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Article

Appraisal of Nigeria's Ceramic Tile Production

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A B S T R A C T

Ceramic tiles are made from clay materials and are mostly fired at very high temperatures. Despite the local availability and accessibility of the materials in abundance in Nigeria, only 11% of ceramic tiles consumed in the country are produced locally and imported raw materials are employed to achieve this. Hence, this work tends to provide quality data on the availability of ceramic raw materials and their locations within the country. Studies on the production of ceramic tiles from materials collected locally were considered in this paper. This current work highlighted the various categories of ceramic products and focused on the availability and feasibility of clay materials collected from Nigeria for ceramic tiles production. It also looked at Nigeria's ceramic tiles industry and Nigeria's placement among the nations of the world in ceramic tiles manufacturing and consumption. This review offers an evaluation of the studies carried out on the production of ceramic tiles for covering walls and floors in residential and non-residential buildings.

1. BACKGROUND

1.1 Introduction

Ceramic tiles are flat pieces of fired clay usually described by researchers as a triaxial composition that are frequently used to cover floors and walls (Irabor *et al*., 2014; El Nouhy, 2013; Martín-Márquez *et al*., 2008; Alan, 2005; Iqbal and Lee, 2000). Ceramic tiles are brittle, rigid, and strong in compression but, weak in shearing and tension, just like any other ceramic materials. They have a higher tendency to withstand chemical erosion than many other materials and do not disintegrate at higher temperatures, ranging from 1000 °C to 1600 °C (Carter and Norton, 2007; European Commission, 2007; Jung, 2008). It is typically created by heating a mixture of three silicate minerals, such as kaolin, quartz, and feldspar, which react with one another when exposed to high temperatures. (Iyasara *et al*., 2014).

For thousands of years, humans have used clay minerals, a key component of ceramic raw materials, for both industrial and commercial purposes (Murray, 1997; Yuan, 2004). Today, clay minerals are still employed as natural nanomaterials. Clay material was first used to whiten and remove grease and stains from clothing in Cyprus and Greece, according to historical records (Beneke and Lagaly, 2002; Robertson, 1986). Other historical uses included internal and external medicine, cosmetics, building, art, religion, sealing, roofing, and many food-related purposes (Beneke and Lagaly, 2002).

Recent research has shown that the processing of clay materials can be traced back to around 2400 BC in China, Egypt, Mesopotamia and India. The first and oldest pottery discoveries in southern Japan date to about 8000 BC and 9000 BC (European Commission, 2007; Alsop, 1998). According to numerous reliable sources, burnt bricks were used to construct palaces, towers, temples, fortifications, and fortresses as early as 4000 BC in Egypt, which is located in the northeastern corner of the African continent (El Nouhy, 2013). The skill of creating China porcelain has been practiced in China since 1000 BC, while the creation of glazed ceramic items began in Egypt in 2600 BC. These items were utilized as wall decorations in the pyramids. Brickmaking was popularized by the Romans more than 2000 years ago in a number of European countries (European Commission, 2007).

Nigeria, a sub-Saharan African nation with a surface area of 923,768 km^2, has a long history of using ceramic materials. Its use may be linked to the ancient pottery industry, which dates back to the Stone Age (Obaje, 2009). As far back as the late Stone Age, the inhabitants of these areas made good use of clay, according to archeological evidence from the ancient pottery areas of Nigeria, including Rop in Plateau State, Iwo-Eleru near Akure in Ondo State, Bida in Niger State, Okelele in Kwara State, Kagoro in Kaduna State, Ipetumodu in Osun State, Ijero in Ekiti State, and Afikpo (Fatunsin, 1992; Oke and Omoleye, 2006).

At the moment, ceramic materials are used in a wide variety of products, including roofing granules, extenders in paint, paper filling, paper coating, filling in plastics and rubber, cosmetics, leather tanning, desiccant, cracking catalysts, fiberglass, pencil leads, foundries, adhesives, pharmaceuticals, cement, pastes and glues, insecticides, enamels, sizing, food additives, carriers, textiles, bleaching, medicines, plaster, filler aid (Adnan et al., 2011; Murray, 1999).

Among all the ceramic products, the demand for ceramic tiles is increasing at a fast rate in the international market due to the growing population and government legislation (European Commission, 2007; Fonseca *et al*., 2016; El-Fadaly, 2015; Abadir *et al*., 2002). While Nigeria imports over 89% of ceramic tiles used in the country (Oaikhinan, 2015; Stock, 2015). The growing demand for ceramic tiles in the global market and their continued importation into Nigeria; despite the abundant availability and accessibility of the raw materials locally (Oaikhinan, 2015; Idowu, 2014; Adelabu, 2012), have necessitated the need for the study which evaluates the feasibility of ceramic tiles produced locally as well as the availability of the basic raw materials used and their locations within the country. The study also assessed the ceramic tiles' industries in Nigeria and their production capacity, challenges as well as the placement of Nigeria in the production, consumption and importation of ceramic tiles, among the nations of the world.

1.2 Research Purposes

The purpose of this research is to provide a comprehensive evaluation of the ceramic tile industry in Nigeria, focusing on the feasibility of locally produced ceramic tiles, the availability and locations of essential raw materials, and the operational capacity and challenges faced by the industry. The study aims to assess Nigeria's position in the global context of ceramic tile production, consumption, and importation, with a view to identifying strategies for enhancing local production capabilities, reducing dependence on imports, and leveraging Nigeria's abundant raw material resources for economic development and sustainability in the ceramic tile sector.

