press, magnified 1000×; (h) MCP3 green slip casting, magnified 200× and (i) MHP3 green free-hand press, magnified 200×.

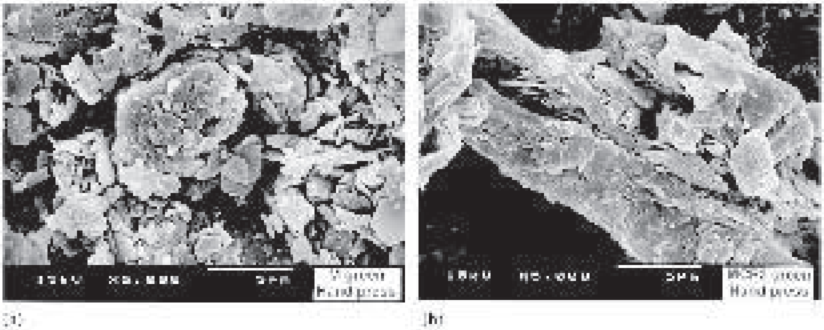


Fig. 7. SEM photomicrographs of the M mother porcelain and MCP3 paper-composite porcelain green samples produced by free-hand press casting method: (a) M green free-hand press, magnified 3500× and (b) MCP3 green free-hand press, magnified 3500×.

As shown in Fig. 6h and i, the orientation of the fibrous structure is random in the paper-composite porcelain sample. Hence, the fibrous structure distribution in the paper-composite porcelain is not very homogeneous. The composite material obtained is very heterogeneous.[16] Bonding between fibres and matrix is created during the manufacture of the composite material. This has a fundamental influence on the mechanical properties of the composite material. The paper fibre influenced the heterogeneity in the formation of the paper composite porcelain sample, which is a non-uniform distribution of fibres in the matrix.

Fig. 6f and h show that the MCP3 sample has a coarser pore structure than the MHP3 samples (Fig. 6g and i). The MHP3 sample has a denser and better packed surface morphology, while MCP3 shows a rough and highly porous surface. The MHP1 sample shows a denser structure that consists of finer particles compared with MCP1. The MHP1 body structure is more similar to the M body structure than MCP1 is to M.

Fig. 6f and h showed that there were no significant differences in the microstructure between the samples produced by the two different production methods: slip casting and free-hand press casting. The type of paper fibre (compare from Fig. 6h to i) or the amounts of paper (compare from Fig. 6a, c to f, i) in the paper composite porcelain influenced the observed body structures.

In Fig. 7, SEM images show the morphologies of M and MCP3 green samples at the same magnification. Figs. 7a and b show the typical surface structure changes achieved by combining the paper fibre in porcelain. The high porosity fibrous structure is clearly visible in the structure of the MCP3 green sample, which also illustrates the degree of the heterogeneity in its microstructure. It was also observed that clay minerals covered the paper fibres in the paper-composite porcelain body structure (Fig. 7b).

Through the SEM examinations, a fibrous structure was characterised in a paper composite porcelain body, in its green state, and has a different body structure to its mother porcelain body. The structure of the paper composite porcelain body had fibre bundles formed in the construction of fibre bridging. This result is related to the interaction between the clay raw materials and paper fibre during the paper-composite porcelain clay preparation process. These observations indicate that once the body preparation process is finished, the effect of the paper fibre is as a binder and results in a complex network structure in the paper-composite porcelain body. This is believed to give the strength to its body properties in its green state.

4.3. *Linear drying shrinkage, weight-loss and mechanical strength*

Table 3 lists the average values of the linear drying shrinkage from wet to dry, weight-loss from wet to dry, mechanical green strength and the standard deviation of mechanical green strength from the respective results. The result of mechanical strength represents the average based on a number of individual tests.

4.3.1. *Linear drying shrinkage*

Table 4 show that with the exception of the MCP4 press, all MCP and MHP samples have a lower shrinkage ratio than the M sample in both production methods. The production method, amount of paper fibre in the composition, and type of paper fibre were the major factors influencing the linear drying shrinkage of MCP and MHP samples.

From the results, the production method is a minor factor in influencing the drying shrinkage of paper composite porcelain when the amount of paper fibre is small. However, the production methods become an important concern in the MCP samples when the amount of paper fibre is increased.

All MHP samples show less shrinkage ratio than the MCP samples. These results show that the type of paper fibre is an important factor in influencing the drying shrinkage in paper-composite porcelain.

The water content in body composition is an important factor for controlling the drying shrinkage. In this study, the samples prepared for slip casting have a water content of 45 wt.% while samples for free hand press casting have 30 wt.%. In

Table 3
Physical properties of M (mother porcelain), MCP and MHP (paper-composite porcelain) samples in the green state produced by free-hand press and slip casting methods

	Linear drying shrinkage from wet to dry (%)	Weight-loss from wet to dry (%)	Mechanical strength (MPa, N/mm²)	Standard deviation of mechanical strength
M press	4.3	8.0	5.9	0.3
M slip	4.5	8.0	5.8	0.3
MCP1 press	4.1	22.0	7.8	0.5
MCP1 slip	4.2	23.9	7.6	0.5
MCP2 press	4.2	21.1	9.6	0.5
MCP2 slip	4.5	23.1	9.4	0.4
MCP3 press	4.0	23.5	10.0	0.4
MCP3 slip	4.3	27.7	9.7	0.4
MHP1 press	3.5	21.6	9.1	0.5
MHP1 slip	3.5	25.3	9.0	0.5
MHP2 press	3.5	23.1	10.2	0.4
MHP2 slip	3.7	25.4	10.0	0.3
MHP3 press	3.4	22.3	11.5	0.5
MHP3 slip	4.1	25.4	11.1	0.5

the two production methods, the samples produced by a free hand press casting method showed a smaller shrinkage than the samples produced by a slip casting method.

4.3.2. *Weight-loss*

The test results of weight-loss from wet to dry showed that in the green state all MCP/MHP samples have a higher weight and higher weight-loss ratio than the M samples. Furthermore, an increase of the amount of paper fibre in the MCP/MHP samples body composition had an effect on the increase in the weight-loss as shown in Table 3. The weight-loss increased slightly in the MCP/MHP samples when produced by the free hand press casting method.

This result indicates that the most important feature is that when the paper fibre is combined as an additive and as a binder in the body composition, this clearly increases weight-loss rate in the green state.

4.3.3. *Mechanical strength*

Table 3 shows that the MHP samples have a higher mechanical strength than the MCP samples.

In the mechanical green strength test, it was observed that no MCP/MHP samples were completely broken into two pieces. Instead, they cracked in the middle of the bar but the paper fibres still held the cracked bar together. Multiple bonding fibres were observed directly in the cracks of the paper-composite porcelain bars. Comparably, all M samples were completely broken into two pieces.

Figs. 8–11 show that the mechanical green strength is significantly increasing with the increase of the paper fibre amount in the body composition.

The characteristic green surface microstructures of the M and MCP/MHP press samples are shown in Figs. 6 and 7. The MHP press samples in Fig. 6c, e, g, and i showed that the MHP press samples have a less porous and better

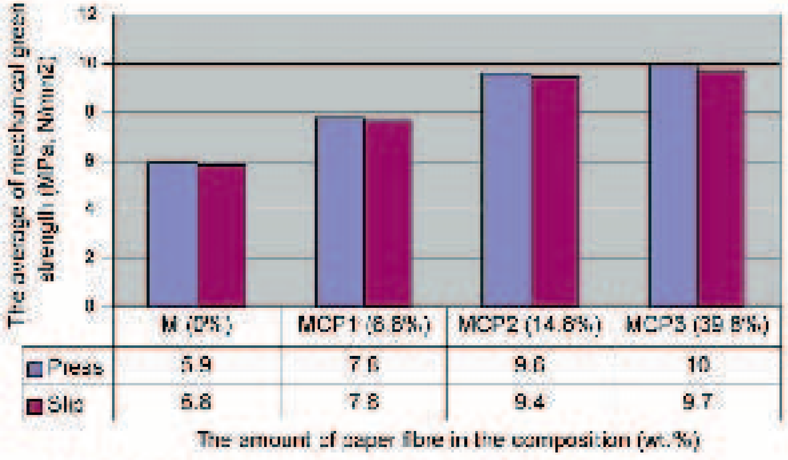


Fig. 8. Mechanical green strength of M and MCP samples produced by two different methods.

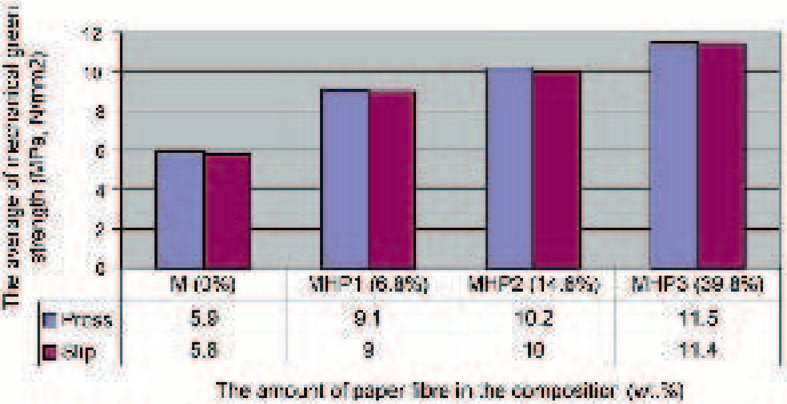


Fig. 9. Mechanical green strength: M and MHP samples produced by two different methods.

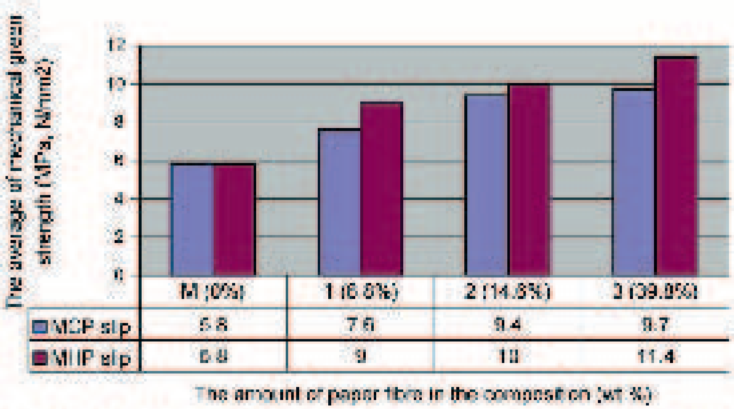


Fig. 10. Mechanical green strength, M, MCP and MHP samples produced by [illegible] press casting method.

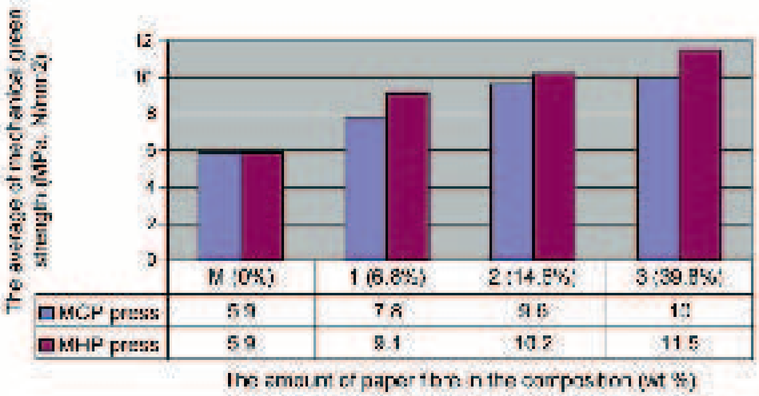


Fig. 11. Mechanical green strength: M, MCP and MHP samples produced by slip casting method.

packed surface morphology, while the MCP press samples showed a rougher and more porous structure. All these green morphologies match the green strength behaviour shown in Figs. 8–11.

A clearly uniformed formation and a low shrinkage ratio are very important in achieving a dense green surface morphology. The MHP slip/press samples have a higher mechanical strength than the MCP slip/press samples. The micro-bonding structure in Fig. 6 is considered when understanding the result. With the denser and less porous green microstructure of MHP slip/press samples as in Figs. 8–11, the lower green strength of the MCP slip/press samples was expected. The effects of the amount of paper fibre in the body composition were significant. In Figs. 8 and 9, the type of production method and the type of selected paper fibre are not the major factors for the green strength. The primary factors are the adding of paper fibre as a binder in the porcelain, and the amount of paper fibre added in the body composition. So far, the slightly higher strengths appeared in the samples produced by the free hand press casting method rather than the samples produced by the slip casting method, and MHP samples rather than MCP samples.

In Figs. 10 and 11, all MCP/MHP press/slip samples are clearly stronger than the M press/slip samples in the green state. The biggest differences in mechanical green strength are almost double in MCP3/MHP3 press samples compared to the M press sample.

All MCP/MHP press/slip samples showed that their green strength increases according to the increase in weight loss ratio and shrinkage ratio. The increasing amount of the paper fibre in the body composition also implied an increase in the green strength, the weight loss ratio, and the drying shrinkage ratio.

All test results from the physical properties provide evidence that the MCP/MHP press/slip samples have less shrinkage, a lighter weight and a higher mechanical strength than the M press/slip samples, except for the MCP3 press sample which showed same dry shrinkage ratio as the M press. It is believed that the reason for lower shrinkage, a lighter weight and a higher mechanical strength of the paper composite porcelain is that the paper fibres act as binders in the microstructure. The strong inter fibre bonding, interlocking fibres, build fibre bridging between the clay particles and bind them together, which influences the properties of the paper composite porcelain.

5. Conclusions

This study characterised the material properties of paper-composite porcelain in its green state. It concludes that paper-composite porcelain is practically attractive because of its high strength, high weight-loss and low drying shrinkage. The use of paper fibre in the porcelain resulted in a 3.51% drying shrinkage ratio in the MHP1 slip sample compared to 7.8% in the M slip sample. The highest weight loss in the paper-composite porcelain was 32.67% in the MCP3 slip sample compared to 16.34% weight-loss in the M slip sample. The highest green strength in the paper composite porcelain was 11.5 MPa in the MHP3 press sample while 5.9 MPa in the M press sample. Between the two different types of production methods, the samples produced by the free hand press casting method showed a lower shrinkage ratio and a higher green strength than the samples produced by the slip casting method.

The role of paper fibre is as a binder and it results in a complex network structure in paper-composite porcelain. It gives a higher green strength, a lighter weight and a lower green shrinkage in the paper-composite porcelain that gives better working characteristics in the green state than that of its mother porcelain. This makes it beneficial for usage in the traditional practices of ceramic art, and it may be worth developing it for industrial ceramic design production. It is believed that the origins of these effects are fibre bridging, fibre binding, and an interlocking of the fibres in the microstructure of the paper composite porcelain. The bonding between fibres and matrix is created during the preparation process of the samples. This has a fundamental influence on the technical properties of the paper-composite porcelain in the green state.

Considering all properties, it can be concluded that the major factors in influencing the technical properties were not only the role of paper fibre itself in the structure of paper-composite porcelain but also the amount of paper fibre in the body composition, the type of paper fibre, and the production method.

Acknowledgements

Access to XRD facility provided by Dr. Vratislav Langer, Department of Environmental Inorganic Chemistry, Chalmers University of Technology in Sweden, and valuable discussions are gratefully acknowledged. The author would also thank Dr. Häggström Cecilia, HDK, Gothenburg University in Sweden, for helpful discussions.

References

1. Santacruz, I., Nieto, M. I., Moreno, R., Ferrandino, P., Salomoni, A. and Stamenkovic, I., Aqueous injection moulding of porcelains. *J. Eur. Ceram. Soc.*, 2003, 23(12), 2053–2060.
2. Lightwood, A., *Working with Paper Clay and Other Additives*. The Crowood Press, Wiltshire, 2000, p. 27.
3. Peterson, S., *The Craft and Art of Clay (3rd ed.)*. L. King Pub., London, 1996, pp. 154–155.
4. Gault, R., *Paper Clay*. A&C Black, London, 1998, p. 14.
5. Kim, J. K., The characterisation of paper composite porcelain in a fired state by XRD and SEM. *J. Eur. Ceram. Soc.*, 2004, 24(15–16), 3823–3831.
6. Hlaváč, J., *The Technology of Glass and Ceramics (Glass Science and Technology, 4)*, ed. K. Nemecek. Elsevier, Amsterdam, 1983, p. 203.

8. ASTM C 326-82, *Standard Test Method for Drying and Firing Shrinkages of Ceramic Whiteware Clays*. ASTM International, 1982.
9. ASTM C 373-88, *Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products*. ASTM International, 1999.
10. ASTM C [illegible], *Standard Test Method for Modulus of Rupture of Unfired Clays*. ASTM International, 1995.
11. Dawson, S., *The Art and Craft of Papermaking*. Aurum Press, London, 1995, p. 14.
12. Whitney, R. P., Chemistry of paper. In *Papermaking Art & Technology*, ed. P. Long. World Print Council, San Francisco, 1979, pp. [illegible]–41.
13. Heller, J., *Papermaking*. Watson-Guptill Publications, New York, 1978, pp. 36–62.
14. [illegible], Paper clay. *New Zealand Potter*, 1994, 36(3), 17–18.
15. Chen, P. W. and Chung, D. D. L., Low-drying-shrinkage concrete containing carbon fibers. *Composites Part B*, 1996, 27B, 3–4, 269–274.
16. Gay, D., In *Composite Materials Design and Applications*, ed. S. V. Hoa and S. W. Tsai. Trans. CRC Press LLC, Florida, 2002, pp. 1–4.

