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Research on Porcelain Material for Product Design and Manufacturing in Kenya: Assessing SiO_2 Al_2O_3 Content

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Abstract

This study describes interdisciplinary research with the objective of identifying local raw material resources that can be used for manufacturing high-quality Kenyan porcelain products. The study details experiments on a kaolin raw material (Kisii soapstone) at Jingdezhen Ceramic Institute. A high-temperature, white stoneware slip-casting slurry is developed. X-ray fluorescence (XRF) and X-ray diffraction (XRD) analysis, shrinkage and product assessment tests are used to gauge the material's excellence. A detailed comparative analysis is provided of the SiO_2 Al_2O_3 chemical properties with those of raw materials used in Chinese porcelain manufacturing during the Yuan dynasty. The comparative analysis indicates SiO_2 Al_2O_3 similarities with those of the Kenyan raw materials and acknowledges the suitability of these Kenyan materials for manufacturing high-quality porcelain equivalent to that made in Jingdezhen. The purpose of the research is to align Kenyan ceramic raw material resources to 21st-century product manufacturing technologies and applications for manufacturing high-quality products.

Keywords: Chemical properties, Kisii soapstone, porcelain technology, product design application, SiO_2 Al_2O_3, slip casting

I. Introduction

Kisii soapstone is a kaolin raw material resource found in Kisii county, Kenya. It can be used for manufacturing high-temperature porcelain materials. In Kenya, Kisii soapstone is majorly used for stone carvings in unique hand-made functional and aesthetic works of art widely sold on markets at home and abroad. Akama and Onyambu's[1] historical investigations mention the transformation of soapstone products from traditional utility items to handicrafts sold to tourists, and the role they play in promoting a sustainable livelihood for the people of Tabaka, in Kisii county. Even though soapstone crafts still remain a major source of economic activity for the Tabaka community and in the Kisii environs today, they are on the decline. In Kisii, quarries and carving sites have a lot of leftover material waste that has accumulated from carving activities. The material wastage, which raises concerns about environmental issues and raw material resource optimization, can, however, be harvested, recycled and used as substitute material in ceramic product manufacturing. The soapstone carving trade also has highly skilled artisans who can be a valuable human resource for ceramic product design and manufacture.

The Kisii County Government Milestones Magazine[2] mentions that the bedrock of Kisii soapstone spreads over 40 square kilometres, and experts estimate that only 20 percent has been exploited so far. Kisii soapstone is readily available from community quarries and on the ground a square foot sells for about \$ 2.60 to \$ 4.50 while a ton goes for about \$ 800.00. In Kisii, much of the soapstone is mined crudely,exported as a raw material or used locally by soapstone carvers to make figurines. According to the relevant literature[2], the miners, carvers and artists have, however, not yet fully benefitted from the potential of the raw materials. Kisii basalt comprises subaquatic basalt and andesitic basalt, as described in Pinna *et al.*[3]. Meert *et al.*[4] states that the metamorphism in the Kisii stone series resulted from syngenetic hydrothermal activity (forming the famous Kisii soapstone) slightly affected (by normal faulting) during the development of the East African rift. Obwori's *et al.*[5] study mentions that from surface outcrops, the Kisii stones at Tabaka occupy an area 500 m long from north to south and 400 m wide from west to east. The deposit, however, is found on a ridge with rather steep slopes. Pekkala and Mulaha[6] state that Kisii soapstone consists of two main minerals: kaolinite (30 – 50 %) and sericite (40 – 50 %); minor quantities of pyrophyllite (5 – 20 %) are present and opaque minerals may constitute 10 – 20 % of the rock and are usually very fine-grained. According to Pulfrey[7], soapstones from the Kisii local area are largely a mixture of a kaolinitic mineral and a sericitic mica, derived as a result of the hydrothermal alteration of lava.

This study therefore experiments on the production of a high-quality slip-casting clay using Kisii soapstone slurry. It includes tests on chemical analysis of Kisii soap-

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stones using X-ray fluorescence (XRF) and X-ray diffraction (XRD) analysis. A theoretical argument is formulated on its suitability for the local production of high-quality porcelain clay bodies as an equivalent to Jingdezhen porcelain. This is based on a comparison of the similarities of SiO_2 and Al_2O_3 in Kisii soapstones with kaolins found in Mingsha, Xingxi, Linchuan and Mingsha (Jingdezhen), China in the literature[7, 8], and a comparison of the similarities of SiO_2 and Al_2O_3 in Eburru white (a high-silicate porcelain raw material found in Eburru) as described in the literature [9, 10]with porcelain stones found in Qimen, Sanbaopeng, Nangang, Shiceng, Wutou, Siban and Baomei China detailed in the literature[8]. The comparative analysis is used to assess their suitability to produce high-quality porcelain clay bodies for product design and manufacturing, drawing theoretical conclusions from comparisons of the chemical properties of SiO_2 and Al_2O_3 content with porcelain raw material combinations that were used during Yuan dynasty to manufacture porcelain material in Yanyi[8]. Yanyi[8] states that “Yuan dynasty porcelain technology was invented for the purpose of making high-quality porcelain wares, which was intended to correct vessel deformation in product manufacturing.” The purpose of the research is to align Kenyan ceramic raw material resources to 21st-century product manufacturing technologies and applications for high-quality product development.