2. EXTENSIVE LITERATURE REVIEW

2.1 Local Availability of Ceramic Raw Materials

Several studies have shown that ceramics tiles are produced from three main raw materials (clay, quartz and feldspars) which are blended together (El Nouhy, 2013; Abdel-Aziz *et al*., 2015; Kamseu *et al*., 2007). While ceramic tiles are given plasticity, shape and opacity by clay; durability, hardness, controlled density, porosity and resistance to chemical corrosion are improved by feldspar; and shrinkage is regulated as well as rigidity, and support is provided by silica sand (El Nouhy, 2013; Casasola *et al*., 2012). Though, these raw materials are available and accessible in abundance in Nigeria; they suffered extreme neglect (Oaikhinan, 2015; Idowu, 2014; Adelabu, 2012). Table 1 lists the principal ceramic raw materials and where they can be found in Nigeria.

Table 1. Materials connected to clay and where they can be found in Nigeria.

S/N	Mineral	Site Location	State	Estimated Reserve (tonnes)	Remark
1	Kaolin	Kankara	Katsina	20,000,000	Residual
		Major porter, Jos	Plateau	19,000,000	Residual
		Oshinde	Ogun	………..	Residual
		Iseyin	Oyo	………..	Residual
		Ifon	Ondo	………..	Residual
		Ozubulu	Anambra	769,000	Sedimentary
		Illo	Sokoto	………..	Residual
		Darazo	Bauchi	10,000,000	………..
		Kpaki; Pategi	Niger	………..	………..
		Igbanke; Ozonnogogo	Edo	………..	Sedimentary
2	Ball clay	Abeokuta	Ogun	………..	Black
		Auchi; Ujogba	Edo	………..	Black; Cream
		Nsu	Imo	………..	Cream
		Giru	Kebbi	………..	………..
3	Common clay	Mararaban-Rido	Kaduna	5,500,000	Gray
4	Feldspar	Abeokuta	Ogun	………..	Potash
		Lanlate	Oyo	………..	"
		Egbe	Kogi	………..	"
		Bari	Niger	………..	"
		Okene	Kogi	………..	"
		Gwoza	Borno	………..	"
		Osogbo	Osun	………..	"
		Ijero	Ekiti	………..	Soda
5	Quartz/Silica	Pankshin; Shabu	Plateau	27,962	White; Sand
		Biu	Borno	2,540,000	White
		Ijero	Ekiti	………..	Sand
		Lokoja	Kogi	4,000,000	"
		Ugheli	Delta	………..	"
		Badagry	Lagos	………..	"
		Epe	Lagos	………..	"
		Igbokoda	Ondo	………..	"
		P/Harcourt	Rivers	………..	"
6	Talc	Shagamu	Ogun	………..	………..
		Kumunu	Niger	40,000,000	………..
		Ilesha	Oyo	………..	………..
		Okolom	Kogi	………..	………..
		Zonkwa	Kaduna	………..	………..
7	Bentomite	Geshua	Yobe	………..	………..
		M/Belwa	Adamawa	………..	………..
		Esan/Isan	Edo	………..	………..
8	Limestone	Okpila	Edo	10,161,000	White
		Jakuru	Kogi	68,000,000	"
		Igumala	Benue	30,161,000	………..
		Mfamoging	C/river	26,000,000	Grey
		Nkalagu	Eboyi	720,000,000	"
		M/Belwa	Adamawa	………..	………..
		Esan/Isan	Edo	………..	………..
9	Limestone	Okpila	Edo	10,161,000	White
		Jakuru	Kogi	68,000,000	"
		Igumala	Benue	30,161,000	………..
		Mfamoging	C/river	26,000,000	Grey
		Nkalagu	Enugu	720,000,000	"
		Ewekoro	Ogun	7.1 Billion	Clayey
		Arochuku	Imo	101,000,000	………..
		Shagamu	Ogun	………..	Grey
		Isekulu	Delta	………..	………..
		Sokoto	Sokoto	………..	………..
10	Dolomite	Osara	Kogi	2,000,000	White
		Itobe	Benue	1,000,000	"
		Igara	Edo	………..	"
		Mura	Plateau	………..	"
		Elebu	Kogi	………..	"
		Igbeti	Oyo	………..	"
		Burum	FCT	8,000,000	"
		Kwakuti	Niger	2,540,000	"

B/Gwari	Kaduna	…………	…………

Source: (Adelabu, 2012; Raw Materials Research and Development Council, 2010)

2.2 Feasibility of Local Ceramic Materials for Tiles Production

According to Mbahi (1999), it is wonderful to make use of available local materials and human resources to bring about national development. Meanwhile, a number of local academics have investigated the viability of using local resources to produce tiles in an effort to facilitate and advance the manufacture of ceramic tiles in Nigeria (Irabor *et al*., 2014; Idowu, 2014; Abubakar *et al*., 2014; Alege and Alege, 2013).

In order to determine whether clay samples from four different places in Nigeria's Anambra and Bida Basins were suitable for making ceramic articles, Alege and Alege (2013) carried out the characterization of the samples in line with ASTM standards. The clay samples' chemical composition includes trace elements like sulphur oxides, titanium, and phosphorus as well as the following: calcium oxide (0.01% to 0.24%), alumina (9.76% to 24.35%), iron oxide (1.27% to 7.78%), silica (52.66% to 79.17%), alkali (K2O+Na2O) (1.42% to 1.75%), magnesium oxide (0.11% to 0.14%), and others. The mean range of burned linear shrinkages (at roughly 150 ºC) is 7.7-12.3%, whereas certain selected clay samples show a mean range of drying linear shrinkages of 6.5-11.6%. The flexural strength of the clays varies from 2.7 to 11.7 MPa during drying, and from 6.3 to 16.3 MPa during firing. Loss-on-Ignition (LOI) varies between 5.3 and 12.8%. The characteristic behavior of the fired samples showed color changes from white to white, grey to light brown, milky white to brilliant brown, and light brown to bright red from dry to firing. This demonstrates that the clay samples are appropriate for use in a variety of ceramic article applications, such as white ceramics, vitrified brick wares, floor and wall tiles, and colored vases.