Paper III

Paper-composite porcelain in practice: Artistic applicability and technical properties

Submitted for publication

Table of contents

Paper-composite porcelain in practice: Artistic applicability and technical properties

Jeoung-Ah Kim
School of Design and Crafts HDK, Göteborg University
Box 131, 405 30 Gothenburg, Sweden

This study focused on basic problems associated with the making of traditional porcelain in comparison to paper-composite porcelain. The study proceeds along a rational path, from issues on ceramic art and design practice to issues concerning materials in which material research is a basic component. This is an interdisciplinary study in which scientific experimental methods from material science, inorganic chemistry and micro-physics are applied in combination with artistic practice and observations. The paper-composite porcelain, with its merits, provided not only solutions to the initial problems of working with traditional porcelain, but also a potential artistic tool. Furthermore, its special properties can be developed in an artistic context.

Keywords: Ceramic art and design; Design problems; Interdisciplinarity; Problem solving; Technology

Porcelain was discovered in China during the Hou-Han Dynasty (A. D. 25–220). It was gradually refined over many years into the hard-paste porcelain that emerged during the Tang Dynasty (A. D. 618–906) (Lane, 1980). The porcelain was introduced in Europe in 1295 by Marco Polo, who was also the first to apply the name porcelain (Rado, 1969). The arrival of Chinese porcelain in Europe signalled a major artistic revolution and stimulated the search for porcelain recipes and ingredients to discover the secret of how it was made (Lane, 1980). Böttger discovered European porcelain in Meissen in 1709 (Rado, 1969). This fundamental research established the European porcelain and china industry. Furthermore, the porcelain research became one of the most important bases for the development of ceramic art and design and the European ceramic material research of today.

Porcelains are nowadays extensively used in ceramic art, decorative ware, tableware, sanitary ware, electrical insulators and dental prosthetics. In general, porcelain is a vitreous whiteware of more or less translucent character when fired to 1250°C or more. In traditional hard-paste porcelain, the temperature of biscuit firing is between 900°C and 1000°C, while the gloss firing temperature ranges from 1300°C up to 1450°C. The traditional hard-paste porcelain is primarily composed of 50% kaolin, 25% feldspar and 25% quartz (Rado, 1969).

Kaolin is a plastic raw material, and quartz and feldspar are non-plastic raw materials. Non-plastic materials are added to kaolin to obtain a finer structural packing because the grain-size distribution of kaolin is wide, which causes it to crack or distort during drying and firing. Non-plastic materials also lower the firing temperatures particularly that of kaolin, which has a higher melting point than any other clay, about 1800°C. In porcelain, quartz assists the formation of glass and improves the resistance of the body to warping, giving it hardness and other mechanical strengths (Rhodes, 1964). Feldspar is used as a natural flux, which assists the standing-strength of porcelain (Fournier, 1973).

1. Problems of traditional porcelain and paper-composite porcelain in ceramic art and design practice

1.1. Problems with traditional porcelain

In spite of its unique properties of hardness and high density, the traditional porcelain body has many weaknesses which give limited artistic options in the development of porcelain products. The most severe problems are due to its lack of plasticity, its heavy weight, fragility, high shrinkage in the green state, high deformation rate and short firing range.

The following studies and literature describe the difficulties in porcelain ware production.

- According to Cooper and Royle (1978), the necessity of using a large proportion of materials which have a low level of plasticity, such as kaolin, gives a body that is difficult to handle by the traditional methods of the studio potter. Rhodes (1971) and Fournier (1973) reported that the range of forms which can be achieved with porcelain by plastic shaping is rather severely limited by the non-plastic character of porcelain bodies.
- The green strength of the porcelain body is inevitably very low, as is the high wet-to-dry shrinkage (Fraser, 1986).
- The high-vitrified body quickly collapses if only slightly over-fired (Cooper and Royle, 1978; Hamers, 2004; Rhodes, 1971). Because of the high firing temperature of porcelain, the ware must be able to survive high temperatures: this is one of the difficulties of making porcelain. The body, as it nears maturity, becomes so soft and glass-like that warping and slumping are very likely to occur. Careful design of the shapes, handling, curving, decoration, drying and setting and careful firing always present ceramists with difficulties, but losses are inevitably highest in porcelain manufacture, in comparison to other clay bodies. Thus, porcelain is an expensive choice for the artists/potters/designers. French (1972) pointed out the limitations of porcelain as being greater than those of any other type of clay body. Although it has many merits, the potter's scope for artistic expression is clearly more limited than with other clay bodies. Industrial ceramic designers who always require highly precise designs in final form face even more serious problems in designing porcelain shapes than ceramic artists or studio potters who have more freedom when making decisions regarding final artistic pieces.
- The addition of ball clay improves both green strength and plasticity; however, it reduces translucency and decreases whiteness. It also increases the shrinkage ratio and impurities (Cooper and Royle, 1978; Fraser, 1986; Rhodes, 1971). In addition, it causes serious problems in practice such as increasing the tendency to warp during drying and firing (Fournier, 1973). Plasticity and green strength may instead be improved by adding bentonite, although, as with the addition of ball clay, this will also increase the wet-to-dry shrinkage, have a detrimental effect on the casting rate of casting slips and increase the production time (Fraser, 1986).

The identified problems with traditional porcelain are therefore:

- The lack of plasticity and the heavy weight.
- The fragility and high shrinkage in the green state.
- The high deformation rate and short firing range in the fired state.

1.2. Problems with paper-composite porcelain

The recipes for clay bodies have developed over time through the usage of different techniques, with different characters and values. Clay, in combination with natural fibres, has been used to make unfired bricks since the beginning of the Neolithic period, 10,000 years ago (Peterson, 1995). In the ceramic art field, "individuals have added a variety of tempers to clay bodies to improve working qualities and dry strength (Baker, 1998, p. 46)". In the 1970s, the artist Rauschenberg mixed adobe clay with seeds, powdered gum and paper pulp to get dry strength for artistic purposes (Lightwood, 2000). In the 1990s, Paper clay (Gault, 1998; Soong and Ling, 1995) was introduced to the ceramic art field by several potters. The term "Paper-composite porcelain" (Jeoung-Ah, 2004) stands for any kind of porcelain that is combined with paper. Paper-composite porcelain is a type of paper clay that consists of plant-based fibre pulp and mineral additives. The introduction of paper clay to the field of ceramic art has resulted in more independence in the artistic process. Conversely, new problems follow new materials particularly when the characteristics or properties of the material are still unknown.

The following studies and literature describe paper fibre combined with porcelain clay bodies and/or the practical difficulties of working with the resulting material:

- The type of combination that was studied in this project – paper-composite porcelain at high firing temperatures with hard-paste porcelain body and high paper fibre content – is relatively new in this field (Jeoung-Ah, 2004 and 2006). The term of paper-composite porcelain was coined only a few years ago (Jeoung-Ah, 2004). Therefore there are no previous research studies that are exactly comparable.
- Juvonen (1995) studied a low-temperature porcelain body with a high percentage of ball clay, 25%, a very small amount of silica, 10%, and feldspar, 10%, and mixed paper fibre, 2–20% in weight. She fired the bodies up to 1250°C, reporting absorption and shrinkage in the fired state between 1100–1250°C and deformation in the fired state between 1120–1200°C. Unfortunately, the report lacked more detailed information: for example, there were no details of physical properties such as porosity, weight loss, density and strength in the fired state, and no information

above 1250°C or below 1100°C in either the fired state or the green state. She stated that the paper fibres burned away from the clay during firing, leaving the object porous; however her report did not outline any studies or present any evidence of the chemical composition in the fired state or the microstructure in the green and fired states. In making the model, she stated that paper clay has a tendency to attach to a plaster mould, especially with a slip that had a high paper fibre ratio, which made casting difficult.

- Stevens (2002) stated that the paper pulp burnt out at 250°C, but no test results were shown in her paper. Stevens combined a porcelain body with 17% ready-made paper pulp and fired to cone 8 (1250°C according to Fournier, 1973; 1280°C according to Hamers, 2004). She stated that she sewed sheets of the fired bodies to make a three-dimensional form of artwork because of the problems with the desired forms, such as sharp angles when using the paper-combined porcelain. No scientific test results were presented in her paper.
- Gault (1998) described paper clay which was mixed with up to 50% paper pulp by volume, and up to 20% by volume for porcelain and fired to 1250°C. She showed a single photo of paper clay by SEM with 30% paper pulp by volume fired to 700°C. The biscuit firing temperature for porcelain paper clay was recommended at 1000°C. However, no test results are reported in her book. She encouraged more research on microstructure by SEM, warping in the fired state and trace minerals from paper (1993).
- Goldate (2001) reported difficulties in casting paper slip with more than 50% paper content by volume, and small bubbles in the walls and on the surface of the casting piece.
- Lightwood (2000) reported porcelain clay tile mixed with paper pulp up to 50% by volume. The tiles were fired to 1000, 1100, 1240 and 1280°C. The reported results are from shrinkage, deformation and absorption tests. She described some difficulties of working with porcelain paper clay, such as that complex shapes are not easy to cast and paper clay tends to have a slightly lumpy surface. She also mentioned that the fibres in clay make it difficult to trim satisfactorily and its handing character needs to be improved, citing this as one reason why very little domestic ware is produced.

The identified problems with paper-composite porcelain are thus:

- The lack of information makes it difficult to plan the final work. No information was found from the previous studies regarding high firing temperatures (above

1300°C), hard-paste porcelain bodies, high paper fibre content as a percentage of weight (above 20%) and physical properties such as porosity, weight-loss, density and strength in the fired state, temperatures above 1280°C or below 1100°C in the fired and green states, or gloss firing temperatures.

- There is not enough information about the chemical composition or microstructure of the material in either the green or fired states, or their influence on visual effects in the fired state.
- Technical difficulties in artistic practice: a tendency to attach to a plaster mould during casting, especially with a slip having a high paper-fibre ratio, problems with the desired forms, with sharp angles, fine surface or complex shapes, and difficulties in slip casting with high paper-fibre content due to poor workability, and the appearance of the final product.

2. Aims of this study

Rhodes (1964) and Kingery and Valdiver (1986; and 1990) stated that ceramic material research needs to be linked to ceramic art and design practice to understand the principles that govern the behaviour of this material, in order to bring the ceramic process under some measure of control and to achieve the desired effects.

> To make full use of the medium, the ceramist or potter not only needs skill, imagination, and artistic vision, but he also needs to have a sound knowledge of the technical side of craft. This knowledge has not been easy to come by, and many of those seriously engaged in pottery have learned through endless experimentation and discouraging failures (Rhodes, 1964, no page number). In most cases, the difficulties which arise in pottery making are due to the large number of variables involved. Even, when all the materials are bought in prepared form, the variables of forming techniques, drying, firing and glaze application remains (ibid.).

This is why it is important to go through the process of ordinary ceramic art practice, from raw material to final application. Thus, based on the basic knowledge of materials, ceramic practitioners are able to more accurately choose the optimal material for the particular purpose of their practical work. Since the character of paper-composite porcelain is still undetermined, further investigations are required in order to solve practical problems and characterise the technical properties, especially in comparison to traditional porcelain.

The purpose of this study was to understand the artistic applicability of paper-composite porcelain as well as the underlying facts which may explain the problems with paper-composite porcelain, as well as to gain reliable knowledge about the properties and behaviour of paper-composite porcelain.

The artistic part of this study aims to investigate the workability and applicability of the material by exploring paper-composite porcelain in various casting models. In line with the artistic study, the surface and texture of the final paper-composite porcelain product and the casting of fine lines and forms with sharp angles were tested. The design application produced prototype tableware.

The technical part of this study investigated the properties of paper-composite porcelain in comparison to traditional porcelain. This part was concerned with establishing the workability of paper-composite porcelain with various amounts of paper fibre, fragility/handling problems in the green and fired states, the behaviour of the materials during the casting process and the fired state, and the physical properties in fired state.

3. Research methods

The research was divided into the following areas:

- Model artwork
- Material testing
- Comparisons of outcome: Traditional porcelain vs. paper-composite porcelain

The research was interdisciplinary, combining artistic experiments used in the making of model artworks with laboratory experiments from the field of material science. The experiences from the artistic experiments are compared in a qualitative manner. The data from laboratory experiments to test the materials are compared in the explicit manner used within material science. Finally, qualitative and quantitative outcomes are compared.

In this study, the qualitative studies concerned different casting body recipes, production methods and firing temperatures. Artistic experiments were conducted to provide practical information to ceramic artists/studio potters who are experienced in the field of porcelain. This study covers the main formative stages, from the preparation of the porcelain bodies to the final firing process, including observations of the surface and texture of the final paper-composite porcelain objects.

The technical part of this study applied scientific methods to the investigation of the materials used in the study: porcelain and paper-composite porcelain. The technical investigation is part of an extended study which was conducted by using X-ray diffraction (XRD) and scanning electron microscopy (SEM) to characterise this material in both the green state (Jeoung-Ah, 2006) and the fired state (Jeoung-Ah, 2004). In this study, the quantitative studies were carried out by way of destructive tests, to measure and analyse the properties of the porcelain and paper-composite porcelain: shrinkage, weight-loss, porosity, absorption, density, strength and deformation.

4. Artistic experimental procedure of the design application

The artistic experimental procedure of the design application concerns the workability of the paper-composite porcelain. The artistic production procedure which was used in this study was the same as for an ordinary studio porcelain product: preparation of raw materials for slip casting and glazing, casting of plaster moulds, mixing of slips and glaze, slip casting, drying, biscuit firing, glazing and gloss firing. Casting slips with different paper ratios were tested to estimate how the different paper content ratios would affect the paper-composite porcelain body. The paper-composite porcelain slips mixed with CP (MCP slips) were used for casting after 24 hours of ageing, and with non-aged MCP slips to study the difference in behaviour due to ageing. Fragility and handling problems were observed in the green and fired states, as well as the behaviour of the material during the working process. The models produced by mother porcelain (M) and MCP slips were both biscuit fired at 1000°C in order to compare them in a similar state. The gloss firing temperature was selected at 1300°C, since studio potters rarely use firing temperatures above 1300°C.

4.1. Materials

In both the artistic and technical experiments, the porcelain raw materials were kaolin, feldspar and quartz. The porcelain clay body was then mixed with waste paper to make the paper-composite porcelain bodies.

4.1.1. Waste paper as an additional raw material of paper-composite porcelain

Various types of office copy/print waste papers (CP) were used as waste materials due to easy availability.

4.1.2. Porcelain raw materials

The porcelain raw materials were English kaolin (ECC International standard porcelain, Imerys mineral Ltd, 2000), Norwegian potassium feldspar (NGP kali feldspar, Norflux 75) with a ceramic grade 200 mesh (North Cape mineral AS, 2003) and Swedish quartz with a ceramic grade 270 mesh (Fyleverken Industrimineralberednings IMB AB, 2003). The recalculated oxides of the raw materials are shown in Table 1.

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	L.O.I	Total
Kaolin	48.0	36.5	0.68	0.02	0.07	0.30	0.10	1.65	12.5	99.82
Feldspar	65.9	18.6	0.07	0.002	0.4		2.9	11.8	0.14	99.812
Quartz	99.5	0.15	0.035	0.05					0.2	99.935

Table 1. Chemical compositions of the porcelain raw materials (wt.%)

4.1.3. Plaster

For moulds, a commercial type of plaster, Primosupra 68 white/beige (Heidelberg cement, Wilhelm Priem GmbH & Co. KG, Germany), was used. 1.6 parts plaster was mixed with 1 part water for casting plaster moulds.

4.1.4. Glaze raw materials

The raw materials of the glaze were: Norwegian sodium feldspar (FR/FS natrium feldspar, Forshammar, North Cape mineral AS, Norway), Swedish quartz, Danish calcium carbonate (Omya A/S, Denmark) with approximately 98% $CaCO_3$, English kaolin (ECC International super standard porcelain, Imerys minerals Ltd, France) with approximately 48% silica, 37% alumina and 12.8% H_2O, and German zinc oxide (Grillo zinc oxide white seal, GmbH Goslar, Germany) with approximately 99.6% ZnO.

4.2. Casting slip preparation

4.2.1. Waste paper

CP was reduced to pulp before being mixed with the porcelain powders. The waste paper was first soaked in hot water and then broken to disintegrate the fibres. A large mesh screen was used to get a pulp with a water content of 20%. This was then squeezed to get rid of excess water. The excess water was recycled and mixed with porcelain powders and paper pulps.

4.2.2. Porcelain slip

The slip composition of the mother porcelain (M) is shown in Table 2.

