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Suitability of Itakpe Iron Ore Tailing in Kogi State for Glass Ceramic Production

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Abstract

This paper detailed the production of glass ceramic from waste glass, kaolin, iron ore tailings waste and bentonite (binder). The methodology includes: collection, chemical analysis and slip production and compaction, sintering the batches to form glass ceramic 750 ^{0}C, mechanical property and microstructure analysis of the glass ceramic. Ternary phase diagram was used to determine the granulometric composition of 21 different mixtures with varying proportions. The waste glass, kaolin and iron ore tailing were analyzed for their chemical composition by X-ray fluorescence spectrometer (XRF). The compact 21 samples were arranged in a kiln and sintered at a temperature of 750 ^{0}C with holding time of two hours each. The results showed 73 % of SiO_2, kaolin has 54 % and iron ore tailing 65 %. The density of the sample 21 recorded the highest weight. The compressive strength of the sample 21 showed highest strength and this could be due to 20% tailing and 80% glass composition. Therefore, the potential for utilizing waste materials like soda-lime-silica glass, kaolin, and iron-rich phases in the production of advanced materials like glass-ceramics is justified.

Keyword: Waste, Mechanical, Iron Ore Tailing, Glass, Ceramic, Kaolin.

Introduction

Iron ore tailings in Nigeria are mainly generated from the Itakpe iron ore processing plant in Kogi State. The plant is operated by the National Iron Ore Mining Company (NIOMCO) and it generates about 2.15 million tons of tailings annually [1]. The tailings are mainly composed of hematite, quartz, and minor amounts of magnetite, mica, and other minerals. However, a study by [2] found that incorporating iron ore tailings into the ceramic tile production process resulted in improved mechanical properties and reduced porosity, compared to tiles produced without the tailings.

In another study, Oke *et al*. [2] observed that the addition of iron ore tailings improved the mechanical properties of the glass ceramics, including increased hardness and fracture toughness. In addition, the influence of phase transformation on properties of ceramic membrane needs to be distinguished to find out iron tailing-based glass ceramics with desirable properties.

Xingwen *et al*. [3], opined that glass-ceramic materials are a class of materials obtained by controlled crystallization of glass. Some of these glass-ceramic materials became commercial products and found their applications in the field of abrasion-resistant materials, which includes industrial floor coverings, wall facings, abrasion-resistant linings, and high-temperature insulators. Application of glass-ceramic to make construction and decorative materials is also a common process. As part of efforts to put this waste into judicious use, Itakpe iron-ore deposit–was used to develop glass ceramic.

The naturally occurring starting materials for making glass-ceramic are available in various locations across the country. Most of the available raw materials have not been characterized to determine their properties and suitability for making glass-ceramics using different methods. The mining of iron ore causes air pollution in the form of nitrous oxide, carbon dioxide, carbon monoxide and acid that drains from the mines [4]. Thus, converting iron ore tailings, waste glass and kaolin will reduce the problem of waste management; health hazard and also reduce the importation of raw material making for glass ceramic production.

Kankara *et al*. [4], emphasize the importance of utilizing iron ore tailings to reduce environmental pollution associated with mining operations. Iron ore tailings contain valuable components such as iron and other minerals. By incorporating these tailings into glass ceramics, a secondary resource can be created, reducing the dependency on primary raw materials. This contributes to resource conservation and sustainable material utilization. The utilization of iron ore tailings in glass ceramics production can create economic benefits by converting a waste material into a valuable resource. This can contribute to job creation, economic growth, and the development of a circular economy. Oke *et al*. [2], investigated the optimization of glass ceramics production using iron ore tailings and emphasized the economic potential of utilizing these tailings. The high performance of glass ceramics and low leachability of hazardous metals shed light on the potential application of iron tailings in building and decorative materials [5]. Also, Kankara *et al*. [4] believes converting the tailing waste into a useful product would justified that, environmental problem caused by the waste is minimized or eliminated. Also, the extraction and importation of the raw materials used for insulator production continuously have damaging effects to our environment and the economy.

Therefore, an attempt was be made in this research to find out the suitability of using iron ore tailing, kaolin and waste glass for making glass ceramics by sintering as this type of glass ceramics material has a wide variety of applications. This research aimed to find out the suitability of using iron ore tailing, kaolin and waste glass for making glass ceramics by sintering as this type of glass ceramics material has a wide variety of applications.

Materials and Methods

The production of glass ceramic from waste glass, kaolin and iron ore tailings. The experiment was done at the Department of Metallurgical Engineering and Department of Chemical Engineering in Ahmadu Bello University Samaru main campus Zaria, Kaduna State.