Using feldspar that was mined from three separate sites in Nigeria, Mathew and Fatile (2014) performed a characterisation technique on vitrified porcelain tiles. Nigerian feldspar samples came from Ajaokuta, Okpella, and Ijero-Ekiti, all in the states of Kogi, Edo, and Ekiti. These three feldspar samples were combined to create compositions for vitrified porcelain tiles that are comparable to those used in industrial settings. The feldspar samples that were taken from the three locations were subjected to a chemical analysis. At 1218 ºC, sintered samples of tiles made under very favorable conditions were also created. The samples were evaluated for their physico-mechanical qualities using tests for water absorption, flexural strength, and abrasion resistance. The findings demonstrated that the products' abrasion resistance, flexural strength, and water absorption (resistance ranges from 45.4 to 37.14, ranges from 73 to 87 N/mm^2, and less than 0.4%) are all superior to the ISO norm. The findings indicated that the deposits included all of the ingredients necessary to make porcelain tiles.

In 2014, Abubakar et al. looked at the viability of utilising the clay deposit in Gwandu, Kebbi State, Nigeria, as a source of ceramic raw materials. In order to analyze chemical and physical characteristics such as cold crushing strength, bulk density, refractoriness, thermal shock resistance, and linear shrinkage, an X-ray fluorescence spectrometer was used in this study. According to the chemical examination, the clay minerals are constituted primarily of SiO_2, but also of Al_2O_3, Fe_2O_3, CaO, K_2O, and TiO_2 in traces. According to the chemical analysis, kaolinite and quartz make up the majority of the clay deposit. According to the analysis of the physical property tests, the clay had a bulk density of 1.81 g/cm^3, an apparent porosity of 2.46%, estimated refractoriness of 1349 ºC, loss on ignition of 4.46%, linear shrinkage of 6.8%, cold crushing strength of 14,138 Nm^{-2}, and thermal shock resistance of seven cycles. As a result, it was discovered that clay was a good supply of raw materials for making ceramics and refractory brick.

Idowu (2014) produced ceramic tiles from Kaolin that were collected from Ifon, Silica, from Igbokoda, and Feldspar, from Ijero, all locations in Southwestern Nigeria. The study used a 5 step Tri-axial blend method to predict the twenty-one-member blending ratio for the three materials. Results of testing on the flexural strength and water absorption of a ceramic sample made from a mixture of 17% Kaolin, 19% Ball Clay, 50% Feldspar, and 13% Limestone and fired to a temperature of 1280 ºC makes the best sample when compared to both the International Organization for Standard and Nigerian Industrial Standard.

Patrick *et al*. (2015) produced ceramic tiles from clay collected from the Otukpo deposit in Nigeria, using a plastic-forming process. Different clay mixtures with quartz, feldspar, filler, and grog were used to create various tile samples. The physico-mechanical properties (colour change, absorption, bulk density, acid resistance, flexural strength, compressive strength, thermal shock resistance, shrinkage, and plasticity) of the tile samples were examined. All the samples produced showed good resistance to thermal shock, acid contact, good plasticity and, high compressive and flexural strength. The tile's documented qualities indicated that it could be useful as a quarry, floor, and wall tiles.

Elakhame *et al*., (2016) produced ceramic tiles samples by varying the blend of milled glass with clay by weight. The physio-chemical characteristics of seven different samples were then established using weight ratios of 3:7, 4:6, 5:5, 6:4, 7:3, 8:2, and 9:1 for the production of clay to mild glass. It was discovered that the amount of mild glass present in the tile samples directly correlates with their porosity. The sample of tile with the highest compressive strength contained 40% milled glass and 60% clay. The results also showed that the best chemical characteristics were found in samples with clay-to-mild glass ratios of 4:6, 5:5, 6:4, and 7.

Abiola *et al*., (2021) assessed the mechanical properties of ceramic tiles made in Osun State and how the properties are affected by the production firing temperature. The idea is to define the best processing for the tiles. Clay, silica sand, and feldspar were blended in various weight ratios (8:1:1, 7:1:2, 6:1:3, 6:2:2, 5:1:4, 5:2:3, 5:3:2, and 5:4:1), respectively. Three samples of replicas were created using the technique of Three replica samples were created by dry forming and burned at 1200, 1300, and 1400 °C. On a universal testing machine, the samples were then put through a series of tests to determine their breaking and flexural strengths, as well as their hardness using the Mohr's scale. According to the findings, the sample with the best mechanical qualities was burnt at 1320 °C and contained 60% clay, 10% feldspar, and 30% silica sand.

2.3 Production of Ceramic Tiles

The ceramic industry which was among the earliest achievements of Nigerian business was a strategic enabler for the growth, innovation and sustainability of the economy until the 1980s; but now, the nation values her ceramics tiles importation at over $600 million annually (Oaikhinan, 2015; Stock, 2015). Today, the industry in Nigeria has not been able to continue to grow due to the disregard for the solid mineral sector, a lack of qualified labor, and a lack of industries to process the raw materials needed to make ceramic tiles (Idowu, 2014).