Porcelain raw materials in powder	**Percentage (wt. %)**
Kaolin	50
Feldspar	25
Quartz	25
Total	100

Addition	**Percentage (wt. %)**
Deflocculant	0.25% of the porcelain raw material weight
Water	45% of the porcelain raw material weight

Table 2. Composition of a mother porcelain (M) slip

The content of added water was 45 wt.%. In order to enhance slip stability, a commercial organic deflocculant, Dolapix PC 67 (Zchimmer & Schwarz GmbH, Germany) was introduced in amounts of 0.25 wt.%, based on the weight of the porcelain raw materials. The powder porcelain raw materials were then added. The slip was mixed in for 3 hours and then sieved through an 80-mesh screen three times.

4.2.3. Paper-composite porcelain slip

MCP slips were prepared with three different paper ratios (50%, 70% and 90% by volume, as 6.8%, 14.6% and 39.8% in weight). The paper pulp was thoroughly mixed with the other porcelain raw materials, and deflocculant and water were added. The formulations of the MCP slips are shown in Table 3.

	MCP 1	MCP 2	MCP 3
Kaolin	46.60	42.70	30.10
Feldspar	23.30	21.35	15.05
Quartz	23.30	21.35	15.05
CP	6.80	14.60	39.80

Table 3. Paper-composite porcelain (MCP) formulations (wt.%)

4.3. Model production process

4.3.1. Casting and drying

Models were produced in different plaster moulds by the slip casting method. The casting of prototypes of the M and MCP slips followed the usual slip casting procedure. All models were air-dried at room temperature.

4.3.2. Biscuit firing

Biscuit firing was carried out in an electric kiln (Nabertherm, Germany) which was heated with kanthal A1 elements in an oxidised atmosphere. The models were biscuit fired at a selected temperature of 1000°C. This temperature was chosen in order to obtain uniform conditions for both the M and MCP bodies, which have different biscuit firing temperatures. The results of the tests which show the approximate biscuit firing temperatures for the M and MCP bodies are described in Section 6.2. During the practical experiments, biscuit firing was first conducted at several different temperatures: 950, 1000, 1050, 1100, and 1150°C in order to select the most favourable temperature for biscuit firing. The outcomes of the practical experiments at these firing temperatures are described in Section 5.3.

4.3.3. Glaze

A transparent glaze was applied to biscuit-fired M and MCP models by means of spray glazing. The transparent glaze was used to ensure the visibility of the clay body. The formulation of the glaze is shown in Table 4.

Transparent glaze raw materials	Percentage (%)
Feldspar	35.36
Quartz	28.66
Calcium carbonate	18.06
Kaolin	14.26
Zinc oxide	3.66

Table 4. Composition of a transparent glaze (wt.%)

4.3.4. Gloss firing

Biscuit-fired models were glazed and then fired at a temperature of 1300°C . The models were first heated to 250°C (90°C/hour), then to 600°C (150°C/hour). The firing proceeded at full rate to the final temperature, with a dwell time of 5 minutes. All models were fired using a fixed programme in order to obtain uniform conditions.

5. Observation and results of the artistic experiments

5.1. Casting slip preparation

The waste paper was first soaked in hot water and then beaten to disintegrate the fibres. It was easier to disintegrate the paper fibre in hot water than in cold water. The paper that was torn into small threads dissolved more quickly than the paper that was not torn. Shredded paper was also effectively dissolved.

The ageing of the MCP slip improved its workability and plasticity. After firing, small pinholes were observed on the surface of models that had been produced by non-aged MCP slips. Models produced by aged MCP slips showed fewer or no pinholes. The models using the aged MCP slips had a very fine surface. One problem with the aged MCP slip was that it became very thick, almost porridge-like in consistency, and needed additional water in order to be used as a casting slip. It was difficult to control the amount of water and the slip easily lost viscosity and plasticity. However, the added water made the slip work better in areas with sharp lines and narrow angles.

5.2. Casting

The casting time differed according to the different paper fibre content composition of the slips. The casting time for the MCP slips was usually shorter than for the M slip. The casting time for the MCP 3 slip was the shortest. During casting, MCP 2 and MCP 3 slips needed extra wet brushing and wet sponging to smooth the parts with sharp angles and to control the thickness. Wet sponging the plaster mould before pouring the MCP slip reduced the sticking of the slip to the mould and helped to control the thickness of the slip during casting. It also made it easier to remove the casting body from the mould. Undesirable substances such as small dried pieces of slip or other impurities from the working tools which accidentally fell into the slip during casting were difficult to remove from the MCP slips during the casting process because of the large amount of paper fibre that would have been removed if the slip were re-sieved. The M slip was re-sieved for each casting. Since the drying shrinkage is less with MCP slip bodies than with an M slip body (see Table 5), the casting body required a longer drying time in the mould until the object had shrunk enough to be easily removed, although the MCP slips dried much faster. It was necessary to continuously mix both the M and the MCP slips to keep the materials evenly distributed in the slip, since the raw materials sank to the bottom of the bucket. During the casting process, the MCP slip bodies had fewer visible cracks than the M slip body. In the green state, the models produced by MCP slips were noticeably stronger to handle than the models produced by the M slip. The models produced by the M slip were very fragile, especially in their plastic stage.

5.3. Drying, firings and glazing

The casting bodies produced by MCP slips dried much faster than those produced by the M slip and without cracking or warping. At this stage, working with MCP slips was less complicated than working with an M slip, which needed close attention to avoid cracks and warping during the casting process.

The biscuit-fired models showed that a biscuit-firing temperature of 1000°C was not a sufficiently high temperature for the MCP bodies. The results of the biscuit firing test showed that the models produced by the MCP bodies and biscuit fired at 1050°C or 1100°C performed better in glaze absorption and handling than those fired at or below 1000°C. 950°C proved to be too low a temperature for the MCP bodies. Models produced by MCP bodies which were biscuit fired at 950°C were more fragile to handle and absorbed more glaze than models produced by the M body which were biscuit fired at the same temperature. The best temperature for glazing biscuit-fired MCP bodies was 1100°C. Fired at this temperature, the biscuit-fired models were easy to sand and clean. However, the 1100°C biscuit-fired M body did not absorb the glaze and it was almost impossible to sand and clean the surface as the body became too dense. The test result from the biscuit-firing process showed that MCP bodies required a temperature that was at least 100°C higher than that required by the M body. All models that were fired at 1300°C, whether they were produced by M or MCP slips, resulted in a good handling strength.

As mentioned in the discussion on porcelain problems (see Section 1.1), the addition of ball clay or bentonite to improve the lack of plasticity and the green strength of porcelain decreases the whiteness and translucency in its fired state. Thus the degree of whiteness and translucency of the MCP bodies in the fired state was of interest.

A visual observation revealed that there was no difference in whiteness between M and MCP bodies. However, the MCP bodies showed a silky lustre in comparison to the M body. On the glazed MCP bodies, the glaze had a deeper and more translucent effect than on the M body. It was assumed that these effects were due to the extra anorthite which was identified in the fired MCP (Jeoung-Ah, 2004). According to studies of the effects of anorthite on porcelain bodies by Kingery (1993; Kingery and Vandiver, 1983), the anorthite will influence the visual qualities of the porcelain body and glaze: anorthite will give a soft, silky lustre and a deep translucent effect to the surface of the fired porcelain body and increase the degree of translucency when it interferes with the composition of glaze.

5.4. Design and models

The purpose of the model was to achieve an experimental function to enable the observation and description of the workings of the material, as well as a comparison with the results of the technical experiment. Among the possible porcelain design models, tableware and tile design were considered, since these are representative of the traditional pottery design working areas. In previous phases of this research, artistic experiments were conducted on tiles (Kim, 1993). The flat, thin shape of the tile really pushes the material to its limits, maintaining control of a flat shape, without involving the more complex qualities of more intricate designs. The chosen tableware models are designed to test the material with respect to the ability to control shapes that are difficult to cast, particularly those of certain sizes, with wide mouths, self-supporting walls, fine surface texture and deformations.

A selection of the models produced by MCP slips is shown in Figures 1–6.

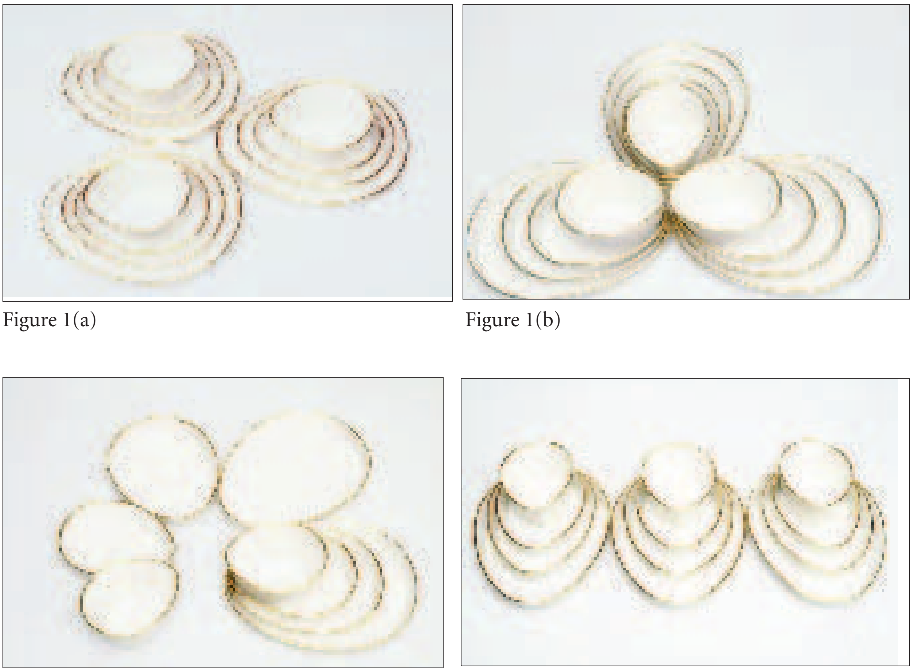


Figure 1(a)

Figure 1(b)

Figure 1(c)

Figure 1(d)

Figure 1. A serving set consisting of four different items

Figures 1(a)–(d) show a serving set consisting of four different items. The forms have sharp, clean lines, with wide mouths that require a careful production process to prevent warping or deformation. In addition, the models were to have a fine surface texture. This design was applied to the M slip and three different MCP slips to see how the materials behaved during the production process.

A thickness of less than 1.5 mm resulted in warped mouths for both M and MCP slips. Achieving a fine surface and clean lines was easier with the MCP slips than with the M slip. The MCP slips only needed extra wet sponging to get a satisfactory result; however, the M slip had pouring lines in the centre of the dishes. Furthermore, there was a problem with warped mouths. The finest surface and texture among the final MCP slip products was obtained with the least amount of paper fibre. However, even the final MCP slip product with the highest paper-fibre content obtained fine lines and sharp angles.

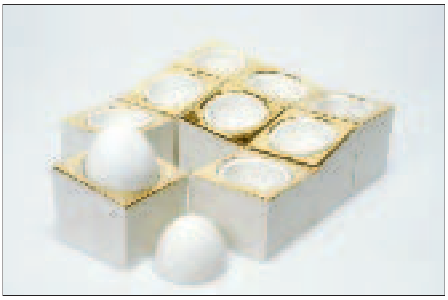


Figure 2(a)

Figure 2(b)

Figure 2. Multi-functional egg cups

Figures 2(a) and (b) show a series of multi-functional egg cups. Each egg cup has a deep egg holding section and sharp angles. An extra holder should fit exactly in its eggcup. In this respect, the result of the final shrinkage of the slip bodies from the technical experiment was crucial to determining the final size of the egg holders.

It was easy to cast sharp angles with the M slip, but it was difficult to cast the deep and narrow holding sections. The M slip body often cracked at the sharp top part, which was ripped off when separating it from the mould. Among the casting MCP slips, the MCP 1 was best at maintaining its shape. It was difficult to work on fine lines and sharp angles with the MCP 2 and MCP 3 slips, since they were very thick and sticky. The thick slip did not go through the narrow section and it became stuck after it was poured into the mould. Adding water to the slip helped to make it thinner. A thin oil paintbrush was used to blend the slip during the thickening process while it was in the mould, at the stage before pouring out the excess slip. This significantly improved the casting of fine lines and sharp angles.

Figure 3(a)

Figure 3(b)

Figure 3(c)

Figure 3(d)

Figure 3. A serving set consisting of five different items

A stackable serving set consisting of five different items – three bowls, a vase and a plate – are shown in Figures 3(a)–(d). Although the items have simple and functional forms, such designs are usually very difficult to cast, as the wide mouth of each bowl can easily warp and the plate can easily bend. The simple form clearly makes any faults apparent.

The M slip body showed clear warping and bending of form. The MCP slips were easier to handle than the M slip. Uneven surface texture was smoothened by applying extra wet sponging at an early stage of the casting process. All the MCP bodies resulted in forms with less warping.

Figure 4(a)

Figure 4(b)

Figure 4(c)

Figure 4. A serving set for Sushi

Figures 4(a)–(c) show a serving set consisting of three plates (Fig. 4a), with two different items (Fig. 4b) for serving rice rolls and rice-balls. The deep slanted shapes posed serious problems during production. The casting bodies retained casting cracks due to the large distance between the lowest and the highest levels. Although a successful body was formed, it was ripped at the lowest line when the plate was separated from the mould.

No plate was successfully produced using the M slip, the main problem being the fragile green strength and low plasticity. The material characteristics of MCP slips were well suited to this production, especially due to their higher green strength.

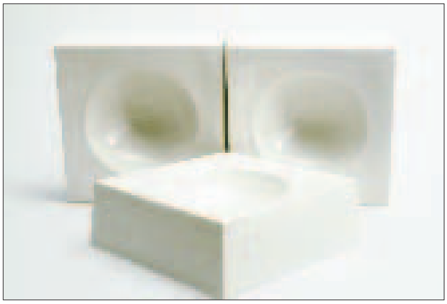


Figure 5(a)

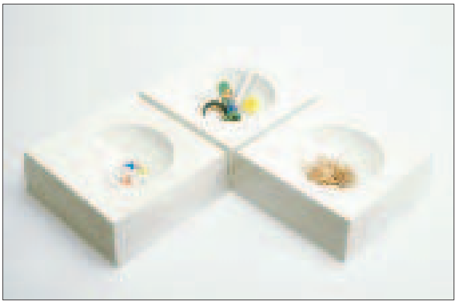


Figure 5(b)

Figure 5. Multi-functional service

Figures 5(a)–(b) show a compressed cubic form with a concave hemispherical bowl in the middle. The hollow section was the major problem in producing this design. The four side walls needed to be strong enough to support the weight of a hemispherical shape, as the shape is deep and wide (see Figure 5a).

The M slip stuck tightly to the hemispherical part of the mould and cracks developed around the mouth of the casting body. It was ripped along the circle line when it was separated from the mould. The M bodies collapsed as the four side walls could not withstand the weight of the inside bowl.

None of prototypes in this form was successfully produced by the M slip, however the MCP slips withstood the production process. The prototypes produced by MCP slips are shown in Figure 5.

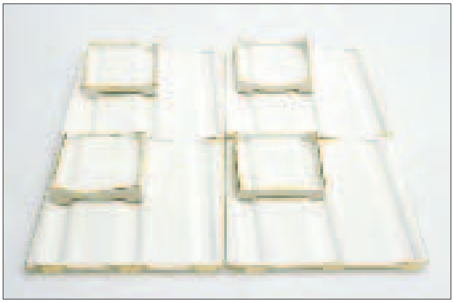


Figure 6(a)

Figure 6(b)

Figures 6. Plate serving set

Figures 6(a)–(b) show plates for serving small fried items.

The two problems with this plate were the wide surface without any holding walls and its low height. As a result, the M slip body was seriously bent during drying and firing. The MCP slip bodies were bent during firing but less so than the M slip body. As deformation results show in Table 6, the differences between MCP 1, 2 and 3 are not significant.

6. Technical experiments in a fired state

Technical experiments were carried out to characterise the MCP in its fired state in comparison with the M body. The aim of the technical experiments was to investigate the material properties from an artistic perspective. Part of the experiments aimed to study how the different paper–fibre contents affected the properties of the MCP slip bodies.

All tests were performed at normal room temperature. The test results were recorded using an average value of five measurements (one measurement for each of the five specimens). The physical properties in its green state were characterised according to the international standard test methods with respect to linear drying shrinkage (ASTM C326), and weight-loss as the weight change (ASTM C373). An Instron universal testing machine was used to determine mechanical strength in a three-point bend mode, which was tested according to ASTM C689. Test bars were obtained in a plaster mould. Just de-moulded as well as wholly dried test bars were measured for their weight to 0.01 g and length. The linear drying shrinkage was determined by the difference in the length of the test bar before and after drying. The thickness and length were measured using a vernier caliper to 0.01 mm. Every experimental step in this study kept the test conditions as similar as possible so that a fair comparison could be made. The average depth of distortion was measured in the deformation test (see Section 6.2 of this paper).

