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ORIGINAL ARTICLE

Investigation into the viability of the properties of porous glass-ceramics produced from granite dust and maize cob for use in thermal insulation of external walls of residential buildings

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ABSTRACT – Given the enormous need for cost-effective wall insulation materials in the developing countries and Nigeria specifically, this study, explores the viability of porous glass-ceramics production from granite dust and maize cob using one-step sintering technology. The chemical compositions of the locally sourced materials used including granite dust, ball clay and maize cob were obtained using XRF. 300µm of granite dust and ball clay as well as 425µm of maize cob powder were used. Different amount of granite dust and maize cob powder were mixed with constant amount of a mixture of NaOH and Na_2SiO_3 in three different groupings to formulate the porous glass-ceramics samples. The formulated samples were uniaxially pressed at 10MPa and sintered in a gas kiln at 850°C for 3 hours. The sintered samples were subjected to experimental tests. The results showed water absorption, apparent porosity, bulk density, compressive strength and thermal conductivity of 25.6%–46.7%, 43.5%–75%, 1.45g/cm^3 – 1.9g/cm^3, 0.7MPa–9.7MPa and 0.11W/m.K–0.53W/m.K respectively. The mineralogical properties of the sintered samples were obtained using XRD. The results indicated a viable material for use in thermal insulation of residential buildings.

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INTRODUCTION

Energy consumption in buildings is enormous. This is expected to further increase because of improving standards of living globally and with the rate of the increasing world population. Buildings are also responsible for increasing global greenhouse gas emissions due to the use of active cooling devices such as conditioners and fans to provide thermal comfort in buildings. In response to the green-house gas emission challenge, reducing carbon emissions of new buildings and improving the energy efficiency of existing buildings becomes more imperative than ever before. Therefore, all over the world, there is an increasing need for energy-efficient building design which uses design features and technology that makes a building climate responsive. Nigeria is located in the tropical region and is exposed to a mean total solar radiation of 500W/m^2 annually [1]. Nigeria is situated within the lowland humid tropics and is characterized by high temperatures almost throughout the year, with a mean maximum temperature 32°C and a mean minimum temperature of 13°C in the Southern part as well as a mean maximum temperature of 41°C and a mean minimum temperature of 21°C in the Northern part [2]. As buildings in the world's tropical regions such as Nigeria are constantly exposed to solar radiation [3], thermal discomfort is not an uncommon occurrence in buildings in the country, especially during the dry season. Odebiyi et al. [4] described Africa as the hottest continent as well as the world's largest consumer of biomass energy, which accounts for two-thirds of total energy consumption, contributing about 3.7% of total world energy-related carbon emissions. It can be deduced from this that Nigeria being the most populated country in Africa must have contributed a huge share to Africa's energy consumption and carbon emission. For instance, according to [5], energy consumed by residential buildings is responsible for more than 50% of the overall energy consumed in the country.

Due to the influence of climate change, people are often being exposed to extreme hot and cold weather, the world over. For instance, The Nigerian Metrological Agency (NMA) in April 2019 reported the case of an extreme heat wave with temperatures increasing to about 42.2°C in certain parts of the country [6]. In light of this, it is noteworthy that the need for thermal insulation in buildings in the country cannot be overemphasized. Insulation is an important one among other passive cooling strategies. It acts as an obstruction to heat flow, keeping buildings warm in winter by reducing heat loss and cool in summer by reducing heat gain [7]. Therefore, thermal insulation materials are suitable for use in any form of building, be it offices or residential given the fact that thermal comfort is required in any type of building. It is also important to note that thermal insulation materials can be appropriately used in any region of the country, be it cold or hot zone, due to their climate responsiveness. Nevertheless, wall thermal insulation is considered mostly needed in residential buildings given the fact that most people spend more time of the day at home than at work, and most especially thermal comfort at home makes sleeping at night more comfortable.

Given that humans' long exposure to extreme weather condition could result into health hazard, it is obvious that there is an increasing need for Nigeria to implement its Building Energy Efficiency Code (BEEC). However, since the use of

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mechanical or electrical driven devices to provide heating and cooling in buildings has been observed to contribute immensely to world's energy consumption and carbon emission, thermal insulation is a climate responsive means that provides a better alternative for heating and cooling of buildings. Despite the urgent need for energy-efficient building design in the country, building designs in Nigeria hitherto seem to have emphasized more on the aesthetic appearances, while paying little or no attention to energy efficiency [8]. According to [9], the power supply to the rapidly growing population in Nigeria is insufficient and consequently overdependence on private generators for electricity supply has resulted into high expenditures on fossil fuels and noise pollution. Therefore, encouraging massive use of wall insulation in buildings will help in promoting energy-efficient building design which will help in reducing carbon emission, noise disturbance and energy bills [10]. The use of thermal insulation in buildings contributes immensely to comfort promotion, enhanced façade design, sustainable development as well as economic and environmental benefits [11]. An external wall thermal insulation system guarantees a superior performance from the point of view of energy savings: proper insulation reduces the cost of heating / cooling a building and this also leads to considerable savings in terms of the carbondioxide released into the environment [12].