The material used for this experimental research includes waste glass, kaolin, iron ore tailing waste, bentonite and water. The tailing sample that was used in the present study came from the flotation process in the mineral processing plant of Okehi Kogi State Nigeria. The equipment are hammer, ball mill, British Standard (BS) sieves, weighing balance, digital Vernier caliper, kiln, plastic containers, plastic spoon, compression strength testing machine, electric furnace, multipurpose compacting machine.

Size reduction was done on the tailing waste using a ball mill at ceramics section Department of Industrial Design Ahmadu Bello University Zaria, to obtain homogeneous samples. The waste glass was obtained by collecting waste glass samples from Sun Glass Bottling Company in Kaduna State and beneficiation was done by washing, sorting and crushing with the aid of a glass processing machine at the Glass and Silicate Technology laboratory and kaolin was sourced was ball milled at Ceramics Section at the Department of Industrial Design. The tailing, powdered glass and kaolin were sieved to obtain a finer particle size, this was achieve by using a BS sieves 200μm to 70μm sieve, because finer particle size enables the possibility of obtaining homogeneous distribution of the 21 sample particles.

The waste glass, kaolin and iron ore tailing were analyzed for their chemical composition by X-ray fluorescence spectrometry (XRF) machine with a brand name Xenemetrix at National Steel Agency Kaduna State. The waste glass and kaolin were subjected to both scanning electron microscopy (SEM), while the iron ore tailing waste was subjected to SEM with energy dispersive spectroscopy (EDS). The system was controlled by a PC running the dedicated Mini Pal analytical software.

The waste glass, kaolin and iron ore tailing was weighed on a weighing balance (BP-N series digital pocket scale) and mixed with bentonite and 5mml of water to form slip. Ternary phase diagram was used to determine the granulometric composition that would result in the highest packing factor among the particles to be used in the production of the glass composite. 21 different mixtures with varying proportions of the three granulometric ranges were tested. Each side represents one binary mixture and area in this triangular diagram represents ternary components. Each of three corners of the triangle represent 100% by weight of one component (A, B or C). Thus, the lines AB, BC and CA are used for the three (3) components.

Table 1: Mixture of Composite Materials

Sample 1 A-100 B- 0 C- 0 100	Sample 2 A- 80 B- 20 C- 0 100	Sample 3 A- 80 B- 0 C- 20 100	Sample 4 A- 60 B- 40 C- 0 100	Sample 5 A- 60 B- 20 C- 20 100	Sample 6 A-60 B-0 C-40 100	Sample 7 A-40 B-60 C-0 100
Sample 8 A-40 B-40 C-20 100	Sample 9 A-40 B-20 C-40 100	Sample 10 A-40 B-0 C-60 100	Sample 11 A-20 B-80 C-0 100	Sample 12 A-20 B-60 C-20 100	Sample 13 A-20 B-40 C-40 100	Sample 14 A-20 B-20 C-60 100
Sample 15 A-20 B-0 C-80 100	Sample 16 A-0 B-100 C-0 100	Sample 17 A-0 B-80 C-20 100	Sample 18 A-0 B-60 C-40 100	Sample 19 A-0 B-40 C-60 100	Sample 20 A-0 B-20 C-80 100	Sample 21 A-0 B-0 C-100 100

The mixture of each sample with a binder was poured into the plastic bowl, and 5 % water was added to form a slip. The compacting machine was used to compact each sample slip at 10 kN; and the compact was removed from the machine. Each slip was used to produce 6 pieces of the 21 samples and it was allowed to dry at room temperature.

Plate I: The compact samples

The compact samples were arranged in a kiln and sintered at a temperature of 750 ^{0}C with holding time of two hours each. The samples were left in the kiln to cool before removal. The mechanical property tests that was conducted on the glass ceramic are density, compressive strength test and vickers hardness test. The tests were conducted at the Department of Material and Metallurgical Engineering laboratory Ahmadu Bello University Zaria.

The density was in accordance with BS 1881: Part 114:1983 by placing each sample on a measuring scale to check its weight. Density is calculated by the relation in equation 1:

$$\text{Density} = \frac{\text{W (kg)}}{\text{V (m2)}} \text{------ ------} \mathbf{1}$$

The compressive strength tests of concrete specimen were determined according with BS 1881: Part 116:1983. Compressive strength is calculated by the relation in equation 2.

$$\text{Compressive streght} = \frac{\text{Pmax}}{\text{A}} \text{-- ------} \mathbf{2}$$

Results and Discussion

Table 2: Physical Properties Pulverized Glass, Kaolin and Iron Ore Tailing

Physical Properties	Pulverized Glass (PG)	Kaolin (K)	Iron Ore Tailing (IOT)
Bulk Density (kg/m^3)	1382	1050	1335
Surface Texture	Smooth fine	Smooth fine	Smooth fine
Colour	White	Light brown	Grey

Table 2 shows that kaolin has more moisture content and absorption than pulverized glass and iron ore tailing; this is due to the surface area of the kaolin. The bulk density of the pulversied glass is higher than the kaolin and tailing and this is due to chemical composition.