6.1. Linear shrinkage, weight-loss, porosity, absorption, density and strength

Slip 1300°C	Linear shrinkage from wet to dry (%)	Total linear shrinkage from wet to fired (%)	Weight-loss from wet to dry (%)	Weight-loss from wet to fired (%)	Fired apparent porosity by volume (%)	Water absorption by weight (%)	Fired bulk density (g cm^{-3})	Green strength (Mpa, N/mm_2)	Standard deviation of green strength	Fired strength (Mpa, N/mm_2)	Standard deviation of fired strength
M	4.80	15.73	16.04	24.82	0	0	2.46	5.80	0.26	56	7
MCP 1	4.13	15.67	25.93	33.58	0.25	0.11	2.39	7.60	0.47	47	8
MCP 2	4.53	16.13	30.06	37.23	0.98	0.42	2.37	9.40	0.43	43	5
MCP 3	4.67	16.53	37.67	44.22	1.19	0.50	2.36	9.70	0.41	43	3

Table 5. Linear shrinkage, weight-loss, porosity, absorption, density and strength of M and MCP slip bodies fired at 1300°C

Table 5 shows the results of the tests of linear shrinkage, weight-loss, porosity, absorption, density and strength in the fired state.

The results proved that a higher paper-fibre content in a slip body gives lighter weight, higher porosity and absorption, lower density and lower strength in the fired state. Surprisingly, the MCP 2 and MCP 3 show a total linear shrinkage that was larger than that of the M body in the fired state but smaller in the green state. The differences in fired density and strength between the M and MCP slip bodies were noticeable. The differences due to the paper-fibre content were not significant, but could nevertheless be detected, particularly between MCP 2 and MCP 3. This result showed that an increased amount of fibre improved the green strength, however it decreased the strength rating in the fired state.

6.2. Degree of deformation

Deformation occurs at the temperature at which a ceramic body can no longer hold its shape due to the formation of molten compounds within the body (Fournier, 1973). According to Norsker (1987) the degree of deformation is an indication of the approximate degree of body vitrification, sintering point, biscuit firing point and gloss firing point. Hamers (2004) states that vitrification begins at 800°C and is related to porosity, sintering and biscuit firing temperature. In practical pottery, the biscuit firing temperature ranges from 850–1000°C when clay particles begin to shrink and deform the body. The body shrinks during vitrification, and the process is completed at the point at which the whole body is melted into glass. At this point, the porosity becomes zero. According to Fournier (1973), Hamers (2004) and Richerson (1992), sintering occurs when all individual clay particles stick to each other but the liquid phase has not yet begun; thus an intermediate and densification stage occurs during the firing of a ceramic and near to the biscuit firing temperature before the process of vitrification is completed.

Slip bodies	950°C	1000°C	1050°C	1100°C	1150°C	1200°C	1250°C	1300°C
M	0	0.8	0.8	0.8	1.3	2.0	4.8	7.3
MCP 1	0	0	0	0	0.7	1.7	4.0	6.0
MCP 2	0	0	0	0.1	1.7	2.2	4.5	6.5
MCP 3	0	0	0.2	0.5	3.2	3.2	6.0	6.7

Table 6. Degree of deformation (average/mm) of M and MCP slip bodies in fired states

Table 6 shows the results of the deformation test of the M and MCP slip bodies in the fired states. The purposes of this test were:

- To obtain information for use in the planning of the work procedures for the final artwork
- To compare the warping in the M and MCP bodies in order to see how to prevent this at high firing temperatures, as this is one of the main problems of working with porcelain
- To find out the approximate biscuit firing temperatures of these bodies
- To find out the approximate sintering starting temperature of these bodies
- To find out the approximate vitrification starting temperature of these bodies.

The results and conclusions from the above tests were:

- At the highest firing temperature in this study at 1300°C, the M body warped 7.3 mm while MCP 1 warped 6.0 mm, which means that MCP bodies have better resistance against warping at the porcelain firing temperature of 1300°C. This result indicates that products made by MCP bodies can keep their forms better than those made by M bodies, which has direct consequences for artistic practice (see Sections 5.3 and 5.4 of this paper).
- The approximate starting temperatures for biscuit firing and sintering were: between 950–1000°C for M, between 1100–1150°C for MCP 1, between 1050–1150°C for MCP 2 and between 1000–1050°C for MCP 3. The starting temperature for MCP 3 was the closest to M, about 50°C, while MCP 1 had the highest difference, about 150°C. Thus it can be said that the biscuit firing temperature for MCP bodies are around 50–150°C higher than for the M body (see Section 5.3 of this paper).
- The approximate starting temperatures for vitrification were between 1200–1250°C for M, MCP 1 and MCP 2, while for MCP 3 they were between 1100–1150°C. This indicates that combining paper fibre or a higher paper–fibre content does not decrease the sintering temperature in comparison to that of the M body. The MCP 1 with lowest paper–fibre content has the lowest vitrification temperature and the lowest degree of deformation, while the MCP 3, with the highest paper–fibre content, has the highest vitrification temperature among the MCP bodies.

The interesting points of these test results are as follows:

- The results at 1300°C show that all MCP bodies have lower vitrification than M.

This indicates that to obtain the same translucent effect in MCP bodies as in the M body, they have to be fired at a higher gloss firing temperature until they reach the same degree of vitrification as the M body. According to Rado (1969), a complete body vitrification is a prerequisite for translucency. The complete vitrification point was explained by Hamers (2004) as the point at which porosity becomes zero. A better understanding can be obtained if the results showing the absorption and porosity of the bodies fired at 1300°C from Table 5 are compared to the degree of deformation presented in Table 6. All MCP bodies have a porosity between 0.25 and 1.19, which can be compared to the deformation of all MCP bodies having a lower degree of vitrification. However, Hamers also mentioned that when a body reached the point at which it was absolutely non-porous it was also so glassy that it tended to fracture more easily. Thus, it can be said that at the same gloss firing temperature, the M body can be more easily fractured than the MCP bodies.

- The results also indicate that all MCP bodies have a wider firing range at the high gloss firing temperature than the M body, which has a shorter firing range. This is one of the main problems of the porcelain body. Thus the MCP bodies will result in a higher rate of production than the M body, since MCP bodies will have a lower loss rate from firing than the M body. This is because the M body is highly sensitive to collapse, even at temperatures that are only slightly higher than its firing temperature.
- Test results at 1150°C and 1200°C show that at these temperatures, MCP 2 and MCP 3 have a higher degree of deformation than M. However, the porcelain gloss firing temperature is normally above 1250°C. This will therefore not affect the final product in practice, since the degree of deformation will be lower than that of the M body between 1200–1250°C. This particular phenomenon at those firing temperatures was explained by Fournier (1973), who observed that deformation is normally a slow and continuous process, but can be quite sudden in high-calcium bodies. This explains why MCP 2 and MCP 3 bodies showed sudden changes, since these two bodies have a higher amount of extra calcium carbonate from the paper than MCP 1.

7. Conclusions

In agreement with the problems (see Chapter 1 in this paper) and aims (see Chapter 2 in this paper) of this study, we can conclude that the following contributions have been made to the field by demonstrating results of the artistic and technical experiments with paper-composite porcelain. The results showed that the paper-composite porcelain bodies can be used to solve the problems encountered when working with ordinary porcelain in practice. The material can therefore be used as an optional choice instead of porcelain. The achievements of this study are described below.

Regarding the identified deficiencies of porcelain (see Section 1.1 of this paper):

- MCP has a lighter weight and less shrinkage in both the green and fired states and a higher strength in its green state than M. The artistic experiment showed that the strong fibre bonding structure supported the plastic stage during the casting process and gave better control, particularly in complicated shapes (see Chapter 5 in this paper). The results from the technical experiment provided information about the shrinkage, weight-loss, porosity, absorption, density, strength and deformation of the material properties (see Chapter 6 in this paper).
- The cracking, warping, bending and deformation of the MCP were much less than in the M in artistic practice (see Chapter 5 in this paper). All MCP bodies have lower deformation degree than M at the highest firing temperature 1300°C (see Section 6.2 of this paper).
- All MCP bodies have a wider firing range at a high gloss firing temperature than M, which has a shorter firing range as one of its main problems (see Section 6.2 of this paper).
- No difference in whiteness could be observed between the M and MCP bodies, however MCP bodies had a silkier lustre in comparison to M. The glaze on the MCP bodies had a deeper and more translucent characteristic than on the M body (see Section 5.3 of this paper).

Regarding the identified problems with paper-composite porcelain (see Section 1.2 of this paper) and the aims (see Chapter 2 in this paper) of the study:

- The entire working procedure, characteristics and physical properties of the paper-composite porcelain are described and facilitate the planning of the final artwork for practicing ceramicists.
- In artistic experiments, complicated shapes and fine lines were achieved by MCP slip casting. The results showed that the MCP behaviour varied according to the amount of paper fibre in the clay body. The best results were achieved by using the least amount of paper in the casting process. In addition, the finest surface and best texture were obtained with the least amount of paper fibre. Nevertheless, even the final MCP slip product with the highest amount of paper fibre had fine lines and sharp angles. The M slip was difficult to work with because of its fragility in

the green state and cracks in the forms, with sharp angles appearing in both the green and fired states (see Chapter 5 in this paper).
- The MCP bodies were more fragile than the M body in the biscuit fired state, but were stronger in the green state. An increased amount of fibre decreased the strength rating in the fired state. However, they showed good handling strength in the fired state (see Chapter 5 in this paper).

Other contributions and results:
- Only waste paper was used, since it can be easily obtained, and at little or no cost. The amount of wastage was thus able thus be partially reduced and the ceramic work was produced as a sustainable product (see Section 4.1.1 of this paper).
- The slip preparation of paper-composite porcelain is a new method. The excess water was recycled as additional water when mixed with the porcelain powders and paper pulp (see Section 4.2.1 of this paper). It is important to mention that the material characteristics, physical properties and final effects of art products which are produced using the paper-composite may not be the same if ceramicists use readymade paper pulp or washing paper, or sieve away the excess water. The readymade paper pulp may not contain same minerals as those used in this research. In this project, the paper pulp was made manually from waste paper and no readymade paper pulp was used. All excess water was recycled so as not to lose any minerals or chemical compounds from the paper. Thus, this clay body preparation method of the paper-composite porcelain is completely different from that described in other forms of (Gault, 1992 and 1993; Goldate, 2001; Juvonen, 1995; Stevens, 2002) paper clay manufacture in which the excess water is discarded.
- Large quantities of paper fibre were mixed. In this study, the proportions of paper fibres used were 50%, 70%, and 90% in volume respectively (as 6.8%, 14.6% and 39.8% in weight) which is higher than the paper pulp contents that were previously reported in similar studies. The highest ratio reported was the 50% paper pulp volume that was tested by Gault (1993), Goldate (2001) and Lightwood (2000).
- All raw materials used in this study were produced in European countries, which may benefit European ceramicists (see Section 4 in this paper).
- This study identifies the biscuit firing temperature of MCP bodies as 100–200°C higher than that of the M body, based on the test results of the physical properties and deformation characteristics (see Sections 5.3 and 6.2 of this paper).
- In this study, the high firing temperature was tested. It is assumed that MCP bodies can be fired at up to 1550°C, since its mother recipe, a hard-paste porcelain clay

body, can normally be fired at up to 1450°C. .

- All MCP bodies require a higher gloss firing temperature than that of the M body to get a translucent effect and complete vitrification (see Section 6.2 of this paper).
- It is clear that extra calcium carbonate from the paper and extra anorthite in the fired state directly influenced the visual effects of the paper-composite porcelain, both the body and the glaze (see Sections 5.3 and 6.2 of this paper).

Acknowledgements

This research was made possible through financial support from Göteborg University and a grant from the Estrid Ericsons Stiftelse in Sweden. The author would like to thank Dr. Häggström Cecilia for her invaluable advice.

References

Baker, W. L (1998) Spraying paper-reinforced clay *Ceramic Monthly* Vol 46 No 9 pp 46–49

Cooper, E and Royle, D (1978) *Glazes for the studio potter* B T Batsford Ltd, London, UK

Fournier, R (1973) *Illustrated dictionary of practical pottery* Van Nostrand Reinhold company Ltd, London, UK

Fraser, H (1986) *Ceramic faults and their remedies* A & C Black, London, UK

French, N (1972) *Industrial ceramics: Tableware* Oxford University press, London, UK

Fyleverken Industrimineralberednings IMB AB (2003) *Technical data* Fyleverken Industrimineralberednings IMB AB, Eriksdal, Sjöbo, Sweden

Gault, R (1992) Amazing paperclay *Ceramic monthly* June/July/August pp 96–100

Gault, R (1993) Second generation ceramic sculpture: technical and aesthetic potential of paperclay. In: *Interaction in ceramics*, Valkonen, A. (ed.), UIAH, Helsinki, Finland, 1993, pp 72–79.

Gault, R (1998) *Paper Clay* A & C Black, London, UK

Goldate, S (2001) Working with paperslip *Ceramics technical* No 13 pp 78–80

Hamer, F. and Hamer, J (2004) *The potter's dictionary of materials and techniques, 5th ed.*, A & C Black, London, UK

Imerys mineral Ltd (2000) *Typical data* Imerys mineral Ltd, Paris, France

Jeoung-Ah, K (2004) The characterisation of paper composite porcelain in a fired state by XRD and SEM *J. Eur. Ceram. Soc* Vol 24 No 15–16 pp 3823–3831

Jeoung-Ah, K (2006) The characterisation of paper-composite porcelain in a green state *J. Eur. Ceram. Soc* Vol 26 Issue 6 pp 1023–1034

Juvonen, L (1995) Using paper fibre as a substitute in ceramic clays. In: *Proceeding of the 8th CIMTEC World Ceramics Congress 1994*, Vincenzini, P. (ed.), Faenza, Italy, pp 193–200

Kim, J. A (1993) To construct by repetition to reflect time and space for subject interpretation through the ceramic works by the use of paper clay. In: *An exhibition catalogue of MFA examination*, Göteborg University (ed.), Tryckeri AB Framåt, Gothenburg, Sweden

Kingery, W. D and Vandiver, P (1983) Song Dynasty Jun (Chun) ware glaze *Ceramic Bullentin* Vol 62 No 11 pp 1269–1279

Kingery, W. D and Vandiver, P (1986) *Ceramic masterpieces* Macmillan Publishing Co., New York, USA

Kingery, W. D (1990) *The changing roles of ceramics in society* American Ceramic Society, Westerville, USA

Kingery, W. D (1993) Internal structure and visual effects of ceramics. In: *Interaction in ceramics*, Valkonen, A. (ed.), UIAH, Helsinki, Finland, 1993, pp 87–98

Lane, P (1980) *Studio porcelain* Pitman house, London, UK

Lightwood, A (2000) *Working with paper clay and other additives* The Crowood Press, Wiltshire, UK

Norsker, H (1987) *Clay materials for the self-reliant potter* Vieweg, Germany

North Cape mineral AS (2003) *Technical data* North Cape mineral AS, Rud, Norway

Peterson, S (1995) *The craft and art of clay*, *2nd ed.,* The overlook press, New York, USA

Rado, P (1969) *An introduction to the technology of pottery* Pergamon press, London, UK

Rhodes, D (1964) *Clay and glazes for the potter* Sir Isaac Pitman & Sons Ltd, London, UK

Rhodes, D (1971) *Stoneware & porcelain* Pitman publishing, London, UK

Richerson, D. W (1992) *Modern ceramic engineering, 2nd ed.*, Marcel Dekker Inc, New York, USA

Soong, D. K and Ling, Y. C (1995) Determination of PCDD/DFs in paper clay samples. *Chemosphere* Vol 30 Issue 9 pp 1799–1803

Stevens, G (2002) An investigation into the properties of porcelain paperclay. *Ceramics Technical* No 14 pp 72–77

Paper IV

A perspective on knowledge in ceramic art, craft and design: Examples of porcelain manufacture and paper-composite porcelain

Submitted for publication

Table of contents

A perspective on knowledge in ceramic art, craft and design: Examples of porcelain manufacture and paper-composite porcelain

Jeoung-Ah Kim
School of Design and Crafts HDK, Göteborg University
Box 131, 405 30, Gothenburg, Sweden

The field of ceramic art, craft and design has traditionally been deeply rooted in tacit knowledge. This has recently become an issue, particularly with respect to communication practices, education and the development of further research in this field. By means of explicit knowledge, the field can be strengthened in deficient areas, however it cannot stand on its own without tacit knowledge. This study focused on the role of tacit and explicit knowledge, using examples to illustrate how important it is to develop both forms of knowledge in the field of ceramics in parallel.