It is noteworthy that porous glass-ceramics serves as an effective thermal insulation material with numerous benefits. Interesting properties of porous glass-ceramics that makes its advantageous over polymeric foams include but not limited to good moisture absorption, high thermal and acoustic insulation and high chemical resistance as well as non-toxicity and non-flammability [13, 14]. Synthesis of porous glass-ceramics by sintering can be done by two-step or one-step route. The one-step sintering route of porous glass-ceramics which involves the combination of two processes (that is, glass phase and pore formation) in one helps in reducing the cost of production [15] as well as reducing energy input required for its production [16]. Sometimes, chemical reagents can be used to facilitate the one-step production process of porous glass-ceramics at a lower temperature as in the case in this study. According to [17], it is possible to save energy required in the production of porous glass-ceramics obtained from naturally occuring silicate and aluminoslicate containing rocks by eliminating preliminary melting of glass in such a way that both the glass formation and formation of cellular structure are combined in a single process [17].

Since in developing countries such as Nigeria, cost is one of the important criteria that impedes substantial adoption of thermal insulation in buildings [10], the possibility of developing porous glass-ceramics from wastes using one-step sintering presents a viable path for cost-effective thermal insulation materials which is mostly needed in buildings both in the temperate and tropical regions of the world. Porous glass-ceramics can be developed from cheap natural resources such as granite dust and maize cob. According to National Bureau of Statistics, Nigeria produced 9.62 million tonnes of granite in the 2018 fiscal year, representing 17% of the total 55.85 million tonnes of total solid minerals produced in the year [18]. Nigeria's maize production as at 2019 has increased to about 20 million metric tonnes annually [19]. It can be deduced from these statistics that granite dust and maize cob are available in abundance in the country. However, these wastes have not been fully utilized. Rather than culminating into environmental pollution, granite dust and maize cob which are mining waste and agricultural waste respectively can be used for the production of thermal insulation materials. While maize cob (corn cob) has been used as pore-forming agent in the development of porous ceramics in previous studies [20, 21], it is noteworthy that there is no research yet on synthesis of porous glass-ceramics from granite dust using maize cob as a pore-forming agent. This research aims to fill this gap in literature.

According to [22], before using any material for its desired purpose, its compliance to acceptable standards must be verified by subjecting it to different forms of characteriztions which include but not limited to its chemical, mechanical, thermal and mineralogical properties as this helps to ascertain that it can function without failure in its real-life application when used for the intended final product. Given the need for low cost thermal insulation materials in residential buildings in Nigeria, this research investigated into the physico-mechanical, thermal and mineralogical properties of porous glass-ceramics obtained from cheap and local materials with a view to providing documented procedures of a building material that will promote green and energy efficient environment.

METHODS AND MATERIALS

Sourcing and Processing of Raw Materials

This study used the following materials: granitic dust, ball clay, maize cob powder, caustic soda (NaOH) and sodium silicate (water glass, Na_2SiO_3). Sourcing and purchasing of raw materials was limited to Itaogbolu and Akure in Ondo State, Nigeria, due to accessibility of all the materials within the state. All the sourced raw materials were processed by sun drying, grinding into powdered form, milling and sieving. Chemical reagents including NaOH solution and sodium silicate were used as the sintering aid to enable the production of porous glass-ceramics by one-step sintering method. Granite dust, ball clay and maize cob powder served as the core raw material required for glass formation, binder and pore-forming agent respectively.

Chemical Compositions of Raw Materials

The chemical compositions of the sourced raw materials for developing porous glass-ceramics were determined using X-ray Flourescence (XRF) Spectrometer, SKYRAY INSTRUMENT, Model: EDX3600B as shown in Table 1.