II. Materials and Methods

(1) X-ray fluorescence (XRF) and X-ray diffraction (XRD) analysis

The Kisii soapstone sample was analysed at Jiangxi Ceramic Testing Center, National Ceramic Product Quality Supervision and Inspection Center (Jiangxi), by means of an X-ray fluorescence spectrometer, Axios Advanced, from PANalytical Netherlands, and an X-ray diffractometer, Advance D8, from Bruker, Germany. The XRF and XRD data analyses are shown in Table 1 and Fig. 1, respectively.

XRF analysis GB/T 14506.28 – 2010 AXIOS X fluorescence spectrometer, room temperature: 23 °C, humidity: 52 %.

The XRD raw data was re-analysed, and the results are shown in Fig. 1. It can be seen from the XRD pattern that the crystal phases in the samples are muscovite, kaolinite, dickite, and clinochlore. Kaolinite and dickite endow the raw material with good plasticity, while muscovite and clinochlore reduce the sintering temperature of the samples, so that the samples can be used in lower-temperature porcelain. From the XRF analysis, it can be seen that the content of K_2O+Na_2O in the sample is 4.71 %, which can significantly reduce the temperature of porcelain, making it conducive to firing.

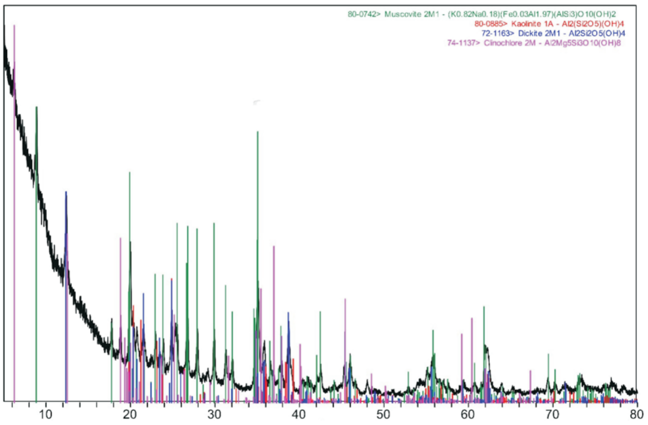

Fig. 1: Interpretation of the X-ray diffraction (XRD) analysis.

In a comparison of the XRF results with the composition of the kaolinite mineral, it is shown: the chemical composition of kaolinite is Al_2O_3 39.53 %, SiO_2 46.51 %, H_2O 13.96 % (the main source of ignition loss). In terms of composition, the content of Al_2O_3 in the raw material is close to that of kaolinite, while the content of SiO_2 is slightly lower.

(2) Clay processing technology

Table 2 lists the step-by-step clay processing technology that was used in developing a slip-casting clay slurry.

Step 1: Particle reduction: The stone was disintegrated with a grinder and stone crusher to break down the stone sizes into particles small enough for milling.

Step 2: Milling: Wet milling in a high-efficiency rotating porcelain ball mill jar processor that produced a fine smooth slurry with minimal residues and minimal contamination.

Table 1: Chemical composition: Tabaka Kisii soapstone GB/T 14506.28 – 2010.

Chemical Composition (wt%)														
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	TiO_2	SrO	Cr_2O_3	V_2O_5	CuO	ZrO_2	IL
44.32	**39.46**	0.16	0.08	0.05	4.25	0.46	0.01	1.88	0.01	0.01	0.07	0.02	0.03	9.19
Note: The inspection method at this center does not include IL (loss on ignition) and V_2O_5 detection. The detection limit of CaO is 0.10 %, and the detection limit of MgO is 0.20 %. The measured value of this element in the analysis is for reference only.														
Source: (Jiangxi Ceramic Testing Center: Jingdezhen Ceramic Institute)														

Table 2: Clay processing technology.

No.	**Procedure**	**Application process and technology**	**Observations**
Step 1	Particle reduction	Grinder and stone crusher	Off-white
Step 2	Milling	Wet milling: porcelain ball mill jar	Off-white
Step 3	Sieving/drying	Manual sieving: 74 µm mesh	Off-white
Step 4	Slip preparation	Stone powder + water + liquid glass	Off-white fine slurry

Step 3: Sieving and drying: The slurry was manually sieved through a 74-µm mesh to remove unprocessed residues. It was then dried and manually sieved through a 74-µm mesh to produce a fine smooth powder for further testing.