Keywords: Communication; Design practice; Problem solving; Research methods; Technology

The use of pottery began “about 15,000–10,000 B.C. with the dawn of the Neolithic age” as “the first synthetic material to be discovered by man” (Rado, 1969, p. 2). For thousands of years, ceramics have developed through potters’ own experiences. The skills of the potters’ trade were passed from generation to generation or obtained through apprenticeships. Many potters were at the lowest socio-economic levels of their societies until at least the twentieth century. This is one of the reasons why most of the early written documents describing pottery were recorded by historians or scholars, rather than by the potters themselves. Moreover, potters kept their clay, glaze, firing and much of the skilful aspects of their work methods to themselves in order to survive the strong competition in their profession. Some potters did not want to pass their knowledge or profession on to the next generation while they themselves lived under poverty-stricken and hard-working conditions. The social status of potters was very low, which caused many potters to either completely or partly abandon their pottery profession (Cooper, 2002; Kerr and Wood, 2004; Longworth, 2005; Matson, 1965). Similarly, much of the important know-how in pottery could not be passed onto the next generation, since there was no explicit way of teaching it. Without an apprentice, the knowledge disappeared when the potter died. There was no active means of communication between potters in different areas, people in domestic situations and at international levels as far as acquiring information and transferring their knowledge for the development of pottery was concerned; instead pottery has developed through the potters’ own actions. In fact, communication, access to information or the transfer of knowledge was also difficult for the potters due to their working and living environments. Many lived in mountains, forests or wasteland areas. These areas had suitable raw material for pottery production (clay, fuel and water) but were located far from towns or villages. Gathering information and communicating became an important part of pottery making when the pottery trade gained an international focus, though the focus was not on individual potters until the beginning of the twentieth century, when potters started to build independent art studios (Cooper, 1981; Cooper, 2002; Morley-Fletcher, 1987).

When Marco Polo introduced porcelain to Europe in 1295, it fascinated the Europeans. Porcelain products became highly valuable collection items for the aristocracy. However, Europeans did not have enough knowledge at the time to produce the unique quality of porcelain. The high commercial value in the enormous European market for porcelain encouraged efforts to discover the secret of its manufacture (Cooper, 2002; Lane, 1980). The effort to reproduce Chinese porcelain took several hundred years of research and intensive experimentation in pottery throughout all of the countries in

Europe until Böttger discovered European hard porcelain in Meissen in 1709. This successful research also became a basis for industrial ceramics in Europe. The mid-eighteenth century was a golden age in pottery, transforming the traditional craft into an industry, and putting it at "the forefront of technological development as the most progressive industry" (Rado, 1969, p. 207). This modernisation was driven by Wedgwood, who not only introduced modern business methods for industrial progress and commerce and improved the standards of living for his workers, but also "applied explicit scientific methods in his experimentations" (Ibid.). It was a significant time in Europe, which changed pottery from craft to industry/design and made potters aware of the need for the explicit mediation of knowledge.

During the time when there was no other method of mediating the knowledge of pottery-making than through personal know-how, the search for knowledge of porcelain-making caused a war in Northeast Asia. In 1594, Japan invaded Korea in what is called the "Porcelain War." Many Korean potters were brought back to Japan as prisoners. One of them was "Li Sanpei," who is considered to be the founder of the porcelain craft in Japan and is still called Dojo (the ancestor of porcelain) by Japanese. He was also the first potter to discover kaolin clay in Japan. In 1605, he launched porcelain-making in Japan (Cooper, 2002; Rhodes, 1964; Trilly, 1987). The resulting products made Japanese porcelain famous in Europe, since large quantities of porcelain were exported during the eighteenth century, when China had difficulties exporting porcelain due to its own civil war. The centre of the Japanese porcelain production is still on the island of Kyushu, where the Korean potters started produce porcelain and where a large amount of kaolin is available. Consequently, porcelain productions throughout the whole of Korea were abandoned, as there were no porcelain masters who could continue the production of porcelain. The new pottery traditions Sa-Ki and Bun-Chung were subsequently started in Korea by local potters. This is an example of the spread of tacit knowledge in ceramic history.

The nineteenth century was a time in which scientists started to study pottery. One of them was Hermann Seger of Germany, who contributed much to the technical knowledge in ceramics today. In his efforts to understand ceramic oxides and predict the outcome of firing with his invention of cones, the scientific ceramic pioneer Seger laid the foundation for today's ceramic technologies, including that of the studio potters.

According to Fournier (1973), Hamers (2004), Norton (1956) and Richerson (1992), the origins of the word "*ceramic*" can be traced back to the Greek word "*keramos*", meaning "to burn", and refers to products made from the application of fire to earthy materials. However, modern usage of the term broadened the meaning to include inorganic non-metallic materials. Up until the 1950s or so, the most important ceramic material was the traditional clay, which was made into pottery, bricks, tiles and similar items, along with cement and glass. The traditional ceramic crafts are described as pottery. In 1822, fireproof ceramics were made for the first time. These were not made of "clay", but were prepared using ceramic methods (the mixture was first wet, then formed, dried and fired). The term "*Ceramic*" maintained its original meaning, but was still applied to clay-made objects and was therefore used to refer to all materials produced by this method. In the course of time, the expression "*Ceramic*" was expanded to include all non-clay materials used in electricity, nuclear energy and engineering, having applications in high temperature environments. In 1920, the Ceramic Research Institute in the United States declared the "*Ceramic*" to be a generic term which was expanded to mean the art and preparation of objects by the ceramic method or objects made by this method. Ceramics has advanced far beyond its beginning in clay pottery. Ceramic tiles cover the space shuttle as well as our kitchen floors. Consequently, ceramics are divided into two professional areas: the field of advanced ceramics, which includes most of scientific and technical ceramics, and the field of arts, which includes ceramic art, craft and design based on traditional clay-based materials. Ceramics can thus be divided into two classes: "*traditional ceramics* and *new ceramics*" according to Richerson, 1992, pp. 374–376).

1. Background and aim of this study

Advanced ceramics are significantly concentrated on technical ceramics, rather than traditional clay-based ceramics. The work is largely undertaken for commercial reasons and tailored towards industrial requirements and social demands. Advanced ceramics are highly explicit, which is both practical and efficient, as the knowledge can make the outcome of an application predictable. The field of ceramic art and craft remains reliant on mainly tacit knowledge. Most contemporary potters work in isolated studio environments. Some of them are unwilling to share their knowledge with others, which makes it more difficult to develop explicit skills in ceramic art and craft. The craftsmanship and skills employed in ceramic art and craft depend largely on a self-learning process and long experience of developing tacit knowledge. Smith (1997) describes our contemporary craft "as the obvious signifier of modernity's opposite: tradition." (p. 20). Since the art and craft debates of the 1980s, craft has been criticised for its lack of explicitness (Rowley, 1997). Smith (1997) stressed that the position of modern craft had become detached, in relation to modern art, referring to it as (p. 21) "*marginalised and devalued*" (p. 22). Cochrane (1997) argues that there is an urgent need to extend our understanding of practical work through theoretical development (p. 59). However, knowledge of practical ceramic art/craft/design is difficult to represent in explicit terms alone. As such, it is difficult to argue about the correct representation of ceramic art/craft/design practice. The idea of tacit knowledge refers to the concept that "*we can know more than we can tell*", as Polanyi (1983, p. 4) stated, implying that not all knowledge can be articulated and codified. It means that we cannot relate everything we can do or know. Indeed, the achievements of science would perhaps not have been accomplished without tacit knowledge. The personal, tacit knowledge cannot be abstracted; according to Polanyi (2002), codified, explicit knowledge may only be the tip of all available knowledge. Thus, the knowledge of ceramicists with years of experience and the quality of their work performance cannot all be codified. Nevertheless, tacit knowledge must not be the only effective knowledge and learning process. Much of the technical problems and understanding of materials in pottery making can be treated explicitly. For this reason, the personal tacit knowledge needs to be developed together with the explicit knowledge in order to create effective uses and results in the field of ceramic art/craft/design.

Rhodes (1964) characterises knowledge in pottery as an embracing imagination, an ability to form an artistic vision and skill, as well as "a sound knowledge of the technical side of craft" (no page number).

> This knowledge has not been easy to come by, and many of those seriously engaged in pottery have learned through endless experimentation and discouraging failures. (Ibid.).

Brown (1997) suggests that when glass making is introduced to the faculties of fine arts the relation to knowledge becomes problematic, since the use of glass "is only incidentally and not systematically related to the technology of glass making" (p. 3). According to Brown (1997), the less explicit tradition of knowledge becomes, in the academic context, an identification problem of the crafts, making them liable to either neglect or elimination (p. 4). The development of high status technological research on traditional craft materials such as textile, ceramics and metals also "threatens the relevance of traditional practice" (p. 5). Thus, ceramics must build a role for itself but without decreasing its traditional craftsmanship. The necessity of long internships to acquire proper competence in craftsmanship is, according to Brown, generally accepted. However "post-conventional autonomy over their crafts, that is, freedom to act with professional independence comes eventually and only through theoretical reflection" (Ibid).

The aim of this paper is to highlight the importance of balanced knowledge in practical ceramic art/craft/design and research, recognizing the value and interdependence of tacit and explicit knowledge, by looking at examples of the craft of porcelain making and paper-composite porcelain.

2. Clay, ceramicists and knowledge of porcelain making

According to Rado (1969), pottery represented the four elements of the world to the ancient Greeks, since it was "made of *earth*, shaped with *water*, dried in *air*, and made durable by *fire*" (p. 1). Thus, clay, or earth, is the main material in pottery. Norton (1956) describes clay as "the backbone of the ceramic arts" (p. 126). Rhodes (1964) characterises clay as a material that, despite being relatively formless and having no value, can be made into valuable objects (p. 1).

> ...clay imposes certain limitations of shape...But, within these limitations, the potter is free to express his preference in form, and the forms of objects made from clay have been characterized by tremendous freedom and variety. (Ibid.)

Among the clay materials, porcelain is one of the most popular in ceramics (Conrad, 1980). According to Sheaf, porcelain "dominates the whole field of ceramics and has been an overriding stimulus to potters everywhere" (Sheaf, 1987, p. 71). Lane argues that the very nature of porcelain provides "opportunities for expression" that no other clay can offer. However, it also "demands a special kind of respect, patience and understanding at all stages of manufacture" (Lane, 1980, p. 9)

According to Rhodes (1964), the advantage of true porcelain is that not only is the body vitreous and translucent, but the glaze is very hard, scratchproof and lustrous. In addition, the contact between glaze and body is so intimate and so indistinct that the glaze, instead of appearing as a glassy coating, appears as an integral part of the body. However, disadvantages and difficulties related to the knowledge of porcelain making are also described by Lane (1980). He claims that few studio potters "are tempted to use it seriously" due to the unavailability of reliable, commercially-prepared bodies, which in turn necessitates much time-consuming and uneconomic experimentation and testing of raw materials ”for anyone wishing to explore its potential” (p. 7).

Cooper and Royle (1978), Fraser (1986), and Lane (1980) mean that many ceramicists realise that it is important to have a thorough understanding of the material in order to avoid technical problems during the porcelain-making process and to be able to get an expected result, yet many others tend to regard explicit scientific experiments as non-creative, non-artistic and requiring far too complicated efforts to acquire scientific knowledge and conduct explicit material experiments. According to Rawson (1971), the ceramicist is usually aware that the knowledge of the materials' characteristics will influence the whole idea and the final artefact and thus use trial and error to learn how to make their particular choice of materials.

Also, given that the unfinished product will shrink on drying and again on firing, thereby introducing extra strain, it is a testament to both the skill of the ceramic artists/studio potters and the versatility of clay if acceptable levels of good quality products are completed for further processing. As Richerson (1992) mentioned, every clay body has its own special characteristics, both good and bad. The essential properties of clay are its plasticity or workability when water is added and its ability to become hard and impermeable when fired. Rhodes (1964) makes a similar statement about clay.

> Clay shrinks when it dries and shrinks even more when fired, and this creates all sorts of problems in making pottery. The reaction of clay to the fire may seem unpredictable, and even under the most carefully controlled conditions a certain amount of uncertainty attends to all of these problems connected with making things out of clay ... (p. 1).

Norton (1956) argues that “some knowledge of methods of calculation for making up bodies and glazes” is necessary for anyone who seriously wishes to embark upon a career in the field of ceramics. Furthermore, we can get a hint of what to expect when using it in a body through chemical analysis, “particularly how it will behave on firing” (p. 129). To be able to select and blend clays intelligently and form mixtures to suit the purpose, potters need to have a general knowledge of clays suited to ceramic art (p. 126).

Fraser (1986) argues that the faults that arise in clay ware or biscuit ware “are by no means surprising given the variable nature of the raw materials and the numerous stages involved before the article is completed” (p. 1). According to Fraser, there are common causes for many of the faults that appear in the various stages of clay processing. “Frequently, the nature of the clay body or the way in which the clay ware is dried will be responsible for defects appearing in many diverse ways” (Ibid.).

For technical reasons, the first ideas that a potter has in the beginning tend to change very much during the practical process, either by accident, or intentionally. Potters may not be able to explain the results when unexpected ones, such as cracks, are obtained. Fraser (1986) points out that “cracks do not just ‘happen’; they are caused. Furthermore, they do not suddenly arise; they begin from some defect or point of maximum stress, and then grow” (p. 12). It is basically possible to provide explicit and technical explanations for each stage of the entire ceramic production process.

In 2003, a world famous ceramic artist had an exhibition in Sweden. The artist, who is well established within the academic world as a professor in ceramic art, is not only famous for the aesthetic and artistic quality of her work, but also for the skilful craftsmanship displayed in her pieces. Among the exhibited works was a big porcelain vase, the surface of which had a special effect resembling a huge lava rock. A visitor was curious as to how this effect had been produced. The ceramic artist replied,

> *“I don’t know why it happened. It came out like this when I removed it from the kiln and it was totally unexpected. Sometimes, firing is like a magic and I cannot explain why it happened.”*

This is one of the typical answers of a ceramic artist or a studio potter who can demonstrate an item using tacit knowledge but cannot explain the result explicitly.

The correct answer could have been, “This is a crawling effect, which is obviously a glaze fault in ceramics, but ironically it gives a rich decorative effect to my porcelain.” Crawling can have various causes (Cooper and Royle, 1978, pp. 97–98; Fraser, 1986, pp. 66–67). However in this case, the glaze was either coated too thickly or the glazed biscuit was stored for too long a time before firing, so the bond between the glaze and the porcelain body was weakened. As a result, the glaze bunched up in places and left other parts bare.

> For some potters, this is yet another part of the mystery which involves all effects obtained in the kiln. For others, it is part of a well-understood scientific phenomenon (Cooper and Royle, 1978, p.143).

According to Cooper and Royle (1978) there are basically two approaches to the study of clays and glazes: the tacit learning approach, i.e., by trial and error, and the scientific approach, in which calculation and explicit experiments are used to predict results. They argue that even though the Chinese potters, who had no knowledge of glaze calculations, were able to successfully develop their craft over many centuries, it would be inconceivable to not, make use of the scientific knowledge that is available today.

> The present understanding of the structure and behaviour of atoms and molecules and mathematical calculations which can reveal such changes are fascinating and open up many possibilities for the glaze chemist which trial and error, with its time consuming methods, denied. Few potters, however, are such mathematical wizards as to be able to quickly understand and use such knowledge. Being for the most practical people, potters need to combine actual experiments with scientific calculations so as to get the best of both worlds (p. vii).

Lane (1980) makes a similar observation.

> Remarkably few of the potters who I consulted have any real interest in, or deep knowledge of, the chemistry of clays and glazes beyond the basic essentials for the successful practice of their craft. Many told me that they had no time to spare for what, for them, would be an unnecessary labour. (p. 55)

Thus, ceramicists would benefit from having a basic knowledge of chemistry, physics, mineralogy and material technology as they would be better equipped to deal with the variety of ceramic materials and instruments that they encounter, and to proceed throughout the different stages of the production process. Linking explicit and tacit knowledge with an explanation of the factors involved and how to obtain the expected results can bridge the gap between the two disciplines.

3. Illustrating the combination of technical and tacit knowledge in artistic practice using the example of paper-composite porcelain

The term “*Paper-composite porcelain*” (Jeoung-Ah, 2004) represents any kind of porcelain that is combined with paper. Paper-composite porcelain is a type of clay mixed with paper that mainly consists of plant-based fibre pulp and mineral additives.

Clay mixed with paper was introduced in ceramic art in the 1990s. It is now used to produce artistic objects, largely because it has better green strength and lightweight qualities in comparison to other clay bodies. Unfortunately, the lack of technical information has been problematic for carrying out practical application work with this material. According to several potters (Gault, 1998, p. 7; Juvonen, 1995, p. 193; Stevens, 2002, p. 74), the paper burns out and leaves a porous structure in the fired state, hence the body's light weight. It is commonly known that paper will burn out when mixed with the clay body and fired. However, it is possible that the inorganic mineral additives from paper may not simply burn away, but could change form while interacting with other clay raw minerals. In two previous interdisciplinary studies (Jeoung-Ah, 2004; Jeoung-Ah, 2006), it was proved that calcite paper filler from paper melts with the kaolinite during the firing process. The composition transforms to anorthite, which is found in the microstructure of the paper-composite porcelain that is fired at 1300ºC. With scanning electron microscopy (SEM), it could be observed that the microstructure of paper-composite porcelain bodies showed different body structures in comparison to the mother porcelain body. The structures of the paper-composite porcelain bodies had special fibre binders that were covered with anorthite, which made up a construction of fibrous bridges and tunnels. This indicated that its body composition had changed. X-ray diffraction analysis (XRD) showed that up to a temperature of 1300°C, the fired paper-composite porcelain bodies consisted of different minerals which compared closely to the mother porcelain. The calcite paper filler from paper changed its form to anorthite in the structure of the paper-composite porcelain in its fired state (Jeoung-Ah, 2004). The results of these two studies contributed new information about the residue minerals left in a paper-composite porcelain body, in that and the added paper in paper-composite porcelain changes the original characteristics of the porcelain body. Paper-composite porcelain has a higher green strength, lower shrinkage, lower degree of deformation and wider firing range than traditional porcelain at firing temperatures of 1300°C and 1350°C. These studies applied interdisciplinary research methods to interpret the structure and behaviour of the material.