Table 1. Chemical compositions of raw materials used in this study (wt%)

Oxide	Granite dust	Ball Clay	Maize Cob
Al_2O_3	12.82	21.60	13.79
SiO_2	59.72	58.15	27.75
P_2O_5	0.44	0.21	1.42
SO_3	0.82	0.71	6.37
K_2O	5.74	2.30	9.28
CaO	5.67	0.15	7.19
TiO_2	0.35	1.81	-
V_2O_5	0.04	0.02	0.02
Cr_2O_3	-	0.01	0.02
MnO	0.07	0.03	0.15
CoO	0.23	0.35	0.33
Fe_2O_3	11.29	14.40	20.88
NiO	0.04	0.05	0.26
CuO	0.04	0.04	0.22
ZnO	0.09	0.09	0.72
WO_3	0.12	0.05	1.15
Au_2O	-	0.05	-
Rb_2O	0.07	0.01	0.01
Nb_2O_5			0.12
MoO_3	0.25	-	0.92
SnO_2	1.14	-	4.66
Sb_2O_3	1.10	-	4.74

Formulation of Porous Glass-ceramics Samples

Sieved through British Standard sieves, 300µm, 300µm and 425µm of granite dust, ball clay and maize cob powder were used. Addition of 50% ball clay to 100% granite dust was found to give adequate bindability to enhance the compaction of the non-plastic material (granite dust), having varied the the ball clay from 5% upward. The raw material that supplied the glassy base (owing to high content of silica) thus consist granite dust and ball clay mixed in ratio 2:1 and was labelled as GrC. Different compositions of GrC and maize cob powder, mixing up to 100g was used for each sample. 40% NaOH solution and sodium silicate (Na_2SiO_3) were mixed in ratio 1:1. Different amount of granite dust and maize cob powder were mixed with constant amount of a mixture of NaOH and Na_2SiO_3 in three different groupings to formulate the porous glass-ceramics samples as shown in Table 2. Each of the obtained samples were mixed thoroughly, the homogenized composition was then dispensed into a 50mm x 50mm x 50mm mould, pressed unixially at 10MPa, dried in the electric oven at 110°C for 6 hours and sintered in the gas kiln up to 850°C for 3 hours.

Table 2. Formulation of porous glass-ceramics samples

Sample Number	Sample Designation	Samples Grouping	Sample Formulation	GrC (g)	Maize cob powder (g)	NaOH (cm^3)	Na_2SiO_3 (cm^3)
1	C_1		95%GrC + 5% maize cob powder + 7.5 %Na_2SiO_3 + 7.5%NaOH	95	5	7.5	7.5
2	C_2	1	90%GrC +10% maize cob powder + 7.5 %Na_2SiO_3 +7.5%NaOH	90	10	7.5	7.5
3	C_3		85%GrC +15% maize cob powder + 7.5 %Na_2SiO_3 +7.5%NaOH	85	15	7.5	7.5
4	R_1		95%GrC + 5% maize cob powder +10%Na_2SiO_3 +10%NaOH	95	5	10	10
5	R_2	2	90%GrC + 10% maize cob powder + 10%Na_2SiO_3 + 10%NaOH	90	10	10	10
6	R_3		85%GrC + 15% maize cob powder + 10%Na_2SiO_3 + 10%NaOH	85	15	10	10

Table 2. Formulation of porous glass-ceramics samples (cont.)

Sample Number	Sample Designation	Samples Grouping	Sample Formulation	GrC (g)	Maize cob powder (g)	NaOH (cm^3)	Na_2SiO_3 (cm^3)
7	C_1		95%GrC + 5% maize cob powder + 12.5%Na_2SiO_3 +12.5%NaOH	95	5	12.5	12.5
8	C_2	3	90%GrC +10% maize cob powder + 12.5%Na_2SiO_3 + 12.5%NaOH	90	10	12.5	12.5
9	C_3		85%GrC +15% maize cob powder + 12.5%Na_2SiO_3 +12.5%NaOH	85	15	12.5	12.5

Measurement of the Properties of Samples

Water absorption, apparent porosity, bulk density, compressive strength, and thermal conductivity of the sintered porous glass-ceramics samples were determined by experimental tests.

Water Absorption, Apparent Porosity and Bulk Density

The water absorption, apparent porosity and bulk density and apparent porosity tests were conducted according to ASTM C20-00 [23] and were calculated using:

$$Wa = Ws - Wd / Wd \times 100 \tag{1}$$

$$\text{Apparent porosity, } A = W_2 - W_1 / W_2 - W_3 \tag{2}$$

$$\text{The bulk density, } \rho b = W_1 \times \rho w / W_2 - W_3 \tag{3}$$

where Wa, A, ρb, ρw, W_1, W_2 and W_3 represents the water absorption rate, apparent porosity, bulk density, density of water (g/cm^3), sintered weight, soaked weight and suspended weight of the sample, respectively.

