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Original Research Article

Comparative Studies of the Physico-Mechanical Characterization of Ugwuoba Clay with Admixtures of Corncob and Sugarcane Bagasse Ashes

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Abstract

An investigation into the effects of combustible materials on the refractory properties of Ugwuoba clay, using sugarcane bagasse ash and corncob ash has been undertaken. Ugwuoba clay was sourced from Ugwuoba town in Oji River Local Government Area of Enugu State. Sugarcane bagasse were collected at Lokpanta, a Fulani settlement in Okigwe Community, Imo State, while corncobs were collected at New Artisan Market in Enugu Metropolis. The clay was processed using standard beneficiation and purification procedures at the Ceramics Department of Projects Development Agency (PRODA), Enugu. The sugarcane bagasse and corncobs were each and separately calcined into amorphous ash by heating in a furnace at 650ºC. The refractory blends were compounded at the ratio of 90:10, 80:20, 70:30, and 60:40 for Ugwuoba clay (UGC) to Sugarcane Bagasse Ash (SBA) and Ugwuoba Clay (UGC) to Corncob Ash (CCA) separately and respectively. These blends were subsequently molded into the standard test pieces for the various properties determination and subjected to firing at temperatures of 900ºC, 1000ºC, 1100ºC and 1200ºC. Thereafter, the fired samples were characterized for fired shrinkages, total shrinkages, apparent porosities, water absorption coefficients, apparent densities, bulk densities and moduli of rupture. The results obtained for each of the blends showed that the values were within the tolerable limits for industrial refractories with the 10%SBA and the 20%CCA blends showing the best results. Comparatively however, the 10%SBA produced the better of these properties than the 20%CCA. A conclusion is drawn to the effect that both sugarcane bagasse ash and corncob ash can serve as good organic admixtures for refractory bricks production for the lining of melting furnaces in the metals industry, hence opening new frontiers for recycling of these agricultural wastes for environmental safety and economic development in Nigeria.

Keywords: Ceramics, Corncob, Sugarcane-Bagasse, Refractories, Clays, Agriculture.

INTRODUCTION

Clays are defined from several perspectives including particle size, processing characteristics and chemical nature. Their classification methods include chemical composition, physical appearance, location of their natural deposits, and much more significantly, commercial utility, based on which the following clay types are distinguished, namely kaolin (or China clay), ball clay, fire clay, stoneware clay, and red-brick clay (Nwajagu & Idenyi, 2003). For instance, Kaolin is used as fire bricks because of its unique properties such as natural whiteness, fine particle size, non-abrasiveness and chemical stability. In addition to the general properties mentioned above, it is soft and has low viscosity at high solid contents (Kirabira, Johnson & Byaruhanga, 2003).

Refractories on the other hand belong to the class of ceramic materials which are employed for high temperature applications, usually above 1100ºC (Mokwa and Salihi, 2011). Besides being used as furnace linings, refractory materials find applications in kilns, incinerators, and reactors or other heat bearing equipment. They are also used to make crucibles and molds for casting glass and metals and for surfacing flame detector systems for rocket launch structures (Mokwa *et al.,* 2019). The determining factor for

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refractoriness of furnace bricks is the alumina content of such refractories. The higher the alumina contents of the clay, the higher the refractoriness (Nwajagu & Idenyi, 2003).

Some Nigerian clays are unsuitable for ceramic and many industrial applications because they have intolerable high levels of impurities such as iron oxides. Recent studies have tended towards finding ways of improving on the quality of our existing clays, while efforts continue in exploring new clay deposits. Part of these measures include but not limited to the use of natural organic waste materials that can be benefited as admixtures to the clay to improve on their refractory properties. Therefore, beneficiation of these locally available raw materials in view of upgrading their properties to that of standard commercial clay of various type is of paramount importance (Mohammadu, 2013; Dansarai *et al*., 2020).

The industrial utilization of a clay deposit depends on its geological, mineralogical, chemical and physical properties. Some of the commonest and important applications of clays are in the manufacture of paper, paint, plastics, ink, roofing sheets, pottery, bricks, ceramics, floor tiles and rubber. Clays also find various applications in the manufacture of cement, fertilizers and insecticides (Asamoah *et al*., 2018; Ndaliman, 2007; Ndanusa *et al*., 2004; Nurudeen, 2010). They are used in advanced chemical processing because of their reactivity and catalytic activity (Vieira *et al*., 2010). Clays are also utilized in pharmaceuticals and food processing industries (Murray, 2007; Elngar *et al*., 2009; Jablonowski *et al*., 2010). Some of these applications require the processing or the blending with other materials so as to improve on some desired characteristics of the finished product (Emofurieta *et al*., 1994; Jardim *et al*., 2012; Jones & Kooli, 1996).

Numerous studies exist on clay deposits that are widely spread in Africa and especially Nigeria (Irabor, 2002; Odo & Nwajagu, 2003; Jongs *et al*., 2018; Kipsanai *et al*., 2017). Some clay deposits in Nigeria have been investigated for various applications. Several clay deposits in Southern Nigeria have been evaluated and found potentially suitable for the manufacture of bricks, refractories, tiles and pottery (Akpokodje *et al*., 1991; Attah *et al*., 2001; Attah, 2008). The mineralogical, physical, geochemical and economic appraisals of some clay and shale deposits in South Western and North Eastern Nigeria have been discussed (Emofurieta *et al*., 1994; Kirabira *et al*., 2003; Musa *et al*., 2012; Musa & Aliyu, 2011).