From my own personal experiences as a ceramicist I was able to form a hypothesis, while making the ash glaze, that the inorganic mineral additives from paper would not just burn away, but would instead change form while interacting with other clay raw minerals. Thus, my tacit knowledge guided me in articulating the initial research questions and hypothesis. However, it would not have been possible to predict how the added paper would change the structure of paper-composite porcelain if I had not used a scientific experimental method, SEM, to conduct microstructure observations. In addition, without XRD analysis, it would not have been possible argue that it was the residue from the paper that had changed the chemical composition of the paper-composite porcelain. Furthermore, the results from the physical properties tests helped me to decide which shapes and production method to use, as well as which temperature to select for firings, and what results I could expect from my artistic experiments. Thus, the combination of artistic and scientific studies enabled the application of personal experience of practical craftwork, thus maintaining the artistic perspective, while the scientific perspective reduced the requirement for trial and error in practice. The above two interdisciplinary studies exemplify the combination of tacit and explicit methods using practical experiences and scientific experiments in ceramic art/craft/design.

Technical problems affect every ceramicist, as no one has complete knowledge. The problems are often very complex in the production process. Rowley (1997) gives the following description of ”skill” as an ability to apply technical knowledge in a practical way.

> Skill involves an understanding of materials and an ability to work with them to create something. This ability to work with materials is grounded in *technical knowledge*–knowledge of the properties of the materials, of techniques, and the nature of the tools. ‘How it is done’ may be learnt in a variety of ways: from the tacit acquisition of knowledge through observation and practice to the systematic learning of codified knowledge through instruction of various kinds. It is not necessary that a practitioner be able or willing to describe this knowledge in words or illustrations: the realisation of the application of technical knowledge—in performance or product—testifies to the depth of understanding of materials and techniques. (pp. xiv–xv)

It is very difficult to separate the tacit and explicit knowledge due to the practical aspects of ceramic art/craft/design, since these two forms of knowledge should be well harmonised to solve the different types of problems in this field. The application of technical knowledge in the process or product testifies not only to the depth of understanding of materials and techniques but also to the competence of ceramic artists/craftsmen/designers in being able to practise their art. This leads to better control over the process and of the results of the final products. As Shortland and Gregory (2002) also mentioned, there are many economic and social benefits to be gained from wider scientific knowledge.

4. Balanced knowledge of ceramics

According to Polanyi (1983), tacit knowledge includes all experiential knowledge that human beings have, even though it cannot be expressed by means of verbal concepts. It includes both manual skills and knowledge of the skill and thoughts, which characterise the traditional form of craftsmanship that potters have. The practical application of knowledge in the field of ceramic art/craft/design includes setting up the work or production process, experimenting on an artistic or novel process, creating or inventing a new artwork or product, finding a client or entering an art or crafts market; these are all related to tacit knowledge. The knowledge related to abilities, routines, know-how or specific practical skills that are derived from experience cannot simply be codified. Knowledge in ceramic art/craft/design practice tends to be highly tacit. Explicit knowledge or scientific knowledge is related to the theoretical understanding and to scientific principles, so it has the characteristic of being fully codified. The codification refers to an explicit form of knowledge that is exclusively related to the scientific results of basic research and innovative activity which is composed of facts, information, principles and practical understanding of science. This explicit knowledge is the opposite of tacit knowledge, which is a personal property of knowledge. Tacit knowledge is linked to the abilities that individuals possess based on elements of knowledge that were acquired through practical experience. Thus, craft skills, routines and workmanship stem from tacit knowledge, particularly in the field of ceramic art/craft/design.

Personal know-how and explicit knowledge characterise the two areas in ceramics: ceramic art/craft/design in the arts arena and ceramic technology in the science arena, though both work with the same material, i.e., clay. Personal know-how is the most important quality to individual ceramic artists and potters, as this enables them to mould their individual art and craft creations according to personal ideas and taste. Explicit knowledge is one of the most important elements of science in the sense that it does not depend on individual secret forms of insight.

The world in which the contemporary ceramicists live is very different from the era in which potters were completely dependent on personal know-how. More than ever, the world is man-made rather than natural and is incomparably richer in artefacts than the pre-industrialised world. The cultural value of this material wealth might be controversial, but there is no doubt about the complexity and the explosion of art, craft and design products. An essential part of science is to reduce the complexity of an object by creating a simplified, abstract representation that can be transmitted in an explicit form. On the other hand, this is not necessary to distinguish scientific knowledge from the knowledge that potters have. The knowledge that researchers or scientists employ to reduce complexity is largely tacit, much like that of a potter. This is reflected in the very personal approach at the beginning and in the final decision-making stage of each research or artwork. The use of tacit knowledge is often the only way to arrive at solutions when dealing with real-life, complex problems that are hard to define and which do not conform to formalised representation. At those stages, it is important that the person possesses the mental agility and capacity to deal with this kind of complexity; a "scientist's personal judgement" (Polanyi, 1964, p. 39) thus enters as an element of solution that is not different from the potter's knowledge. Tacit knowledge is an implicit, personal, informal, individual or procedural knowledge which enables us to perform an activity in varying and natural contexts, while explicit (codified or formalised) knowledge is more retrospective in nature with regards to the knowledge of established facts. Thus, tacit knowledge is a complementary partner for explicit knowledge, in that it helps to minimise complexity and solve problems (in research and/or many other circumstances). Prasad (2005) also pointed out genres of scientific inquiry that have strong elements of craftwork. Hence, science in practice becomes an inventive form of craftsmanship that is constantly engaged in adjusting and reconfiguring scientific protocols to meet the concepts of each unique empirical situation.

Tacit knowledge has been around in the form of art and craft long before scientists such as Polanyi identified it. It continues to be a powerful tool for coping with an environment that cannot and probably never will be fully codified. Dormer (1997) points out that the craft may suffer since it relies on tacit knowledge.

> Tacit knowledge is practical know-how, and it exists in people. Consequently tacit knowledge is learned and absorbed by individuals through practice and from other people; it cannot usually be learned from books (p. 147). If knowledgeable people fail to pass on their tacit knowledge then that knowledge will disappear. When practical knowledge disappears it is hard and time-consuming to rediscover it. (p. 148)

Indeed, through the contribution from scientists, tacit knowledge has become a recognised tool in the generation of novelty and innovations. Conversely, one of the greatest hindrances to solving problems through tacit knowledge is the time limitation, which is a critical point. This does not only concern artistic or craft practice or the design of new products, but is also crucial for scientific work that has to be put on the market quickly in order to be competitive. The importance of tacit learning through trial and error is significantly reduced when there are time-limited problems at work.

5. Conclusions

The aim of this paper was not to argue for choosing between tacit knowledge and explicit knowledge, but rather to point out the need for a balance between the two. Explicit knowledge has the advantage of being relatively easy to communicate, particularly in research on ceramic art/craft/design in which scientific and technical methods are applied. Explicit knowledge which does not remain dormant stimulates innovation and pushes the borders for artistic novelty and creative ideas. Tacit knowledge is a perfect base for innovation, artistic novelty and creative ideas. The limitation of tacit knowledge is the difficulty of communicating it to others.

The efficiency of knowledge application in ceramic art/craft/design could therefore be improved by a balanced combination of tacit knowledge and explicit knowledge that could support both artistic novelty and communicability. An understanding of the structure and behaviour of materials through explicit knowledge could open up many possibilities for ceramic artists, studio potters and ceramic designers to reduce trial and error, which is a both time-consuming and costly method of obtaining the best result. In this way, craftsmen could create a piece of work with their own hands, using craft skills born out of experience and based on scientific knowledge. This would enable them to understand the materials they use, predict how the materials will react and explain the characteristics to others. It would also enable them to experiment with factors that really are not predictable. For this reason, it is important to connect tacit and explicit knowledge.

The historic roots of the largely tacit knowledge in ceramic art/craft/design can be balanced in combination with formal, scientific knowledge. This could lead to a unified and formalised knowledge base that could be accessed for the development of ceramic art/craft/design and science. Furthermore, a form of tacit knowledge would continue to exist in the combined contextual knowledge. Both undefined and complex practical and time-limited practical problems could be solved as a result. The well-balanced knowledge would enable craftsmen to move more directly towards their goal of creating an item with a minimum of lost effort. It would also enable them to evaluate the technological problems they face and help them to improve their productivity and profitability and add value to their finished products by meeting the current demands of art and craft markets. Furthermore, it would be a base for a more effective form of research in this field, and improve the quality, both quantitatively and qualitatively.

Acknowledgements

This research was made possible financial support by Göteborg University in Sweden. The author would like to thank Dr. Cecilia Häggström for valuable discussions.

References

Brown, N. C. M (1997) Theorising the crafts: new tricks of trades. In: *Craft & contemporary theory*, Rowley, S. (ed.), Allen & Unwin, Sydney, Australia, pp 3–17

Cochrane, G (1997) Keeping content: craft, history and curatorship. In *Craft & contemporary theory*, Rowley, S. (ed.), Allen & Unwin, Sydney, Australia, pp 53–62

Conrad, W. J (1980) *Contemporary ceramic formulas* Macmillan Publishing Co,. Inc. New York, USA

Cooper, E and Royle, D (1978) *Glazes for the studio potter* B T Batsford Ltd, London, UK

Cooper, E (1981) *A history of world pottery* B T Batsford Ltd, London, UK

Cooper, E (2002) *Ten thousand years of pottery* The British museum press, London, UK

Dormer, P (1997) Craft and the Turing test for practical thinking. In: *The culture of craft*, Dormer, P. (ed.), Manchester University Press, UK pp 137–157

Fournier, R (1973) *Illustrated dictionary of practical pottery* Van Nostrand Reinhold company Ltd, London, UK

Fraser, H (1986) *Ceramic faults and their remedies* A & C Black, London, UK

Gault, R (1998) *Paper Clay* A & C Black, London, UK

Hamer, F and Hamer, J (2004) *The potter's dictionary of materials and techniques, 5th ed.,* A & C Black, London, UK

Jeoung-Ah, K (2004) The characterisation of paper composite porcelain in a fired state by XRD and SEM *J. Eur. Ceram. Soc* Vol 24 Issue 15–16 pp 3823–3831

Jeoung-Ah, K (2006) The characterisation of paper-composite porcelain in a green state *J. Eur. Ceram. Soc* Vol 26 Issue 6 pp 1023–1034

Juvonen, L (1995) Using paper fibre as a substitute in ceramic clays. In: *Proceeding* *of the 8th CIMTEC World Ceramics Congress 1994*, Vincenzini, P. (ed.), Faenza, Italy, pp 193–200

Kerr, R and Wood, N (2004) *Science and civilisation in China* Chemistry and chemical technology Vol. 5, Ceramic technology Part XII, Kerr, R. (ed.), Cambridge University press, UK

Lane, P (1980) *Studio porcelain* Pitman house, London, UK

Longworth, C (2005) Buckley ceramics in the seventeenth century *Interpreting ceramics* Issue 6 Electronic journal http://www.interpretingceramics.com

Matson, R. F (1965) *Ceramics and man* Aldine publishing company, Chicago, USA

Morley-Fletcher, H (1987) T*echniques of the world's great masters of pottery and ceramics* Phaidon Christie's, Oxford, UK

Norton, F. N (1956) *Ceramics for the artist potter* Addison-Wesley Publishing Company, USA

Polanyi, M (1964) *Science, faith and society* The University of Chicago Press, Chicago, USA

Polanyi, M (1983) *The tacit dimension* Peter Smith, Gloucester, Massachusetts, USA

Polanyi, M (2002) *Personal knowledge: Towards a post-critical philosophy* Routledge & Kegan Paul Ltd, London, UK

Prasad, P (2005) *Crafting qualitative research* M. E. Shape, Inc., London, UK

Rado, P (1969) *An introduction to the technology of pottery* Pergamon press, London, UK

Rawson, P (1971) *Ceramics* Oxford University Press, UK

Rhodes, D (1964) C*lay and glazes for the potter* Sir Isaac Pitman & Sons Ltd, London, UK

Richerson, D. W (1992) *Modern ceramic engineering* Marcel Dekker Inc., New York, USA

Rowley, S (1997) *Craft and contemporary theory* Allen & Unwin, Sydney, Australia

Sheaf, C (1987) Chinese blue and white. In: *Techniques of the world's great masters of pottery and ceramics*, Morley-Fletcher, H. (ed.), Phaidon Christie's Limited, Oxford, UK, pp 68–77

Shortland, M and Gregory, J (2002) *Communicating science* Addition Wesley Longman Limited, Essex, UK

Smith, T (1997) Craft, modernity and postmodernity. In: *Craft & contemporary* *theory,* Rowley, S. (ed.), Allen & Unwin, Sydney, Australia, pp 18–28

Stevens, G (2002) An investigation into the properties of porcelain paperclay. *Ceramics Technical* No 14 pp 72–77

Trilly, W (1987) Japanese blue and white. In: *Techniques of the world's great masters of pottery and ceramics*, Morley-Fletcher, H. (ed.), Phaidon Christie's Limited, Oxford, UK, pp 78–83

Appendices I–VII

List of appendices

I. Solo exhibition “Paper in porcelain -Exploratory application models-” in 12 January – 6 February 2002 at a craft gallery, Sintra, in Gothenburg in Sweden.

II. Newspaper article about the solo exhibition and research project, published 15 January 2002.

III. Public article in Form design about my exhibition and research, published in 2002 Nr 2.

IV. Electronic newspaper article on the solo exhibition.

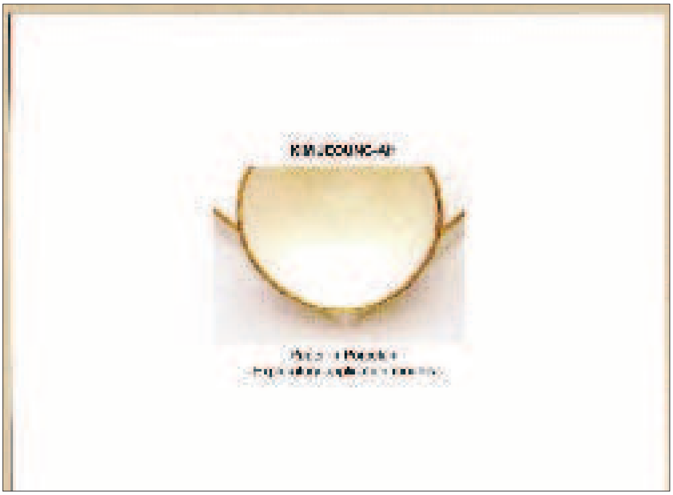
V. Electronic article by the gallery on the solo exhibition.

VI. Home page “Recycling of paper in porcelain” from 2001 until March 2006 (www.hdk.gu.se/forskning/kim). Among many inquiries through the home page, selected questions are accounted for in Appendix.

VII. Selected articles by author during 1996-2006 about Scandinavian ceramic art and design.

Appendix I

Solo exhibition “Paper in porcelain —Exploratory application models” from January 12 –February 6, 2002 at a craft gallery, Sintra, in Gothenburg in Sweden.



Solo exhibition “Paper in porcelain —Press release, 2002

Porcelain is the most attractive clay body to me, and has been so since I started working with ceramics 24 years ago. Eleven years ago, I began experimental work and research on the recycling of paper in porcelain with the aim of strengthening the body and overcoming the demerits of porcelain.

This exhibition is a presentation of the experimental application work from one of my ongoing projects, ”Recycling of porcelain”. It constitutes a part of my doctoral research at HDK/GU. The exhibition shows a selection of prototype application models which were produced with main focus on the composition of the paper-in-porcelain-clay-body itself. Traditional classic hard paste porcelain has been mixed with recycled paper. The amount of paper mixed with the porcelain body was 30% (P1), 50% (P2), 70% (P3), and 90% (P4) in volume. The thickness of the casting body has been varied to find out how it works in the application models. In order to maintain the visibility of the clay body, only transparent glaze has been used. All models were produced by the slip casting method and the main firing temperature was more than 1300°C. Some of the models are decorated by gold and platinum.

More information about ‘Recycling of porcelain’ may be viewed on the HDK website. http://www.hdk.gu.se/forskning/kim/index.html

The project was carried out with financial support from Gothenburg University, Estrid Ericsons Stiftelse and Kerstin Wijk-Broströms stiftelse.

The result of the project will be published at the end of 2002.
Please leave your address if you are interested in obtaining a copy of the final publication of this project.

I am grateful to my supervisor Cecilia Häggström, co-supervisor Professor Elisa Heland-Hansen and all of the staff at KFN and HDK/GU.