Table 3: Chemical Composition of Pulverized Glass, Kaolin and Iron Ore Tailing

		Concentration (%)		
S/N	**Compounds (%)**	**PG**	**K**	**IOT**
1.0	SiO_2	73.025	54.90	65.23
1.1	V_2O_5	0.020	0.03	0.031
1.2	K_2O	0.353	12.88	1.061
1.3	Al_2O_3	2.487	36.00	7.000
1.4	Fe_2O_3	0.993	3.37	18.85
1.5	MgO	0.024	0.77	2.16
1.6	CaO	20.011	0.58	0.977
1.7	Cl	0.831	0.007	0.644

Table 3 presents the XRF results of the raw materials. It is observed that the chemical composition of pulverized glass, kaolin and tailing is predominantly based on SiO_2, which are typical of silicate minerals. The tailing contain high Fe_2O_3 more than the pulverized glass and kaolin due to where it was sourced based on the XRF analysis. The presence of K_2O, MgO and CaO is important because these alkaline and earthy alkaline elements act in the formation of the liquid phase, which is the main sintering mechanism of ceramic materials.

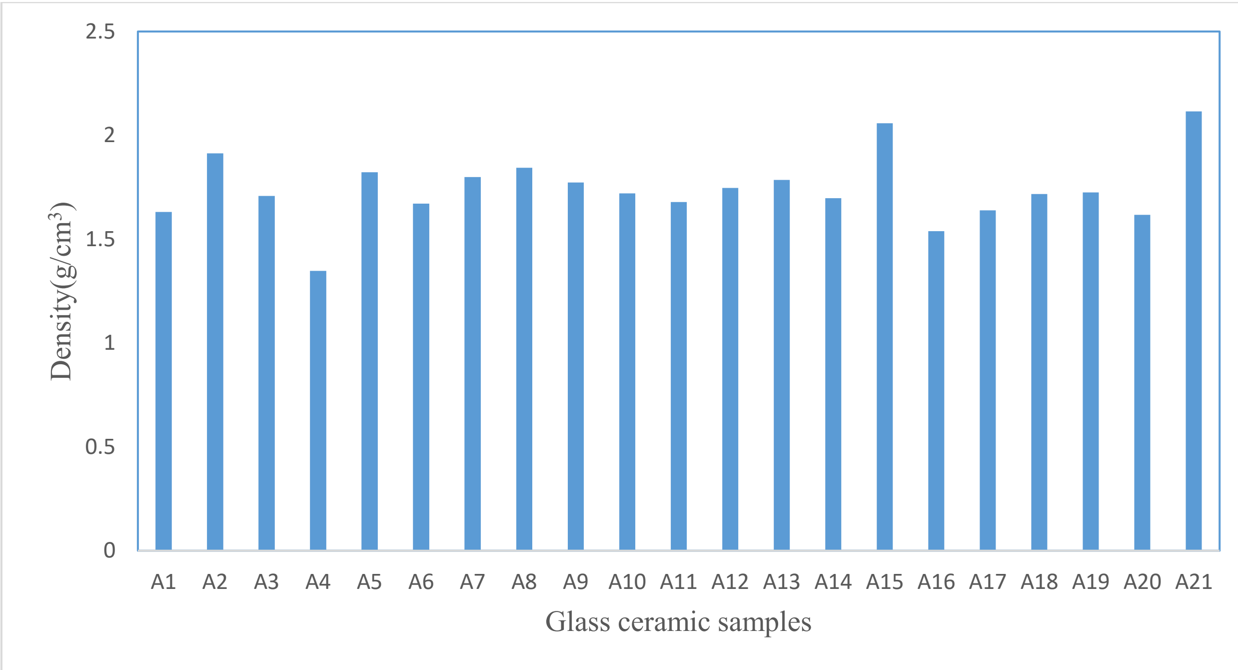

Figure 1: Density of the samples

Figure 1 shows the density of the samples after sintering. Sample A21 has 2.114 g/cm^3 recorded the highest value, sample A15 has 2.058 g/cm^3 due to 100% glass in the batch, sample A2 has 1.912 g/cm^3, sample A8 has 1.844 g/cm^3 and sample A5 has 1.821 g/cm^3 while sample A4 has the lowest density with 1.346 g/cm^3 due to 60% tailing and 40% kaolin. [7], observed that as the calcination temperature increases, the apparent density of the ceramic material increases, as does the linear shrinkage. This behavior is the pattern of this type of material and has already. However, the glass waste promoted an increase in the densification of the ceramic material, which is directly related to the formation of a liquid phase and greater sintering of resistant phases in the material. A negative characteristic is that the use of the waste promoted an increase in the firing shrinkage, which was already expected based on the other results.