Step 4: Slip preparation: The slip was made using a combination of processed stone powder + water + liquid glass (sodium silicate).

(3) Shrinkage tests

The shrinkage tests were conducted using clay slabs that were made by pouring slip into a flat plaster mould to form one slab of clay. This slab was then cut into three equal parts measuring 12 cm length x 3 cm width. A pin tool was used to mark the slabs with 10-cm length markings, which were used to measure and determine shrinkage variations at the temperatures 1 150 °C, 1 250 °C and 1 300 °C in an electric-powered firing. Fig. 2 shows images from the shrinkage sample tests, and Fig. 3 shows the shrinkage variation scale bar, with observations recorded in Table 3.

Fig. 2: Slab 1:1 150 °C, Slab 2:1 250 °C & Slab 3:1 300 °C respectively.

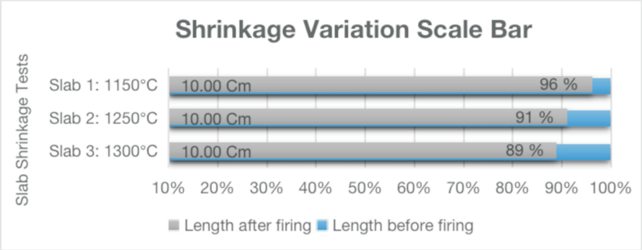

Fig. 3: Shrinkage variation scale bar.

(4) Product assessment tests

The product development consisted of slip-cast cups that underwent two firing stages. First, the cups were bisque-fired at a temperature of 900 °C, as shown in Fig. 4. Second, they were fired in a gas reduction firing at 1 300 °C in Fig. 5a and Fig. 5b. In Fig. 5a, the cup is shown with an applied transparent glaze before the second firing, while the cup in Fig. 5b was fired without glaze in the second firing. Observations on the end-product indicated good quality, non-porous material with high-pitch sound after firing at a temperature 1 300 °C for both cups. The product assessment test result is recorded in Table 4. It indicates that the application of transparent glaze caused a further 5-% shrinkage in comparison with the unglazed cup in Fig. 5b. Fig. 6 shows their shrinkage variation scale bar.

III. Comparative Analysis

(1) Porcelain clay technology

Tite *et al.* [11] mentioned that "towards the end of the first millennium AD, stoneware technology attained a high level, and production of porcelain, a white translucent variety, and high-quality, green-glazed stoneware, were well established in China." Observations on the chemical properties of high-temperature stoneware and porcelain clays used for ceramic production in South and Northern China revealed patterns of high concentrations of SiO_2 and Al_2O_3, as described in the literature[11,8]. SiO_2 and Al_2O_3 are key elements for high-temperature porcelain clay manufacturing, Al_2O_3 is more responsible for the high-temperature resistance[8,12]. Katsuki *et al.* [12] demonstrate "the addition of 20 – 40 wt% Korean kaolin to Yanggu white clay required to produce well-fired Korean white porcelain without bloating at temperatures over 1 175 °C." Taskiran *et al.* [13] has developed "the composition for making porcelainized stoneware based on anorthite ($CaO \cdot Al_2O_3{\cdot}2SiO_2$) crystal formation, defined as extremely hard, highly dense, impervious and unglazed vitrified ceramic obtained by fast firing, between 1 200 – 1 230 °C."

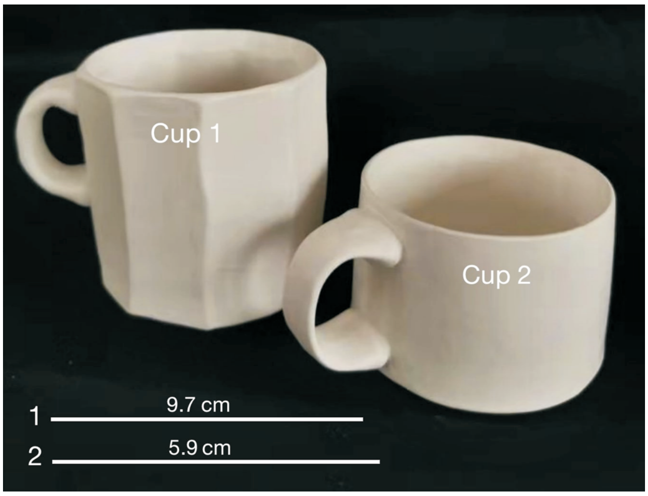

Fig. 4: Cup 1 and Cup 2: Electric bisque firing 900 °C.