Most research work carried out on refractories in Nigeria had centred on testing for their physical and chemical properties to ascertain their suitability in the production of fire bricks for lining furnaces. Characterization of Ugwuoba clays have been carried out by previous researchers (Odo, *et al*., 2003), but their blends with other materials admixtures are yet to be investigated. This study seeks to address this knowledge gap by compounding various blends of the clay with corncob ash and bagasse ash and subjecting them to characterization processes to establish their industrial suitability. Successful modification of these clay blends for refractory applications will serve as source of refractory materials to the local industries and this may trigger off the establishment of small-scale industries for making refractory bricks, which will create jobs for the locals and help improve the economy which is everyday dream of our country Nigeria for the youth. Additionally, with the current economic challenges facing the country, the need to source our refractory materials for the metals industry locally cannot be overemphasized. The current efforts by government to revitalize our ailing steel industries in Ajaokuta and Aladja give great impetus to the crucial need to develop and produce our refractories locally. This research therefore would be one such attempt at addressing this essential need of the present time.

METHODOLOGY

Equipment

The equipment used for this study were principally a digital weighing balance and muffle furnace (Gallenkamp, max. temperature of 1500°C).

Materials

Clay Sample

Samples of the clay was sourced from Ugwuoba a rural town in Oji River Local Government Area of Enugu State, Nigeria. The clay deposit sites were dug to a depth of two meters into the earth using an iron digger and samples were collected at distances of about 10 meters apart. About 50 kg of the clay sample was collected and thereafter transported to PRODA ENUGU for the characterization.

Corncob and Bagasse

The bagasse was collected in very large quantities at the Hausa Settlement, Lokpanta along Enugu-Okigwe Expressway, where the Depot for sugarcane coming from the Northern Nigeria is situated.

In the same vein, corncobs were sourced around New Artisan Layout Enugu where corn roasters stay to sell corns.

Materials Preparations

Clay Preparation

The clay sample was subjected to beneficiation process involved washing of the clay, sieving, and sun drying.

Thereafter, the clay sample was placed inside the oven and further dried for a period of eight hours at a temperature of 50°C. The dried clay was pulverized to smaller sizes, and subsequently ground to finer sizes using the laboratory crusher and the ball mills, respectively. It was then sieved and kept for further processing.

Corncob and Bagasse Preparation

The corncob and bagasse were separately dried in the sun, crushed and ground before being loaded into the muffle furnace. The furnace was set at 650°C allowed to stand for 3 hours to allow for proper calcination into amorphous ash.

Subsequently, the clay sample was mixed to varying proportions of 90:10, 80:20, 70:30, 60:40 for each of the corncob and bagasse separately.

Characterization

All the experiments for this work was carried out at Ceramic Laboratory of Projects Development Agency (PRODA), Enugu. The proportioned clay-admixture blends were subjected to firing in an electric furnace at temperatures of 900°C, 1000°C, 1100°C and 1200°C at a predetermined firing rate of 5°C/minute. Thereafter, the samples were subjected to physico-mechanical properties determination using the Nigerian Industrial Standards (NIS ARS 1302:2018) Specification procedures which included:

Bulk Density

$$Bulk\ density = \frac{W_d}{W_s - W_p} \qquad \text{(Eqn. 1)}$$

Where **W**

Where $\mathbf{W_d}$ is the dry weight of the sample, $\mathbf{W_s}$ is the soaked weight of the sample and $\mathbf{W_p}$ the suspended weight of the sample.

Moisture Content

$$Moisture\ content\ (MC) = \frac{M_W - M_D}{M_D} \times 100\% \qquad \text{(Eqn. 2)}$$

Where MC = moisture content, M_w = mass of the wet sample, M_D = mass of the sample after drying.

Shrinkages

$$Dry\ shrinkage\ (D_S) = \frac{O_L - D_L}{O_L} \times 100 \qquad \text{(Eqn. 3)}$$

$$Fired\ shrinkage\ (F_S) = \frac{D_L - F_L}{F_L} \times 100 \qquad \text{(Eqn. 4)}$$

$$Total\ shrinkage\ (T_S) = \frac{O_L - F_L}{O_L} \times 100 \qquad \text{(Eqn. 5)}$$

Where O_L= original length, D_L = dry length, F_L = fired length.

Water Absorption

$$Water\ Aborption\ (WA) = \frac{W_S - D_W}{D_W} \qquad \text{(Eqn. 6)}$$

Where W_S = weight of Soaked specimen suspended in air, D_W = Dried weight of specimen.

Apparent Porosity

$$Apparent\ porosity = \frac{W - D}{W - S} \times 100 \qquad \text{(Eqn. 7)}$$

Where D = weight of dry sample, S = weight of the sample suspended in water, W = weight of sample in air.

Specific Gravity

$$Specific\ gravity\ (SG) = \frac{W - W_P}{(W - W_P) - (W_2 - W_1)} \qquad \text{(Eqn. 8)}$$

Where W_p = Weight of bottle, W_1 = weight of bottle + water, W = weight of bottle + sample, W_2 = weight of sample + bottle + H_2O after boiling.

Refractoriness

$$PCE = \left[\frac{360 + \%Al_2O_3}{0.228}\right] - RO \qquad \text{(Eqn. 9)}$$

Where RO is the sum of all other chemical constituents in the material excluding Al_2O_3 and SiO_2

Cold Crushing Strength

Cold crushing strength is calculated using this formula:

$$CSS = \sigma_{\max}^{compressive} \Big/ A_{x-section} \qquad \text{(Eqn. 10)}$$

RESULTS AND DSICUSSION

Results

Tables 1 represents the chemical compositions of Ugwuoba clay, while Table 2 represents the chemical compositions of Corncob ash and Sugarcane Bagasse ash. Tables 3 and 4 represent the chemical compositions of the blended samples Ugwuoba – Corncob Ash and Ugwuoba – Sugarcane Bagasse Ash admixtures correspondingly. Figures 1 – 7 and 8 – 14 separately represent the plots of the various physico-mechanical properties against firing temperatures for the blends of Ugwuoba clay – Corncob Ash and Ugwuoba clay – Sugarcane Bagasse Ash admixtures respectively.