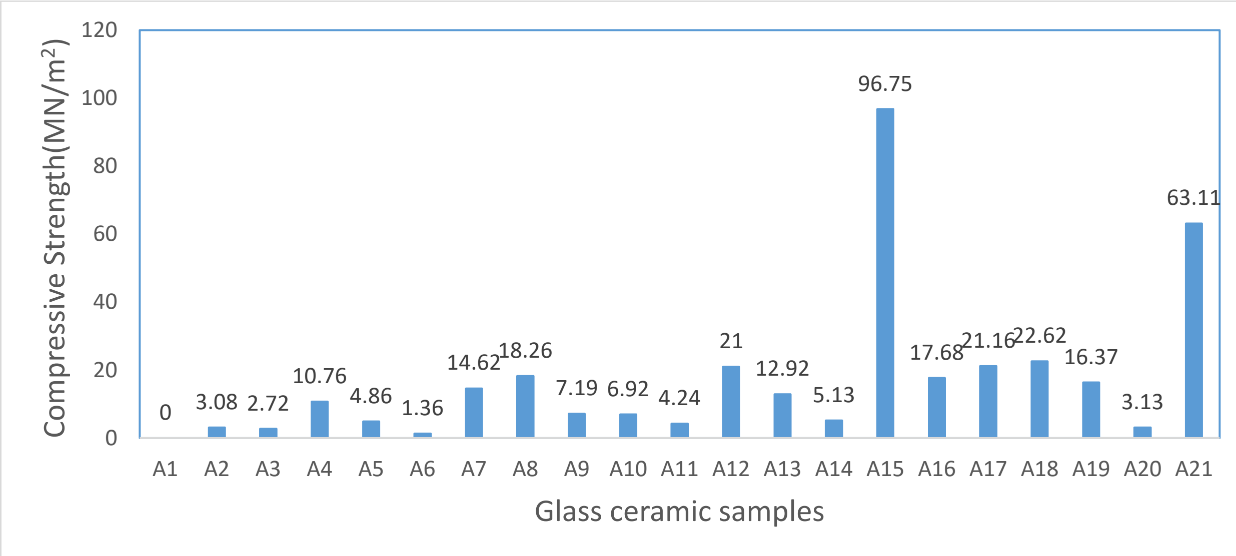

Figure 2: Compressive strength

Figure 2 shows sample A15 recorded the highest value with 96.75 MNm^{-2}, this is due to 20% tailing and 80% glass. Sample A6 recorded the lowest strength with 1.36 MNm^{-2}**,** this is due to 60% tailing and 40% tailing. Based on the discussion of the results, the effect of pulverized glass as ceramic materials is clear [7]. It is observed that the role of natural sand is to act as a source of quartz for ceramic materials. In ceramic materials, quartz has the function of controlling shrinkage and reducing defects in the material. Quartz replacement, therefore, should be limited so as not to exacerbate these problems. The presence of pulverized glass contributes to a decrease in the firing temperature and an increase in the apparent density, resulting in a reduction in porosity and an increase in compressive strength.

Conclusion

1. Kaolin has more moisture content and absorption than pulverized glass and iron ore tailing; this is due to the surface area of the kaolin. Bulk density of the pulversied glass is higher than the kaolin and tailing.
2. Chemical composition of pulverized glass, kaolin and tailing is predominantly based on SiO_2, which are typical of silicate minerals. The XRF indicated that tailing contain high Fe_2O_3 more than the pulverized glass and kaolin due to where it was sourced based on the XRF analysis.
3. Density of the sample A21 has 2.114 g/cm^3 which recorded the highest value, while sample A4 has the lowest density with 1.346 g/cm^3 due to 60% tailing and 40% kaolin.
4. Compressive strength of the sample A15 recorded the highest value with 96.75 MNm^{-2}, this is due to 20% tailing and 80% glass while sample A6 recorded the lowest strength with 1.36 MNm^{-2}**,** this is due to 60% tailing and 40% tailing.
5. Therefore, iron ore tailing, waste glass and kaolin have proved to be potential alternative

sustainable materials in materials science and engineering in the 21st century.

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