Collection, beneficiation, and processing of raw materials (milling, drying, and mixing) are a few of the processes involved in making ceramic tiles; shape formation; drying of products; surface treatment and decoration; Firing; and polishing (Idowu, 2014; Abiola *et al*., 2021). Apart from the raw materials needed for tiles production, some researchers have worked on developing equipment and machinery required to smooth operation in ceramic tiles production.

Golkar and Prabuwono (2013) developed an image processing algorithm with a view to determining the sizes of ceramic tiles in order to improve tiles classification in the industry. It was found that the algorithm has an accuracy of about ±2mm.

Morakinyo *et al*. (2014) developed a ceramic tile molding machine from where different sizes of tiles were formed. The machine was designed to produce tiles using the method of extrusion from different blends of ceramic raw materials. Tiles produced from this machine were subjected to hardness, tensile, and impact resistance tests and the result revealed that the properties of these tiles are comparable to the unglazed floor tiles and other hard lining surfaces used in China.

Fonseca *et al*. (2016) recognized that processing is a major factor in promoting innovative technology and improving industrial output. This is of concern in the ceramic industry where technologies such as laser sintering of tiles is been investigated. The application of laser sintering of tiles revealed that there are emissions of nanoparticles and the patterns of this emission have a strong link to the chemical composition of the tiles as well as the sintering temperature. In addition, Nano-sized particles and ultrafine airborne were also generated and released into the environment during the sintering process. The study, therefore, suggests that occupational risk factors are inevitable when exposure to this type of technology.

2.4 Types of Ceramic Tiles

The ceramic industry which was among the earliest achievements of Nigerian business was a strategic enabler

Typically, ceramic tiles are inflexible, brittle, and hard. They have strong chemical resistance, are good electrical and thermal insulators, and have low shock resistance. (Lukkassen and Meidell, 2003). According to Bolton, (1998), Marcin and Jorge (2012), ceramic products can be grouped into the following categories:

2.4.1 Traditional or Domestic Ceramic

This is primarily made from clay, silica and feldspar (Marcin and Jorge, 2012). It is usually used in floor and wall tiling. It depends mostly on the material's composition, usage and properties of the product.

a) Porcelain tile

It is a type of vitrified ceramic material that is widely used for wall covering and floor paving in both indoor and outdoor applications (Martn-Márquez et al., 2010). Porcelain tile is described as a nearly waterproof, high-density, stain-resistant, and smooth product by the American National Standard Specifications for Ceramic Tile (Ece and Nakagawa, 2002). Porcelain is a vitrified product made of clay, quartz, and feldspar mixtures with grain and bond-type microstructures. Large filler particles (often quartz) are held together by a finer matrix that is almost entirely dense and made of mullite crystals and a glassy phase. It is a type of ceramic tile that is widely prized for its beauty and strength. Fiandre, one of the top Italian porcelain tile makers, debuted it towards the end of the 1980s, and in recent years it has become the most popular ceramic tile on the global market (El-Fadaly, 2015; Abadir et al., 2002). It is a durable, white, typically translucent, and nearly impermeable material that is typically manufactured from a triaxial dry-pressed composition of kaolin, quartz, and feldspar and fired at a temperature between 1200 and 1400 °C (Ece and Nakagawa, 2002; Griese, 2007). To encourage high mullite production, porcelain is fired over a period of time (24 hours or more) (Martn-Márquez et al., 2008). It is classified by the American tile industry as either glazed or unglazed ceramic tile with minimal water absorption (0.5%). (ISO 10545, 1996). It is a very popular product among tile products due to its great technical qualities (zero or almost zero apparent porosity, high mechanical strength and frost resistance, high hardness, chemical and stain resistance, etc.) and wide range of aesthetic options (Amoros *et al*., 2007).

b) Stoneware tile

It is one of the most common forms of ceramic tile and is often fired to a dense body at a temperature of about 1200 ^{0}C. They are heavier, darker and opaquer than Porcelain (Reed, 1988)). Stoneware is typically thought of as a non-equilibrium material and is created using a quicker firing cycle, during which the tiles are only heated for 60 to 90 minutes. (Martín-Márquez *et al.*, 2008).

c) Terracotta tile

It is known as Mexican tiles. It is traditionally fired at lower temperatures (between 600 to 1000 ^{0}C) and has more natural variation in the individual tiles (Martin, 2011). Modern terracotta tiles come in both glazed and unglazed varieties, and they occasionally need surface treatment to be sealed after installation. They frequently produce a less formal, more rural feel.

d) Quarry tile

On industrial and commercial floors, quarry tiles are frequently used as flooring. Instead of being pressed, like other ceramic tiles, it is extruded. This results in a little more uneven finish, a relatively high porosity, and more shape variability. Although quarry tiles are often reddish-brown, they can also be found in a variety of colors grey and black. (Quirion *et al.*, 2008).

e) Mosaics

It is made up of many product types and can be either unglazed or glazed. These product types include vitrified or earthenware ceramic, porcelain, natural stone and glass, which are all formed from individual tesserae (Friendly, 2001).

2.4.2 Natural Ceramic

The ceramic raw materials are generally referred to as natural ceramics (Heinrich and Gomes, 2017). This includes rocks, stones and minerals as well as bones and ice.

