THE UTILIZATION OF SELECTED LOCAL RAW MATERIALS IN THE PRODUCTION OF BONE CHINA

by

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DECLARATION

I, Abdullahi Danladi Adinoyi UMAR, solemnly declare that the contents of this thesis is the report of my study "Utilization of Selected Local Raw Materials in the Production of Bone China."

I gathered, processed and made samples of Bone China as stated in this thesis and that I took and passed the following courses as a prerequisite for the award of M.A. (Industrial Design).

ID 501 D Research Techniques

ID 503 D Advance Colour and Design

ID 506 D Seminar in Ceramics

ID 505 D Advance Studio Practice

ID 509 D Media Research

CERTIFICATION

This Thesis entitled The Utilization of Selected Local Raw Materials in the Production of Bone China meets the regulations governing the award of the degree of Masters of Art (Industrial Design) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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D E D I C A T I O N

To:

Jamila Umar
Ahmed Abubakar Umar
Umar Hussain Ahmed
Bashar Abubakar Umar
and to the new generation

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ABSTRACT

UMAR, Abdullahi Danladi Adinoyi

The Utilization of Selected Local Raw Materials in the Production of Bone China. M. A. (Industrial Design), July 1988.

The study is concerned with the identification and use of local raw materilas in procelain production. It has the specific objective of using bone as main raw material. It is hoped that the result will be of benefit toward mass production of tableware.

Material sampled were Feldspar and Quartz from Kwara State, Kaolin from Katsina State and Bone and Secondary Clay from Kaduna State. The sampled materials were processed by calcination to 900 C; crushing and watermilling for at least 7 hours. The clays were processed by levigation. A Rational Analysis of the previously analysed raw materials was carried out.

Formulation of bodies was done via a 66-tile triaxial blend of Feldspar, Kaolin and Bone Ash. Further tests like shrinkage, porosity, modulus of rupture, slip casting and firing tests were carried out on the selected bodies. Test bodies were made up and milled for 4 hours and were cast in simple drop out moulds. Such pieces were then fired supported with calcined Kaolin and Silica sand or unsupported.

Discussion and analysis of results based on physical observation were made. It was observed that Bone China slips dry fast, set fast and crack easily especially if the drying rate at the surface is not synchronised with the flocculation of the plaster mould. It was also observed that slips high in clay are a little stronger. 20% addition of both Bomo Clay and Okene Quartz, however, stained the paste and produced glassy results. Test pieces with cracks deteriorated further in firing, an evidence of the irreversible nature of casting faults of Bone China.

A firing range of between 1260°C and 1280°C was established as being adequate as overfiring caused warpage and translucency is attained upon maturity. Faulty shaping accounts for warpage as thin areas easily gave way in firing resulting in distortions.

In conclusion, the following points were raised:

That there exist in abundance local raw materials suitable for Bone China production; that if the three raw materials are processed and manipulated as suggested, they could be adequate for Bone China production especially if slips are cast for between 90 and 120 seconds to produce a thickness that is both economical, as well as, posessing the potentials of surviving 1280°C. Further, it was recommended that:

1. Service industries specialising in the processing of raw materials such as Quartz, Feldspar, and Clay be established.
2. Attempts be made to produce tableware from such processed materials.
3. The Department of Industrial Design be further equipped to cope with researches into materials and techniques.
4. Further research be directed towards finding fritted glazes for this ware.

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DESCRIPTION OF SPECIAL TERMS

1. Alchemy - Medieval Chemistry especially applied in the attempt to turn base metals to gold.
2. Alumina Wash - Refractory kiln furniture coating made from Alumina powder or calcined Kaolin to protect wares from sticking on to shelves in the event of running.
3. Ball Clay - A highly plastic secondary clay.
4. Biaxial blend - A line blend of two materials.
5. Bisque Firing - First firing give "green wares" usually up to $900^{o}C$.
6. Body - An admixture of clay and other materials producing a workable material suitable for manufacturing process.
7. Calcination - Purifying or breaking down by action of heat of up to $1000^{o}C$.
8. Capillary - Space between particles of clay and plaster.
9. China - A general term used to describe white stonewares and porcelains given higher bisque treatment and glazed at lower temperature.
10. Cobalt blue - Blue pigment in decoration derived from cobalt oxide.
11. Delftware - Tin enamelled ware. Tin glazed earthen ware produced in Delft, The Netherlands.
12. Earthenware - Low-fired pottery (below $1200^{o}C$) usually red or tan in colour with absorbency of between 5-20%
13. Eutectic - The ability of two or more minerals when combined to melt at a temperature lower than the melting point of either.

14. Feldspathic Stones - Rocks with similar properties to Feldspar. They are alumina silicates and melt at between 1100°C and 1300°C.

15. Flux - An oxide which promotes ceramic fusion by interacting with other oxides.

16. Glaze Firing - Second firing of up to 1300°C and beyond when fusion of minerals takes place to produce glass.

17. Miaolica - Decorated tin-glazed earthenware soft fired with lead glaze and made opaque by tin oxide.

18. Opacification - Crystaline opacity occurs when crystals form within ash at the surface of a glaze during cooling.

19. Plasticity - The quality of clay that allows it to be manipulated and still maintain its shape without cracking or sagging.

20. Plasticizer - A plastic material that is added to bodies to improve their workability.

21. Proto-Porcelain - The forerunner of porcelain. A white bodied. stoneware that is not translucent.

22. Recipe - The constituent of the mixture of materials for glaze or body.

23. Silicosis - The sealing of the lung capillaries by lung tissues which surround inhaled silica particles.

24. Stoneware - A high fired ware above Cone 8 (1250°C) usually grey in colour. Similar in many respects to porcelain. The main difference being the impurities such as iron present in stoneware bodies.

25. Suspension - A state in which the settling of solid materials is retarded.

26. Translucent - Letting light pass through. Semi transparence.

27. Triaxial blend - A blend involving three materials or compounds.

28. True-Porcelain - The white paste, hard and translucent porcelain fired at 1300^{o}C and above.

29. Vitrification - The process of being converted into glass.

30. Warping - Distortion in the shape of a pot in drying or firing.

Sources:

Nelson, G. C. A Potter's Handbook, 1971

Hamilton, D. Pottery and Ceramics, 1982

Gate, J. Pottery, 1977

MAP OF NIGERIA SHOWING
SOURCES OF CERAMICS RAW MATERIALS



SOURCE: Oyintoke, R. S., 1987

MOH'S SCALE OF HARDNESS

MINERAL	NO
Talc	1
Gypsum	2
Calcite	3
Flouspar	4
Apatite	5
Feldspar	6
Quartz	7
Topaz	8
Corundum	9
Diamond	10

Source: Harmer, F. The Potters Dictionary of Materials and Techniques, 1975

COMMON CERAMIC RAW MATERIALS

S/N	CERAMIC RAW MATERIALS	RAW FORMULA	COMPOUND MOLECULAR WEIGHT	EQUIVALENT WEIGHT	FIRED FORMULA
1	Bone Ash	$Ca_3(PO_4)_2$	310	103	CaO
2	Calcium Carbonate	$Ca\ Co_3$	100	100	CaO
3	Cobalt Oxide	Co_3O_4	241	80	CoO
4	Copper Carbonate	$CuCo_3$	124	124	CuO
5	Potash Feldspar	$K_2OAl_2O_36SiO_2$	557	557	$K_2Al_2O_36SiO_2$
6	Soda Feldspar	$Na_2OAl_2O_36iO_2$	524	524	$Na_2OAl_2O_36SiO_2$
7	Kaolin	$Al_2O_32siO_22H_2O$	258	258	$Al_2O_32siO_22H_2O$
8	Flint/ Quartz	SiO_2	60	60	SiO_2
9	Sodium Carbonate	Na_2Co_3	106	106	Na_2O
10	Talc	$3M_gO4SiO_2H_2O$	379	126	$3M_gO4SiO_2$

Source: Nelson, G. C. A Potter's Handbook, 1971

Chemical Symbols			Name
SiO_2	..	..	Silica
Al_2O_3	..	..	Alumina
Fe_2O_3	..	..	Ferric Oxide
FeO	..	..	Iron Oxide
CaO	..	..	Calcium Oxide
MgO	..	..	Magnesium Oxide
MnO	..	..	Manganese Oxide
K_2O	..	..	Pottasium Oxide
Na_2O	..	..	Sodium Oxide
TiO_2	..	..	Titanium Oxide
P_2O_5	..	..	Phosphorous Pentoxide

ABBREVIATIONS

T	Test
TT	Test Tile
QAT	Quartz Addition Test
SCAT	Secondary Clay Addition Test
QSCAT	Quartz Secondary Clay Addition Test

CHAPTER ONE

1.1 INTRODUCTION

Porcelain was defined by Hamer (1975) as a vitrified, white and translucent ware usually fired at 1300°C plus and by Rhodes (1973) as a stoneware body that cannot be made from a single natural material, but from a proportional mixture of such several ingredients as Kaolin, Feldspar and Flint.

Porcelain originated in China where it actually developed from a white-bodied stoneware (Proto-porcelain) during the T'ang period (618-906 A.D.).

According to Nelson (1971):

> The T'ang period was a time of great experimentation in form and technique. Trade contacts with the Middle East were common as reflected in the echoes of Greek and Roman vase forms, impressed decorative motifs and marbelized clay bodies. The stoneware bodies were more refined and it becomes a matter of opinion whether to term some pots stoneware or porcelain.

Porcelain production did not attain great heights however, until the Ming period (1368-1644 A.D.).

Hughes (1955) describe the true hard-paste porcelain of China as being made from two main ingredients. The fusible natural silicate of alumina, a brilliant white, fine grained material called 'petuntse' and a primary clay called 'Kaolin'. These natural earths blended and fired to a very high temperature, produce a vitreous ware with a metallic note when lightly struck and breaking with a clean smooth fracture disclosing a fine sparkling grain of compact texture.

Chinese porcelain is of high quality especially when decorated with blue cobalt. It, therefore, became popular in Europe.

In 1577, the Portuguese East India Company set up a settlement at Macao near Canton from where it began exporting porcelain to Europe.

According to Hamilton (1982), during the 16th and particularly the 17th Century, Chinese porcelain reached Europe as sea trade superceeded overland routes. Tin glazed pottery began to be painted in Chinese styles and in time, forms tended towards the Chinese.

In England, as well as, other parts of Europe, contact with China and by implication Chinese pottery helped influence the production of other kinds of wares. Wares such as Miaolica and Delftware.

The English court in 1694 banned the importation of Chinese porcelain for economic reasons. A vacuum was thus created. Attempts made by English potteries to fill this vacuum yielded mere imitations.

Soon the hunt for True-Porcelain was on. The reasons according to Hamilton (1982) were both economic and aesthetic. Most of the experiments took place under the status of revenue seeking patronages of Dukes and Princes.

The result of these experiments was the discovery of Soft Porcelains. Soft Porcelains are, however, flawed because they chip off easily. It was in the course of this search for True-Porcelain that one Josiah Spode in 1750 discovered that by mixing cornish stone with calcined bone one gets a good quality translucent ware that can easily pass for porcelain. Spodes porcelain was christened "Bone China".

Spodes China was made from 50% calcined bone, 25% Kaolin and 25% cornish Stone. This formula remains the standard Bone China formula. Other potteries adopted the formula which is used to date especially in England as substitute for hard porcelain.

In Nigeria, research into the feasibility of Porcelain production from local materials is intensifying.

Gukas (1985) discovered six mixtures for hard and soft porcelains from materials found around Kaduna and Katsina States.

Okoruwa (1986) also found eight bodies suitable for casting tableware using materials from around the country.

The use of calcined bones in ceramics production is seen as a cost-saving measure. Bone Ash when used in Bone China does both fluxing and glass forming.

Elimination of quartz in the body makes it possible to have a ware that matures at low temperature (lower than what is required by a quartz laden body).

Spodes formula for Bone China has seen some modifications over the years. It is, however, not known if calcined bone will work with Nigerian Feldspar and Kaolin to make the Nigerian Bone China.

1.2 THE PROBLEM

This study is concerned with the identification and use of raw materials such as Cattle bone, Feldspar and Kaolin for the production of high quality porcelain.

1.3 PURPOSES AND OBJECTIVES OF THE STUDY

1. To identify procelaineous materials suitable for use in the production of Bone China bodies.
2. To procure and process essential raw materials for the formualtion of Bone China bodies for slip casting.
3. To produce fine, hard, translucent China that has potentials for the mass production of tableware.
4. To produce a Bone China that matures at 1280^{o}C (Cone 9).