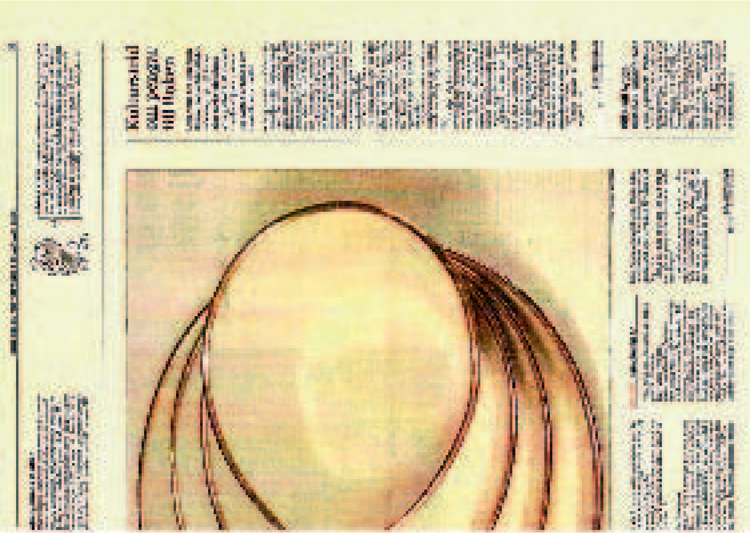
My very special thanks go to my parents and my 5-year-old son Peter for their love, encouragement and understanding of a ghost mama during the last two months of the project.

Kim Jeoung-Ah

Gothenburg, Sweden
03 January 2002

Appendix II

Newspaper article about the solo exhibition and research project, published by Göteborgs-Posten (p. 1 and pp. 38-39) in 15 January 2002. Article written by Catarina Testart and photographs by Elisabeth Alvenby.



Gränslöst

Papper i leran gör den stark

Appendix III

Article in Form Design about the solo exhibition and research project, published in 2002, Nr 2, p. 22 and p. 28. Article written by Love Jönsson and photographs by Jeoung-Ah Kim.

Appendix IV

Electronic article by the newspaper Göteborgs-Posten about the solo exhibition, published on January 15, 2002.

"Hon ska vara varm, sensuell och fylld av levnadsglädje"

GP Guiden

Konsthantverk & Design

Papper i leran gör den stark

dekorativ struktur åt godset. Det blev också lättare och hållbarare. Hon prövade olika procentsatser, 90 procent lera och 10 procent papper, hälften av varje och upp till 90 procent papper och bara tio procent lera. Den sista kombinationen blev mest hållbar.

1992 var hon på en föreläsning med konstnären Rosette Gault från Seattle, expert på papperslera för keramisk skulptur. Hon hävdade att pappret försvinner från leran under bränningen. Men Kim Jeong-Ah hade kommit till ett helt annat resultat.

– Jag såg att det fanns rester kvar, men ingen trodde mig. Jag tog kontakt med forskare bland annat på Chalmers för att ta reda på varför inte pappret i min lera försvann. Alla sa att jag hade fel, det kunde inte finnas kvar. De var inte intresserade av att testa. Jag var tvungen att själv ta reda på varför.

För att kunna fortsätta sina studier flyttade hon till Helsingfors eftersom HDK då inte hade doktorandutbildning. Keramikutbildningen på högskolan för design och konst i Helsingfors ligger i anslutning till porslinsföretaget Arabia så Kim Jeong-Ah kunde också använda deras laboratorium.

– Där kunde jag experimentera med olika temperaturer och material. Jag ville få fram en lera som både fungerar som ett konstnärligt material och som är miljövänlig.

Hon hade varit ett halvår i Kina bland annat för att studera den ursprungliga porslinsleran som kommer från staden Gaoling. Kaolin, namnet på vit porslinslera, kommer därifrån.

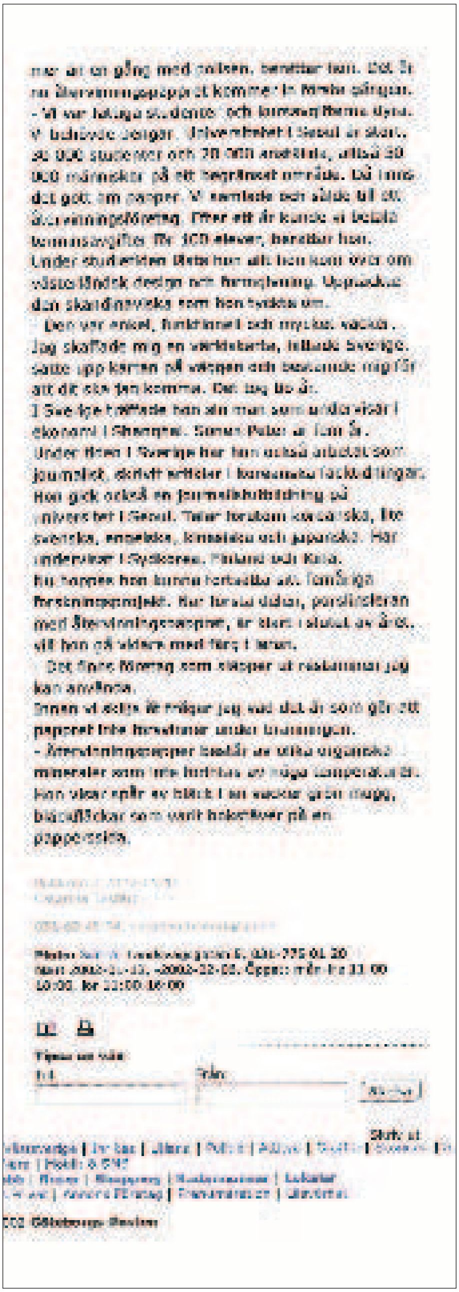
– Det betyder höga kullen, berget där man hämtade leran. I dag finns varken staden eller berget kvar. Vilket vittnar om utarmningen av vår miljö. Det är ett av skälen till att jag vill dryga ut leran med annat material.

Kim Jeong-Ah berättar att hon har en speciell känsla för återvinning och returpapper. Hon växte upp under militärdiktaturen i Sydkorea. Tidigt i skolan valdes barn med speciella talanger ut för extraundervisning. Hon togs till en grupp där man satsade på konst och musik.

– Egentligen ville jag bli barnläkare eller advokat men lärarna tyckte jag skulle ägna mig åt något konstnärligt. Jag fick en speciallärare i keramik. 1978, när jag var 16 år fick jag börja studera traditionell koreansk keramik för en av mästarna. Men jag ville inte hålla på med sådant andra gjort före mig, jag ville experimentera och göra något nytt.

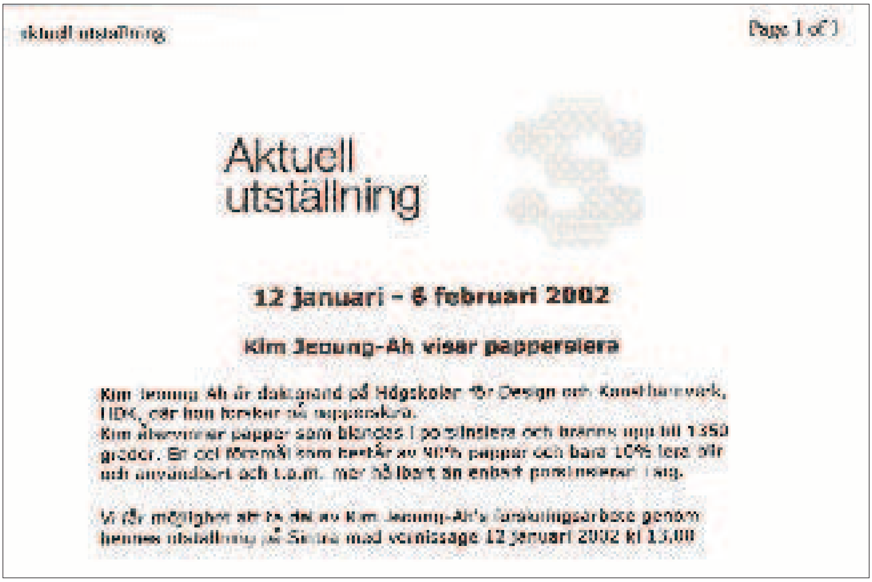
Efter två år började hon på högskola i Seoul och vidare på universitetet. Var politiskt aktiv, militärdiktaturen hade fallit, hon ledde demonstrationer och olika aktiviteter för att studenterna skulle få det bättre. Konfronterades

ap/jsp/Crosslink.jsp?d=190&a=65332



Appendix V

Electronic article by the gallery, Sintra, about the solo exhibition. Text by the gallery and photographs by Jeoung-Ah Kim.



aktuell utställning

Page 1 of 1

Aktuell
utställning

12 januari – 6 februari 2002

Kim Jeoung-Ah visar papperslera

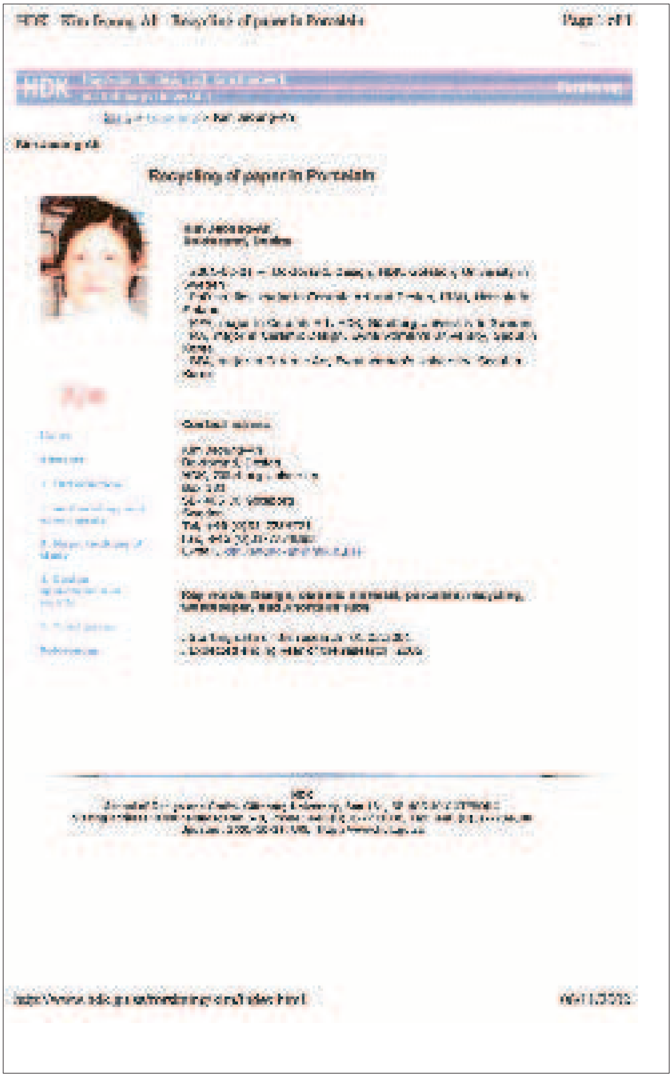
Kim Jeoung-Ah är doktorand på Högskolan för Design och Konsthantverk, HDK, där hon forskar på papperslera.
Kim återvinner papper som blandas i porslinslera och bränns upp till 1350 grader. Ett [illegible] föremål som består av 90% papper och bara 10% lera blir och användbart och t.o.m. mer hållbart än enbart porslinslera i sig.

Vi får möjlighet att ta del av Kim Jeoung-Ah's forskningsarbete genom hennes utställning på Sintra med vernissage 12 januari 2002 kl 13,00

Appendix VI

This appendix contains my research home page "Recycling of paper in porcelain", which was launched in 2001 and remained active until March 2006 (www.hdk.gu.se/forskning/kim).

Home page "Recycling of paper in porcelain"



Recycling of paper in Porcelain

Some selected inquiries

Selected questions from the website are presented in the Appendix. All names are withheld in accordance with research ethics for protecting privacy. Inquiries were received from UK, USA, Canada, Australia, France, Denmark, Norway, Sweden, India, Pakistan, Bangladesh, South Africa, Iran, Russia, etc. Inquiries are listed by date. Many of those inquiries, to which no answers could be provided at the time, are answered in this thesis.

02/19/2002
Subject: Fibres mixed with clay
I found your web information most interesting. As a Civil Engineer specialising in Geotechnics I am looking at mixing waste nylon fibres with clay soils to improve their load carrying properties, reduce their weight, reduce their permeability and increase their ductility. Some of your results seem to encourage me with my own work, even though you of course are looking at a very different 'product' to my own. I think there might be opportunity for future discussions between us if you felt this might be useful?

11/21/2002
Subject: Questions
I found your paper on the web. Very good. Your study certainly shed light on a seemingly contradictory area. How can paper reinforce a fired clay body? A phenomenon that I know from experience to work but, also one I could not fully appreciate before your research. Congratulations! I would like to have a number of technical details. As I am experimenting with paper as the primary binders for a ceramic business, I was hoping you could answer some of my technical questions. What did you find the chemical composition of recycled papers to be? I would like to know what the results of physical properties and strength tests were. Can you give me tables, figures and detailed technical information?

11/24/2002
Subject: Request for detailed information about the recycling of paper in porcelain
At first I would like to thank you for your article provided on the website about Recycling of paper in Porcelain. As a student of business it helped me extensively to get innovative ideas about product design based on recycling. For the purpose of preparing a term paper on the product and process you have provided over the web, I need some additional information about it. I am sending some questions here regarding the topic. What is the industrial impact of porcelain on developing countries? What is the cost-benefit ratio for producing such products?

01/23/2003
Subject: Inquiry
Very interesting paper. You ran a number of tests using high levels of paper. Were any conclusions reached regarding which of those test bodies yielded the best results for a functional production, as compared to the parent body? Your home page shows application of tiles: did you apply your paper clay to tableware productions?

03/24/2003
Subject: Request
I intend to use your results in my work. However, I have not found more detailed information about the casting technique using a mould. Can you give me any comments on this? I am especially interested in knowing the effects on the role of the paper in firing. What is going to happen to the structure of the product during firing?

10/22/2003
Subject: Warping
I have read your article and found it very interesting. I am a ceramist. I am now in a position to begin experimenting with paper in porcelain. How much does it warp during drying, as well as during the firing process? What are the ranges for the firing temperature?

11/25/2003
Subject: Questions
You indicate that your tests included a number of different forming techniques. Can you give me the results from these techniques? Were any of these forming techniques more satisfactory than the others?

01/28/2004
Subject: Percentage of paper
Your work is inspiring. I have a question regarding the process with paper porcelain to which I cannot find the answer in the bookstore. I want to use porcelain slip and I prefer a fine texture which is similar to normal porcelain. How much paper pulp is required to make the green strength stronger, without losing the fine texture?

10/05/2004
Subject: Paperclay research
I read your research paper and found it very interesting. I have been reading all I can about paper clay lately. You have used a higher percentage of paper than anyone I have ever heard of. If you have any more research on this, I would be interested in reading it. Can you tell me what kind of recycled paper you used and what are the differences in these papers?

22/11/2004
Subject: Sound experiments
I am a final year Master's Degree student at University of Technology. My professor recommended that I read your article which was published in the journal of the European Ceramic Society. I also read your home page and ADC paper. I wonder if you could help me with my sound experiments using your clay products. Have you done any sound experiments such as sound proof or reflection testing?

05/01/2005
Subject: Paper in porcelain research
I am a ceramist working with porcelain. I read about your article and I am very interested in more information published about your work. Can you send me any other articles or books you wrote on this subject?

05/02/2005
Subject: Quotation?
I am a Master's Degree student from South Africa. I read your articles from journal of the European ceramic society and home page which inspired my study. I would like to get permission from you to use two pictures in your home page for my thesis. Can you send me your article published in ADC? I could not find it. Can you also give me some details of physical properties of paper-composite porcelain?

04/08/2005
Subject: Paperclay research
I read your article with great interest. Your results are certainly contributing to our knowledge. I am teaching at the College of the Arts in Australia. I have read all the books I could find, but have been unable to find explicit information on both the technical and practical matters through the procedures. I hope to be able to get this information if you could it to provide me in the near future.

09/28/2005
Subject: Publication
I found one of your papers related to composite materials: ”The characterisation of paper composite porcelain in a fired state by XRD and SEM” and I think it is relevant to our encyclopaedia on carbon nanotubes and their application fields. I would appreciate it if you could take a minute to let me know if we can present your research in the encyclopaedia.

02/24/2006
Dr. Prof. Clas Wihlborg, Denmark

Cross disciplinary aspects of Kim Jeoung-Ah's research on ”Recycling of Paper in Porcelain” from an economist's point of view.

Kim Jeoung-Ah's research is pioneering a new vision of product material and design in the ceramic field. The research leads to a number of cross-disciplinary extensions. From a social science point of view and in particular from an economics point of view an important issue is how the new raw material affects the economics of porcelain production from the point of view of the individual artist and from the point of view of the porcelain industry. Access to, and the cost of raw materials have always been important for the location of the industry including individual artists, as well as the organisation of the industry consisting of both individual artists/entrepreneurs and larger scale firms. Innovation of the type discussed may influence the relative advantages of small-scale and large-scale activities, as well as the location preferences of the artists and the firms. The importance of these aspects could be particularly relevant in developing countries, where some regions depend heavily on the concentration of small scale artists/entrepreneurs. New technology also has an impact on the ability of artists to finance their activities.
The environmental properties of the new material will have additional effects on the industry. Environmental constraints on activities could be relaxed, and if governments provide incentives for environmentally friendly raw materials, the possibilities for the individual artist to finance activities can be improved. The design of government incentive schemes and environmental restrictions will be important for the impact on the individual artist/entrepreneur relative to larger firms.