2.4.3 Amorphous Ceramics (Glass)

Glass and glass-ceramic materials come under this category. Although the amorphous state is conceivable, ceramics are typically crystalline. If silica is cooled very slowly while still molten, it will crystallize at the freezing point. However, if the molten silica is cooled more quickly, it will not be possible to arrange all of its atoms in the way that a crystal requires, leading to the formation of a glass, which is a chaotic solid. There is also a category known as ceramic glass. The controlled crystallization of glasses yields these fine-grained polycrystalline materials (Andreola *et al*., 2012).

2.4.4 Advanced Ceramic

Among these are engineering ceramics (oxides, carbides borides, nitrides and silicates). Engineering frequently uses such materials for products like furnace components, combustion tubes, tooltips, and grinding tools. (piezoelectric, ferrites, ferroelectric, semiconductors and superconductor ceramics); electro-optical; biocompatible (hydroxyapatite); and zirconia-based ceramics.

3. METHODOLOGY

The methods to derive results from the research on ceramic tiles in Nigeria encompass a combination of experimental investigations, material characterization, and industry analysis to assess the feasibility of local ceramic tile production, the availability of raw materials, and the challenges and capacities of the ceramic tile industry in Nigeria. Here's a synthesized approach based on the information provided:

1. **Material Collection and Preparation**:
   Raw materials such as clay, kaolin, silica sand, feldspar, and other locally available materials were collected from various locations across Nigeria. These materials were then processed through beneficiation, milling, drying, and mixing to prepare them for tile production.

2. **Experimental Formulation and Testing**:
   Different formulations were created by blending the processed raw materials in various ratios. Experimental tiles were produced using methods such as dry pressing and plastic forming. The tiles underwent firing at different temperatures to determine optimal firing conditions that yield the best mechanical and physical properties.

3. **Characterization of Raw Materials and Tiles**:
   The chemical and physical characteristics of the raw materials and the fired tiles were analyzed using techniques such as X-ray fluorescence spectrometry (XRF) for chemical composition and various tests for physical properties (e.g., cold crushing strength, bulk density, water absorption, flexural strength, and abrasion resistance). These characterizations helped in determining the suitability of the local raw materials for ceramic tile production and in optimizing the tile formulations.

4. **Mechanical Properties Assessment**:
   The mechanical properties of the produced ceramic tiles, such as breaking strength, flexural strength, and hardness, were evaluated using a universal testing machine. These properties were assessed at different firing temperatures to identify the best production parameters.

5. **Industry and Market Analysis**:
   The research also involved an analysis of the current state of the ceramic tile industry in Nigeria, including production capacity, challenges faced by the industry, and consumption patterns. This analysis was supported by data collection from active ceramic businesses, import and export statistics, and market demand studies.

6. **Comparative Analysis**:
   The findings from local material and tile production were compared against international standards (e.g., ISO norms) and practices in other countries. This comparison aimed to benchmark the quality of Nigerian ceramic tiles and to identify areas for improvement or innovation.

7. **Environmental and Technological Assessment**:
   The environmental impact of tile production

processes and the potential occupational risks associated with new technologies like laser sintering were evaluated. This included studying emissions, nanoparticle release, and the sustainability of the production methods.

Through this multidisciplinary approach, the research aimed to provide comprehensive insights into the feasibility of enhancing ceramic tile production in Nigeria, leveraging local raw materials, and addressing the challenges faced by the industry to meet both domestic and international market demands.

4. RESULTS AND DISCUSSION

4.1 Ceramic Tile Industries In Nigeria

Going back in time, about five significant domestic ceramic industries in Nigeria were operating at their best before the 1980s. These included Richware Ceramics in Lagos, Modern Ceramics in Umuahia, Nigergrob Ceramics in Abeokuta, Ceramic Manufacturer in Kano, and Quality Ceramics in Shagamu

The glass, cement/gypsum/lime, white wares and porcelain enamels, refractory and structural clay product sectors can be used to categorize the ceramic industry in Nigeria. The category of structural clay products includes ceramic tiles.

Nine ceramic businesses are now active in Nigeria, eight of which make ceramic tiles and function in diverse ways. PNT is the second-largest producer of ceramic tiles, and Ceramics (ROYAL) is the industry pioneer (Nwagbara, 2019). Out of the eight ceramic tiles-producing industries operating in Nigeria, six are 100% Chinese investment, while the other two are Indian investment tiles companies.

4.2 Production and Consumption of Ceramic Tiles

Compared to other ceramic products, the growth rate of the world's production of ceramic tiles has accelerated since the year 2000. Ceramics' position in the tile market has actually been secured by their great technical properties and improved aesthetic look (El-Fadaly, 2015).

Researchers have shown that the production and consumption of ceramic tiles are on the increase every year (El Nouhy, 2013; Fonseca *et al.*, 2016; El-Fadaly, 2015; Abadir *et al.*, 2002; Oaikhinan, 2015; Stock, 2015). According to Stock (2015) and Beraldi (2017), global production of ceramic tiles has grown by 5.7% between 2015 and 2016 as shown in Table 2. Local consumption increased by 5.0% within the same period while the import and export growth numbers rose by 5.2% and 2.1% in the same period (Beraldi, 2017). As shown in Table 2, Nigeria is not documented among the leading producer of ceramic tiles while Table 3 shows that her importation increases every year and ranked the number six importer of ceramic tiles importing 90,000,000 million square meters in the world by the year 2014 from 89% of her local consumption. This is primarily due to Nigeria's neglect of her raw materials which are locally available and in abundance (Idowu, 2014; Adelabu, 2012).

Table 2: Ceramic tiles top producing countries.