1.4 SIGNIFICANCE OF THE STUDY

The study seeks to establish the fact that Nigerian Ceramics industries can utilize an abundant raw material hitherto unused, to produce high quality porcelain. If achieved, this will save the nation millions of Naira spent on the importation of raw materials for industries and finished ceramics.

Okoruwa (1986) quoting Onaji reported that the cost of ceramic materials in 1985 reached ₦100 million mark. It has become imperative then to find local substitutes, especially, now that the nation is looking inwards for solutions to its economic problems.

Gukas (1985) said that many Nigerian ceramists and industrialists have realised that stoneware and porcelain bodies are ideal medium for household utensils most especially now that high-fired products are in high demand in the local and international markets. A good result from this study will help industries specialising in ceramics production identify and process their raw materials.

Hard porcelains require higher temperature to mature than Bone China but the quality remains almost the same when used in producing tableware.

If Bone China replaces porcelains on our tables, the cost of production will be reduced because the firing period will be shorter.

With this study, it will be possible for manufacturers to produce a type of China with little or no Quartz or Flint. Eliminating Quartz means eliminating a long process of purification (milling) as well as a potent source of silicosis.

The study will contribute to knowledge by adding to the little exisitng literature on porcelain and Bone China production in Nigeria.

Local production of Bone China will put to good use the tonnes of animal bone derived annually from abbatoirs around the country.

1.5 LIMITATIONS

1. Use of facilities currently available in the Ceramics Section of the Department of Industrial Design, Ahmadu Bello University, Zaria for the manipulation and treatment of raw materials constitutes a limitation.
2. Possible use of some raw materials and concerned only describing superficially the historical and geological derivation of such materials and workings of machinery also constitute a limitation.
3. The study ONLY intends to make the MANUFACTURE of Bone China in Nigeria a reality.

1.6 DELIMITATIONS

Blending of materials was for the purpose of an intensive study delimited to the feldspathic stones and Quartz of Kwara State, Nigeria, Bone from Zaria abbatoir and Clays from Kaduna and Katsina States.

1.7 BASIC ASSUMPTIONS

For the purpose of this study, it was assumed that:

1. Bone Ash will suffice as calcium phosphate source with its formula remaining $Ca_3(PO_4)_2$
2. The formula for Okene Feldspar is $K_2O\ Al_2O_3\ 6SiO_2$. That it is an Orthoclase Feldspar and a Pottasium and Silica source.
3. The formula for clay remains $Al_2O_3\ 2SiO_2\ 2H_2O$ and will suffice as Silica and Alumina source.
4. These materials in certain proportion exposed the heat in the Kiln will behave in a predictable manner.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The search for 'True-Porcelain' began with the appearance of Chinese Porcelain in Europe.

Chinese porcelain also known as 'True Porcelain' has the formula of equal parts of 'Kaolin' (a local Chinese clay) and 'Pentuntse' (Chinese Feldspar). Several attempts were made at producing local porcelains in Europe but all failed as they yielded either white-bodied stonewares or earthenwares but not the fine-grained, translucent porcelain.

According to Hughes (1955) "Spasmodic endeavours were made in Europe from the middle of the 15th Century to reproduce Chinese porcelain . All attempts were, however, concerned with the alchemy rather than the chemistry.

An attempt to reproduce Oriental porcelain in England in 1506 resulted in failure. Materials were unsitable and casualities in the Kiln far too costly for the experiement to continue.

The growing popularity of Chinese porcelain according to Hughes (1955), coincided with increased economic activities and so, successful reproduction of Chinese porcelain became a matter of importance. The country first to acquire the secret of making porcelain was certain of an enormous profit making monopoly.

The reasons for failure in attempts to reproduce Oriental porcelain lie in the erronous notion held by European potters that porcelain clay was obtainable naturally. This theory was disproved when in 1709 a German alchemist, Johann Freidrich Bottger made the first European porcelain in Saxony.

More tests were carried out to improve on Bottger's result. These tests were of inclusions, eliminations and increasing one contituent above the other. These tests yielded different porcelain bodies maturing at differnt temperatures.

A typical porcelain body consists of:

Kaolin	50%
Feldspar	25%
Quartz	25%

A typical German porcelain body is:

Kaolin	54%
Feldspar	20%
Flint	25%
Whiting	1%

This mixture matures at 1410^{o}C (Cone 14).

A slight moderation in this mixture reduces the maturing temperature as can be seen in ths French mixture.

Kaolin	44%
Feldspar	30%
Flint	25%
Whiting	1%

Feldspar in the mixture acts as a flux and brings the temperature down to 1350^{o}C. (Cone 12)

Other tests reveal that the addition of Ball clay (Secondary Clay) not only makes the body workable, but also reduces maturing temperature.

For example:

Kaolin	40%
Ball Clay	10%
Feldspar	25%
Flint	25%

This mixture matures at 1320°C (Cone 11).

By subtracting certain percentages of Kankara Kaolin and replacing same with 'Bomo Clay' (a secondary clay), Gukas made tests involving 5%, 10% and 15% subtractions and additions. Having fired these tests to 1300°C found the following: 5% addition gave a whitish pink but porous body, 10% and 15% additions lost their colour but are easier to manipulate. He concluded that the mixture with 10% addition of secondary clay is promising because it is hard when fired and workable when wet.

2.2 SOFT PORCELAINS

Soft porcelains according to Gukas (1985) are a number of different bodies that are all vitreous, white and translucent. They vitrify below 1350°C (Cone 12) and most even vitrify at lower temperatures.

Soft porcelain came about from the search for true porcelain. Experiments by European potteries using such odd materials as soap stone yielded a variety of soft porcelains.

Soft porcelains are disadvantaged because they chip off easily. Their utility is thus limited.

In the modern context, soft porcelains are those high in Feldspar and low in Kaolin and Flint. Singer and Singer (1963) gave the mixture of a soft porcelain maturing at 1150°C (Cone 4) as:

Ball Clay	25%
Quartz	45%
Feldspar	30%

It can be noticed that this mixture has no Kaolin!

2.3 BONE CHINA

According to Honey (1963), Ash of Calcined bone which is pure white in colour was first proposed as an ingredient in porcelain composition in Germany in 1649 and was previously used as an ingredient in milk white glass.

Hughes (1955) said:

> The fragility of soft porcelains and their liability to get misshapen in firing and crack at the touch of hot liquids was overcome to an extent when non-frit Bone China appeared combining the materials of hard paste porcelain with bone ash. For the first time, a white paste of even translucency was marketed at a reasonable price.

Bone China is really a porcelain intermediate (between hard and soft). Its translucence being due to the formation of glassy material by a combination of bone ash and feldspar.

There are similarities between Bone China and Porcelain. Bone China has some qualities of denseness, vitreousity and to an extent translucency as porcelains. The fluxes used in the bodies are, however, different.

Rhodes (1973) said fluxes such as bone ash, calcium, magnesium, wollastomite, talc and wood ash are associated with Bone China whereas Soda and Potash Feldspar are basically the fluxes for porcelain. Porcelain fluxes are characterised by long, slow and steady action of their melting.

Bone China according to Hughes (1955) unifies many of the best qualities of hard and soft porcelains. The formula consist chiefly

of basic materials of hard porcelain 4 parts of China Stone or 'petuntse', 3½ parts of China Clay or 'Kaolin' and 6 parts of Bone Ash.

Singer and Singer (1963) observed that Feldspar in Bone China bodies releases alkali silicates which make the water alkaline and viscous.

Bone Ash reacts more quickly giving soluble acid calcium phosphates and even phosphoric acid which increases plasticity of the body.

The three manufacturing difficulties in the traditional Bone China body Singer and Singer (1963) went on are:

1. Lack of plasticity
2. Short firing range and large firing shrinkage
3. The tendency for the body to go blue or brown in firing especially when the Kiln fires in reduction.

The first problem can be solved by adding plasticizers like bentonite or a secondary clay.

The short firing range can also be remedied by formulating bodies closer to 'True Porcelain'.

The third problem can be contained by firing in wholly oxidized Kilns.

Singer and Singer (1963) found grinding of the body to increase translucency.

Cattle-bone has remained the chief bone ash source. Bones of pigs and horses according to Singer and Singer (1963) are unsuitable. They are known to give yellowish stains to the body as a result of their high Iron percentage.

Human bones on the other hand apart from prohibitive cost are known to contain salts.

TABLE 2.1

BONE CHINA BODIES

MINERAL OXIDE	SPODES CHINA	GENERAL A	GENERAL B	GENERAL C	COMMON CHINA	FRENCH	APATITE	AMERICAN	GENERAL CONE 9
China Clay	12	26	25	30	14	28	35	30	26
Ball Clay	-	-	-	-	14	3	-	-	-
Cornish Stone	25	-	18	18	32	28	-	-	26
Bone Ash	38	44	50	47	35	34	-	45	45
Flint	25	30	-	-	5	-	14	-	3
Frit	-	-	-	-	-	7	-	-	-
Bisquit Grog	-	-	5	-	-	-	-	-	-
Feldspar	-	-	-	-	-	-	19	25	-
Apatite	-	-	-	-	-	-	32	-	-

SOURCE: Singer and Singer (1963) Industrial Ceramics

These days, apatite, another natural stone, is used in place of bone ash in the Bone China body as can be seen in mixture No. 7 in Table 2.1.

Bone China is given a high bisque firing (1280°C) and low glaze firing (1080°C).

2.4 KAOLIN (Al_2O_3 $2SiO_2$ $2H_2O$)

Kaolin is a fine textured, white primary clay. Due to its geological origin, it is supposed to be free of impurities. This property makes it refractory, a strength that approaches the 1750°C mark.

Hamilton (1982) said of the process of Kaolinisation:

> A very high proportion of the rocks forming the earths crust is feldspathic. Where this mineral has been subjected to the action of water, the feldspar undergoes certain changes. Such rocks decompose to form deposits of Kaolin. Occassionally, steam will emanate from the hot interior of the earth and where this occurs beneath a feldspathic rock, the feldspar changes to produce Kaolinite. This process called 'hydrothermal' leaves the purest type of Kaolin deposit.

According to Gukas (1985) a relatively fine Kaolin should consist 39.8% Alumina, 46.3% Silica and 13.9% chemically combined water.

Where impurities such as Iron are present, the clay does not burn white.

Hamer (1975) gave the ultimate analysis of a typical China Clay thus:

SiO_2	...	46.6
Al_2O_3	...	38.3
TiO_2	...	0.1
Fe_2O_3	...	0.4

CaO	...	0.3
MgO	...	0.3
K_2O	...	0.7
LOI	...	13.1

In porcelain and China bodies, Kaolin introduces Silica, Alumina and where impure, some oxides such as Iron.

Cardew (1969) gave the formula for this ideal or theoretically pure Kaolin as:

SiO_2	...	46.5
Al_2O_3	...	39.5
H_2O	...	14.0

Deposits of Kaolin exist in Katsina, Kaduna, Bendel, Kwara, Bauchi and Sokoto States.

Hendsman (1974) gave the analysis of Kankara Kaolin, a primary clay from Katsina State as:

Silica	-	SiO_2	-	44.55
Alumina	-	Al_2O_3	-	31.45
Iron Oxide	-	FeO	-	1.07
Magnesia	-	MgO	-	0.87
Lime	-	CaO	-	0.28
Sodium	-	Na_2O	-	0.17
Potassium	-	K_2O	-	0.30
Excess water	-	H_2O+	-	12.03
Chemical water	-	H_2O	-	9.06
Titania Oxide	-	TiO_2	-	0.41
Manganese	-	MnO	-	0.01
Sulphur	-	SO_4	-	0.05

Kankara Kaolin which burns white has according to Gukas (1985) the following qualities.

6%	Dry shrinkage
2%	Bisquie shrinkage
6.5%	Glaze shrinkage
14.5%	Total shrinkage
and	
13.5%	Bisque Porosity
12.2%	Porosity at $1300^{o}C$

(see Table 2.2)

2.5 FELDSPAR

Nelson (1971) defined Feldspar as a crystaline rock composed of the Alumina Silicates of Potassium, Sodium and Calcium. These silicates are never found in pure state but as a mixture with one predominating.

Cardew (1969) gave the formula for the three common Feldspars as:

Potash Feldspar (Orthoclase) $K_2O\ Al_2O_3\ 6SiO_2$

Soda Feldspar (Albite) $Na_2O\ Al_2O_3\ 6SiO_2$

Lime Feldspar (Anorthite) $CaO\ Al_2O_3\ 6SiO_2$

Singer and Singer (1963) said Feldspar is one of the most important flux used in bodies and glazes They also said that Feldspar is the most convenient form of introducing nearly insoluble alkalis.

Feldspar according to Cardew (1969), can be recognised by their cleavage, lustre, hardness and colour. Feldspar has two cleavages while quartz has none.