Compressive Strength

Compressive strength machine, INSTRON SERIES 3369 at a fixed crosshead speed of 10 mm min^{-1} was used to measure the compressive strength of the produced samples of porous glass-ceramics in accordance to ASTM C240-97 [24]. When the each of the test samples failed under the applied load, it automatically calculates and displays the compression strength value on the display unit (screen). The compressive strength was calculated using the equation:

$$C.S. = \text{Maximum load (kN)} / \text{Cross-sectional area } (m^2) \tag{4}$$

where C.S. is the compressive strength.

Thermal Conductivity

A self-designed type of Lee's disc apparatus was used to measure the thermal conductivity of the samples according to [25, 26], and was calculated using:

$$k = 2.303MC\delta\,[\log \theta_1 / \theta_2] / A.\tau \tag{5}$$

$$\theta_1 = Ts - T_1 \tag{6}$$

$$\theta_2 = Ts - T_2 \tag{7}$$

Where k, M, C, δ, Ts, T_1, T_2 and τ and A represent the thermal conductivity of the specimen in W/m˚C, the mass of water in a conical flask in kg, specific heat capacity of water in a conical flask (4200J/kg˚C), thickness of sample in m, temperature of steam in ˚C, initial temperature of water in the conical flask in ˚C, final temperature of water in the conical flask in ˚C, area of the sample in m^2 and time in seconds respectively.

Mineralogical Properties of the Optimum Sample

X-ray diffraction (XRD) pattern of the optimum sample of porous glass-ceramics developed in this study was obtained using BRUKER-binary V4 X-ray diffractometer (θ/2θ system), equipped with Cu-Kα radiation (λ=1.54060Å), measured at 25°C, operating at 10 mA, 30 kV, in the 2θ range from 5-90° with 0.026° step size and 56.52s scanning time. The raw data obtained were processed with PANalytical X'Pert HighScore software.

RESULTS AND DISCUSSION

Chemical Properties of the Raw Materials

Table 1 shows that the raw sample of granite dust used in this study mainly consists of 59.72% silica (SiO_2), 12.82% alumina (Al_2O_3) and 11.29% iron oxide (Fe_2O_3) respectively. Since granite dust contains a significant amount of SiO_2, the glass former and Al_2O_3, the stabilizer in glaze formation, it is thus a suitable raw material for supplying the glassy phase required for the production of porous glass-ceramics. It also contains other oxides that serve as fluxes in glass production including 5.74% potassia (K_2O) and 5.67% calcia (CaO) respectively. The raw sample of ball clay used mainly consists 58.15% SiO_2, 21.60% Al_2O_3 and 14.40% Fe_2O_3 respectively. It also contains other significant oxides including 2.30% K_2O and 1.81% titania (TiO_2) respectively. The ball clay shows the quality of a good aluminosilicate material with Fe_2O_3 as the major impurity which is mostly responsible for the brown colouration in ball clay. While the essence of using ball clay in this study is due to its plasticity so as to provide the required binding aid to granite dust (a non-plastic material) which is the main raw material for this study, the presence of high amount of SiO_2 in the ball clay could have served as an additional aid in providing glassy base material for the study. The maize cob powder used mainly consists 27.75% SiO_2, 13.79% Al_2O_3, 20.88% Fe_2O_3, 9.28% K_2O and 7.19% CaO respectively and these are important oxides in glass and ceramic production. It also contains other significant oxides including 9.28% K_2O, 7.19% CaO, 4.74% sulphur oxide (SO_3), 6.37% antimony oxide (Sb_2O_3), 4.66% tin oxide (SnO_2), 1.42% phosphorus oxide (P_2O_5) and 1.15% tungsten oxide (WO_3) respectively. It was observed that all the raw materials are rich in Fe_2O_3. The percentage of Fe_2O_3 present in granite dust, ball clay, maize cob is 11.29%, 14.40% and 20.88% respectively. Abundant content of Fe_2O_3 could serve as a catalytic support in the production of porous glass-ceramics [27]. Table 3 shows the chemical properties of some main raw materials utilized in previous studies compared to granite dust utilized in this study.

