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Preparation and characterization of vitrified tiles from kaolinite clay – waste container glass mixture by sintering method

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Abstract

In this study, vitrified ceramic tiles were made by sintering a mixture of recycled waste container glass powder (RWGP) and kaolinite clays sourced from Nigeria. Initially, waste container glass (transparent color) was obtained from a municipal waste deposit, washed, and crushed before fine milling and sieving to obtain RWGP of approximately 75 µm. Prior to use, the as-received kaolinite clays were also beneficiated and sieved. Three body mixes (VT_1, VT_2, and VT_3) containing 80 – 90 wt. percent RWGP with kaolinite clays and feldspar were homogeneously blended and compacted in a steel mould measuring 200 x 180 x 10 mm. The green compacts were allowed to dry at room temperature before sintering at 1200°C for 2 hours. To evaluate the properties of the developed vitrified tiles, physical, mechanical, phase, and microstructure investigations were carried out. The results showed that bulk density increases across the series, while porosity was 0.5 percent for all tested samples, which is in accordance with ISO 13006. VT2 had higher hardness (6.71 MPa) and compressive strength (2.44 MPa). Quartz and wollastonite were the major phases identified by XRD, with albite, orthoclase, and calcite also present. The microstructure revealed a densified morphology typical of a clay–quartz structure, with little glassy phase resulting from the limited reaction of glass with the clay during sintering.

Keywords: Vitrified tiles; Kaolinite clays; Waste glass; Sintering

1. Introduction

Annually, approximately 11 billion tons of municipal solid waste (MSW) are generated, implying a ton per person, and this value is increasing globally. Among these MSW, more than 130 million tons of waste glasses are generated globally each year, with only 21% recycled despite the fact that glass is 100% recyclable [1].

As of today, Nigeria generates more than 32 million tons of MSW per year, with waste glasses and agro-wastes accounting for more than 70 percent of that total. Given the dangers and threats posed by these wastes to both life and the environment, it is critical to find alternative uses for them through recycling and valorization [2]. As a result, efforts are now being made to incorporate recycled waste glass, either as particles or fine milled powder, into the development of new and useful ceramic products such as tiles, bricks, and porcelains.

Several studies on the use of glass particles as a partial substitute for aggregates [3–5] and cement [6, 7, 5] in concrete have been published. Recently, recycled glass has been used in road construction to replace sand in asphalt mix [8]. Some studies have also shown that waste glass, due to its high silica (SiO2) content and the presence of alkaline earth oxides, can be used as a fluxing agent in the preparation of traditional ceramics [9 – 12, 2]. Assis et al. [13] investigated the use of crushed glass as a cement replacement in mortar and found that the addition of waste glass powder improves sulphate resistance without compromising strength. The use of waste glass as a partial substitute for sodium feldspar in the production of sanitary wares was also investigated [14], with results showing that mullite growth was accelerated

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in the glass substituted feldspar while energy consumption was reduced. Despite numerous reported works on the incorporation of waste glass in the development of ceramic wares, very few studies have been conducted on the reaction of kaolinite – type clays with glass [15, 16], and glass – clay based ceramics are frequently described without reference to the type of clay [17].

In this regard, the current study aimed to prepare and characterize vitrified tiles made from a kaolinite clay – waste container glass mixture using the sintering method. Bulk density, porosity, compressive strength, hardness, phase, and microstructure characteristics were investigated.

2. Material and methods

2.1. Starting materials

In this study, the starting raw materials for the preparation of vitrified tiles were kaolin, white ball clay, feldspar, and waste container glass (transparent color), in that order. Other raw materials (kaolin, white clay, and feldspar) were obtained in their as-received raw state from their respective deposits in Nigeria, with the exception of waste container glass, which was sourced from a municipal dumpsite. These raw materials were crushed, ground, and wet-sieved to obtain 75 µm particles before being oven dried at 105°C. Energy Dispersive X-ray Fluorescence was used to investigate the chemical composition of the processed materials (EDXRF).

2.2. Sample preparation

In this work, three body mixes of vitrified tiles were developed, as shown in Table 1. Before batch mixing, the materials were processed and weighed separately. Each body mix was precisely weighed and semi-dry mixed, with 5% water added to the total body mix to ensure bindability during pressing. Each body mix was then pressed into samples in a 200 x 180 x 10 mm steel mold using a laboratory hydraulic press at 75MPa pressure. The pressed samples were first allowed to dry at room temperature for 24 hours before being oven dried for 12 hours at 105°C. The dried samples were sintered in an electric kiln at 1200°C for 2 hours after soaking. Before offloading, the sintered samples were allowed to cool to room temperature.