Potash Feldspar can be distinguished from Soda Feldspar by its pink colour. Soda Feldspar is white. Both, however, fire white.

TABLE 2.2

BEHAVIORAL ANALYSIS OF KANKARA KAOLIN AND BOMO SECONDARY CLAY

S/N	CLAY	PLASTICITY	DRY SHRINKAGE	BISQUE SHRINKAGE	GLOST SHRINKAGE	TOTAL SHRINKAGE	ABSORBTION AT BISQUE	ABSORBTION AT 1300°C
1	Kankara Kaolin	Low	6%	2%	6.5%	14.5%	13.5%	12.2%
2	Bomo Clay	Good	7%	2%	2%	11%	9.5%	1.3%

Source: Gukas, H. B., 1985

Porcelain makers rely heavily on feldspar for flux in glaze and body.

Cardew (1969) tells of Potash Feldspar melting at 1170^{o}C. This means that feldspar is very important to potters even those specialising in low temperature pottery. By making further additions of quartz, whiting, etc., a strong glaze that is fluid can be obtained. Some feldspars melt into good glazes without additions.

In bodies, the viscosity of feldspar melts become of value for as Cardew (1969) notes, porcelains can become translucent without collapsing.

There are, however, differences in the behaviour of different feldspars in the body.

Okoruwa (1986) observed that Potash Feldspar melts are more translucent than Soda Feldspar melts because more bubbles are released in the course of firing by Potash Feldspar than Soda Feldspar and these bubbles are responsible for translucency.

Okoruwa (1986) quoting Ryan (1978) noted that high Soda Feldspar makes for lower vitrification temperatures in a body than Potash Feldspars and are more prone to warping.

Deposits of Potash Feldspar exist in Osara near Okene and Oguda also near Okene, Kwara State, Gwoza, Borno State while Soda Feldspar can be found at Ungwan-Nungu in Kaduna State.

A comparison of Okene Potash Feldspar is drawn with an analysis of a Potash and Soda Feldspar by Singer and Singer (1963) (Table 2.3)

Okene Feldspar though Orthoclase is low in Alumina and high in Soda. At 3.46, it is higher than the Soda content of the Potash Feldspar, it is being compared with.

It also has a high Iron (Fe_2O_3) content. At 0.22, much higher than iron content of both, the Potash and Soda Feldspar, it is compared with.

TABLE 2.3

A COMPARISON OF
OKENE FELDSPAR WITH TWO FOREIGN FELDSPARS

PARAMETER	OKENE FELDSPAR	POTASH SPAR	SODA SPAR
SiO_2	66.52	66.72	66.22
Al_2O_3	14.02	18.52	21.76
Fe_2O_3	0.22	0.08	0.04
CaO	-	0.30	2.06
MgO	-	TRACE	TRACE
K_2O	9.64	12.10	0.41
Na_2O	3.46	1.82	9.37
L.O.I	ND	0.36	0.16

KEY:

ND = Not Determined

Sources: Singer and Singer (1963)
Musoke, W. L. (1987)

2.6 QUARTZ (SiO_2)

Quartz (SiO_2) is used as source of Silica for glazes and bodies and is introduced to bodies and glazes in powder form or as quartz sand.

Quartz is 7 on Moh's Scale of hardness. It is clear and colourless.

Hamer (1975) said quartz sand added to clay or body acts as a grog. as a non-plastic material, it opens a body, and decreases both plasticity and shrinkage.

He went on 'powdered quartz is occassionally added to stoneware and porcelain to assist in vitrification.'

Cardew (1969) said quartz can aid in controlling crazing by the amount of finely crystalline Silica in the body.

Quartz has a reversible expansion of 1% at 573°C.

In Bone China bodies, quartz aids in vitrication and yielding stronger bodies and helps to balance the activities of Bone Ash and Feldspar which are essentially fluxes.

Some Bone China mixtures contain as much as 30% quartz. The shrinkage for which Bone China bodies are notorious can to an extent be controlled by adding small proportion of quartz.

Quartz sometimes occurs as quartz sand. This is the finely granuled quartz found in large deposits. It is free from impurities and is processed by washing and then ball milling.

Quartz Stone occurs in veins along with Feldspars. A feature like this occurs in Okene where quartz and Feldspar are found in the same area. Deposits of quartz sand exist in Daura and Baure in Katsina State.

2.7 BONE ASH $(Ca_3\ PO_4)_2$

Hamer (1975) observed that fround calined bone is one source of calcium, phosphate and apatite. It is used as a flux where calcia does the fluxing and phosphorous pentoxide does the glass forming. Its stiff glassy character is seen combined with that of feldspar in Bone China.

A small amount of carbon, Hamer (1975) went on "remains in the ash when calcination is controlled. This carbon assists the raw plasticity of the body."

According to Marryat (1857):

> Bone is a very important ingredient in English Porcelain and enters largely into its composition, the phosphoric acid of its ingredient, diffuses itself at a high temperature through all the materials and unites them in a translucid enamel which is less apt to sink and lose its form than porcelain of hard paste.

The use of bone ash in China making is as a flux it is also used an an opacifier in glazes.

Bone Ash contains:

Calcia	-	55%
Phosphorous Pentoxide	-	40%
Silica, Flourine and Alkaline Oxides	-	5%

Webster and Dindsdale (1968) said:

> Bone is a highly complex mixture of organic and inorganic materials formed by crystalization and precipitation from the blood of living animals. The organic part of the bone substance does not concern the ceramist since it it burnt or washed away. Bone consists of hydroxy - apatite in which various ions have been replaced and others absorbed at the surface.

They both suggest calcination of bone to between 750°C and 900°C for best results as lower temperatures yield bone ash of small particle size which is of low value in high temperature pottery.

2.8 PLASTER OF PARIS

Plaster of Paris is semi-hydrated calcium sulphate. It is a white powder prepared from Gypsum ($CaSO_4$ $2H_2O$) by driving off part of the water of crystalisation.

The best Plaster of Paris/water mixture is 100 parts of water to 140 parts of Plaster of Paris. This gives a strong, heavy plaster of 35% absorbency. The setting time is 4 minutes for the 140/100 mix. The weaker mix 110/100 takes 7 minutes to set.

Plaster of Paris is very useful in slip casting shaping method in ceramics. As Singer and Singer (1963) noted, Plaster of Paris plays a dual role not only does Plaster of Paris absorb water and thereby makes the clay stiffer, but the slight solubility of the calcium sulphate in water accompanying the clay, furnishes flocculating ions both calcium and sulphur ions being efficient flocculants. Therefore, a deflocculated casting slip poured into a casting mould is flocculated on the mould surface to give a stiff cast.

Moulds are made using plaster and water. Oyintoke (1987) reports that at CEMA, Kano, there is a table that helps regulate the quantity of both plaster and water required. The ratio ranges from 46/62 of cistern and lid mould, to 58/78 of the wash hand basin mould.

Gukas (1985) used a ratio of 6 mugfuls of plaster to 4 mugfuls of water.

2.9 SLIP CASTING

Slip Casting is considered the bedrock of ceramic manufacturing, Okoruwa (1986).

Slip Casting according to Singer and Singer (1963) was invented some 150 years ago. It is a method of shaping ceramic articles by pouring slip in a porous mould. The use of this according to Okoruwa (1986) was coupled with the knowledge of the use of deflocculants and the density of slip.

Singer and Singer (1963) said when the slip is inside the mould, there is a double action of water removal and flocculation by the calcium sulphate in the mould. This is what makes the body set.

Hammer (1975) listed five requirements of a casting slip.

1. It should contain all the ingredients to form a good pottery body when fired.

2. It must be sufficiently fluid to pour into moulds to fill all the details.

3. It must be reasonably permeable to allow a layer of clay build up in the mould while more water passes through to increase thickness.

4. It must be capable of an accurate impression of the mould.

5. The newly formed cast although still wet must remain firm until it has hardened sufficiently to keep its form as clay.

To meet these requirements, Hamer (1975) also suggested:

A. More than one clay should be used; feldspathic materials to act as siscous fluxes; Flint/Quartz for whiteness and hardness, sand and grog for texture and crystobalite for glaze fit.

B. Fluidity can be achieved by either adding more water but best by using deflocculants.

C. Sieving through 120 mesh.

D. Clays are naturally permeable but with deflocculants, this is lost. So, a balance must be sought between natural state and deflocculation to allow permeability.

E. Suspensions 'set' slightly when allowed to rest. A balance of deflocculants must, therefore, be used.

2.10 DEFLOCCULANTS

Gukas (1985) defines deflocculants as a soluble material which is added to clay slip to increase fluidity.

Nelson (1971) said addition of up to 1% of deflocculants such as Sodium Carbonate and Sodium Silicate to the dry weight of the clay will considerably reduce the amount of water needed to make a fluid slip.

Sodium silicate is made by fusing a mixture of Soda Ash and Silica Sand. It has a melting temperature of between 1000^{o}c and 1100^{o}C.

Sodium Carbonate ($NaCO_3$) is derived by burning a sea weed called 'kelp'.

Deflocculants are also know as 'electrolytes'.

Hamilton (1982) explains one theory about the effects of electrolytes said: 'The electrolyte has the effect of reversing the electrical charge of some of the clay particles so that they no longer tend to join together but repel each other to produce a fluid mixture.

Nelson (1971) advises that not more than 1% of deflocculant to dry weight be used as excess will sometimes cause slip to become pasty and non-pourable; it also gradually seals the pores of the plaster mould with an insoluble film of calcium silicate making it difficult to remove the casting and eventually destroying the mould.

Oyintoke (1987) reports the use .265 grms of deflocculants to every 3 kgs of clay and 1500 mls of water.

Okoruwa (1986) maintained a ratio of 4 grms to every 500 grms of solid ingredients.

CHAPTER THREE

RESEARCH PROCEDURE

3.1 INTRODUCTION

This chapter is devoted to explaining the nature and sources of data. It discusses the standard tests used in gathering data.

The study was divided into three phases.

1. Sourcing of raw materials
2. Processing of raw materials
3. Studio tests and body formation

3.2 POPULATION

Population for the study comprises of the following raw materials: Bone, Feldspar, Quartz, Primary and Secondary Clays and other naturally occuring ceramics raw materials.

3.3 SAMPLING TECHNIQUES

Cluster sampling technique was employed, drawing samples from particular geographical areas.

Samples used were drawn thus: Okene Quartz and Okene Fesldspar considered representative of Quartz and Feldspar used in ceramic production, Kankara Kaolin sampled as primary clay, while Bomo Clay was used as secondary clay and plasticizer. Bone Ash from cattle bone obtained in Zaria was also sampled.

3.4 FIELD TRIPS

The study commenced with two (2) field trips to the sources of especially the stones. Contact was made with the locals who gave information leading to the procurement of the materials from the following places.

TABLE 3.1

MATERIALS AND SOURCES

S/N	RAW MATERIAL	SOURCE
1	Kankara Kaolin	Kankara, Malumfashi District, Katsina State
2	Bomo Clay	Bomo, Zaria District, Kaduna State
3	Okene Feldspar	Oguda, Okene District, Kwara State
4	Okene Quartz	Oguda, Okene District, Kwara State
5	Bone	Zaria, Zaria District, Kaduna State

3.5 ANALYSIS OF RAW MATERIALS

A comprehensive Chemical Analysis of raw materials used was sought for use in further analysis.

TABLE 3.2

CHEMICAL ANALYSIS OF RAW MATERIALS

COMPOUND	KANKARA KAOLIN	BONE ASH	OKENE FELDSPAR
Silica	44.55	ND	66.52
Alumina	31.45	-	14.02
Potash	0.31	-	9.64
Soda	0.17	-	3.46
Calcia	0.28	55	-
Iron	1.07	-	0.22
Magnesia	0.87	-	-
Titania	0.41	-	-
Flourine	-	5	-
Phosphorous Pentoxide	-	40	-
L.O.I.	21.0	-	ND

KEY:

ND = Not Determined

Sources: Gukas, H. J. (1985)

Hamer, F. (1975)

Musoke, W. L. (1987)

TABLE 3.3

RATIONAL ANALYSIS OF RAW MATERIALS
(Feldspar Convetion)

RAW MATERIAL	CLAY SUBSTANCE	FELDSPAR		FREE QUARTZ	OTHERS	LOI
Kankara Kaolin	66.80	2.78		11.06	2.41	16.06
		ortho-clase	albite			
Okene Feldspar	4.75	59.07	29.3	8.02	0.2	

3.6 TREATMENT AND PROCESSING OF MATERIALS

The selected raw materials were processed individually in the Ceramics Studio of the Department of Industrial Design, Ahmadu Bello University, Zaria in the scheme described in Table 3.4.