Table 3. Chemical properties of some main raw materials utilized in previous studies compared to granite dust utilized in this study

Main Raw Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	MgO	P_2O_5	SO_3
Coal Fly Ash [28]	35.42	39.40	2.63	10.4	0.40	-	-	0.217	4.62
TTP Slag [29]	57.5	23.0	10.8	1.9	3.6	-	-	-	-
Glass Cullet [30]	66.0	3.0	0.3	11.2	3.3	12.2	3.7	-	-
Granite Dust*	59.72	12.82	11.29	5.67	5.74	-	-	0.44	0.82

*Authors' Research work (2019)

While Coal fly ash, TTP slag and glass cullet are industrial wastes of high temperature processes, granite dust is an industrial waste of the quarry industry which has not been subjected to any initial heat treatment; however, it can be observed from Table 3 that the chemical composition of granite dust utilized in this study compares favourably with some of the wastes that have undergone heat treatment utilized in previous studies for the production of porous glass-ceramics. This provides one of the reasons for its suitability for use in one-stage sintering technology of porous glass-ceramics processing. One step sintering of porous glass-ceramics in this study was achieved by the use of chemical reagents, that is, NaOH and Na_2SiO_3 as sintering aid.

Physical Apperance of the One-Step Sintered Glass-ceramics Samples

There are notable differences in the resulting physical appearances of each of the porous-glass-ceramic samples sintered at 850ºC based on the addition of varying amounts of NaOH+Na_2SiO_3 (at 7.5%, 10% and 12.5% each) to the mixture of 95%, 90% and 85% granite dust and 5%, 10% and 15% maize cob powder respectively as shown in Figures 1-3. The degree of sintering of the samples at 850ºC was observed to increase as the amount of the mixture of NaOH+Na_2SiO_3 increased from 7.5% to 10% and to 12.5% of each of the two reagents respectively.

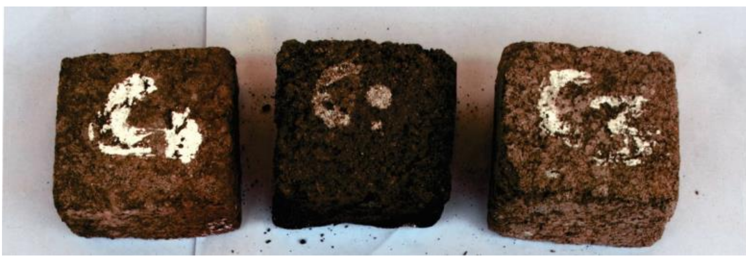

Figure 1. Sintering results of GrC (95-85%) + maize cob powder (5-15%) + 7.5%Na_2SiO_3 + 7.5%NaOH

Figure 2. Sintering results of GrC (95-85%) + maize cob powder (5-15%) + 10%Na_2SiO_3 + 10%NaOH

Figure 3. Sintering result of GrC (95-85%) + maize cob powder (5-15%) + 12.5%Na_2SiO_3 + 12.5%NaOH

Physico-mechanical and Thermal Properties of the Porous Glass-ceramics Samples

The trend in the physico-mechanical and thermal properties of the sintered porous glass-ceramics are as shown in Figures 4-8.