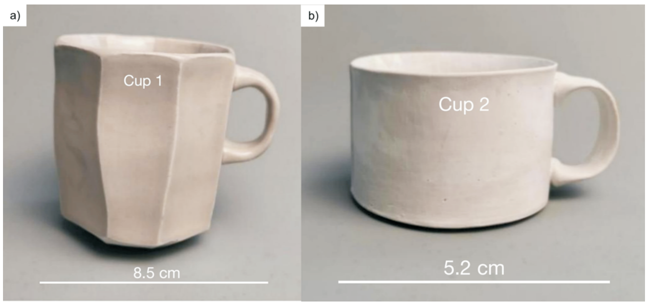

Fig. 5a and 5b: Cup 1, with transparent glaze, Cup 2, without glaze: Gas reduction firing 1 300 °C.

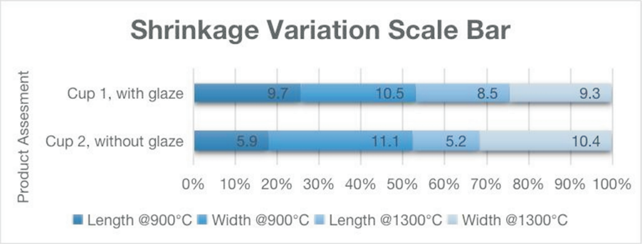

Fig. 6: Shrinkage variation scale bar.

In China, the initial manufacturing of porcelain clay used porcelain stones[8]. Yanyi [8] states that "during the Yuan dynasty, porcelain stones used on their own could no longer meet the technical requirements for large vessel manufacturing, so kaolin was added to correct the deformation tendency of the vessels, and broaden the firing temperature ranges." The combination produced a desired clay composition that met the needs of pottery manufacturing. After the Yuan dynasty, Chinese porcelain clay manufacturing technology developed a system of combining two raw materials to make new porcelain clay bodies, as described by Yanyi[8]. The combinations were made using "porcelain stones and kaolin", which started in Jingdezhen, leading to the famous porcelain made at Jingdezhen[8]. Li and Li[14] mention that "production of the finest wares for the court were produced in Jingdezhen; in kilns and factories that were originally owned by the imperial government."

Porcelain rocks and kaolins are both suitable for the production of whitewares, their chemical properties have high concentrations of SiO_2 and Al_2O_3, kaolins, however, have a higher percentage of Al_2O_3. Seemingly, the higher Al_2O_3 in kaolin provided a higher firing temperature curve, increased strength and ensured a good-quality clay body for porcelain stones[8, 11]. Maniatis[15] states that the understanding of the ancient ceramic technologies developed with the progressive use of scientific techniques and methodologies. The ancient technologies provide information for today's material innovation technologies (the 21st century), as claimed by Maniatis[15]. Regions like Europe began to technically formulate porcelains in laboratories, leading to multiple material engineering technologies. In Europe, Marchand[16] claims that "porcelain's secret recipes were first reproduced by an alchemist in the employ of the Saxon king Augustus the Strong." Finlay[17] claims that "Dentrecolles letters 'of Jingdezhen' disclosed the mystery of technical know-how concerning clay, glazes, and kilns that Europeans had been pursuing for centuries." Tite *et al.*[11] mentions that "although Chinese's ceramic innovations were of great status; today the continuous innovation and manipulation of unique raw materials accessible to practitioners is significant." "Porcelain lost much of its identity as aristocratic ornament, instead taking on a vast number of banal, yet even more cultural significant, roles" as Marchand claims[16] Today, porcelains dominate products in daily use and are technologically integrated in modern engineering, science and technology, across numerous fields. In the 21st century, porcelains are used in modern product manufacturing technologies like 3D printing, which cut down on the duplication of work and material waste, reduce costs, and make the design process healthy and environmentally friendly, as discussed by Wang *et al*[18] at an international conference on future information engineering. In III(2), the study details a comparative analysis that elaborates the SiO_2 and Al_2O_3 chemical properties in Kenyan raw materials, comparing them with raw materials used for manufacturing Chinese porcelain clay during the Yuan dynasty[7, 8, 9,10].

Table 3: Shrinkage testing after electric firing.

No.	Temp.	Length before firing	Length after firing	Shrinkage	Colour
Slab 1	1 150 °C	10 cm	9.6 cm	4 %	Soft white
Slab 2	1 250 °C	10 cm	9.1 cm	9 %	Soft white
Slab 3	1 300 °C	10 cm	8.9 cm	11 %	Soft white

Table 4: Product assessment tests

No.	**Bisque firing 900 °C**		**Gas firing 1300 °C**		**Shrinkage**
	Size (L x W)	***Colour***	***Size (L x W)***	***Colour***	***Percentage***
Cup 1, with glaze	9.7 cm x 10.5 cm	Soft white	8.5-cm x 9.3 cm	Soft white	12 %
Cup 2, without glaze	5.9 cm x 11.1 cm	Soft white	5.2 cm x 10.4 cm	Off-white	7 %