S/N	Country	2010 ($x10^6$ m^2)	2011 ($x10^6$ m^2)	2012 ($x10^6$ m^2)	2013 ($x10^6$ m^2)	2014 ($x10^6$ m^2)	2015 ($x10^6$ m^2)	2016 ($x10^6$ m^2)	% 2016 on world production	% var. 16/15
1	China	4,200	4,800	5,200	5,700	6,000	5,970	6,495	49.7%	8.8%
2	India	550	617	691	750	825	850	955	7.3%	12.4%
3	Brazil	754	844	866	871	903	899	792	6.1%	-11.9%
4	Spain	366	392	404	420	425	440	492	3.8%	11.8%
5	Vietnam	375	380	290	300	360	440	485	3.7%	10.2%
6	Italy	387	400	367	363	382	395	416	3.2%	5.3%
7	Indonesia	287	320	360	390	420	370	360	2.8%	-2.7%
8	Iran	400	475	500	500	410	300	340	2.6%	13.3%
9	Turkey	245	260	280	340	315	320	330	2.5%	3.1%
10	Mexico	210	221	231	230	230	245	267	2.0%	9.0%
	Total	7,774	8.709	9,189	10,270	10,270	10,229	10,932	83.7%	6.9%
	World Total	9.644	10,630	11,320	11,973	12,409	12,357	13,056	100.0%	5.7%

Source: (Stock, 2015; Beraldi, 2017)

Table 3: Ceramic tiles top importing countries.

Country	2010 ($X10^6$ m^2)	2011 ($X10^6$ m^2)	2012 ($X10^6$ m^2)	2013 ($X10^6$ m^2)	2014 ($X10^6$ m^2)	% of 2014 National Consumption	% 2014 World Imports	% Variation 14/13
USA	130	131	139	160	159	68.8%	5.9%	41.4%
Saudi Arabia	117	134	155	155	149	61.0%	5.6%	3.9%
Iraq	66	80	105	121	102	99.0%	3.8%	-15.7%
France	104	110	107	96	99	86.1%	3.7%	3.1%
Germany	86	90	89	89	95	79.2%	3.5%	6.7%

Nigeria	36	47	61	84	90	89.1%	3.4%	7.1%
South Korea	59	63	61	65	76	63.3%	2.8%	16.9%
Rusia	51	63	72	80	73	33.3%	2.7%	-8.8%
UAE	51	50	52	53	54	54.5%	2.0%	1.9%
Philippines	31	31	38	46	53	63.1%	2.0%	15.2%
Total	731	799	879	949	950	66.2%	35.4%	0.2%
World Total	2,128	2,346	2,520	2,655	2,683	22.2%	100.0%	1.1%

Source: (Stock, 2015)

4.3 Production capacity of Ceramic Tiles in Nigeria

In Nigeria, over 65 million square meters of ceramic tiles were imported in 2019, an improvement over the previous year (See Table 3), despite the country's total daily production capacity of only between 100,000 and 150,000 square meters of ceramic tiles. (Foraminifera, 2019). Meanwhile, despite the abundant availability of ceramic raw materials, the President of Oaikhinan Ceramic Foundation, Prof Eguakhide Patric stated that Nigeria, the largest ceramic tile producer in West Africa, produces 40,000 to 45,000 m2 of ceramic tiles daily (Gbonegun, 2019).

4.4 Challenges

Although the consumption of ceramic tiles in the local and global market is on the increase, due to the growing population and government legislation on housing, the production of ceramic tiles in Nigeria has been grossly hampered due to various challenges some of which are:

(1) While the raw materials needed for ceramic tiles production are available and accessible in abundance in Nigeria, it has suffered neglect due to a lack of government support for the sector.

(2) Due to a lack of workers with both general and technical abilities in the ceramics manufacturing industry, the production of ceramic tiles is currently below-installed capacity. Another factor slowing the sector's growth is the lack of opportunities for those with an interest in ceramic manufacturing enterprises to achieve their goals (Gbonegun, 2019).

(3) The dominance of China in the ceramics industry is attributed to low domestic participation, which the president of the Oaikhinan Ceramic Foundation believes may be a result of a lack of awareness as a result of the lack of ceramics education, technology, and engineering in the country's educational system.

(4) The sub-sector of the nation's economy has significant hurdles due to a lack of contemporary production facilities and technology as well as a lack of fundamental infrastructure including motorable roads, a reliable supply of water, and a regular supply of electricity.

4. CONCLUSION

The value of the Naira is dwindling continually due to overreliance on importation and dependence on foreign goods at the expense of locally made items. Increasing demand for ceramic tiles in the international market has not left Nigeria out as importation continues to swell due to Government policies on housing and the ever-growing population. The Nigerian government must put policies in place to support the mining of ceramic materials in other to encourage the local production of tiles. This will in turn lead to reducing importation and increasing exportation of our locally produced tiles, thereby creating jobs, reducing waste, and boosting the Nigerian economy.

Ceramic tiles usually play a major role in the construction industry finding applications in the covering of walls and floors. It is usually produced from clay, silica sand and feldspar and may also consist of additives such as steel slag waste, paper ash, sawdust, bane ash, steel dust, carpet yarn and milled glass all of which are in abundance in Nigeria.

REFERENCES

Abadir, M. F., Sallam, E. H., & Bakr, I. M. (2002). Preparation of porcelain tiles from Egyptian raw materials. *Ceramics International*, 28, 303–310.

Abdel Aziz, D. A., Aly, M. H., Salem, I. A., & Abead S. A. (2015). Effect of air blast furnace slag and γ-alumina content on dielectric properties and physical properties of porcelain insulators. *Physics and Materials Chemistry*, 3(2), 30-36.