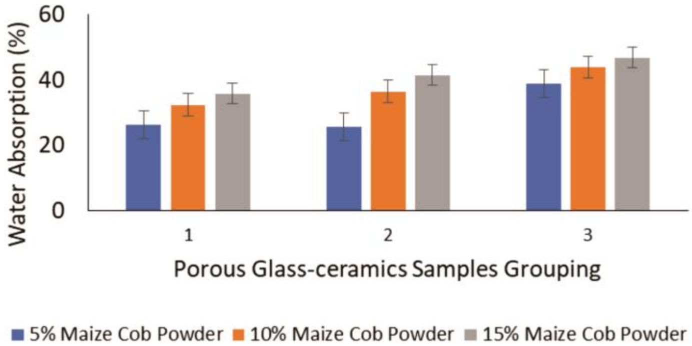

Figure 4. Water absorption rate of the porous glass-ceramics samples

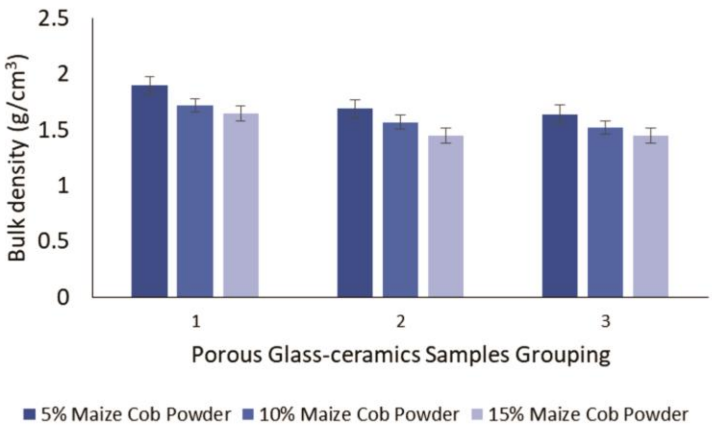

Figure 5. Bulk density of the porous glass-ceramics samples

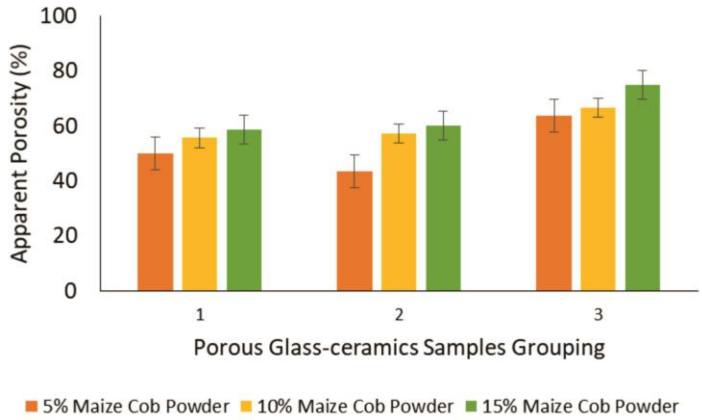

Figure 6. Apparent porosity of porous glass-ceramics samples

Figures 4-6 show increasing values of water absorption, increasing values of apparent porosity and decreasing values of bulk density of the produced samples respectively corresponding with the increasing addition of maize cob powder in each of the three samples groupings. Samples Grouping 1 consisting of Samples 1, 2 and 3 with 5%, 10% and 15% maize cob powder respectively and 7.5%Na_2SiO_3+7.5%NaOH show 26.3%, 32.3% and 35.7% water absorption rate, 50%, 55.6% and 58.8% apparent porosity, 1.9g/cm^3, 1.72g/cm^3 and 1.65g/cm^3 bulk density respectively. Samples Grouping 2 consisting of Samples 4, 5 and 6 with 5%, 10% and 15% maize cob powder respectively and 10%Na_2SiO_3+10%NaOH show 25.6%, 36.4% and 41.4% water absorption rate, 43.5%, 57.1% and 60% apparent porosity, 1.69g/cm^3, 1.57g/cm^3 and 1.45g/cm^3 bulk density respectively. Samples Grouping 3 consisting of Samples 7, 8 and 9 with 5%, 10% and 15% maize cob powder respectively and 12.5%Na_2SiO_3+12.5%NaOH show 38.8%, 43.8% and 46.7% water absorption rate, 63.6%, 66.7% and 75%; apparent porosity, 1.64g/cm^3, 1.52g/cm^3 and 1.45g/cm^3 bulk density respectively. Therefore, Sample 4 shows the lowest value of water absorption of 25.6% and apparent porosity of 43.5% while and Sample 9 shows the highest value of water absorption of 46.7% and apparent porosity of 75% respectively. Samples 6 and 9 tied up to have the lowest value of bulk density of 1.45g/cm^3 while Sample 1 has the highest bulk density of 1.9g/cm^3.