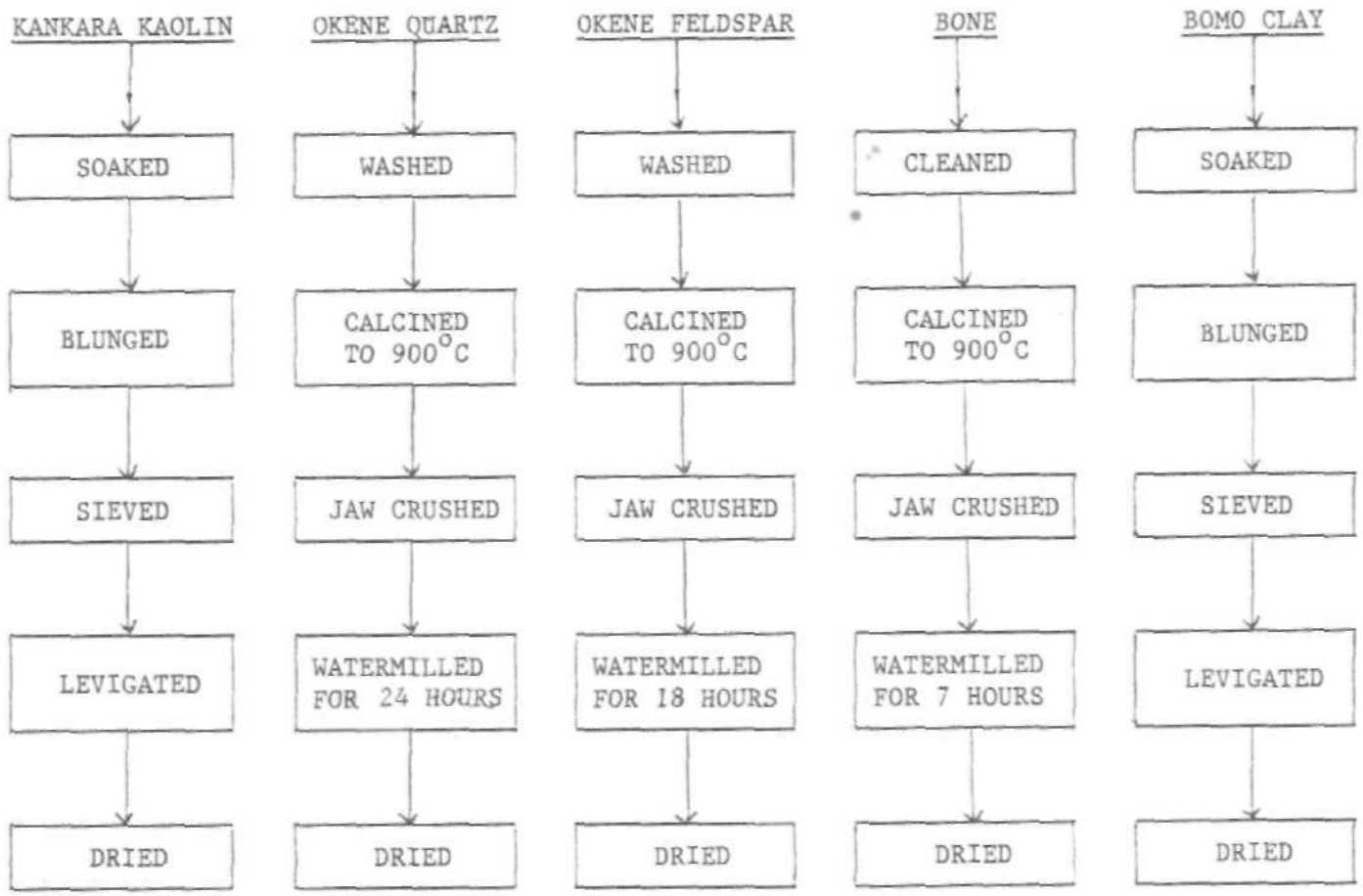
3.6a OKENE FELDSPAR (Potash Feldspar Source)

This pink coloured stone picked at Oguda near Okene was washed, packed in the Kiln and calcined to 900^{o}C. This was necessary as it reduced the Feldspar from its hardness of 6 on Moh's Scale to a crushable flaky mass. The Feldspar was so soft that the hands were used to separate flakes that were further broken to fit into the Jaw Crusher. The resultant small bits were put in the Ball Mill and watermilled for eighteen hours (18 hours).

The ground Feldspar was emptied into a wide container and allowed to settle. Water was then drained and the thick mass dried taking care to avoid contamination. When dry, the now powdery material was packed and stored.

TABLE 3.4

SCHEME FOR PROCESSING OF RAW MATERIALS



3.6b OKENE QUARTZ (The Silica Source)

These almost transparent and stainless stones were picked at Oguda near Okene. They were washed to remove impurities such as earth and other organic matter. The stones were then put in the Kiln and calcined to 900°C. Though harder than Feldspar at 7 on Moh's Scale, this quartz responded to the temperature and was upon removal from the Kiln, soft enough to be broken with a metal hammer.

The quartz was Jaw Crushed and a substantial amount was put in the Ball-Mill and water-milled for twenty-four (24) hours.

The Ball-mill was emptied of the charge which was allowed to settle before water was siphoned off the surface. The thick white mass was carefully dried and stored.

3.6c KANKARA KAOLIN (Primary Clay)

This fine grained material obtained from Kankara was soaked for twenty-four (24) hours. In order to achieve a homogeneous mix, it was further mixed and then sieved through a 60 mesh sieve and levigated by repeatedly allowing the free silica sand to settle while draining the clay in suspension.

The clay slip was then air-dried in drying bowls in a slow but steady manner. The dry stuff was then stored.

3.6d BOMO CLAY (Secodnary/Ball Clay)

This grey coloured local clay is very plastic. It was processed by soaking, sieving and levigating.

3.6e BONE (Calcium and Phosphate Source)

Raw cattle bone was obtained from Zaria Abbatoir and cleaned of it organic matter and some fat. Bits of bone were packed in saggars and put in the Kiln where they were calcined to 900°C. Some carbon

remained in the bones making them black. The calcined bones were then fed into the jaw crusher and crushed into even smaller bits. These were put into the ball mill and water-milled for seven (7) hours. The material was allowed to settle and dried.

Some amount of this ash was returned to the Kiln to rid it of carbon. This came out white.





Plate 1. Raw Materials

3.7 BODY FORMATION

A sixty-six-tile tri-axial blend of the three basic materials was made, i.e. Bone Ash, Kankara Kaolin and Okene Feldspar. This blend was fired to 1280^{o}C (Cone 9).

AIM: The tri-axial blend ensures that thorough blending is done as in most of the blends, not less than one part of a mineral is represented. This way, there are blends of 90-10-0 and 40-30-30!

From the tri-axial test, eight tiles that produced likely bodies were chosen. The contents of the eight bodies are shown in Table 3.5.

TABLE 3.5

THE EIGHT SELECTED BODIES

S/N	TILE No.	BONE ASH	KANKARA KAOLIN	OKENE FELDSPAR
1	TT 34	50	30	20
2	TT 35	50	20	30
3	TT 39	40	40	20
4	TT 40	40	30	30
5	TT 41	40	20	40
6	TT 45	30	40	30
7	TT 46	30	30	40
8	TT 47	30	20	50

These eight formed the foundation for further tests which include:

3.7a SHRINKAGE TEST

AIM: This test was carried out to determine the shrinkage rate of the eight bodies with the aim of identifying the most suitable, i.e. that which comes closest to that acceptable which is 1 part in 8 or 12.5% according to Hamilton (1982).

PROCEDURE: 4 bars 15 cm long were produced from each of the eight bodies. The bars were marked 10 cm within the length (15 cm) and dried. The wet to dry shrinkage was recorded. The bars were then put into the Kiln and fired to 1280^{o}C (Cone 9) and the wet to fired shrinkage recorded. The shrinkage percentage was then determined thus:

$$DS = \frac{PL - DL}{PL} \times \frac{100}{1}$$

where DS = Drying shrinkage

PL = Plastic length

DL = Dry length

and

$$FS = \frac{PL - FL}{PL} \times \frac{100}{1}$$

where FS = Firing shrinkage

PL = Plastic length

Fl = Fired length

3.7b POROSITY TEST

A porosity test of the eight bodies was made.

AIM: This test was aimed at identifying those bodies that satisfy the accepted absorbtion percentage for a porcelain intermediate like Bone China which is 0.5% A% according to Oyintoke (1987).

PROCEDURE: 4 cubes were made from each of the eight selected bodies. The cubes with a wet weight of 30 gms each were dried and the fired to 1280^{o}C (Cone 9) and the weight recorded. They were then

soaked in water for twenty-four (24) hours and weighed again. The Absorbtion percentage was determined thus:

$$A = \frac{SW - FW}{FW} \times 100$$

where A = Absorbtion

SW = Saturated weight

FW = Fired weight

3.7c MODULUS OF RUPTURE TEST

To compliment other tests a modulus of rupture test was carried out on the eight bodies.

AIM: The test seeks to establish the strength of the eight slips to determine suitability of the bodies for mass production.

PROCEDURE: 4 bars each were made from the eight bodies and dried. The bars measuring 10 cm x 1.5 cm x 2.0 cm were each placed on two parallel bars 6.5 cm apart and load mounted on a piece of rod that runs across the breadth of the bar. The weight at which the bar broke was recorded as the Breaking Load and analysed thus:

$$MOR = \frac{3}{2} \frac{(\text{force Max} \times L)}{h^2 \times B} \times 100$$

where Force Max is the Breaking Load

L = Length

B = Breadth

H = Height

3.8 ADDITIONAL TESTS

Having obtained mixtures based on the tri-axial blend, a move was made to 'improve' these bodies. Such test were of inclusions of Okene Quartz, Bomo Clay and of both.

AIM: The tests were aimed at evolving bodies that are strong and workable.

3.8a QUARTZ ADDITION TEST (QAT)

Some Bone China bodies contain as much as 30% quartz. Test of 10% and 20% additions of Okene Quartz were, however, carried out.

PROCEDURE: QAT test No. 34A 35A; 39A 40A 41A 45A 46A and 47A were given 20% addition of Okene Quartz blended and fired to 1280°C (Cone 9).

QAT test No. 34B 35B 39B, 40B 41B, 45B 46B and 47B were given 10% additions of Okene Quartz, blended and fired to 1280°C. Colour as well as fusion of materials observed.

3.8b SECONDARY CLAY ADDITION TEST (SCAT)

China bodies are notorious for their fragility and non-plasticity. This is due to the low clay content. Bone China bodies especially are flawed in this regard. This shortcoming is sometimes remedied by addition of up to 20% of ball clay or plasticizer. This addition makes slips suspend better and bind harder and come off moulds easier. The SCAT test, therefore, is aimed at achieving the aforementioned without destroying one quality for which Bone Chine is loved--whiteness of paste.

PROCEDURE: SCAT No. 34A 35A 39A 40A 41A 45A 46A and 47A were given 20% addition of Bomo Secondary Clay.

SCAT No. 34B 35B 39B 40B 41B 45B 46B and 47B were all given 10% addition of Bomo Secondary Clay.

These mixtures were thoroughly blended and fired to 1280°C (Cone 9). The behaviour of slip and resultant fired colour observed.

3.8c QUARTZ AND SECONDARY CLAY ADDITION TEST (QSCAT)

This is the test that brought together the five materials.

AIM: The aim is to strike a balance in the search for the ideal body in such qualities as hardness, translucency, plasticity, vitrification and whiteness of paste.