Table 1: The chemical composition of Ugwuoba clay

Chemical Compound	Composition (%)
Silica (SiO_2)	64.87
Calcium Oxide (CaO)	0.22
Alumina (Al_2O_3)	20.56
Iron Oxide (Fe_2O_3)	4.75
Magnesium Oxide (MgO)	0.75
Sodium Oxide (Na_2O)	0.15
Potassium Oxide (K_2O)	1.64
Sulphur Trioxide (SO_3)	0.04
Loss on Ignition (LOI)	5.99

Table 2: The Chemical Composition of Corncob Ash and Sugarcane Bagasse Ash

Chemical Compound	Corncob Ash (%)	Bagasse Ash (%)
Silica (SiO_2)	47.78	73.0
Calcium Oxide (CaO)	16.70	2.80
Alumina (Al_2O_3)	9.40	6.70
Iron Oxide (Fe_2O_3)	8.31	6.30
Magnesium Oxide (MgO)	7.80	3.20
Sodium Oxide (Na_2O)	1.89	1.10
Potassium Oxide (K_2O)	5.42	2.40
Phosphorus Oxide (P_2O_5)	N.A.	4.0
Sulphur Trioxide (SO_3)	2.70	N.A.

Table 3: The Chemical Composition of the blends of Ugwuoba Clay with Sugarcane Bagasse Ash

Compound	100% UGC	10%SBA	20%SBA	30%SBA	40%SBA
SiO_2	64.87	65.68	66.50	67.31	68.12
CaO	0.22	0.48	0.74	0.99	1.25
Al_2O_3	20.56	19.17	17.79	16.40	15.02
Fe_2O_3	4.75	4.91	5.06	5.22	5.37
MgO	0.75	0.10	1.24	1.49	1.73
Na_2O	0.15	0.25	0.34	0.44	0.53
K_2O	1.64	1.72	1.79	1.87	1.94
SO_3	0.04	0.04	0.04	0.04	0.04
P_2O_5	1.03	1.33	1.62	1.92	2.22
LOI	5.99	5.48	4.89	4.34	3.79

Table 4: The Chemical Composition of the blends of Ugwuoba Clay with Corncob Ash

Compound	100% UGC	10%CCA	20%CCA	30%CCA	40%CCA
SiO_2	64.87	64.90	64.88	64.91	64.92
CaO	0.22	2.18	1.20	3.15	4.13
Al_2O_3	20.56	18.64	19.60	17.69	16.74
Fe_2O_3	4.75	4.80	4.78	4.83	4.85
MgO	0.75	1.00	0.88	1.13	1.25
Na_2O	0.15	0.15	0.15	0.15	0.15
K_2O	1.64	2.11	1.88	2.35	2.58
SO_3	0.04	0.63	0.34	0.93	1.22
P_2O_5	1.03	1.03	1.03	1.03	1.03
LOI	5.99	5.99	5.99	5.99	5.99

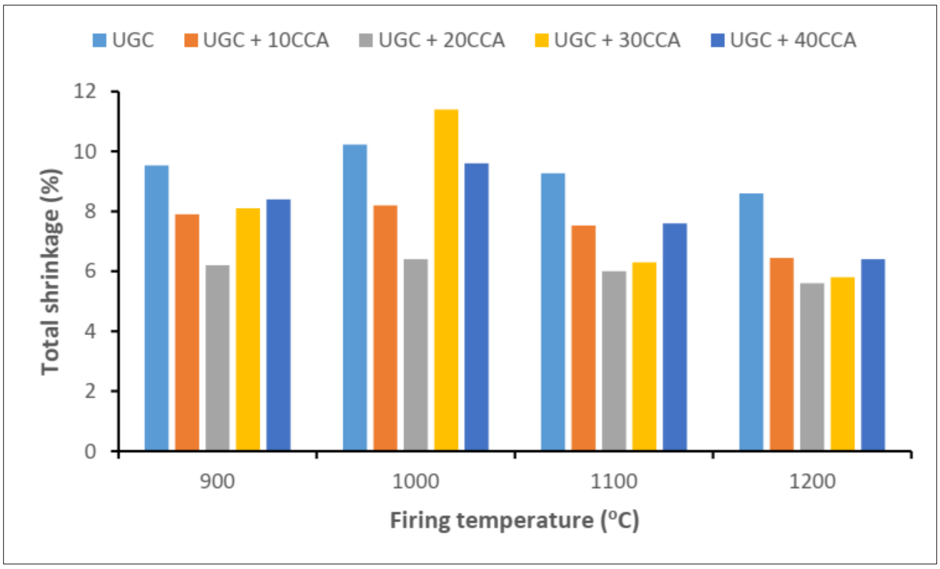

Fig. 1: Total shrinkage against firing temperature for Ugwuoba clay – Corncob ash admixtures