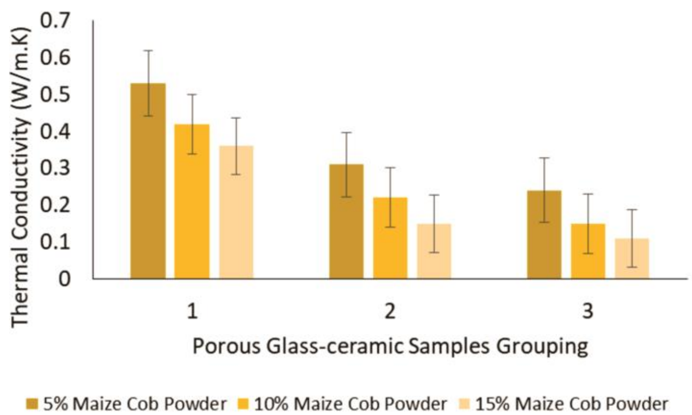

Figure 7. Thermal conductivity of porous glass-ceramics samples

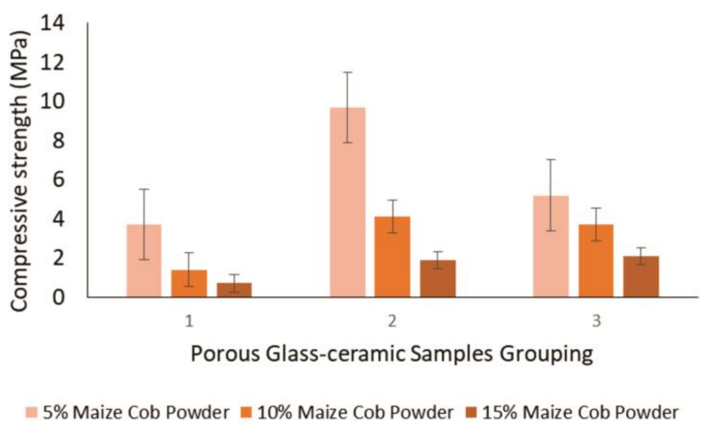

Figure 8. Compressive strength of porous glass-ceramics samples

Figure 7 shows decreasing values of thermal conductivity of the samples corresponding with the increasing addition of maize cob powder in each of the three Samples groupings. The thermal conductivities of Samples grouping 1 consisting Samples 1, 2 and 3 are 0.53W/m.K, 0.42W/m.K and 0.36W/m.K respectively; the thermal conductivities of Sample groupings 2 consisting Samples 4, 5 and 6 are 0.31W/m.K, 0.22W/m.K and 0.15W/m.K respectively; and the thermal conductivities of Samples grouping 3 consisting of Samples 7, 8 and 9 are 0.24W/m.K, 0.15W/m.K and 0.11W/m.K respectively. Therefore, Sample 9 has the lowest thermal conductivity value of 0.11W/m.K while Sample 1 has the highest thermal conductivity value of 0.53W/m.K. In each of the three Samples groupings it was observed that the relationship between the increasing values of water absorption and apparent porosity is directly proportional and inversely proportional to the decreasing values of thermal conductivity, comparing Figures 4, 6 and 7.

Figure 8 shows that as the amount of the maize cob powder increased, the compressive strength of the samples decreased linearly in each of the three Samples groupings. The compressive strength of Sample grouping 1 consising Samples 1, 2 and 3 are 3.7MPa, 1.4MPa and 0.7MPa respectively, the compressive strength of Samples grouping 2 consiting Samples 4, 5 and 6 are 9.7MPa, 4.1MPa and 1.9MPa; and the compressive strength of Samples grouping 3 consisting Samples 7, 8 and 9 are 5.2MPa, 3.7MPa and 2.1MPa respectively. Therefore, Sample 3 has the lowest compressive strength of 0.7MPa and Sample 4 has the highest compressive strength of 9.7MPa. It was observed that in each of the three Samples groupings, the relationship between the decreasing values compressive strength and the decreasing values of bulk density is directly proportional, comparing Figures 5 and 8.

In this study, the main reason for utilizing maize cob powder as a pore-forming agent is to obtain a considerable reduction in thermal conductivity values of the samples through an increase in porosity, as this is expected to improve the energy efficiency performance of the material when used to provide thermal insulation in buildings. The inverse relationship between the decreasing values of thermal conductivity and increasing porosity is regarded as a rule in porous ceramic materials [31]. Since the thermal conductivity value of air is low compared with solid phase, introducing porosity into a material enables a significant decrease in its effective thermal consuctivity [32].

Generally, in each of the three Sample groupings, an increase in the amount of maize cob powder produced a corresponding increase in the degree of porosity of the porous glass-ceramics. The increasing values of apparent porosity of the samples obtained in this study are in agreement with [33] that the creation of more pores in a thermal insulation material can be facilitated by the increasing addition of organic additives. The decreasing values of bulk density of the samples corresponding with the increasing amount of maize cob powder is also in agreement with [34] that addition of more quantity of a pore-forming agent will generate an increasing amount of gas which enables a decreasing trend in the bulk density values of a porous ceramics. Sample 4 was considered as the optimum sample in this study since it has the highest compressive strength of 9.7MPa which corresponds with thermal conductivity value of 0.31W/m.K.