(2) *Comparisons of raw materials used for porcelain clay technology*

(a) *Comparisons of Kenyan and Chinese kaolin raw materials*

Kisii soapstones are more closely associated with altered lavas than with sandstones, their characteristics suggest that lavas form an interrelation in the sandstone series, and soapstone is an alteration product of portions of lavas, as discussed in detail by Pulfrey[7]. Table 1 shows the chemical composition of Tabaka Kisii soapstone GB/T 14506.28 – 2010; a sample of a Kisii soapstone rock collected from Tabaka, Kisii has 44.32 SiO_2 and 39.46 Al_2O_3. Pulfrey[7] has chemically analysed six varieties of Kisii soapstone samples, recording 46.59, 46.42, 49.53, 46.78, 48.60, 45.66 SiO_2 and 36.83, 37.00, 35.73, 39.70, 32.82, 35.10 Al_2O_3 respectively[7]. Yanyi[8] has performed a chemical analysis of some typical kaolins used in Jingdezhen; for the kaolin samples from Mingsha, Xingxi, Linchuan and Mingsha,49.65, 51.89, 46.57, 47.69 SiO_2 and 33.82, 31.70, 36.29, 36.01 Al_2O_3 were recorded respectively[8]. Kisii soapstones have an average 47.26 wt% SiO_2 (range 49.53 – 44.32 wt%) and an average 36.19 wt% Al_2O_3 (range 39.70 – 32.82 wt%). While Jingdezhen kaolins from Mingsha, Xingzi and Lichuan have an average 48.95 wt% SiO_2 (range 51.89 – 46.57 wt%) and an average 34.45 wt% Al_2O_3 (range 36.29 – 31.70 wt%). Based on their chemical properties, these raw materials are all categorized under kaolin rocks that can be used to produce whitewares, with minimal traces of elements that have a significant impact on colour. Fig. 7 and Fig. 8 show an SiO_2 and Al_2O_3 analysis of Kisii soapstones and Jingdezhen kaolins, and Fig. 9 shows their comparative analysis.

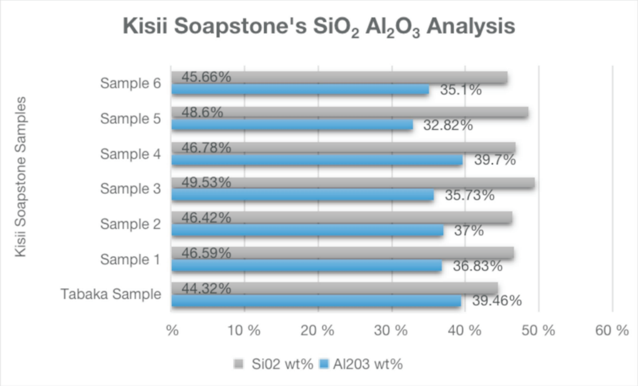

Fig. 7: SiO_2 Al_2O_3 analysis of Kisii soapstones.

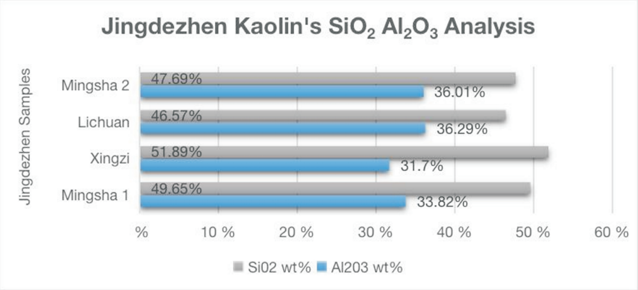

Fig. 8: SiO_2 Al_2O_3 analysis of Jingdezhen kaolins .

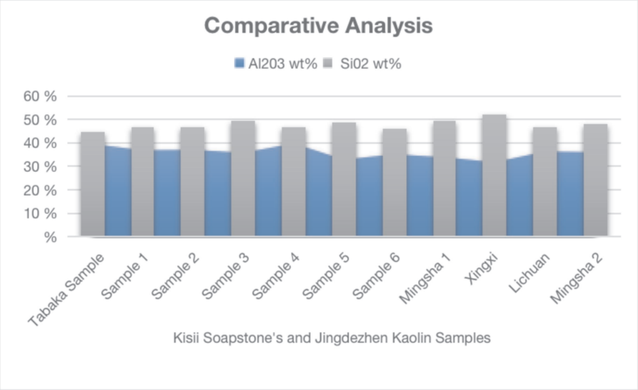

Fig. 9: SiO_2 Al_2O_3 comparative analysis of Kisii soapstones and Jingdezhen kaolins.