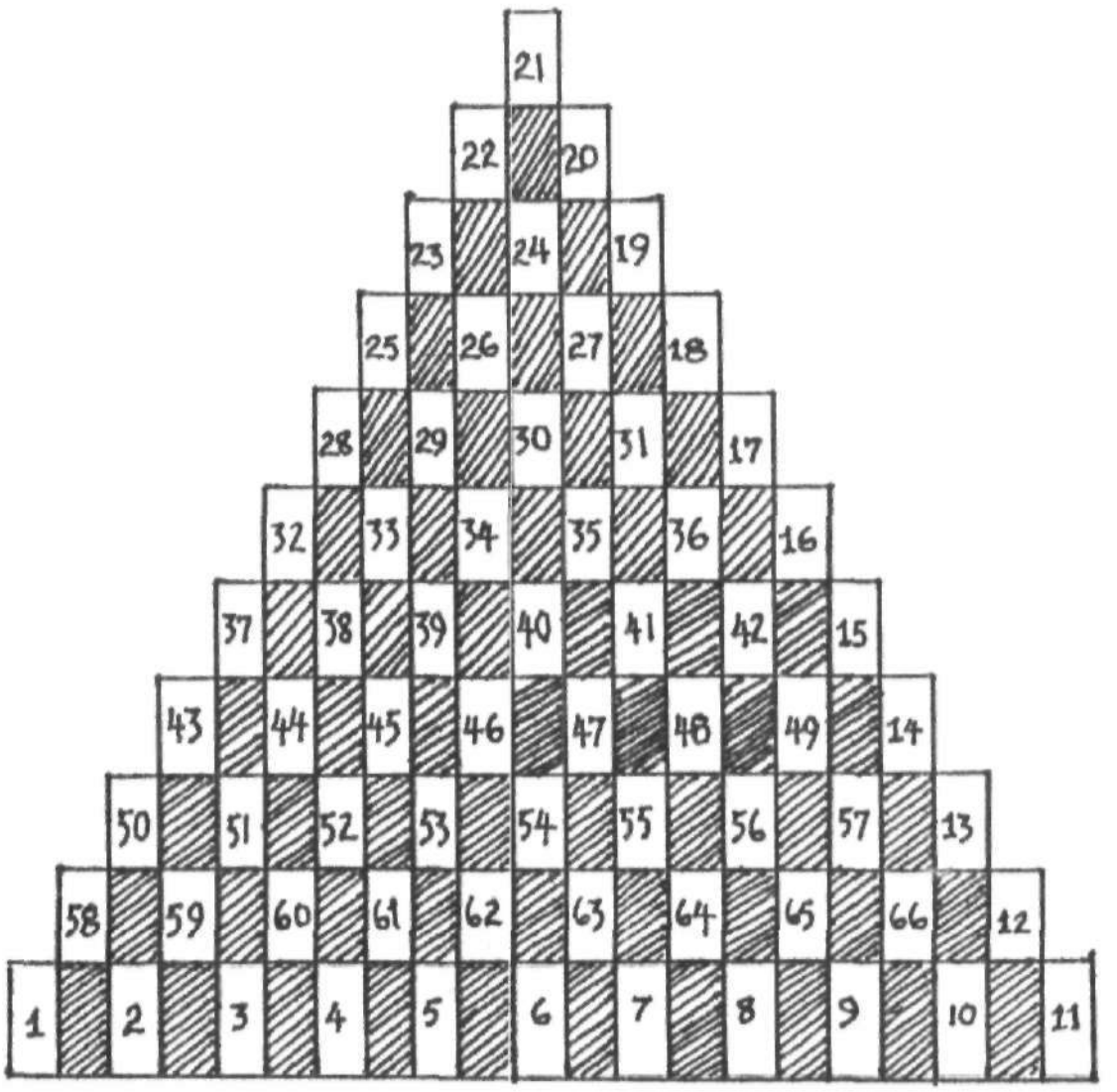


Figure 1. How Triaxial Test Tiles were numbered

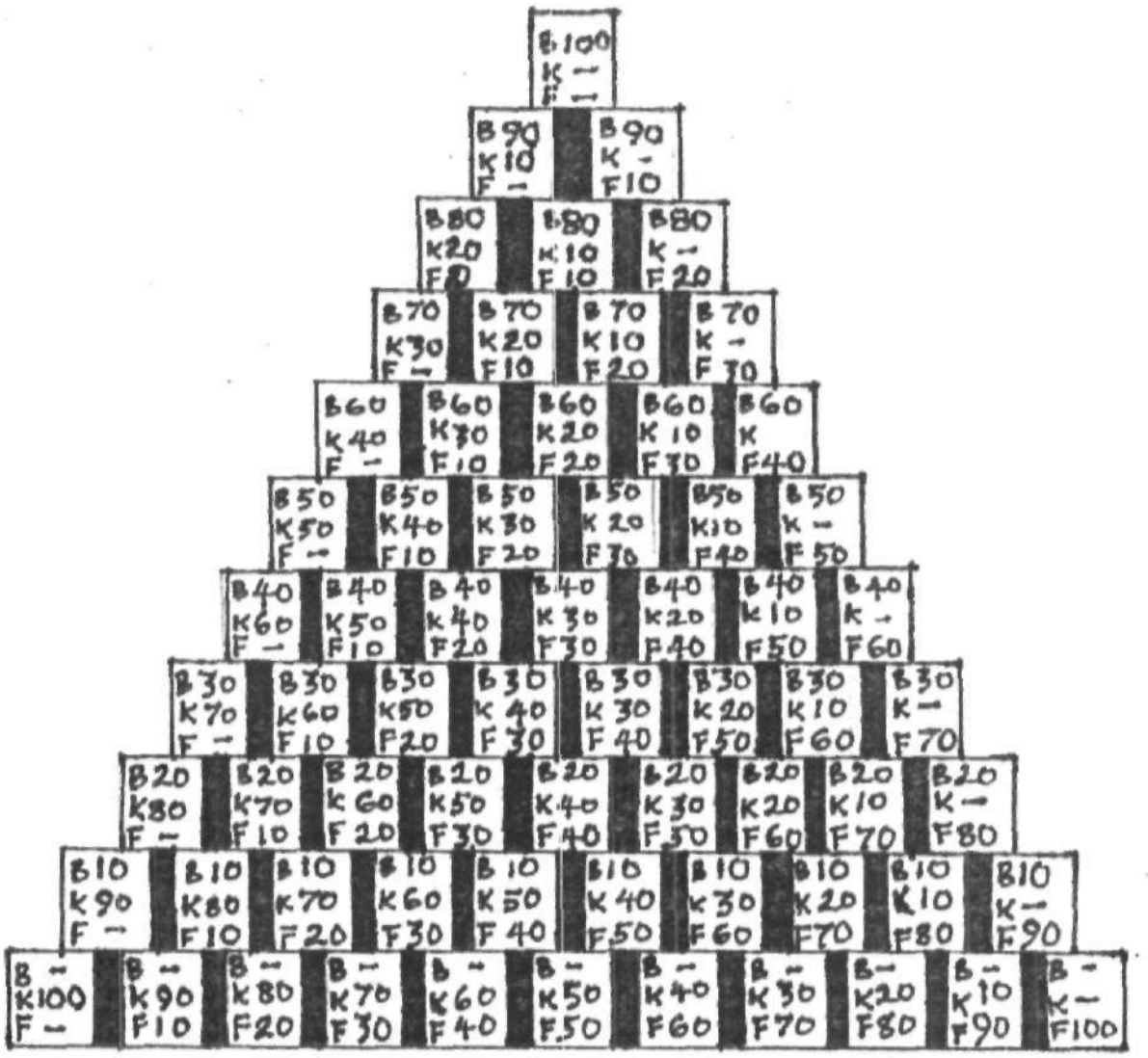


Figure 2. Rational Distribution of materials in the Triaxial blend

PROCEDURE: QSCAT No. 34, 35, 39, 40, 41, 45, 46 and 47 were all given 10% additions each of Okene Quartz and Bomo Secondary Clay. All tests were blended and put on marked tiles and fired to 1280^{o}C (Cone 9)

3.9 PREPARATION OF MOULDS FOR CASTING TESTS

Due to its lack of plasticity, Bone China is best produced by slip casting. Singer and Singer (1963).

This necessitated the making of two moulds and a bat to try out the different mixtures to ascertain their suitability for slip casting.

PROCEDURE: Models of a simple cup and a bowl were made. Commercial plaster of superfine quality was obtained and in agreement with Gukas (1985), Nelson (1971) and Oyintoke (1987) a mixture of 7 parts of plaster to 5 parts of water was used.

The plaster was first sieved to remove lumps and impurities if any. It was then carefully added to the water already in a bowl. This was allowed to settle and then gently stirred from the bottom to expel air bubbles trapped. This mixture set in four minutes and the now thickening paste was poured over the model now secured in its box (see Fig 3). The paste was evenly spread by a flat ruler as it thickened. Th entire plaster was hard in twenty minutes and what followed after was the careful removal of the clay model by removing a bit at a time until clean.

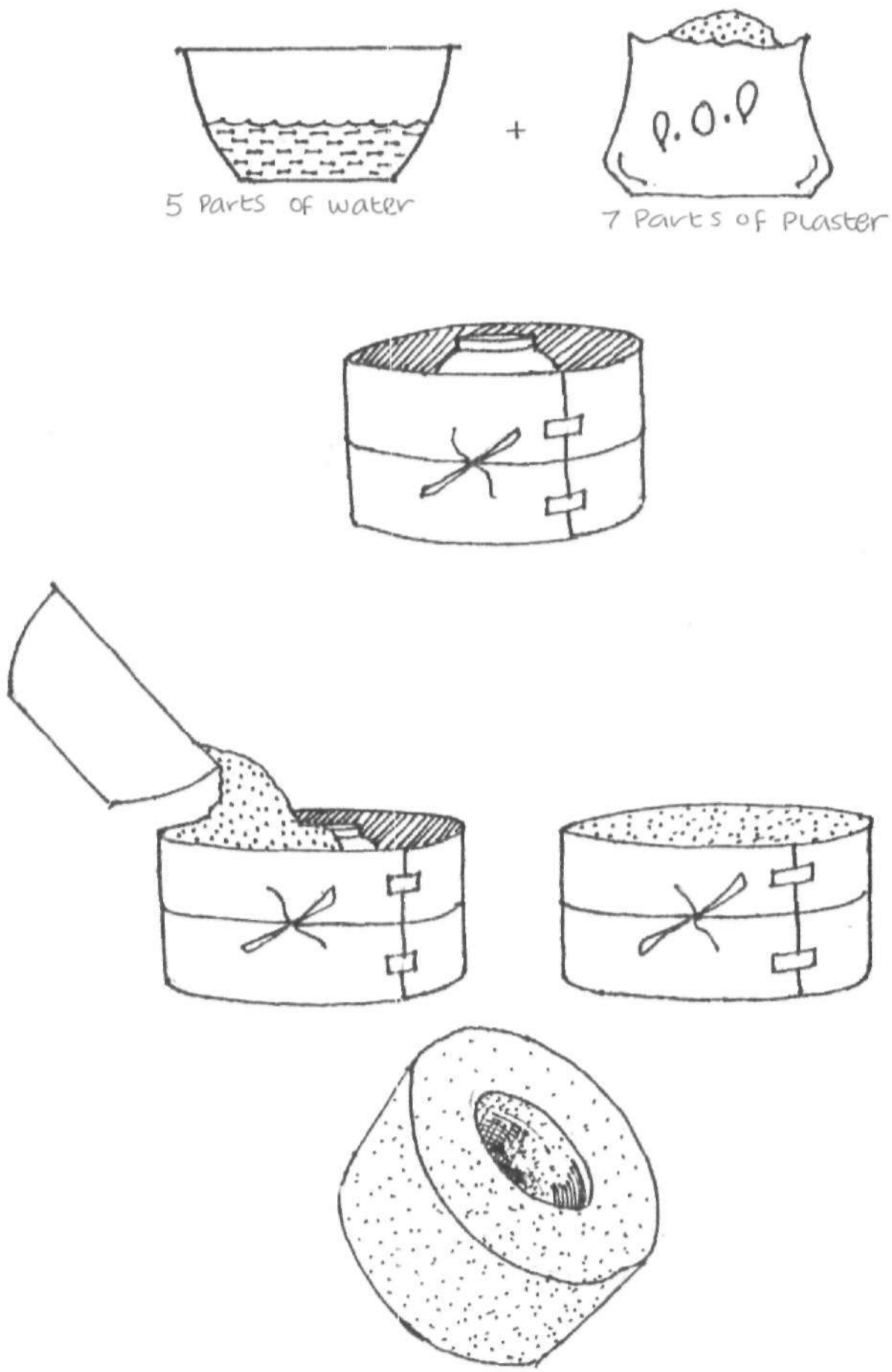


Figure 3. Making of the Plaster Mould

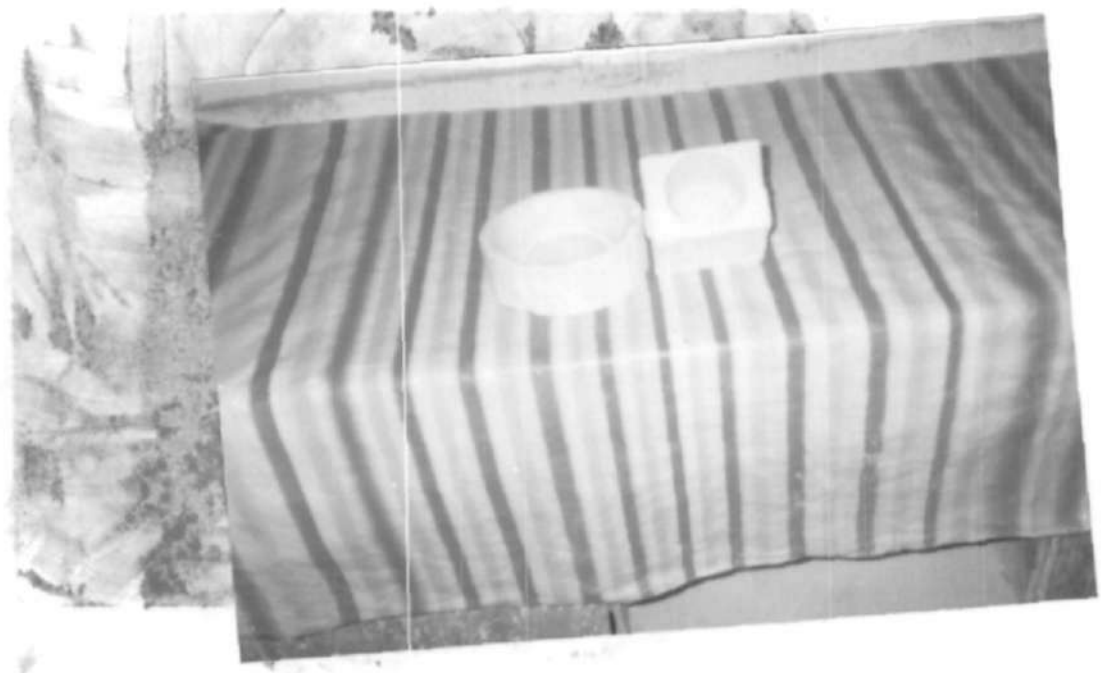


Plate II. Finished Moulds

3.10 SLIP CASTING TESTS

The Bone China body due to its fragility and lack of plasticity allows for a limited number of shaping methods. Slip casting being the most reliable, Singer and Singer (1963).