Mineralogical Properties of the Optimum Sample

The mineralogical properties of the optimum sample of the porous glass-ceramics obtained in the study are as shown by the XRD patterns in Figure 9. The crystalline phases detected in the optimum sample sintered at 850°C are: orthoclase, $KAlSi_3O_8$ (ref: 00-019-0931), gehlenite, $Ca_2Al_2SiO_7$ (ref: 00-020-0199), sillimanite, Al_2SiO_5 (ref: 00-038-0471), leucite, $KAlSi_2O_6$ (ref: 00-038-1423), nepheline syenite, NaAlSiO4 (ref: 00-035-0424), sanidine, (K, Na) $(Si_3Al)O_8$ (ref: 00-019-1227), anorthoclase, $(Na,K)AlSi_3O_8$ (ref: 00-009-0478), albite, $NaAlSi_3O_8$ (ref: 00-019-1184) and microcline, $K(Si_3Al)O_8$ (ref: 00-025-0618). The formation of nepheline syenite, anorthoclase and albite must have been favoured by the reaction of the chemical additives ($NaOH+Na_2SiO_3$) with the SiO_2 and Al_2O_3 that are significantly present in the granite dust, ball clay and maize cob powder. Other crystalline phases found in the sample must have been due to high temperature reactions among CaO, K_2O, SiO_2 and Al_2O_3 present in the starting materials in each case. The formation of orthoclase, sanidine and microcline which are polymorphs could have been due to the temperature changes that brought about order-disorder transformation. The minerals present in the optimum sample of porous glass-ceramics obtained in this study differ from those obtained by [20] which included hematite, rutile, quartz and mullite. This is due to the fact that the mineralogical properties obtained in this study are not only due to the effect of ball clay and maize cob powder at the sintering temperature as in [20] but also due to the effect of granite dust and chemical reagents used.

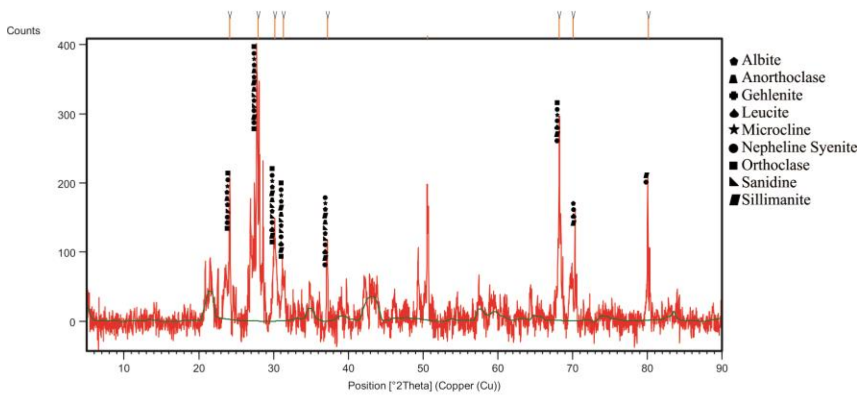

Figure 9. X-ray Diffraction (XRD) pattern of optimum sample of the porous glass-ceramics

CONCLUSIONS

Given that the long run cost of energy bills in buildings is huge and environmental hazards are attached to the long term use of artificial cooling and heating devic, wall insulation is a preferred choice compared to artificial means of cooling residential buildings. In this regards, this study has investigated into the viability of physico-mechanical and thermal properties of porous glass-ceramics produced from granite dust and maize cob powder (through a cost-effective means) for use in thermal insulation of external walls of residential buildings. The results obtained from the experimental tests carried out on the porous glass-ceramics samples showed water absorption of 25.6%–46.7%, apparent porosity of 43.5%–75%, bulk density of 1.45g/cm^3–1.9g/cm^3, compressive strength of 0.7MPa–9.7MPa and thermal conductivity of 0.11W/m.K–0.53W/m.K. Based on the results, the following findings were derived from this study:

1) One-step sintering method can be used to develop porous glass-ceramics when suitable chemical reagents are utilized.
2) Mining and agricultural wastes can be valorized for the production of value-added products such as porous glass-ceramics.
3) As the amount of maize cob powder (pore-forming agent) increased, there was a notable increase in the apparent porosity values and a corresponding decrease in thermal conductivity values in each of the three Samples groupings.
4) Sample 4 which have the highest compressive strength of 9.7MPa corresponding with thermal conductivity value of 0.31W/m.K was considered the optimum sample in this study.
5) The obtained mineralogical properties of the optimum sample showed that phase transformations occurred due to the reaction between the oxides contained in granite dust, ball clay and maize cob powder with the mixture of sodium hydroxide and sodium silicate during heat treatment.

The physico-mechanical, thermal and mineralogical properties of the optimum sample of porous glass-ceramics developed in this study provides a viable indication of its potentiality for use as a cladding for external wall insulation of residential buildings because it compares favourably with 0.36W/m.K thernal conductivity and 5.2 MPa compressive strength of the optimum sample of cellular ceramics derived from coal fly and waste glass sintered at 800^{o}C, which showed an interesting energy conservation effect suitable for thermal insulation of residential buildings when simulated using EnergyPlus software [28]. Hence, simulating the porous glass-ceramics developed in this study for use in external wall insulation of buildings is an important area that will be considered for further research.

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