Appendix VII

Selected published articles by author during 1996-2006 about the Scandinavian ceramic art and design. (In *Korean*)

1. Jeoung-Ah Kim, A solo exhibition by a young Swedish ceramist, Tina Reuterberg, *The Ceramic Art Monthly*, 1996 August, pp. 38-40.
2. Jeoung-Ah Kim, SINTRA, *The Ceramic Art Monthly*, 1996 September, pp. 47-48.
3. Jeoung-Ah Kim, ANNA KÅKS, *The Ceramic Art Monthly*, 1996 October, p. 72.
4. Jeoung-Ah Kim, Konsthantverkshuset, *The Ceramic Art Monthly*, 1996 November, pp. 39-42.
5. Jeoung-Ah Kim, NOBEL SERVICE (1), *The Ceramic Art Monthly*, 1996 December, pp. 40-43.
6. Jeoung-Ah Kim, BIBBI FORSMAN, *The Ceramic Art Monthly*, 1996 December, pp. 54-56.
7. Jeoung-Ah Kim, NOBEL SERVICE (2), *The Ceramic Art Monthly*, 1997 January, pp. 40-43.
8. Jeoung-Ah Kim, Ceramic Art Education in Sweden -HDK-, *The Ceramic Art Monthly*, 1997 February, pp. 13-16.
9. Jeoung-Ah Kim, KARIN BJÖRQUIST, *The Ceramic Art Monthly*, 1997 February, pp. 67-69.
10. Jeoung-Ah Kim, Industrial Ceramics in Sweden: The Success and Failure of Rörstrand (1), *The Ceramic Art Monthly,* 1997 March, pp. 68-69.
11. Jeoung-Ah Kim, Industrial Ceramics in Sweden: The Success and Failure of Rörstrand (2), *The Ceramic Art Monthly,* 1997 April, pp. 62-64.
12. Jeoung-Ah Kim, Industrial Ceramics in Sweden (3), *The Ceramic Art Monthly*, 1997 May, pp. 64-65.
13. Jeoung-Ah Kim, Finland, UIAH, Ceramic Art in University, *The Ceramic Art Monthly*, 1997 May, pp. 58-60.
14. Jeoung-Ah Kim, Industrial Ceramics in Sweden (4), *The Ceramic Art Monthly,* 1997 June, pp. 58-59.
15. Jeoung-Ah Kim, Industrial Design Education in Universities and Industrial Co-operation (1), *The Ceramic Art Monthly,* 1997 June, pp. 62-63.
16. Jeoung-Ah Kim, Industrial Ceramics and Ceramic Art in Finland: Their Honourable Challenge (1), *The Ceramic Art Monthly,* 1997 July, pp. 27-29.
17. Jeoung-Ah Kim, Industrial Ceramics and Ceramic Art in Finland: Their Honourable Challenge (2), *The Ceramic Art Monthly*, 1997 August, pp. 25-27.
18. Jeoung-Ah Kim, Industrial Design Education in Universities and Industrial Co-operation (2), *The Ceramic Art Monthly,* 1997 August, pp. 54-55.
19. Jeoung-Ah Kim, Art Galleries in Helsinki, *The Ceramic Art Monthly,* 1997 September, pp. 24-25.
20. Jeoung-Ah Kim, ARABIA in Finland (1), *The Ceramic Art Monthly,* 1997 October, pp. 28-30.
21. Jeoung-Ah Kim, The Ceramics Research Institutes in Art Schools, *The Ceramic Art Monthly,* 1997 October, pp. 60-63.
22. Jeoung-Ah Kim, ARABIA in Finland (2), *The Ceramic Art Monthly,* 1997 November, pp. 30-33.
23. Jeoung-Ah Kim, Ceramic art, the environment and related techniques in Finland, *The Ceramic Art Monthly,* 1998 January, pp. 28-29.
24. Jeoung-Ah Kim, Ceramic and Glass Restoration Education in Finland, *The Ceramic Art Monthly,* 1998 March, pp. 52-54.
25. Jeoung-Ah Kim, Pot Viapori in Finland (1), *The Ceramic Art Monthly,* 1998 April, pp. 23-25.
26. Jeoung-Ah Kim, Pot Viapori in Finland (2), *The Ceramic Art Monthly,* 1998, May, pp. 21-23.

27. Jeoung-Ah Kim, The outdoors for the new ceramic artist university graduate, *The Ceramic Art Monthly,* 1998 June, pp. 26-29.
28. Jeoung-Ah Kim, Environmental and Architectural Ceramic Art in Finland, *The Ceramic Art Monthly,* 1998 July, pp. 25-27.
29. Jeoung-Ah Kim, Installations and Ceramic Art in Finland, *The Ceramic Art Monthly,* 1998 August, pp. 22-23.
30. Jeoung-Ah Kim, The Ceramic Art and Design Studios of Europe, *The Ceramic Art Monthly,* 1998 September, pp. 14-18.
31. Jeoung-Ah Kim, AIRI HORTLING, *The Ceramic Art Monthly,* 1998 October, pp. 34-35.
32. Jeoung-Ah Kim, Glass Art and Design in Finland, *The Ceramic Art Monthly,* 1998 November, pp. 46-47.
33. Jeoung-Ah Kim, Ceramic artists combine various disciplines in their work, *The Ceramic Art Monthly,* 1999 January, pp. 37-39.
34. Jeoung-Ah Kim, Three ceramic exhibitions in Helsinki, *The Ceramic Art Monthly,* 1999 February, pp. 8-9.
35. Jeoung-Ah Kim, Ceramic artist (I), *The Ceramic Art Monthly,* 1999 April, pp. 43-45.
36. Jeoung-Ah Kim, Ceramic artist (II), *The Ceramic Art Monthly,* 1999 June, pp. 22-24.
37. Jeoung-Ah Kim, The development and expectations of European ceramic art and design, *The Ceramic Art Monthly,* 2000 February, pp. 16-18.
38. Jeoung-Ah Kim, Konstepdemin in Sweden (1), *The Ceramic Art Monthly,* 2000 March, pp. 27-29.
39. Jeoung-Ah Kim, Konstepdemin in Sweden (2), *The Ceramic Art Monthly,* 2000 April, pp. 52-53.
40. Jeoung-Ah Kim, Lerverk, A co-operative society of ceramic and glass handcraft artists in Sweden, *The Ceramic Art Monthly,* 2000 May, pp. 49-51.
41. Jeoung-Ah Kim, The Swedish East India company and the influence of Asian porcelain production in Europe (1), *The Ceramic Art Monthly*, 2000 August, pp. 52-55.
42. Jeoung-Ah Kim, The Swedish East India company and the influence of Asian porcelain production in Europe - East India porcelain from the Gotheborg and Gotheborg III (2), *The Ceramic Art Monthly,* 2000 September, pp. 47-49.
43. Jeoung-Ah Kim, The Swedish East India company and the influence of Asian porcelain production in Europe - The East India porcelain from Gotheborg and Gotheborg III (3), *The Ceramic Art Monthly,* 2000 October, pp. 52-54.
44. Jeoung-Ah Kim, The ceramic festivals of Europe, *The Ceramic Art Monthly,* 2000 October, pp. 29-31.
45. Jeoung-Ah Kim, The modern craftsmanship movement in Sweden and the ceramists in K-Huset, *The Ceramic Art Monthly,* 2000 December, pp. 48-50.
46. Jeoung-Ah Kim, Kitchen-Art by Mariann Hallberg and SINTRA, *The Ceramic Art Monthly,* 2001 January, pp. 44-46.
47. Jeoung-Ah Kim, The support systems for the professional ceramists and the welfare policy for the culture and arts in Sweden, *The Ceramic Art Monthly,* 2001 February, pp. 41-43.
48. Jeoung-Ah Kim, The Department of Ceramic Art at The School of Design and Craft (HDK) in Sweden, *The Ceramic Art Monthly,* 2001 March, pp. 38-40.
49. Jeoung-Ah Kim, The food culture and ceramic design in Sweden, *The Ceramic Art Monthly,* 2001 April, pp. 22-23.

50. Jeoung-Ah Kim, Designers of Rörstrand - Leading 21st-century Swedish industrial ceramic design (1) - Designer Pia Törnell and Grade service, The Ceramic Art Monthly, 2001 June, pp. 60-62.
51. Jeoung-Ah Kim, Designers of Rörstrand - Leading 21st-century Swedish industrial ceramic design (2) - Rim dinner service by Designer Vico Magistretti and Kazuhiko Tomita, *The Ceramic Art Monthly,* 2001 July, pp. 66-69.
52. Jeoung-Ah Kim, Designers of Rörstrand - Leading 21st-century Swedish industrial ceramic design (3) - Designer Jonas Bohlin and Qvint dinner service, *The Ceramic Art Monthly,* 2001 August, pp. 50-52.
53. Jeoung-Ah Kim, Designers of Rörstrand – Leading 21st-century Swedish industrial ceramic design (4) - Designer Alfredo Häberli and Origo dinner service, *The Ceramic Art Monthly,* 2001 September, pp. 48-51.
54. Jeoung-Ah Kim, Red Stone & Swedish Contemporary Craft Biennale, *The Ceramic Art Monthly,* 2001 October, pp. 53-55.
55. Jeoung-Ah Kim, Kitchenware design by BodaNova in Sweden, *The Ceramic Art Monthly,* 2001 November, pp. 57-59.
56. Jeoung-Ah Kim, Industrial ceramic design by Höganäs in Sweden, *The Ceramic Art Monthly,* 2001 December, pp. 57-59.
57. Jeoung-Ah Kim, Höganäs in Sweden, *The Ceramic Art Monthly,* 2002 February, pp. 37-39.
58. Jeoung-Ah Kim, Royal Copenhagen in Denmark and designer Ursular Munch-Petersen, *The Ceramic Art Monthly,* 2002 March, pp. 44-45.
59. Jeoung-Ah Kim, Designer Ursular Munch-Petersen, *The Ceramic Art Monthly,* 2002 April, pp. 52-53.
60. Jeoung-Ah Kim, Designer Ivan Weiss, *The Ceramic Art Monthly,* 2002 May, pp. 60-61.
61. Jeoung-Ah Kim, Denmark and their designers - Designer Ivan Weiss, *The Ceramic Art Monthly,* 2002 June, p. 68.
62. Jeoung-Ah Kim, Designer Ole Jensen, *The Ceramic Art Monthly,* 2002 July, pp. 44-46.
63. Jeoung-Ah Kim, Industrial ceramic design and designer Ole Jensen, *The Ceramic Art Monthly,* 2002 August, pp. 58-60.
64. Jeoung-Ah Kim, Designer Grethe Meyer (1), *The Ceramic Art Monthly,* 2002 September, pp. 46-47.
65. Jeoung-Ah Kim, Designer Grethe Meyer (2), *The Ceramic Art Monthly,* 2002 October, pp. 56-57.
66. Jeoung-Ah Kim, Royal Copenhagen and ‘The white gold’ (1), *The Ceramic Art Monthly*, 2002 November, pp. 60-62.
67. Jeoung-Ah Kim, Royal Copenhagen and ‘The white gold’ (2), *The Ceramic Art Monthly,* 2002 December, pp. 64-67.
68. Jeoung-Ah Kim, The blue porcelain of Royal Copenhagen (1), *The Ceramic Art Monthly,* 2003 January, pp. 50-52.
69. Jeoung-Ah Kim, The blue porcelain of Royal Copenhagen (2), *The Ceramic Art Monthly,* 2003 February, pp. 54-56.
70. Jeoung-Ah Kim, The production process of blue porcelain at Royal Copenhagen, *The Ceramic Art Monthly,* 2003 March, pp. 52-55.
71. Jeoung-Ah Kim, The Flora Danica service (1), *The Ceramic Art Monthly,* 2003 May, pp. 47-49.
72. Jeoung-Ah Kim, The Flora Danica service (2), *The Ceramic Art Monthly,* 2003 June, pp. 68-69.
73. Jeoung-Ah Kim, Industrial ceramic design in Denmark, *The Ceramic Art Monthly,* 2003 July, pp. 48-50.

74. Jeoung-Ah Kim, The beauty of the Scandinavian style of industrial ceramic design in Denmark, *The Ceramic Art Monthly,* 2003 September, pp. 70-72.
75. Jeoung-Ah Kim, The public ceramic art education in Sweden, *The Ceramic Art Monthly,* 2003 October, pp. 33-35.
76. Jeoung-Ah Kim, Twentieth century classicism in Danish ceramics, *The Ceramic Art Monthly,* 2003 December, pp. 65-67.
77. Jeoung-Ah Kim, The world wars, functionalism and art deco in ceramics, *The Ceramic Art Monthly,* 2004 January, pp. 48-51.
78. Jeoung-Ah Kim, From the 1950s to 1970s, the establishment of the welfare society in Northern Europe and Scandinavian design, *The Ceramic Art Monthly*, 2004 February, pp. 48-51.
79. Jeoung-Ah Kim, Individualism and diversity in ceramics, *The Ceramic Art Monthly,* 2004 March, pp. 52-54.
80. Jeoung-Ah Kim, Industrial ceramic design and glass art by the Royal Scandinavia design group: The past and the present, *The Ceramic Art Monthly,* 2004 April, pp. 74-77.
81. Jeoung-Ah Kim, Ceramic sculptures by Eva Hild, *The Ceramic Art Monthly*, 2004 June, pp. 68-71.
82. Jeoung-Ah Kim, The Ice Age by AnnaSofia Mååg, *The Ceramic Art Monthly,* 2004 July, pp. 70-73.
83. Jeoung-Ah Kim, A ceramic artist: Annika Svensson and her tiled stoves (1), *The Ceramic Art Monthly,* 2004 August, pp. 66-68.
84. Jeoung-Ah Kim, A ceramic artist: Annika Svensson and her tiled stoves (2), *The Ceramic Art Monthly,* 2004 September, pp. 64-65.
85. Jeoung-Ah Kim, Contemporary Swedish ceramic art and design by the Swedish X and Y generations, *The Ceramic Art Monthly*, 2004 October, pp. 74-76.
86. Jeoung-Ah Kim, A ceramic jewellery designer: Annika Åkerfelt, *The Ceramic Art Monthly,* 2004 November, pp. 60-63.
87. Jeoung-Ah Kim, Signe Persson-Melin, *The Ceramic Art Monthly,* 2004 December, pp. 50-53.
88. Jeoung-Ah Kim, Nobel and Ikea, *The Ceramic Art Monthly*, 2005 January, pp. 66-69.
89. Jeoung-Ah Kim, Ceramic art education in Scandinavia (1), *The Ceramic Art Monthly,* 2005 March, pp. 50-54.
90. Jeoung-Ah Kim, Ceramic art education in Scandinavia (2), *The Ceramic Art Monthly*, 2005 April, pp. 60-64.
91. Jeoung-Ah Kim, Ceramic art education in Scandinavia (3), *The Ceramic Art Monthly,* 2005 May, pp. 68-72.
92. Jeoung-Ah Kim, Ceramic art education in Scandinavia (4), *The Ceramic Art Monthly,* 2005 June, pp. 72-75.
93. Jeoung-Ah Kim, Ceramic art education in Scandinavia (5), World Ceramic art: University, *The Ceramic Art Monthly,* 2005 July, pp. 64-67.
94. Jeoung-Ah Kim Ceramic art education in Scandinavia (6), World Ceramic art: University, *The Ceramic Art Monthly,* 2005 August, pp. 62-65.
95. Jeoung-Ah Kim, Ceramic art education in Scandinavia (7), World Ceramic art: University, *The Ceramic Art Monthly,* 2005 September, pp. 62-65.

ArtMonitor

ArtMonitor is a publication series from the Board for Artistic Research (NKU) of the Faculty of Fine and Applied Arts, Göteborg University.

1. Mika Hannula, Juha Suoranta, Tere Vadén
Artistic Research – Theories, Methods and Practices
ArtMonitor, Göteborg, 2005
ISBN 951-53-2743-1

2. Mika Hannula
Allt eller inget – Kritisk teori, samtidskonst och visuell kultur
("All or nothing – Critical Theory, Contemporary Art and Visual Culture")
ArtMonitor, Göteborg 2005
ISBN 91-975911-0-6

3. Monica Lindgren
Att skapa ordning för det estetiska I skolan. – Diskursiva positioneringar i samtal med lärare och skolledare.
("Creating order for aesthetics at school. Discursive positioning in conversations with teachers and school managers")
ArtMonitor, diss. Göteborg 2006
ISBN: 91-975911-1-4

4. Jeoung-Ah Kim
Paper-Composite Porcelain. Characterisation of Material Properties and Workabiliy from a Ceramic Art and Design Perspective.
ArtMonitor, diss. Göteborg 2006
ISBN: 91-975911-2-2

Distribution: www.konst.gu.se