(b) *Comparisons of Kenyan and Chinese porcelain stones*

Yanyi[8] describes Chinese porcelain stone as a rock composed mainly of quartz and sericite, the sericite being described as fine-grained hydromuscovite[8]. The chemical structures of Chinese porcelain stones suggests that their silicate ratio makes up around of their composition while alumina accounts for below 20 wt%, as illustrated in Yanyi[8] and Tite *et al.*[11]. Makokha *et al.*[10] has measured "ceramic materials for the manufacture of medium-duty alumina refractory firebrick for an incinerator lining in Kenya and indicates the SiO_2 content of Eburru kaolin as being the highest at 72.4 wt%." Ayieng'a[9] has performed a chemical analysis of 'Eburru white', recording SiO_2 78.04 wt% and Al_2O_3 14.20 wt%. Makokha's Eburru kaolin and Ayieng'a's Eburru white are raw materials from the same location[10, 9]. Table 5 shows the chemical analysis of Eburru white, as given in Ayieng'a[9].

Table 5: Chemical compositions of Eburru white: Atomic absorption spectrometer (Spectr AA-10).

Chemical Composition (wt%)											
SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3	LOI	Cd	Pb
78.04	**14.20**	0.10	-	0.19	0.40	0.14	-	0.65	6.56	ND	ND
Source: Ayieng'a @2016 - Ministry of Mining, Kenya											

Yanyi[8] has analysed Chinese porcelain rocks from Qimen, Sanbaopeng, Nangang, Shiceng, Wutou, Siban and Baomei, recording 73.05, 73.70, 76.12, 73.16, 71.82, 75.91, 78.61 SiO_2 and 15.61, 15.34, 14.97, 17.10, 17.41, 15.30, 12.95 Al_2O_3, respectively. The Chinese porcelain stones have an average 74.62 wt% SiO_2 (range 78.61 – 71.82 wt%) and an average 15.52 wt% Al_2O_3 (range 17.41 – 12.95 wt%). The SiO_2 and Al_2O_3 chemical properties of Eburru's raw material have been likened to Chinese porcelain stones. Fig. 10 and Fig. 11 show the SiO_2 and Al_2O_3 analysis of Eburru white and Chinese porcelain stones and Fig. 12 shows their comparative analysis.

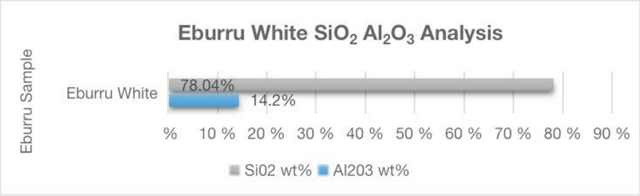

Fig. 10: SiO_2 Al_2O_3 analysis of Eburru white .

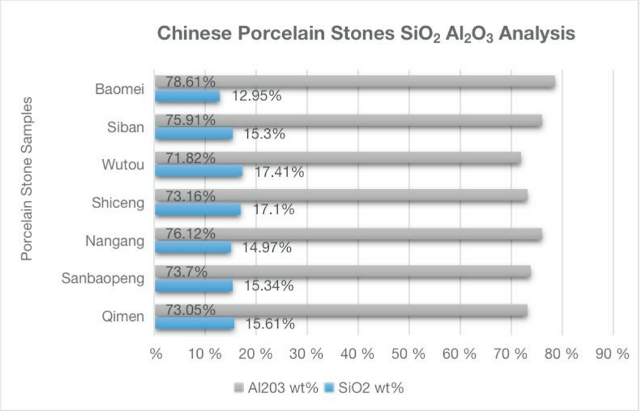

Fig. 11: SiO_2 Al_2O_3 analysis of Chinese porcelain stones .

The comparative analysis is used for identifying local raw material resources that can be used for preparing porcelain clay bodies for manufacturing high-quality products like those seen in Jingdezhen. Further experiments, however, need to be conducted for verification.

IV. Results and Findings

Kisii soapstone can be used to prepare a high-quality white stoneware clay body for product design. The material produced a fine smooth clay slurry used for slip casting, demonstrating 11 % shrinkage after electric firing at a temperature of 1 300 °C. It demonstrated its suitability for making high-quality, slip-cast cups. Observations, however, indicate that the solid plastic clay might require minor readjustments to its elasticity to obtain a consistent ball clay for throwing and hand-building techniques. Nonetheless, Kisii soapstone is suitable for slip casting and can also be engineered for 3D-based ceramic product manufacturing technologies. The comparative analysis of SiO_2 and Al_2O_3 chemical properties with raw materials used during the Yuan dynasty to manufacture porcelain material technology also provides theoretical evidence of the suitability of using a combination of Kisii soapstone and Eburru white to manufacture high-quality white porcelain clays equivalent to those made in Jingdezhen.