Table 1 Vitrified tiles body formulation (wt. %)

Samples	RWGP	Kaolin	White ball clay	Feldspar
VT1	90	-	5	5
VT2	80	-	15	5
VT3	80	5	15	-

*RWGP – recycled waste container glass powder

2.3. Characterization

Several tests were carried out using standard procedures to investigate the properties of the developed vitrified tile samples. The bulk density and porosity were determined using the boiling method, as specified by ASTM C373. Mechanical properties such as compressive strength were tested using an Instron Universal Testing Machine at a strain/load rate of 5 mm/min, while hardness was tested using a Vicker's micro-hardness tester at a load of 10 kg for a dwell time of 10 s. SEM (JSM-6100 JEOL, Japan) was used to examine the microstructure, while an X-ray diffractometer (Rigaku miniflex 600, Japan) was used to investigate the crystalline phases.

3. Results and discussion

3.1. Materials characterization

Table 2 indicates the result of the chemical analysis of the raw materials used by EDXRF in weight percent. The results showed that the recycled waste container glass powder (RWGP) has similar oxides constituent with other materials used which indicate its potential use as admixture in ceramic wares preparation. However, the existence of silica (SiO_2), sodium oxide (Na_2O) and calcium oxide (CaO) indicates the RWGP is soda-lime-silica glass based. The chemical constituents of the white ball clay, feldspar and kaolin respectively also showed they are alumino-silicate bearing materials. However, the moderate content of K_2O (9.86%) observed for feldspar indicate it is an orthoclase feldspar mineral. This result is in tandem with previous works [18, 15].

Table 2 Chemical composition of starting materials used by EDXRF (wt. %)

Materials	SiO_2	Na_2O	MgO	CaO	Al_2O_3	Fe_2O_3	K_2O	P_2O_5
RWGP	69.38	7.22	0.55	15.03	5.03	0.71	0.65	0.09
White ball clay	51.70	-	-	39.96	0.17	2.26	0.58	0.39
kaolin	62.50	-	-	0.16	36.04	1.97	0.63	0.46
Feldspar	66.52			0.71	18.12	0.29	9.86	

3.2. Physical properties

Table 3 displayed the physical properties of the developed vitrified tiles VT_1, VT_2, and VT_3 in terms of bulk density and estimated porosity. The bulk density of the samples increases as the series progresses. This increase in bulk density indicates high compactness and pore closure caused by the glassy or vitreous phase produced by the high glass content at elevated temperatures [19]. In terms of porosity, it was discovered that all of the vitrified tile samples had similar porosities ranging between 0.45 and 0.55 percent. This lower porosity could also be due to the glass content's high vitreous phase, which seals the pores [20, 2]. The observed porosity value is consistent with the ISO 13006 recommended value for vitrified tiles, as reported by Matthew and Fatile [18], because porosity has a direct relationship with water absorption.

Table 3 Physical properties of the samples

Sample	Bulk density (g/cm³)	Porosity (%)
VT_1	0.564	0.5
VT_2	0.5888	0.45
VT_3	0.8478	0.55

3.3. Mechanical Properties

The result of the mechanical properties in terms of micro-hardness and compressive strength is shown on Table 4. For the compressive strength, it is observed across the series that the compressive strength obtained for all the samples is somewhat low, however, sample VT_2 has the highest compressive strength of 2.44 MPa. In terms of micro-hardness, VT_2 also showed the highest hardness value of 6.7 GPa. The better mechanical properties exhibited by VT_2 could attributed to its low porosity and high glassy phase [15].

Table 4 Mechanical properties of the samples

Sample	Compressive test (MPa)	Hardness (MPa)
VT_1	2.12892	6.428
VT_2	2.43767	6.708
VT_3	1.88893	5.031

3.4. Microstructure characteristics

Figures 1 (a – c) showed the representative morphologies of the sintered VT_1, VT_2, and VT_3 respectively. It is observed for all the samples that the microstructure exhibited a typical clay – quartz mixtures similar to what was reported previously [15]. It is also observed that only VT_2 and VT_3 showed good vitreous (glassy) phase on the surface with good compactness with varying degree of open and entrapped pores at the clay-quartz interfaces. VT_3 (Fig. 1c) also showed higher densification on the surface which actually account for its high bulk density.