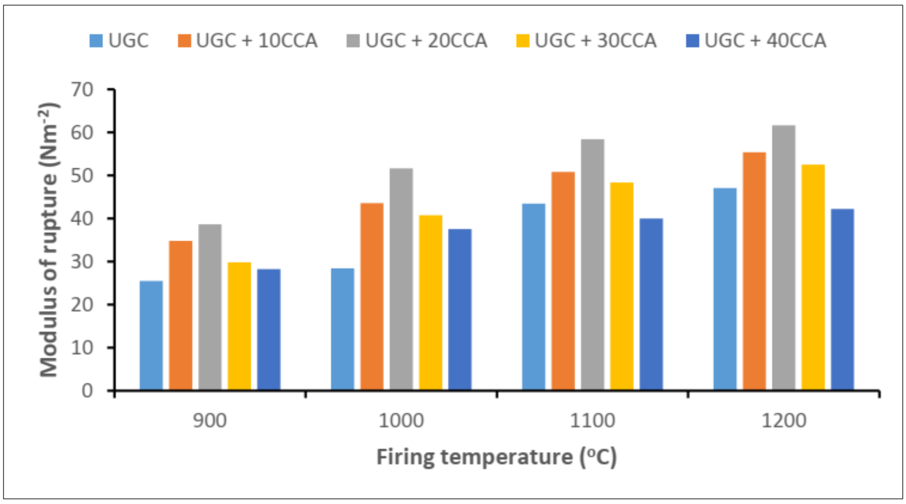

Fig. 2: Modulus of rupture against firing temperature for Ugwuoba clay – Corncob ash admixtures

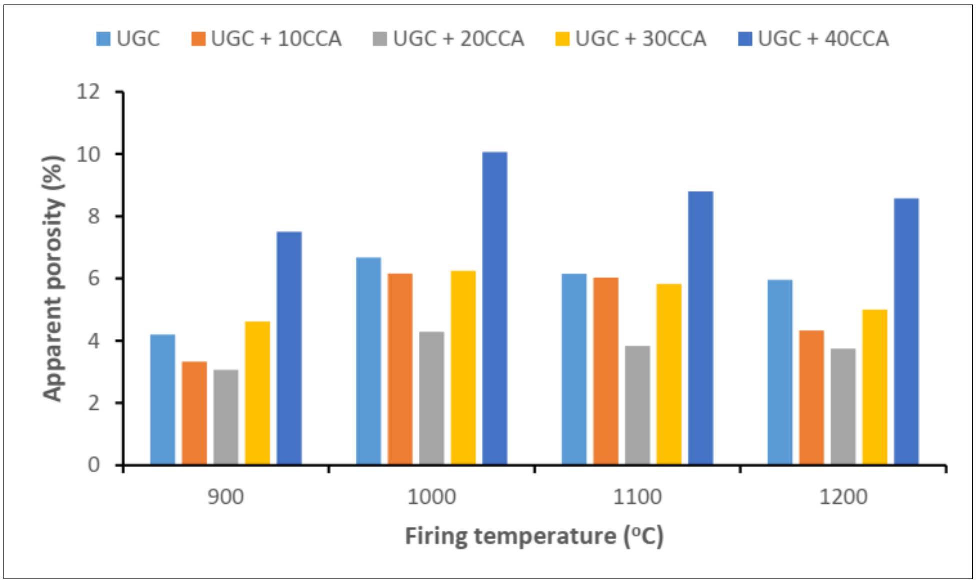

Fig. 3: Apparent porosity against firing temperature for Ugwuoba clay – Corncob ash admixtures

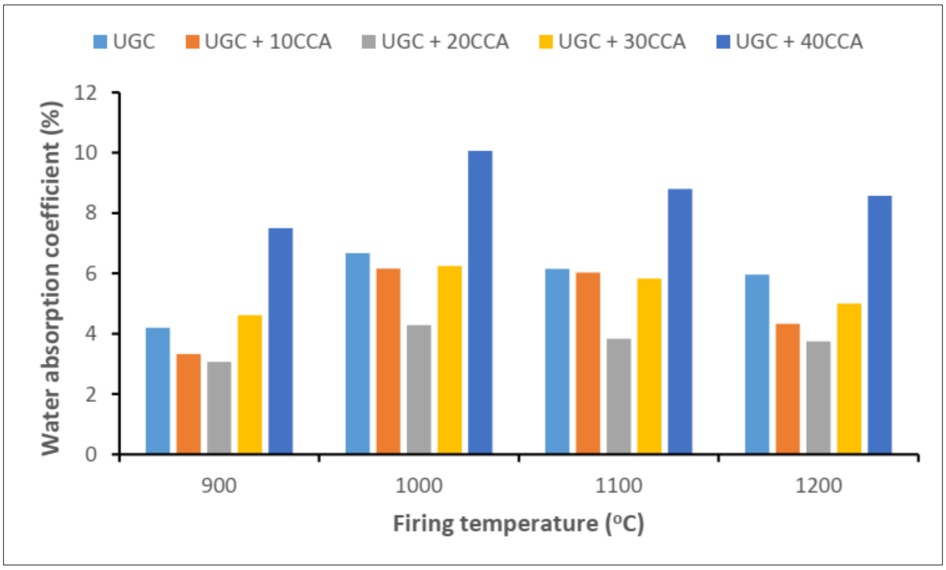

Fig. 4: Water absorption coefficient against firing temperature for Ugwuoba clay – Corncob ash admixtures

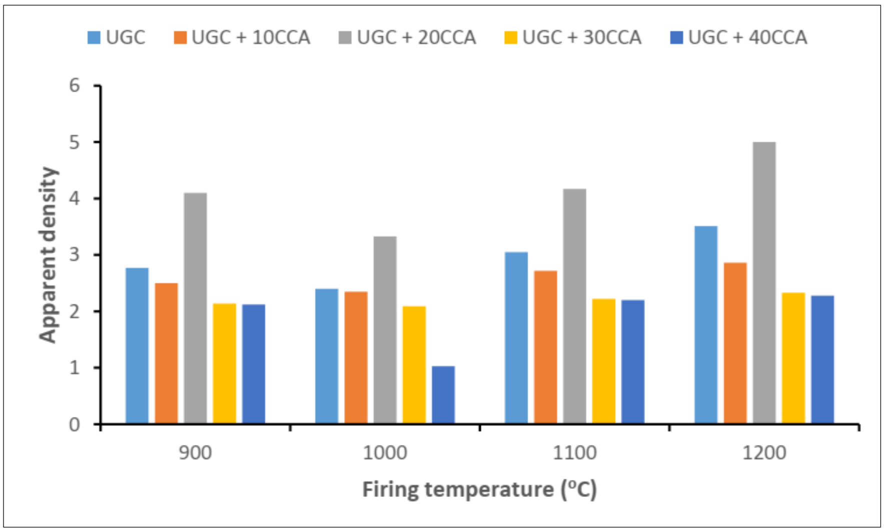

Fig. 5: Apparent density against firing temperature for Ugwuoba clay – Corncob ash admixtures