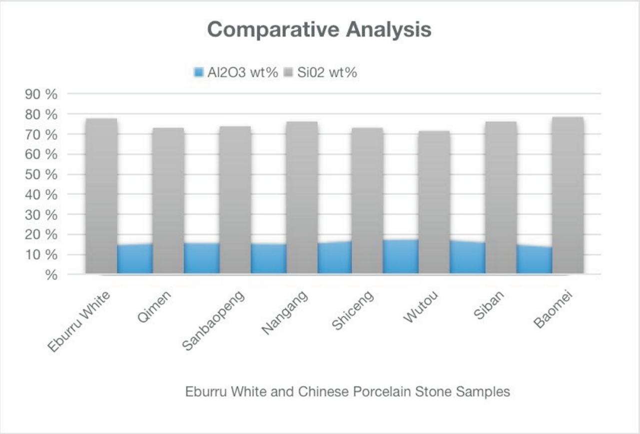

Fig. 12: SiO_2 Al_2O_3 comparative analysis of Eburru white and Chinese porcelain stones.

V. Discussions

The combination of Kisii soapstone and Eburru white demonstrates suitability for the manufacture of high-quality white porcelain clay bodies equivalent to those made in Jingdezhen. Because of the high Al_2O_3 content in Kisii soapstone, it can also be used in combination with other geological materials to manufacture a wide range of good-quality and innovative regional clay bodies. A good example is its combination with KU metallic, as describe in the literature[4]. In an experiment on ceramic coatings: glaze formulations, Ayieng'a[9] has analysed KU metallic properties and recorded its Fe_2O_3 at 40.50 wt%, leading to firing to a metallic black appearance at 1 200 °C. The material properties of KU metallic give leeway for engineering an advanced ceramic material innovation for cookware. In China, the traditional porcelain material technology continues to evolve, and a variety of clays are being developed to meet the needs arising in the 21st century. Today, clay manufacturing technologies are being influenced by trends, techniques and technologies in product design and manufacturing, which include, for example, slip casting, hand building, throwing, 3D ceramic technologies and others. The modern era of nanotechnology, crystalline ceramics, advanced ceramic coatings, bioceramics, safe, efficient and environment-friendly manufacturing materials is influencing product design, leading to it take different directions. It is therefore critical that regional ceramic material innovations are geared towards 21st-century manufacturing technologies. For instance, 3D ceramics printing technologies have become popular technologies that use digitally designed images to enable precision, use less material, save energy, cause less pollution in a fast and efficient process, as discussed in a conference paper given by Wang *et al.*[18]. Chen *et al.*[19] classify the 3D ceramics printing technologies as; 3D slurry-based, powder-based and bulk solid-based ceramic technologies. Such technologies mandate that today's product manufacturing embraces the use of local material in domestic innovations and new inventions. Kenya has a variety of plentiful and yet underexploited ceramic material resources with metallic and frit properties that can be engineered to meet local and international ceramic development needs.

If Kenya is to itemize its ceramic raw material resources, it must slowly begin to align them to 21st-century technologies and applications by engaging communities like those in Kisii that have available material and human resource capacity for revolutionizing domestic industrial growth. The manufacturing of porcelain clay bodies using the combination of Kisii soapstone and Eburru white is a good starting point. Jingdezhen, China provides a good example that can be duplicated. Although ancient, porcelain still remains the worlds' top, most sought-after, well-documented, high-quality ceramic material innovation, which has been widely duplicated and reinvented for high-quality product design abd manufacturing. In Kenya and East Africa, little has been done to identify, research, document and locally manufacture porcelain material for the development of high-quality products. Ceri and Grillo[20] recommend that in East Africa, future directions need, "a new generation of targeted ceramic studies that take a theoretically informed and problematized approach to analysis and novel methods that open up new insight and evidence." This paper has provided a roadmap that identifies and documents Kenyan raw material resources that can be used for manufacturing high-temperature porcelain. It has also provided leads on engineering high-temperature clays, which can range from self-glazing clays that are rich in fluxes to coloured clay varieties rich in oxides like iron, copper, manganese, cobalt, etc. Kenya has a diversity of ceramic materials that can be used to compile an unlimited clay resource register. Exploiting the vast unique geographical material resources of the Great Rift Valley region, which emanates from natural occurrences of the Rift Valley formations, volcanic eruptions, faulting, landslides, quarry excavations, etc., can expand the development of domestic industry. It is important to fundamentally focus on results-oriented projects that maximize utilization of natural material and human resources, like Kisii soapstone material wastage, for ceramic product manufacturing. It is also expedient to engage in local expansion to promote industrial growth, good government policies, integration of multidisciplinary research methodologies, education, research and development. Capacity-building programmes that empower artisans to recycle material waste in Kisii, etc. can influence high-quality product manufacturing in Kenya and Eastern Africa.