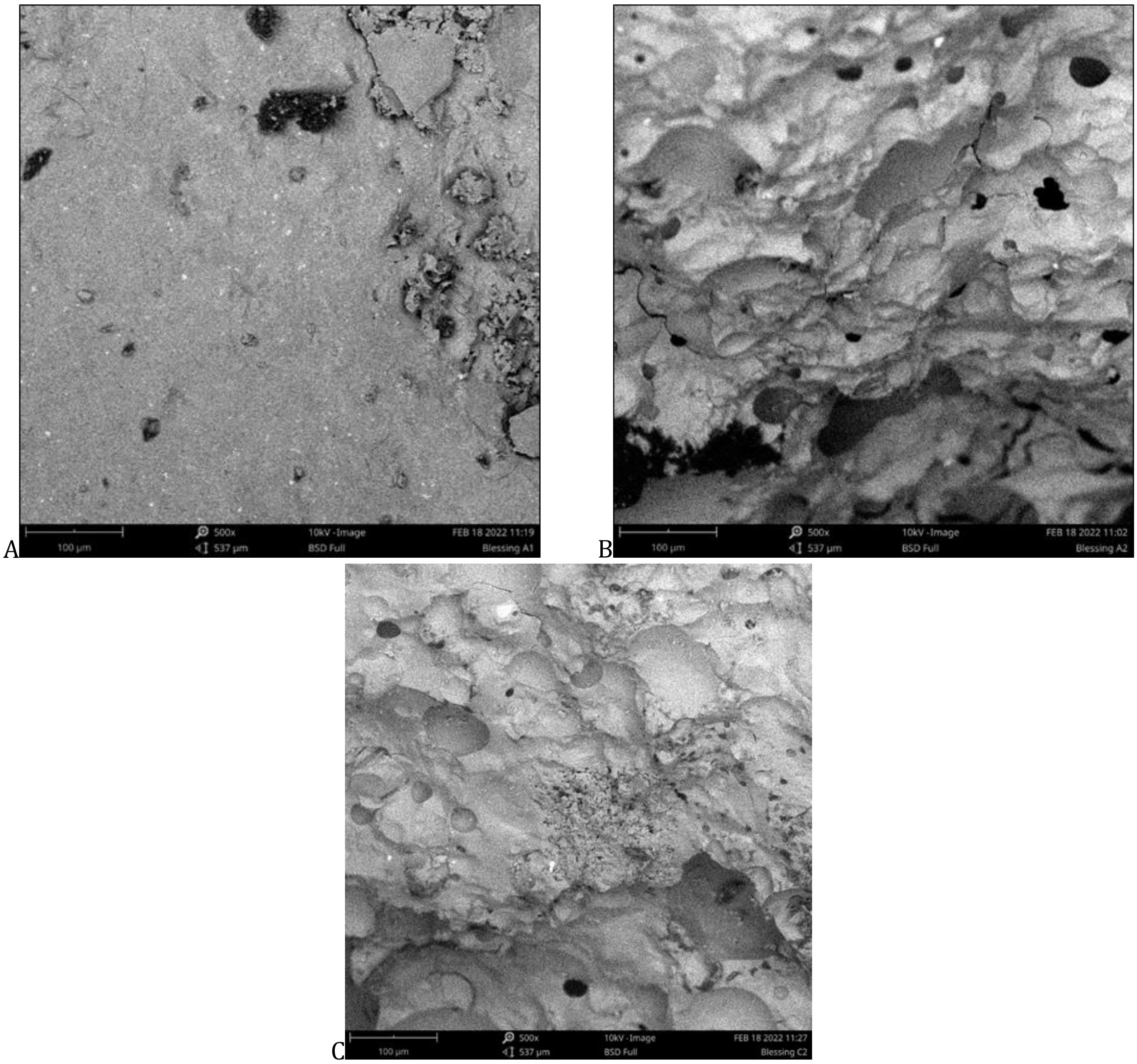
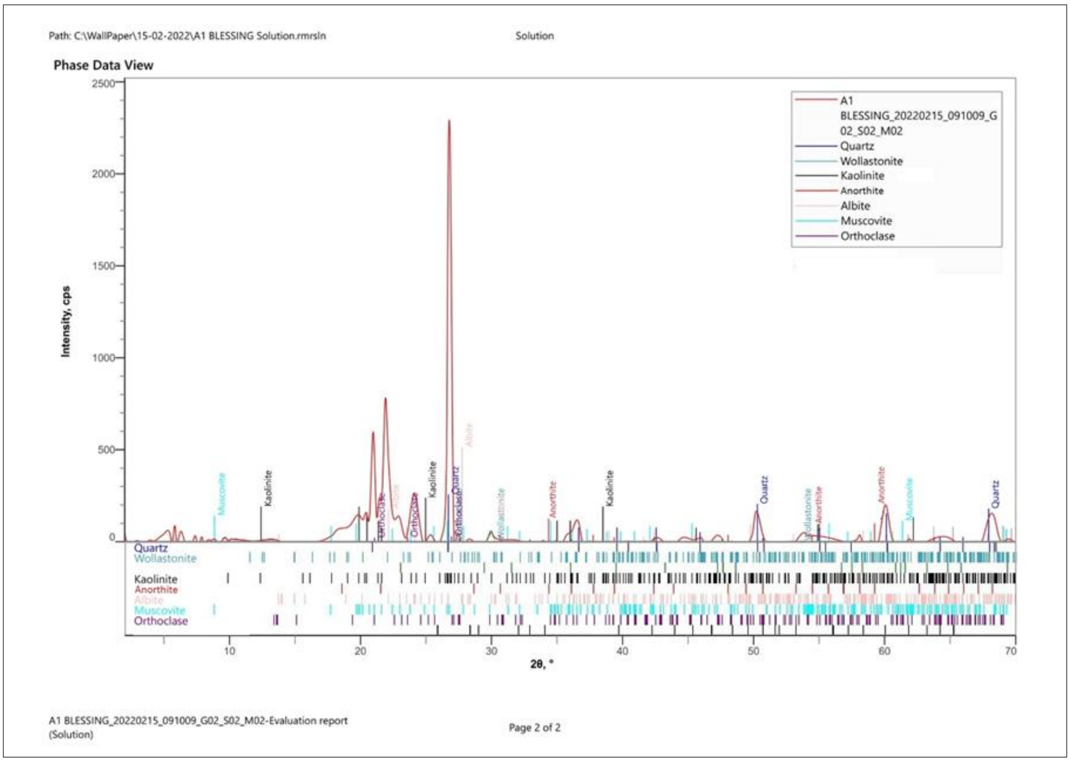