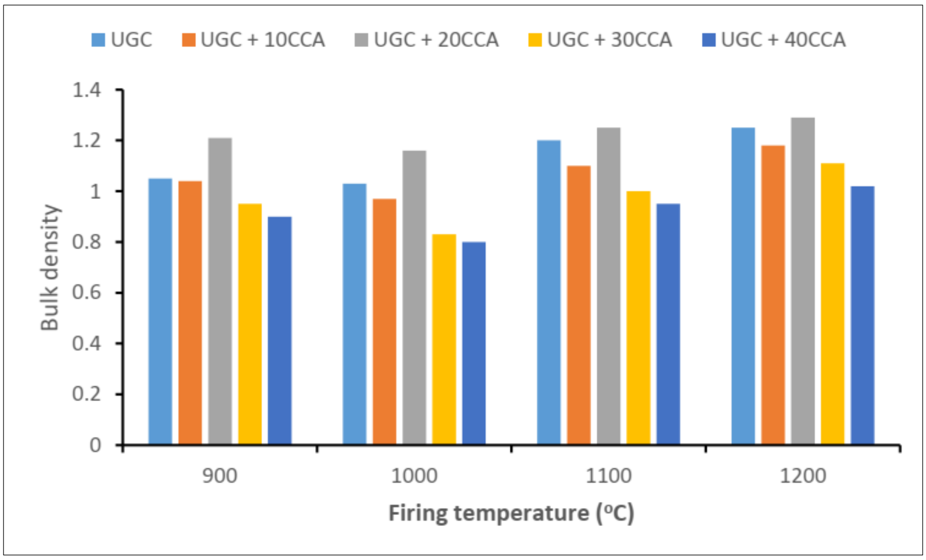

Fig. 6: Bulk density against firing temperature for Ugwuoba clay – Corncob ash admixtures

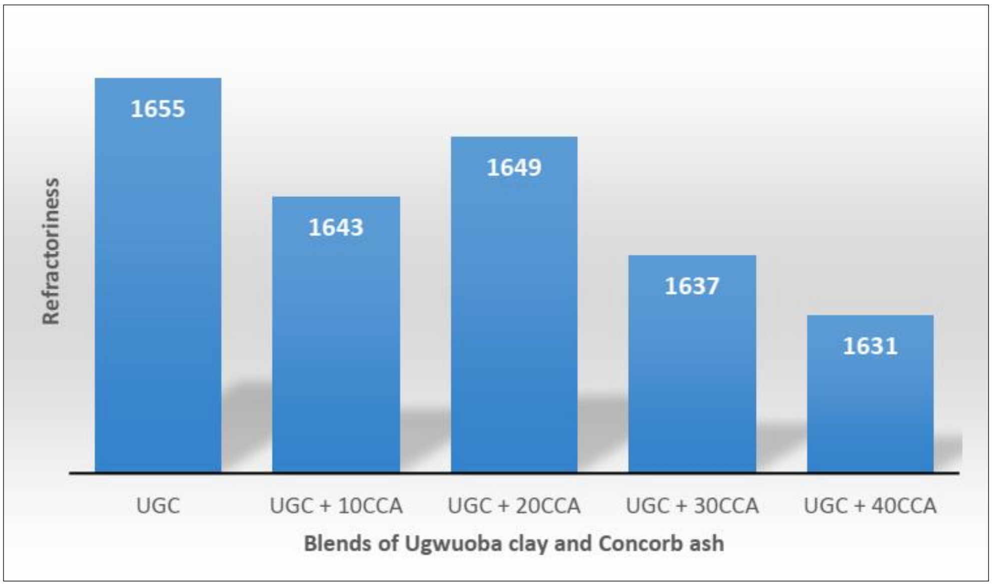

Fig. 7: Refractoriness (Pyrometric cone equivalents) of Ugwuoba clay – Corncob admixtures

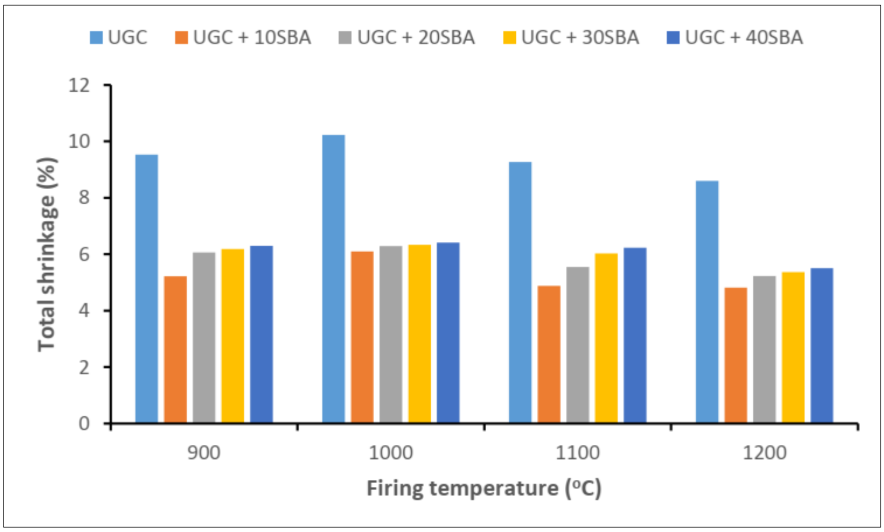

Fig. 8: Total shrinkage against firing temperature for Ugwuoba clay – Sugarcane Bagasse ash admixtures