It was considered necessary to carry out preliminary tests on all bodies mentioned and thorough casting test on very likely bodies.

3.10a PLASTER BAT AND SLIP TEST

A simple plaster bat and slip test was carried out and all bodies subjected to it.

AIM: To determine the suitability of slips from the bodies for slip casting, as well as, test their fluidity under normal conditions.

PROCEDURE: Drops of slip from each of the test bodies were allowed to fall on the plaster bat and with the index finger, attempts were made to dislodge these droplets off the surface of the bat after one minute. Suitable ones were expected to move.

To test fluidity, a piece of stick was dipped in a consistency of slip from each of the bodies including additional test bodies. The running behaviour of these slips was visually recorded. Suitable ones were expected to run evenly.

3.10b SLIP CASTING OPERATION

Having found some mixtures very likely, a thorough slip casting test cum operation was carried out on the following bodies T34, T39, T45, and on SCAT 40B, SCAT 34B and SCAT 45B.

AIM: To find out casting qualities of these very likely bodies with the view of understanding them and agreeing on steps in slip casting operation.

PROCEDURE: The materials for each body were weighed and then sieved. 1% of deflocullant was then added to the dry material along with water which is 1/4 the weight of the dry material.

The mixtures were then put in the Ball Mill and milled for 4 hours. They were then left to settle for 6 hours. This allowed the observation of the action of deflocculants.

The moulds were then readied for casting by dusting with talc powder.

The mixtures were stirred and then poured into moulds and allowed to cast for 45 seconds; 60 seconds and between 90 and 120 seconds for thin, medium and thick casts. These three thicknesses apply to all bodies. The moulds were drained of excess slip and were quickly covered with cellophane to avoid quick drying and cracks.

After 10 minutes, excesses were trimmed and casts allowed to dry and disengage themselves from mould. They were then removed and when hard enough, fettled and dried gradually.



Plate III. Slip Casting Operation

3.11 FIRING TEST

Bone China is given a high bisque firing (1280°C) and a low glaze firing 1080°C. Therefore, whatever quality will be attained by the body will be determined by the bisque firing. It is in this firing that the strength of the bodies as vessels was tested.

Bone China is traditionally fired supported with Alumina and Silica powder or pure Silica sand.

The aim of the first test was to overcome the anormaly of having to support wares in firing and to, if very necessary, devise methods of supporting such wares.

PROCEDURE: In the second round of firing, shards of Bone China were put into the Kiln unsupported and fired to 1280°C. Their behaviour was recorded.

Hollowed vessels were put in the next round of firing unsupported. These were samples of the seven (7) bodies and of the three (3) thickness. They also have thick footrings for additional support.

PACKING: Most wares were made to sit on a layer of calcined Kaolin and Quartz powder. Others were well-supported with calcined Kaolin and pure Silica sand powder and yet others were left unsupported save for the generous coating of Alumina bath to protect Kiln furniture. Some wares were supported with pure river sand.

FIRING: Firing was done in oxidation with all secondary air inlets open.

CHAPTER FOUR

PRESENTATION AND ANALYSIS OF DATA

4.1 INTRODUCTION

The main purpose of this study as stated earlier is to determine the feasibility of Bone China production in Nigeria using 100% local materials.

One of the objectives of the study is to find variants in the Bone China compostion especially such that could mature at high temperature, and such that with some additions, will be on the strong side.

The result of the Tri-axial test and subsequent tests on the potential mixtures forms the bulk of the information processed.

4.2 TRIAXIAL TEST

The Tri-axial Test as the name implies is a test involving three minerals. The three mineral used behaved in the manner predicted. Kaolin and Bone Ash remained refractory at 1280^{o}C; both just sintered while true to character, Feldspar melted into glass. Tests No. T21 to T32, as well as, tests T17 to T19 all in areas of high bone ash activity yielded brilliant white and hard bodies that show little sign of fusing especially in the area where the activities of bone ash and Kaolin are prominent.

In the area where the activities of bone ash and feldspar are more prominent, the behaviour of two active high temperature fluxes is noticable, e.g. in T42, T15, T14 and T13 where some bloating occured. This results from the presence of Calcia in large proportion at that critical point where the fluxing power of Feldspar is evident.

Test T33 yielded hard and white body with bluish tint while Tests T34 and T35 showed signs of vitrifying and glass forming. Tests T36 and T16 remained white and hard. T37 and T38 are also hard and white. This is not unexpected as they all fall in the area of high Kaolin concentration. Test T39 and T40 turned out hard, white with traces of blue and are translucent. This is the very heart of the test where the three materials react in almost equal proportion. Test T41 is also hard and white but is rather glassy, an indication of high Feldspar proportion.

Test T42 and T15 show signs of Felspar activity as they melted into glass with T15 especially showing signs of bloating. Tests T43 and T44 all fall in the area of high Kaolin influence and are hard and white. Test T45 is a thorough blend of the three materials. It is, therefore, strong, white and translucent. Tests T46 and T47 vitrified solid with T47 especially turning glassy. T48, T49 and T14 all high in Feldspar and ash turned glass and foamed.

Test 50, high in Kaolin turned brown and is badly stained. 51 and 52 are white and hard while 53 and 54 vitrified solid and fused completely! Tests 55, 56, 57 and 13 turned glass! Test 58 turned brown and hard, 59 also high in Kaolin fared better by coming out hard and white. Test 60 to 66, as well as, Test 12 all high in Feldspar turned glass.

Test 1 is 100% Kaolin. It is, therefore, white and just sintered. Tests 2 and 3 are also hard and white but the fluxing power of Feldspar overwhelms Kaolin in Tests 4 to 11 as they simply turned glass with Test 11 especially, which is 100% Feldspar forming glass that settles on the test tile like candle wax.

4.3 ADDITIONAL TESTS

4.3a SHRINKAGE TEST

This test aimed at determining the shrinkage rate of all bodies produced some interesting results.

Tests 34 and 35 had 18% shrinkage while 40 and 46 both recorded 15% shrinkage. Tests 41 and 45 had 16%. 47 had 16.8% while 45 had 17% shrinkage. (see Table 4.1)

TABLE 4.1

SHRINKAGE TEST RESULTS

S/No	BODY	PL	DL	DS %	FL	SHRINKAGE %
1	34	10cm	9.27cm	7.3	8.2	18
2	35	10cm	9.02cm	9.8	8.2	18
3	39	10cm	9.3 cm	7.0	8.3	17
4	40	10cm	9.55cm	4.5	8.5	15
5	41	10cm	9.62cm	3.8	8.4	16
6	45	10cm	9.42cm	5.8	8.4	16
7	46	10cm	9.45cm	5.5	8.5	15
8	47	10cm	9.22cm	7.8	8.32	16.8

Source: Studio Tests, 1987

4.3b POROSITY TEST RESULTS

This test also yielded interesting results. The Bone China bodies having attained their highest firing temperature at bisquit stage became so dense that after soaking them for 24 hours, some recorded no absorbtion at all.

Bodies 46 and 47 weighed the same after firing and having spent 24 hours in water they, therefore, record 0% absorbtion. Tests 34, 45, 35 and 39, however, recorded slight increase in weight. All, however, have between 0%-7%porosity. (see Table 4.2)

TABLE 4.2

POROSITY TEST RESULT

S/No	BODY	FW/gm	SW/gm	ABSORBTION %
1	34	20	20.14	0.7
2	35	20.5	20.1	0.5
3	39	20	20.14	0.7
4	40	19	19.1	0.5
5	41	20	20.1	0.5
6	45	20	20.14	0.7
7	46	20	20	0
8	47	20	20	0

Source: Studio Tests, 1987

4.3c MODULUS OF RUPTURE TEST RESULTS

The Modulus of Rupture Test result revealed the strength of the eight bodies. It was the result of this test that necessitated the addition of clay as some bodies turned out very fragile. Bodies 46 and 47 especially were fragile. (seeTable 4.3)

TABLE 4.3

MODULUS OF RUPTURE TEST RESULT

S/No	BODY	BREAKING LOAD/kgs	STRENGTH %
1	34	2.22	48.1
2	35	1.52	32.9
3	39	1.88	40.7
4	40	2.22	48.1
5	41	1.36	29.46
6	45	1.91	41.38
7	46	1.38	29.9
8	47	1.38	29.9

Source: Studio Tests, 1987

4.3d QUARTZ ADDITION TEST (QAT)

Results from this test are not promising as most test bodies especially those with 20% additions of quartz fused beyond expectation.

Bodies with 10% additions yielded white hard and in some cases glassy results. Tests QAT 34, 35 and 39 show promise as with 10% quartz addition they turned dense with slight indications of glass forming.

Tests QAT 41, 45, 46 and 47 turned milky white glass. The quartz doing more harm than good. (see Table 4.4)

TABLE 4.4

QUARTZ ADDITION TEST RESULT

S/No	BODY	RAW COLOUR	STRENGTH	SLIP CASTING	FIRED CHARACTER	FIRED COLOUR
1	34A	DARK	LESS FRAGILE	NEGATIVE	DENSE	WHITE
2	34B	DARK	LESS FRAGILE	NEGATIVE	DENSE	WHITE
3	35A	DARK	FRAGILE	NEGATIVE	FUSED	WHITE
4	35B	DARK	FRAGILE	NEGATIVE	DENSE	WHITE
5	39A	GREY	LESS FRAGILE	NEGATIVE	FUSED	WHITE
6	39B	GREY	LESS FRAGILE	NEGATIVE	DENSE	WHITE
7	40A	BROWN	FRAGILE	NEGATIVE	FUSED	WHITE
8	40B	BROWN	FRAGILE	NEGATIVE	FUSED	WHITE
9	41A	TAN	FRAGILE	NEGATIVE	FUSED	WHITE
10	41B	TAN	FRAGILE	NEGATIVE	FUSED	WHITE
11	45A	TAN	LESS FRAGILE	NEGATIVE	FUSED	WHITE
12	45B	TAN	LESS FRAGILE	NEGATIVE	FUSED	WHITE
13	46A	TAN	FRAGILE	NEGATIVE	FUSED	WHITE
14	46B	TAN	FRAGILE	NEGATIVE	FUSED	WHITE
15	47A	TAN	FRAGILE	NEGATIVE	FUSED	WHITE
16	47B	TAN	FRAGILE	NEGATIVE	FUSED	WHITE

Source: Studio Tests, 1987

4.3e SECONDARY CLAY ADDITION TEST RESULTS

Results from this test were also not promising as there was a double action of bodies vitrifying and changing colour. SCAT 34A, 35A 39A 40A turned very dark and fused. SCAT 41A, 45A 46A and 47A simply turned dark glazes.