Figure 1 Representative SE images of (a) VT_1 (b) VT_2 (c) VT_3 samples

3.5. Phase composition

The result of the phase composition of the vitrified tile samples (VT_1, VT_2 and VT_3) examined by X-ray diffractometer is shown in Figures 2 (a – c) respectively. The XRD spectra indicate all the samples exhibited crystalline peaks of quartz, wollastonite, anorthite, albite, muscovite, kaolinite and orthoclase respectively. The major peak of crystalline quartz observed in all the samples showed that the RWGP has limited reaction with clay during sintering, even if melted. However, the presence of anorthite, albite and muscovite in the samples indicate a limited glass – clay interaction. Similar result has been reported by Djangang et al [15].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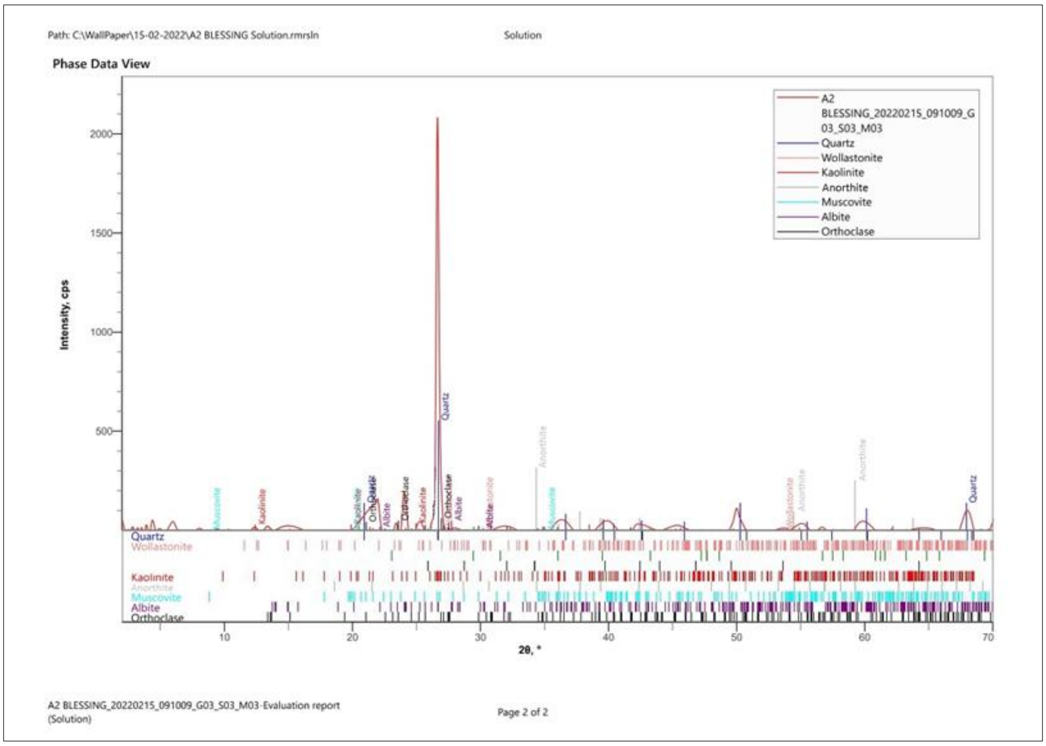
A.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B.