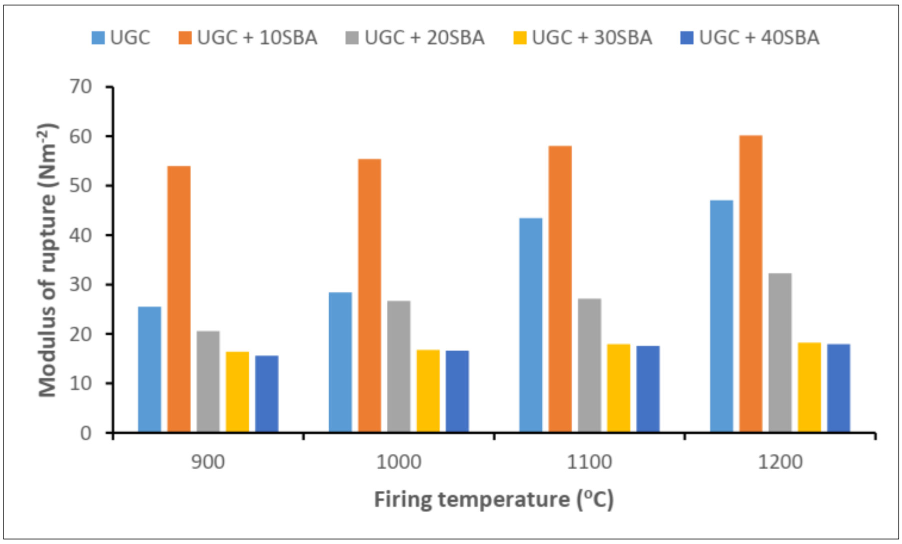

Fig. 9: Modulus of rupture against firing temperature for Ugwuoba clay – Sugarcane Bagasse ash admixtures

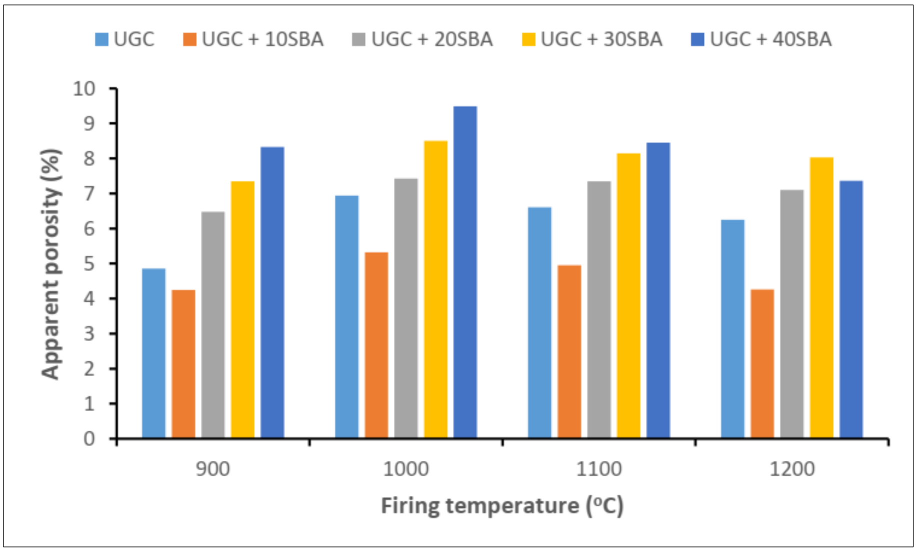

Fig. 10: Apparent porosity against firing temperature for Ugwuoba clay – Sugarcane Bagasse ash admixtures

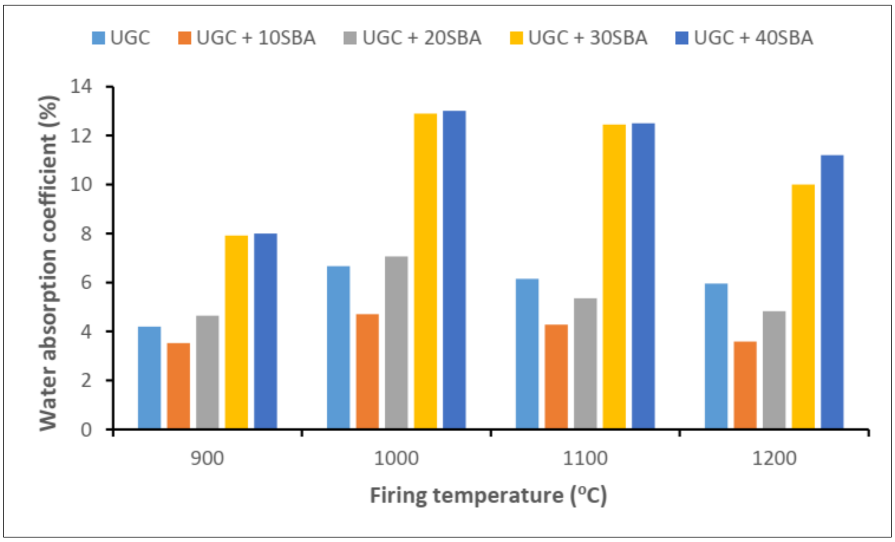

Fig. 11: Water absorption coefficient against firing temperature for Ugwuoba clay – Sugarcane Bagasse ash admixtures