Abiola, O., Oke, A., Omidiji, B., & Adetan, D. (2021). Effect of firing temperature on some mechanical properties of Osun State ceramic tiles. *East African Journal of Engineering*, 4(1), 13-21.

Abiola, O., Oke, A., Omidiji, B., & Adetan, D. (2021). The effect of raw materials on some physical properties of Osun State ceramic tiles. *Journal of Engineering Studies and Research*, 27(1), 7-12.

Abubakar, I., Barnin Yauri, U. A., Faruq, U. Z., Noma, S. S., & Sharif, N. (2014). Characterization of Dabagi clay deposit for its ceramic potential. *African Journal of Environmental Science and Technology*, 8(8), 455-459.

Adelabu O.S. Documentation, application and utilization of clay minerals in Kaduna State (Nigeria), licensee InTech. http://creativecommons.org/licenses/by/3.0 pp 3-20. (Accessed 2020, September 18)

Adnan, M., Sazzad, H. M., & Fakhrul, I. M. (2011). Potential of locally available clay as raw material for traditional-ceramic. *Journal of Chemical Engineering. The Institution of Engineers, Bangladesh*, 26(1), 34-37.

Alan, G.K. (2005). Ceramics Technology and processing, Standard Publisher Distributor,

Ohio
Alege, E. K., & Alege, T. S. (2013). Selected clays of the Bida and Anambra basins of Nigeria: Their characteristics, fired properties and ceramic-suitability. *International Journal of Science and Technology*, 2(7), 560–567.
Alsop, S. (1998). Key properties of ceramics raw materials. *Journal of the Australasian Ceramics Society*, 34(2), 178-184.
Amoros, J. L., Orts, M. J., Garcıa-Ten, J., Gozalbo, A., & Sanchez, E. (2007). Effect of the green porous texture on porcelain tile properties. *Journal of the European Ceramic Society*, 27, 2295–2301.
Andreola, F., Martin, M. I., Ferrari, A. M., Lancellotti, I., Bondioli, F., Ma. Rincon, J., Romero, M., & Barbieri, L. (2012). Technological properties of glass–ceramic tiles obtained using rice busk ash as silica precursor. *Ceramic International*, 39(5), 5427-5435.
Beneke, K., & Lagaly, G. (2002). From fuller's earth to bleaching earth: A historical note. *European Clay Group Association Newsletter*, 5, 57-78.
Beraldi, L. (2017). World production and consumption of ceramic tiles. Machinery Economics Study (MECS) by ACIMAC, 42-48.
Bolton, W. (1998). Engineering materials technology, 3rd ed., Butterworth-Heinemann, Oxford, Auckland Boston, Johannesburg, Melbourne, New Delhi, 290.
Carter, C. B. & Norton, M. G. (2007). Ceramic materials: Science and Engineering, 1st ed., Springer-Verlag, New York, 3 – 4.
Casasola, R., Ma. Rincón, J., & Romero, M. (2012). Glass-ceramic glazes for ceramic tiles – A review. *Journal of Material Science*, 47, 553-582.
Ece, O. I., & Nakagawa, Z. (2002). Bending strength of porcelains. *Ceramics International*, 28, 131-140.
Elakhame, Z. U., Ifebhor, F., & Asotah, W. A. (2016). Development and production of ceramic tiles from waste bottle powder (milled glass), *Journal of Science, Engineering and Technology*, 12(2), 50-59.
El Nouhy, H. A. (2013). Assessment of some locally produced Egyptian ceramic wall tiles, *Housing and Building National Research Center Journal*, 9, 201–209.
El-Fadaly, E. (2015). Characterization of porcelain stoneware tiles based on solid ceramic wastes. *International Journal of Science and Research*, 4(1), 602-608.
European Commission (2007). Reference document on best available techniques in the ceramic manufacturing industry. Available at: http://eippcb.jrc.es. (Accessed 2022, January 9).
Fatunsin, A. K. (1992). Yoruba pottery. National Commission for Museums and Monuments, Lagos, Intec Printers Ltd Ibadan.
Fonseca, A. S., Maragkidou A., Viana M., Querol X., Hämeri K., de Francisco I., Estepa C., Borrell C., Lennikov V., & de la Fuente G. F. (2016). Process-generated nanoparticles from ceramic tile Sintering: Emissions, exposure and environmental release. *Science of the Total Environment*, 565, 922–932.
Foraminifera (2019). Glazed ceramic tiles production in Nigeria, the feasibility report. https://foramfera.com/marketresearchreports/manufacturing-market-research-reports/glazed-ceramic-tiles-production-in-nigeria-the-feasibility-report/. (Accessed 2022, February 24)
Friendly, M. (2001). A brief history of the mosaic display. *Journal of Computational Graphical Statistics*, 11(1), 89-107.
Gbonegun, V. (2019). Experts urge FG to develop $47.7b ceramics market. https://guardian.ng/property/experts-urge-fg-to-develop-47-7b-ceramics-market/. (Accessed 2022, February 24)
Golkar, E., & Prabuwono A. S. (2013). Vision-based length measuring system for ceramic tile borders, *The 4th International Conference on Electrical Engineering and Informatics (ICEEI 2013), Elsevier, Procedia Technology*, 11, 771–777.
Griese, B. (2007). Porcelain in the ceramic tile industry, tilt council of north America's product performance testing laboratory, 70-73. https://www.tcnatile.com/images/pdfs/Porcelain%20in%20the%20Ceramic%20Tile%20Industry.pdf. (Accessed 2021, October 16)
Heinrich, J. G. & Gomes, C. M. (2017). Introduction to ceramics processing, TU Clausthal. www.ceramics-processing.com/.../ceramics/Introduction_to-Ceramics_processing.pdf. (Accessed 2022, June 7)
Idowu, I. O. (2014). Production of vitrified porcelain tiles using local raw materials from southwestern Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)*, 5(6), 421-428.
Irabor, P. S. A., Jimoh, S. O., & Omowumi, O. J. (2014). Ceramic raw materials development in Nigeria, *International Journal of Scientific and Technological Research*, 3(9), 275-287.
Iqbal, Y., & Lee W. E. (2000). Microstructural evolution in triaxial porcelain. *Journal of the American Ceramic Society*, 83(12), 3121–3127.
ISO 10545 (1996). EN ISO norms for ceramic tiles - Testing methods. www.norfloor.no/media/wysiwyg/DIY/ISO_10545-2.pdf. (Accessed 2022, June 25)
Iyasara, A. C., Joseph, M., & Azubuike, T. C. (2014). The use of local ceramic materials for the production of dental porcelain. *American Journal of Engineering Research*, 3(9), 135–139.
Jung, P. (2008). Quality control: Preparation of samples for XRF analysis, Article written for Retsch Inc., Newtown, PA, 23-27.