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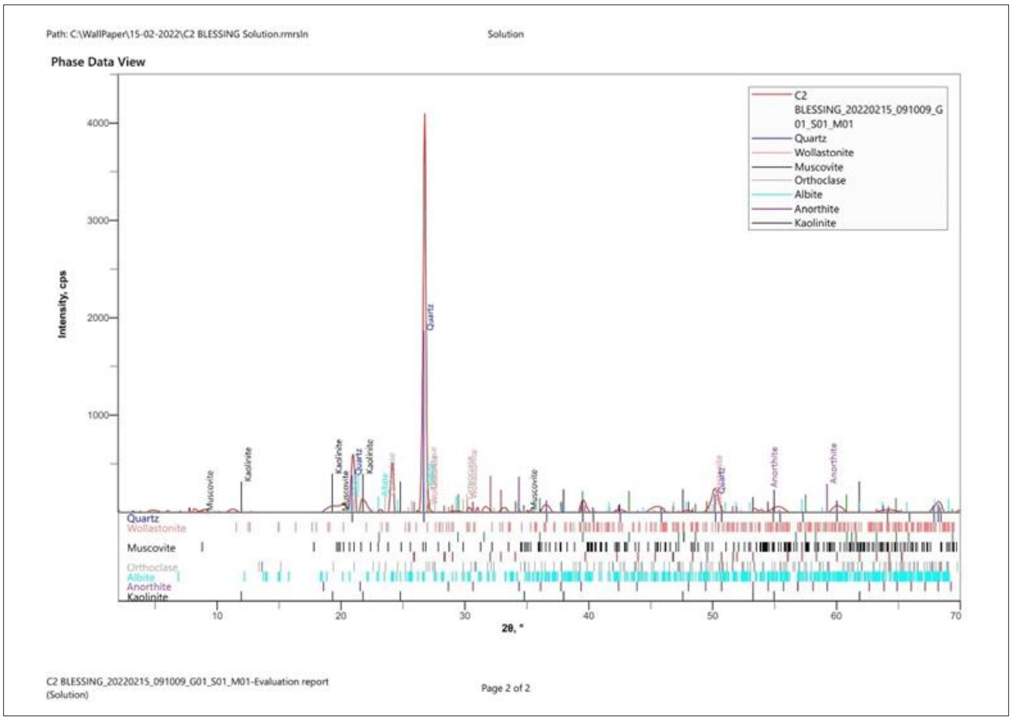

Figure 2 XRD Phase composition of (a) VT_1 (b) VT_2 (c) VT_3 samples

4. Conclusion

The present work has dealt with preparation and characterization of vitrified tiles from kaolinite clay – waste container glass mixture using conventional sintering method. The following conclusions are drawn within the limit of this work:

- Glass wastes can be successfully recycled and used in glass – clay mixture for development of ceramic components like vitrified tiles.
- The physical properties tested showed that the bulk density increased across the series (VT_1, VT_2 and VT_3) while the porosity did not exceed 0.5% indicating a well compact structure.
- The compressive strength and hardness values are somewhat low when compared with previous work which is attributed to less viscous content arising from the limited reaction of the glass with clay during sintering which is confirmed from the phase composition.
- The microstructure showed a typical clay – quartz mixture with little glassy/vitreous phase arising from limited reaction of the glass with clay during sintering.

The phase composition by the XRD affirmed the microstructure with little phase content of anorthite, muscovite and albite while the main crystalline phase is quartz.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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