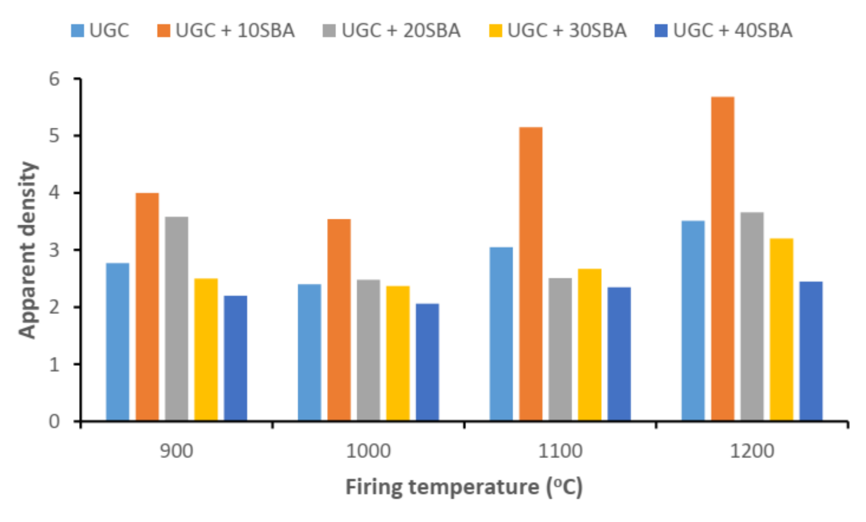

Fig. 12: Apparent density against firing temperature for Ugwuoba clay – Sugarcane Bagasse ash admixtures

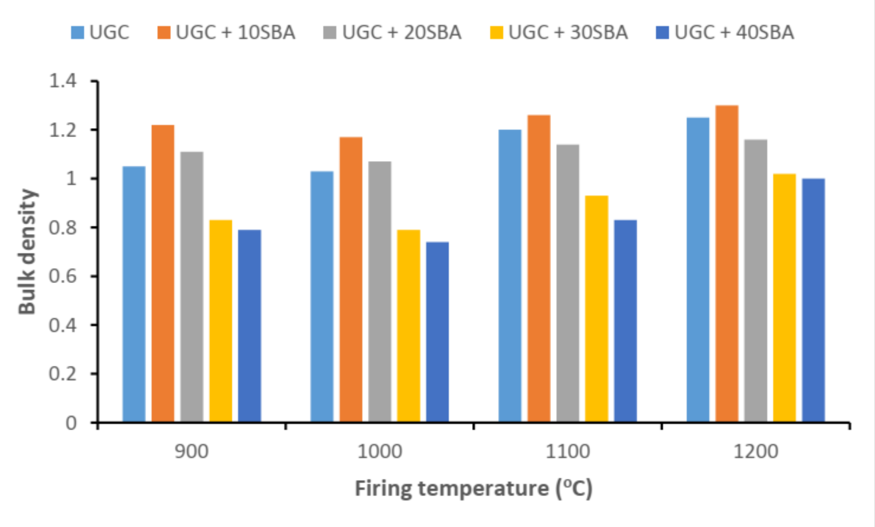

Fig. 13: Bulk density against firing temperature for Ugwuoba clay – Sugarcane Bagasse ash admixtures

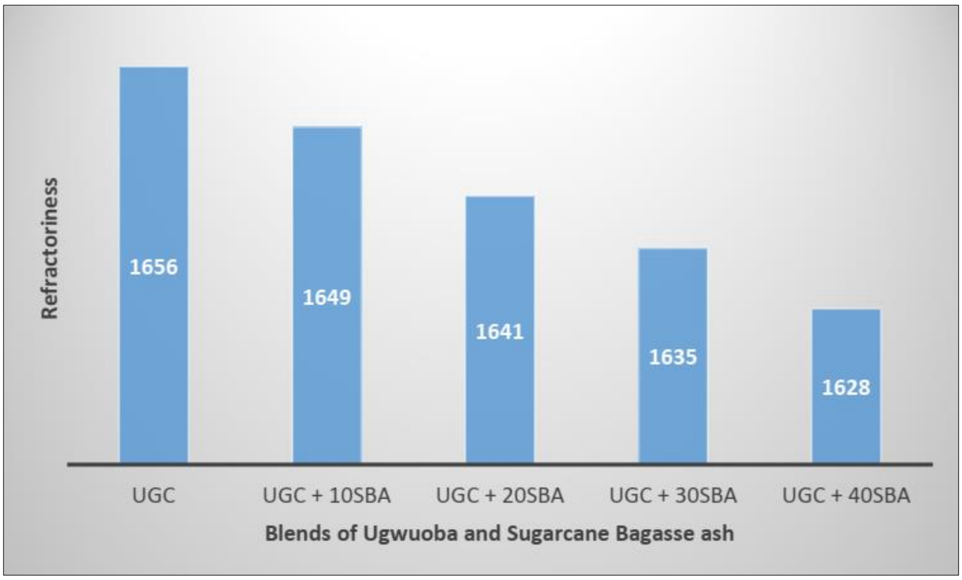

Fig. 14: Refractoriness (Pyrometric cone equivalents) of Ugwuoba clay – Sugarcane Bagasse admixtures

DISCUSSION

Shrinkages

Higher firing temperatures often result in greater shrinkage due to increased densification of the ceramic material as it reaches its sintering point (Chester, 1975, 1983; Copeland, 2012; Ebong *et al*., 2014).

Figures 1 and 8 represent the total shrinkages of the blends of both clays with the respective admixtures. It can be clearly shown from these figures that shrinkages followed the usual trends of increasing with increase in temperature up to a certain temperature, beyond which, it begins to decrease as temperature increases. That certain temperature in this case is 1000°C. However, a cursory look at the figures shows that 10%SBA and 20%CCA presented the best outcomes on shrinkages because they showed the least values among the respective blends. Comparatively, the 10%SBA had better shrinkage values (and therefore more stable at elevated temperatures) than the 20%CCA.