VI. Conclusions

Material science and technology is an essential dynamic for the design and manufacturing of ceramic products today. In Kenya, raw materials resources need to be optimized for the preparation of local porcelain and stoneware clay bodies for product manufacture. The comparative analysis of the SiO_2 and Al_2O_3 chemical properties of Kisii soapstone and Eburru white show their suitability for the manufacture of high-temperature Kenyan porcelains. Utilizing local materials and human resources is imperative for developing regional capacity to manufacture high-quality domestic wares. This is also significant for aligning Kenyan local ceramic material resources with 21st-century innovative clay technologies and applications that impact global development in product design today.

References

1 Akama, J., Onyambu, M.: The evolution and resilience of the gusii soapstone industry, *J. Afr. Cult. Her. Stud.*, **1**, [1], 1 – 17, (2018).

2 Kisii County Government Milestones Magazine.: An official publication of Kisii county government. Council of Governors (CoG). 2021.

3 Pinna, P., Cocherie, A., Thiéblemont, D., Jezequel, P.: The kisii group of western Kenya: an end-Archæan (2.53 Ga) late orogenic volcano sedimentary sequence, *J. African Earth Sci.*, **30**, [1], 79 – 97, (2000).

4 Meert, J.G., Van der Voo, R., Patel, J.: A neoarchean paleomagnetic pole from the kisii series of western Kenya: Implications for crustal mobility, In: *Precambrian Research*, **279**, July, 91 – 102, (2016).

5 Obwori, E.O., Iravo, M., Munene, C., Kaburi, S.: The effect of funding constraints on the growth of small scale enterprises in soapstone industry of Kenya, *Int. J. Arts & Commer.*,**1**, [6], 111 – 127, (2012).

6 Pekkala, Y., Mulaha, T.O.: Assessment of kisii stone deposits, got chaki and tabaka areas, Kenya. [Nairobi]: Republic of Kenya, ministry of environment and natural resources. Mines and Geological Dept, (1991).

7 Pulfrey, W.: The nature and origin of a soapstone from near kisii, *J. Chem. Inf. Model*, **110**, [9], 1689 – 1699, (1946).

8 Yanyi, G.: Raw materials for making porcelain and the characteristics of porcelain wares in north and south china in ancient times, *Archaeometry*, **29**, [1], 3 – 19, (1987).

9 Ayieng'a, L.: Glaze formulation using geological materials from kiambu and nakuru county, Kenya. [Unpublished master's thesis] Kenyatta University, Kenya, 2016.

10 Makokha, J., Kariuki, D., Mwitari, P.: Characterization of Kenyan ceramics for production of medium duty alumina firebrick incinerator linings, *J. Appl. Sci. Environ. Manage.*, **22**, [10], 1543 – 1546, (2018).

11 Tite, M., Freestone, I., Wood, N.: An investigation into the relationship between the raw materials used in the production of chinese porcelain and stoneware bodies and the resulting microstructures, *Archaeometry*, **54**, [1], 37 – 55, (2012).

12 Katsuki, H., Hirata, S., Inada, M., Choi, C., Park, J., Lee, J., Kim, U., Han, K., Kim, J., Cho, W., Hwang, K.: Role of addition of kaolin on the firing of white clay for korean porcelain, *J. Asian Ceram. Soc.*, **8**, [2], 492 – 501, (2020).

[13] Taskiran, M., Demirkol, N., Capoglu, A.: A new porcelainised stoneware material based on anorthite, *J. Eur. Ceram. Soc.*, **25**, [4], 293 – 300, (2005).

[14] Li, S., Li, X.: The role of cultural creative industry in the process of the city development: the case of jingdezhen, *Stud. Sociology Sci.*, **2**, [2], 74 – 78, (2011).

[15] Maniatis, Y.: The emergence of ceramic technology and its evolution as revealed with the use of scientific techniques. In: From mine to microscope: advances in the study of ancient technology. Oxbow Books, Oxford, 2009.

[16] Marchand, S.: Porcelain: A history from the heart of Europe. Princeton University Press, New Jersey, USA, 2020.

[17] Finlay, R.: The pilgrim art: Cultures of porcelain in world history. University of California Press, Berkeley, USA, 2010.

[18] Wang, A., Sai, S., Liu, Y.: The high computer technology application study about the daily-use ceramic products design, In: International conference on future information engineering (FIE 2014), Beijing, China, July 7 – 8, 184 – 189, 2014.

[19] Chen, Z., Li, Z., Li, J., Liu, C., Liu, C., Li, Y., Wang, P., Yi, H., Lao, C., Fu, Y.: 3D printing of ceramics: A review, *J. Eur. Ceram. Soc.*, **39**, [4], 661 – 687, (2019).

[20] Ceri, Z., Grillo, M.: Archeological ceramics from eastern Africa: past approaches and future directions, *Azania*, **50**, [4], 460 – 480, (2015).