Bodies with 10% additions fared better as SCAT 34B, 35B and 39B showed signs of retaining their light colour and at the same time *remain dense but not completely fused as others.*

SCAT 46 and 47 lost their character as bodies and simply turned to glazes. Bomo Clay joined in the action of fluxing and staining. (see Table 4.5)

TABLE 4.5

SECONDARY CLAY ADDITION TEST RESULTS

S/No	BODY	SLIP CASTING	FIRED COLOUR	FIRED CHARACTER	REMARK
1	34A	POSITIVE	DARK	FUSED	STRONG
2	34B	POSITIVE	GREY	FUSED	STRONG
3	35A	POSITIVE	DARK	FUSED	STRONG
4	35B	POSITIVE	LIGHT GREY	FUSED	STRONG
5	39A	POSITIVE	DARK	FUSED	STRONG
6	39B	POSITIVE	GREY	FUSED	STRONG
7	40A	NEGATIVE	DARK	FUSED	FRAGILE
8	40B	NEGATIVE	LIGHT GREY	FUSED	FRAGILE
9	41A	NEGATIVE	DARK	GLASSY	FRAGILE
10	41B	NEGATIVE	LIGHT GREY	GLASSY	FRAGILE
11	45A	POSITIVE	GREY	GLASSY	LESS FRAGILE
12	45B	POSITIVE	LIGHT GREY	GLASSY	LESS FRAGILE
13	46A	POSITIVE	LIGHT GREY	GLASSY	FRAGILE
14	46B	NEGATIVE	LIGHT GREY	GLASSY	FRAGILE
15	47A	POSITIVE	LIGHT GREY	GLASSY	FRAGILE
16	47B	NEGATIVE	LIGHT GREY	GLASSY	FRAGILE

Source: Studio Tests, 1987

4.3f QUARTZ/SECONDARY CLAY ADDITION TEST RESULTS

In this test, few bodies show promise. QSCAT 34, 35 and 39 retained a light grey colour and remained dense. Others vitrified and turned glass and also retained a grey colour.

4.4 SLIP CASTING TEST RESULTS

With the discovery of very likely bodies, an intensive slip casting test cum operation was carried out. The casting results of each slip was recorded as follows:

T34

Recipe

Bone Ash	500gms
Okene Feldspar	200gms
Kankara Kaolin	300gms
Deflocculants	10gms
Water	500mls

The slip was found to run well and cast very very fast. The cast piece cracked easily even while still in the mould and so both mould and cast piece had to be wrapped in cellophane to prevent further cracks.

Three sizes (in thickness) emerged from the varied casting period.

- 45 seconds produced thin wares
- 60 seconds produced medium sized wares
- 90 to 120 seconds produced thick wares

The cast piece dropped out of the mould after 30 minutes and dried evenly and safely even without covering.

SCAT 34B

Recipe

Bone Ash	450gms
Okene Feldspar	180gms
Kankara Kaoline	270gms
Bomo Clay	100gms
Deflocculants	10gms
Water	500mls

This slip runs very well due to the 10% plastic clay but casts slow.

45 seconds of casting period for this slip produced very thin pieces. It was possible to leave both cast and mould open for a while without running the risk of having cracks. This cast piece dropped out of the mould easily and dried out well.

T39

Recipe

Bone Ash	400gms
Okene Feldspar	200gms
Kankara Kaolin	400gms
Deflocculants	10gms
Water	500mls

This slip runs well and casts very fast due to the high ratio of non-plastic materials. It had to be covered with cellophane to avoid cracks. It was easy to make the three sizes desired in 45 seconds, 60 seconds and 90 seconds respectively. The cast dropped out of the mould without difficulty but was fragile for hours.

SCAT 40B

Recipe

Bone Ash	360gms
Okene Feldspar	270gms
Kankara Kaolin	270gms
Bomo Clay	100gms
Deflocculants	10gms
Water	500mls

This slip also runs well and casts and dries slowly. It did not crack in the mould as did T34 and T35.

This slip also cast thinner pieces in the set periods of 45 seconds; 60 seconds and 90 seconds. It is much easier to handle and dropped off the mould easy. It also dried harder as the clay bonded other loose materials.

T45

Recipe

Bone Ash	300gms
Okene Feldspar	300gms
Kankara Kaolin	400gms
Deflocculants	10gms
Water	500mls

This slip without secondary clay also presented some problems as it dried quickly in the mould, developing a network of cracks. This was, however, overcome when mould and stiffening cast piece were wrapped in cellophane to allow for equal drying on both the surface and the action of the plaster flocculating the slip. The piece, however, came off the mould effortlessly.

T46

Recipe

Bone Ash	300gms
Okene Feldspar	400gms
Kankara Kaolin	300gms
Deflocculants	10gms
Water	500mls

The slip high in non-plastic materials like Feldspar and Bone Ash behaved like others of its kind presenting some casting problems. The quick drying of the surface of the cast piece resulting in numerous cracks. This problem was solved by wrapping mould and piece in cellphane as soon as the mould is drained of excess slip. By wrapping in cellphane, the drying rate at the surface and by the plaster from below is synchronised. The cast piece came off the mould well and reasonably thick and thin pieces were made in the alloted time. The dry pieces are, however, very fragile like others.

4.5 FIRING TEST RESULTS

All tests minus the Modulus of Rupture test went into the Kiln at least once. So, apart from cast pieces, other tests like the porosity and shrinkage tests went into the Kiln and helped provide information on the character of the bodies at $1280^{\circ}C$.

In the first round of firings, it was discovered that T34, T39 and T45 retained their denseness consistently. T41 bloated twice while T47 on all ocassions stuck to the selves. T35 bloated in two firings.

All the test pieces shrank considerably. The following was recorded as the thickness of the three sizes cast.

TABLE 4.6

FIRING TEST RESULTS

S/No	TEST BODY	THIN	MEDIUM	THICK
1	SCAT 34B	0.1mm	0.2mm	0.25mm
2	SCAT 40B	0.1mm	0.2mm	0.25mm
3	T 34	0.2mm	0.25mm	0.3mm
4	T 39	0.2mm	0.25mm	0.3mm
5	T 45	0.2mm	0.25mm	0.3mm
6	T 46	0.2mm	0.25mm	0.3mm

Source: Studio Tests, 1988

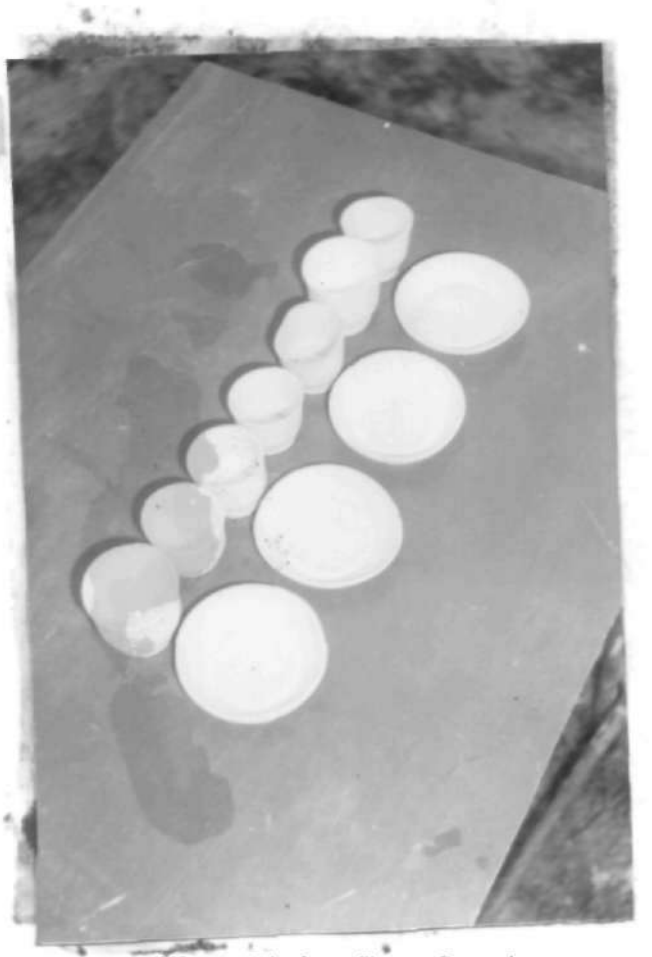


Plate IV. **Firing Test Results**

4.6 DISCUSSIONS

Having carried out the required tests, certain issues that required discussions arose.

Tests, T35, T41 and T47 high in Feldspar and Bone Ash bloated at least once in firing due to the presence of two active high temperature fluxes. Calcia in Bone Ash and Potassium in Feldspar being lime and Alkaline respectively. Because these tests bloated, they were eliminated from subsequent tests. T40 which also showed signs of bloating fared better however, with some improvements as SCAT 40B.

Due to the low clay content, most bodies apart from their fragility, shrinkage and fast drying was severe. Bodies with about 40% Kaolin content or with 10% additions of seondary clay as in SCAT 34B, 35B and 39B shrank less and bonded harder.

The resultant grey colour from 10% to 20% additions of Bomo Secondary Clay stems from the presence of impurities such as Iron, Manganese and Magnesium.

Test pieces with cracks deteriorated further in firing - an evidence of the irreversible nature of casting faults in Bone China.

Faulty shaping also accounted for warpage. This is due to the thinness of some areas which easily gave way in firing resulting in distortion.

Because calcined Kaolin and Silica sand powder supported some test wares from within, they retained their symmetry.

A firing range of 1260^{o}C to 1280^{o}C has been established as adequate. Underfiring occured in the cold part of the Kiln giving an insight into the character of Bone China at about 1250^{o}C. Overfiring also accounted for some losses through warpage.

Use of deflocculants was considered desirable and tests proved so as after six hours slips especially those low in clay showed signs of settling.

15% to 18% shrinkage recorded fall within acceptable limits for porcelains and China. Also 0% to 0.7% absorbtion percent fall within limits.

Translucency is attained upon maturity. Samples from the cold parts of the Kiln though white appeared blank and opaque. This is due to the non-completion of fusion by materials.

Grinding of materials accounted for the translucency and brilliance of especially T39, T47, and T34. All slips were ground for four hours.

Bodies high in Bone Ash, T34, T35 all with 50% Bone Ash while being translucent also are less prone to warpage confirming Singer and Singer's (1963) assertion about the need to formulate mixtures with as much Bone Ash as possible.

4.7 FINDINGS

In the course of the slip casting operation, it was discovered that bodies high in Bone Ash and Feldspar dried fast and crack more. conversely, bodies with secondary clay additions cast and dry slower consequently, they crack less.

Wrapping plaster and piece in cellophane reduced the incidence of cracking as the rate of drying was thus syncronised.

Once off the mould, cast pieces survive the atmospheric conditions and dry out even uncovered.

Bodies high in Kaolin shrank less but absorbed more water.

Mixtures from areas of high Kaolin influence yielded denser and stronger bodies.

Mixtures from areas of heavy Feldspar concentration yielded sticky, glassy bodies and glazes.

Additions of 20% of Okene Quartz and Bomo Clay did more harm than good. These test wares fused and stuck to the shelves. With 10%, some wares came out dense and coloured.

Additions of 10% of Bomo Clay improved on the workability of all bodies.

Thin and medium sized pieces from especially SCAT 34B and 40B, as well as, from other bodies warped badly in firing.

Thick pieces shrank but did not warp as baldy as the thin ones.

10% addition of Bomo Clay gave a greenish tint in bodies SCAT 34B and 40B resulting in slight reduction in translucency.

Supported wares retained their shapes attaining almost 100% symmetry no matter how thin they are. Upon contraction, however, they crack if the rate is more than that of the powder supporting them.

Wares packed in the hottest parts of the gas Kiln, i.e. near the burners melted and collapsed. Others vitrified and warped badly, but are strong and translucent.

Wares in areas of medium heat matured well, giving a sharp note when struck and are also very translucent.

Test wares packed in the coldest parts of the Kiln came out white while apparently underfired giving a dull sound when struck, shrinking less and containing reminants of organic matter on their surfaces; such matter that evaporates only at very high temperature.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This study from the onset was concerned with the utilization of selected local raw materials in the production of Bone China; especially such that can be produced in the most austere conditions.

The contents of this chapter are the summary, conclusions, and recommendations arising from the Studio tests that formed the basis of this write up.

5.2 SUMMARY

The search for the suitable materials for the Nigerian Bone China mixture(s) led to the trial of previously not analysed materials. The study commenced with an analysis of these materials with the aim of proving their worth for commercial exploitation.

A tri-axial blend of Okene Feldspar, Bone Ash and Kankara Kaolin provided the eight mixtures which formed the foundation for further test.

The selected raw materials behaved in the manner predicted and upon further tests yielded bodies suitable for mass production of Bone China.