Kamseu, E., Leonelli, C., Boccaccini, D. N., Veronesi, P., Miselli, P., Pellacani, G., & Melo, U. C. (2007). Characterisation of porcelain compositions using two China clays from Cameroon. *Ceramics International*, 33, 851–857.

Lukkassen, D., & Meidell, A. (2003). Advanced Materials and Structures and their Fabrication Processes, Narrik University College, Hin.

Marcin, G., Jorge, A. R. (2012). Advanced ceramic in structural Engineering. https://orff.uc3m.es/bitstream/handle/10016/17807/Final%20Project%20-%20Advanced%20Ceramic %20in%20Structural%20Engineering.pdf?sequence=2. (Accessed 2022, August 08)

Martin, M. (2011). Rococo and neoclassical interiors. https://www.wellesley.edu/sites/default/files/assets/departments/davismuseum/exhibit%20imgs/PDF/permanent-collection-study-gallery-martin-rococo-study-essay.pdf. (Accessed 2022, October 28)

Martín-Márquez, J., Ma. Rincón, J., & Romero, M. (2008). Effect of firing temperature on Sintering of porcelain stoneware tiles. *Ceramics International*, 34, 1867-1873.

Martín-Márquez, J., Ma. Rincon, J., & Romero M. (2010). Mullite development on firing in porcelain stoneware bodies. *Journal of the European Ceramic Society*, 30(7), 1599-1607.

Mathew, G. O., & Fatile, B. O. (2014). Characterization of vitrified porcelain tiles using feldspar from three selected deposits in Nigeria. *Research Journal of Recent Sciences*, 3(9), 67-7.

Mbahi, A. A. (1999). The role of art in technology. *The Journal of Industrial Design and Technology. FUTA, Akure*, 1(1), 23–31.

Morakinyo, A. D., Sullayman, U. A. A., & Yawas, D. S. (2014). Performance evaluation of unglazed tiles produced from locally developed tile making machine. *Arts and Design Studies*, 23, 78–86.

Murray, H. H. (1999). Applied clay mineralogy today and tomorrow. *Clay Minerals*, 34, 39–49.

Murray, H. H. *Clays for our future in H. Kodama, A. R., Mermut & Torrance J., K. (Eds.) Proc*. 11th International Clay Conference, Ottawa, Canada, (1997). p. 3- 11.

Nwagbara, C. (2019). Ceramic tiles imports into Nigeria to hit ₦761 billion. https://nairametrics.com/2019/12/02/ceramic-tiles-imports-into-nigeria-to-hit-n761-billion/. (Accessed 2022, February 24)

Oaikhinan, E. P. How to revamp Nigeria's moribund ceramic industry. Publication of the Guardian Newspaper, 26 July 2015.

Obaje, N. G. (2009). Geology and mineral resources of Nigeria. Lecture Notes in Earth Sciences Series, Springer, 120, 221.

Oke, A. O. & Omoleye, J. A. (2006). Investigation of domestic water filters made from local raw material. *Nigerian Journal of Mechanical Engineering*, 4(1), 28–40.

Patrick, D. O., Kefas, H. M., John, Y. M., & Ameh, V. I. (2015). Investigation of the physical properties of tiles produced with Otukpo clay. *Leonardo Electronic Journal of Practices and Technologies*, 27, 162-176.

Quirion, F., Massicotte, A., Poirier, P., & Hadjev, N. (2008). A procedure to prepare fouled and worn quarry tiles. *Contemporary Ergonomics*, 657-662.

Raw Materials Research and Development Council (2010). Non-Metallic Mineral Endowment in Nigeria, 12-17. https://nairametrics.com/wp-content/uploads/2013/02/non_metallic_raw_materials.pdf. (Accessed 2021, October 18)

Reed, J. S. (1988). Introduction to the principles of ceramic processing, John Wiley & Sons Inc., New York.

Robertson, R. H. S. (1986). Fuller´s earth. A history, Volturna Press, Hythe, Kent, UK, 1- 83.

Stock, A. (2015). World production and consumption of ceramic tiles, tile today, 27-30. http://www.infotile.com.au/pdfFile/advicetopic/20062016114840.pdf. (Accessed 2022, January 22)

Yuan, G. (2004). Part A: Toxic/hazardous substances and environmental engineering. *Journal of Environmental Science and Health*, 39, 2661-2670.