5.3 CONCLUSIONS

From the results of the numerous tests in this study, it has become clear that:

1. There exist in abudance local raw materials suitable for the production of Bone China.

2. If the three basic materials are processed and manipulated as suggested, they could be adequate for Bone China production.
3. The 10% additon of Bomo Secondary Clay is adequate where a more plastic body is desired. However, it means sacrificing whiteness of paste.
4. A casting period of between 90-120 seconds will produce the required thickness that is economical, as well as, possessing the potential of surviving 1280°C.
5. Thickness is a factor in symmetry of wares. Tests T34 and T35 especially could be fired unsupported if cast thick.
6. Thin wares can be supported with powdered calcined Kaolin and Silica sand and retain 100% symmetry.
7. The higher the Bone Ash content the safer, the stronger and the more translucent.

5.4 GENERAL RECOMMENDATIONS

1. Efforts should be made as a matter of urgency to establish service industries for ceramic industries. Such industries that process raw materials such as Feldspar and Quartz.
2. Attempts should be made by local ceramic industries to produce tableware from locally processed raw materials. This will no doubt save foreign exchange.
3. The Ahmadu Bello University should, as a matter of urgency, procure those facilities necessary for successful research in areas like this. In particular, there is need for new electric Test Kilns equipped with pyrometers.

5.5 RECOMMENDATIONS FOR FURTHER RESEARCH

1. The search for Bone China bodies should continue and in this direction, attention should be given to materials from other parts of the country.
2. There is need for suitable fritted glazes for these bodies. Since research into glazes and glazing is a wide area, future researches into Bone China glazes should focus on the possibility of fritting local materials for medium temperature China glazes.
3. Attempts should be made to find a light coloured secondary clay to serve as plasticizer as even small additions of dark clay discolour the body.
4. Attempts should also be made to use some mixtures like T34, T35 and T39 as foundation for further research into Dental Ceramics.

REFERENCES

Books

1. Adetoro, S. A. (1986) Research Techniques. Zaria: Gaskiya Corporation

2. Cardew, M. (1969) Pioneer Pottery. London: Brydone Limited

3. Drawbell, M. (1953) Making Pottery Figures. London: The Studio Publications

4. Griffiths, R and Radford, C. (1965). Ceramic Calculations. Shewsbury: Livesey Limited

5. Hamer, F. (1975) The Potters Dictionary of Materials and Techniques. London: Pitman Publications

6. Hamilton, D. (1982) Pottery and Ceramics. London: Thames and Hudson

7. Honey, W. B. (1963) European Ceramic Art. London: Faber and Faber

8. Hughes, B. and T. (1955) English Porcelain and Bone China. London: Lutterworth Press

9. Marryat, J. (1857) A History of Pottery and Porcelain Medieval and Modern. London: John Murray

10. Nelson, G. C. (1971) Ceramics: A Potter's Handbook: New York: Richard and Winston, Inc.

11. Rhodes, D. (1973) Stoneware and Porcelain: The Art of High-fired Pottery. Philadelphia: Chilton Book Company

12. Roscoe, W. (1963) Manual for the Potter. London: Alec Tiranti Limited

13. Singer, F. and Singer S. (1963) Industrial Ceramics. London: Chapman and Hall

Unpublished Thesis and Reports

1. Gukas, H. J. (1985) "A Feasibility Study for the Formulation of some Porcelain bodies from local resources." M.A. Thesis submitted to the Post-Graduate School, Ahmadu Bello University, Zaria, Kaduna State

2. Musoke, W. L. (1987) "Development of Pyrometric Cones." M.A. Thesis submitted to the Post-Graduate School, Ahmadu Bello University, Zaria, Kaduna State

3. Okoruwa, P. E. (1986) "The Utilization of some selected local materials for Porceleain Slip Casting and Glazing of moulded ceramics." M.A. Thesis submitted to the Post-Graduate School, Ahmadu Bello University, Zaria, Kaduna State

4. Oyintoke, R. S. (1987) "Report on Industrial Attachment at Ceramic Manufacturers Nigeria Limited, Challawa, Kano, Kano State." B.A. (Industrial Design), ITF Report

Articles

1. Webster, A. and Dinsdale (1969) "The Calcining and Grinding of Bone." Transactions of the British Ceramic Society, Vol. 68 London: The British Ceramic Research Assocation

APPENDIX 1

RECIPE OF ALL TEST BODIES

BODY	BONE ASH	KAOLIN	OKENE FELDSPAR	OKENE QUARTZ	BOMO CLAY
QAT 34A	40	24	16	20	-
QAT 34B	45	27	18	10	-
QAT 35A	40	16	24	20	-
QAT 35B	45	18	27	10	-
QAT 39A	32	32	16	20	-
QAT 39B	36	36	18	10	-
QAT 40A	32	24	24	20	-
QAT 40B	36	27	27	10	-
QAT 41A	32	16	32	20	-
QAT 41B	36	18	36	10	-
QAT 45A	24	32	24	20	-
QAT 45B	27	36	27	10	-
QAT 46A	24	24	32	20	-
QAT 46B	27	27	36	10	-
QAT 47A	24	16	40	20	-
QAT 47B	27	18	45	10	-
SCAT 34A	40	24	16	-	20
SCAT 34B	45	27	18	-	10
SCAT 35A	40	16	24	-	20
SCAT 35B	45	18	27	-	10
SCAT 39A	32	32	16	-	20
SCAT 39B	36	36	18	-	10

BODY	BONE ASH	KAOLIN	OKENE FELDSPAR	OKENE QUARTZ	BOMO CLAY
SCAT 40A	32	24	24	-	20
SCAT 40B	36	27	27	-	10
SCAT 41A	32	16	32	-	20
SCAT 41B	36	18	36	-	10
SCAT 45A	24	32	24	-	20
SCAT 45B	27	36	27	-	10
SCAT 46A	24	24	32	-	20
SCAT 46B	27	27	36	-	10
SCAT 47A	24	16	40	-	20
SCAT 47B	27	18	45	-	10
QSCAT 34	40	24	16	10	10
QSCAT 35	40	16	24	10	10
QSCAT 39	32	32	16	10	10
QSCAT 40	32	24	24	10	10
QSCAT 41	32	16	32	10	10
QSCAT 45	24	32	24	10	10
QSCAT 46	24	24	32	10	10
QSCAT 47	24	16	40	10	10

APPENDIX 2

PYROMETRIC CONES AND MELTING TEMPERATURES

CONE No.	MELTING TEMPERATURE(^{o}C)
01	1080
1	1100
2	1120
3	1140
4	1160
5	1180
6	1200
7	1230
8	1250
9	1280
10	1300
11	1320
12	1350
13	1380
14	1410
15	1430

Source: Nelson, G. C. Ceramics: A Potter's Handbook, (1971)

APPENDIX 3

COLOUR WITHIN THE KILN DURING FIRING

TEMPERATURE (^{o}C)	COLOUR	FIRED WARE
500	dull red	-
750	red	enamels
1,000 1,000	bright red orange red	biscuit and earthen- ware glazes
1,150	bright orange	high biscuit
1,200 1,300	white orange white	stoneware; bone china biscuit
1,350	blue white	porcelain

Source: Hamilton, D. Pottery and Ceramics, 1982

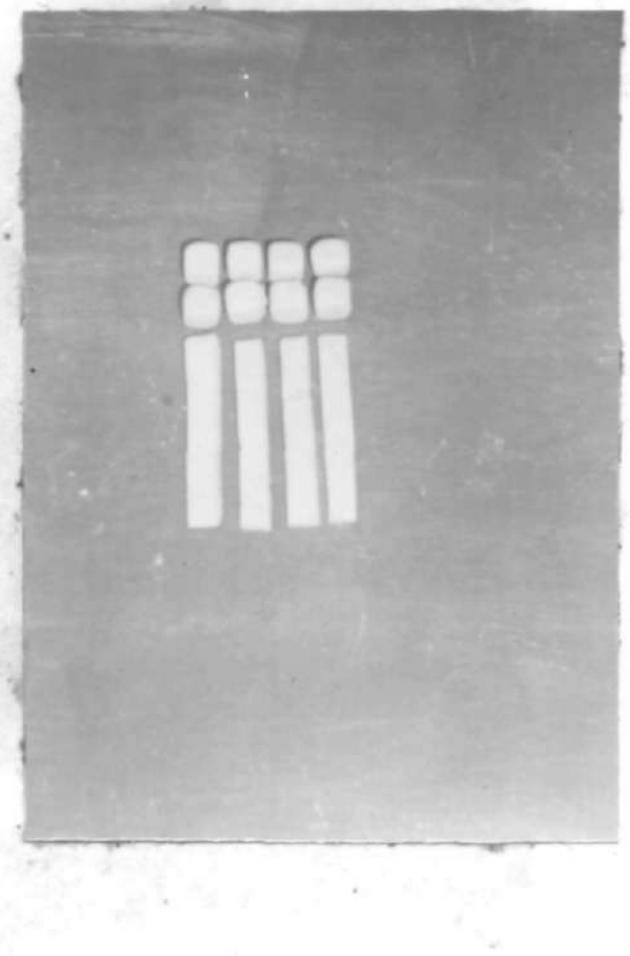
APPENDIX 4

TRIAXIAL TEST



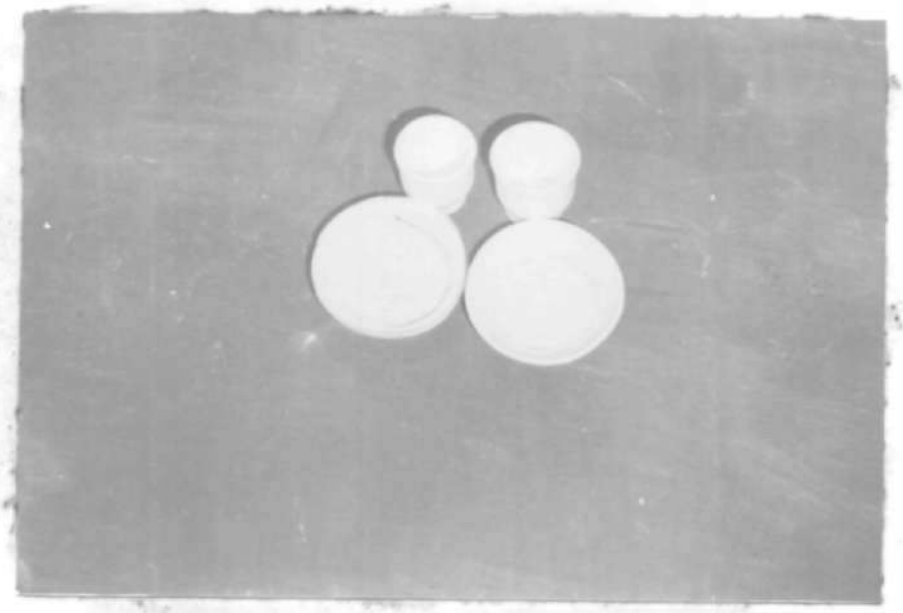
APPENDIX 5

TEST BARS AND TEST CUBES



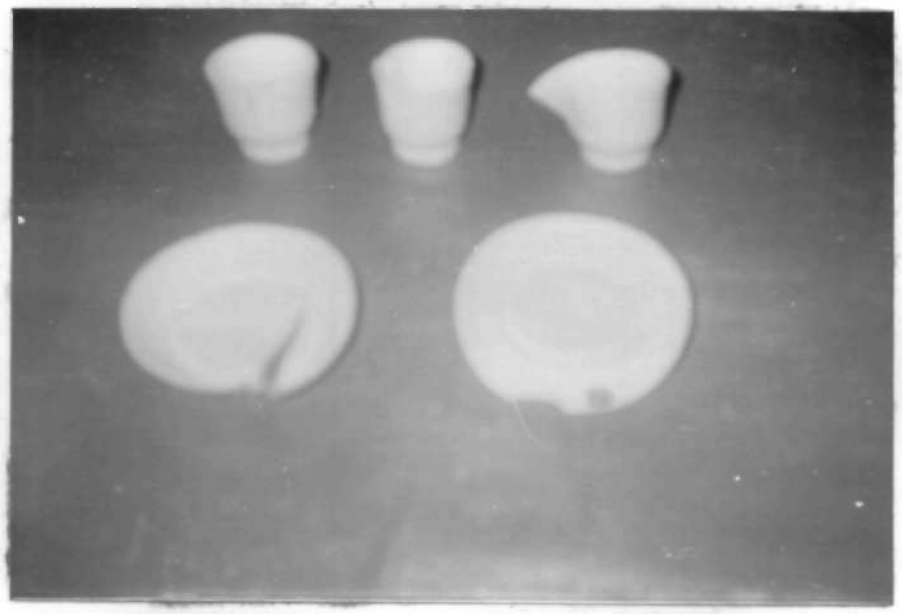
APPENDIX 6

SUPPORTED WARES



APPENDIX 7

FAULT
(Cracks)



APPENDIX 8

FAULT
(Warping)