Modulus of Rupture

Higher firing temperatures can lead to higher modulus of rupture as increased temperature typically results in better bonding between particles, enhancing the strength of the ceramic material (Ameh & Obasi, 2009; Ameh *et al*., 2018).

The modulus of rupture values of all the blends are as shown in Figures 2 and 9 for CCA and SBA respectively. From the figures, the 10%SBA and 20%CCA has the maximum strength values among the blends. Evidently, the addition of SBA and CCA had an influence on the strengths of the clay at the temperatures of firing, but the positive influence diminished as the percentage of the admixtures increased, possibly due to the intermingling of the ash particles within the clay matrix that formed sites of weakening along the inter-particle boundaries, thereby making them more susceptible to brittle failure (Amuda *et al*., 2005; Atanda *et al*., 2012). When compared, the 10%SBA developed greater modulus of rupture than the 20%CCA, which may be attributed to the phytochemical constituents of the bagasse and the corncob.

Apparent Porosity

Firing temperature inversely affects apparent porosity; as firing temperature increases, apparent porosity decreases because higher temperatures lead to better particle packing and decreased void space within the ceramic structure (Eze *et al*., 2012; Fayyad *et al*., 2012; Glen & Richard, 2002).

The usual trend of the behavior of porosity of ceramic materials with firing temperature was observed as shown in Figures 3 and 10. The porosity increased up to a maximum temperature of 1000°C and then began to decrease at further heating. This implies that all the combustible volatile matter may have been burnt off at that maximum temperature producing the highest number of pores, but which volume began to reduce as heating continued due to the closure of those pores as localized melting ensured (Greymore *et al*., 2001; Gupta, 2008; Gupta & Ali, 2013). In this regard, the 10%SBA and 20%CCA presented the best values of apparent porosity, with 20%CCA showing lower values than 10%SBA.

Water Absorption Coefficient

Generally, higher firing temperatures result in lower water absorption coefficients since higher temperatures facilitate better bonding between particles, reducing the ability of water to penetrate the ceramic matrix (Abolarin *et al*., 2004; Amari *et al*., 2018; Nesse, 2000; Murray, 2004, 2006, 2007).

From theoretical perspective also, water absorption coefficient is directly proportional to apparent porosity (Barsoum & Michael, 1996; Olive *et al*., 1989; Bello *et al*., 2016; Omowumi, 2000). This trend was observed in all the blends as can be seen in Figures 4 and 11. As would be expected therefore both admixture blends had the highest water absorption coefficients at the temperature of 1000ºC and subsequently declined as temperature increases. However for each of the blends, the 10%SBA was the best among the Bagasse admixture blends, while the 20%CCA showed the best results for water absorption coefficients among the corncob admixture blends. In comparative analysis however, the 20%CCA showed better water absorption coefficient values than the 10%SBA.

Apparent Density

Firing temperature directly impacts apparent density, with higher temperatures typically resulting in higher apparent densities due to increased densification of the material (Bergaya & Lagaly, 2006; Boggs, 2006; Onyeji, 2010; Oziegbe *et al*., 2019; Pandaa *et al*., 2010).

It is established theoretical knowledge that there is an inverse relationship between density and porosity. Porous materials are generally less dense than materials with limited amounts of porosity (Borode *et al*., 2002; Breuer, 2012; Papadakis *et al*., 2015; Pelaez & Teutli, 2012). Under this premise, all the blends satisfied this theoretical assertion with the least values observed at the 1000ºC temperature point as can be seen from Figures 5 and 12. As observed, among the blends of bagasse admixture, the 10%SBA presented the best values for apparent density, while for the corncob admixture, the 20%CCA had the best values. Examined comparatively, the 10%SBA had better values than the 20%CCA.

Bulk Density

Similar to apparent density, bulk density increases with firing temperature due to the reduction in porosity and increased particle packing (Hassan *et al*., 2014; Hou *et al*., 2017; Qing *et al*., 2019; Rasul *et al*., 1999). Figures 6 and 13 represent the bulk density plots of the various blends of the individual admixtures. It is observed that the density was lowest at the 1000ºC temperature point, after which it increased as the temperature of firing increased. This trend is consistent with theory based on the behavior of the blends in terms of porosity (Raymond & Donahue, 1990; Sarkar *et al*., 2007; Hassan, 1990; Ime & Akaninyene, 2016). Here, for the bagasse admixture blends, the 10%SBA had the highest values of bulk density, while for the corncob admixture blends, the 20%CCA had the highest values. When examined comparatively, it can be seen that the 10%SBA had better bulk density values than the 20%CCA.

Refractoriness

Generally, the refractoriness of clays signifies their ability to withstand high temperatures without undergoing significant changes in their physical or chemical properties. It is a critical factor in determining the suitability of clay materials for specific industrial applications, particularly in contexts where exposure to extreme heat is common (Rochow *et al*., 1961; Smith, 1979; Udikovic & Martin, 2012; Ugwuoke & Amalu, 2018). The ideal range of refractoriness for furnace bricks depends on the specific application and operating conditions of the furnace. However, in general, furnace bricks are designed to have a refractoriness that falls within the range of approximately 1,500°C (2,732°F) to 1,800°C (3,272°F). This range ensures that they can withstand the high temperatures experienced in various industrial and metallurgical processes. Firing temperature is crucial for achieving the desired refractoriness in refractories operated at high temperatures. Generally, higher firing temperatures lead to higher refractoriness as the material undergoes greater densification and achieves higher crystallinity (Waing *et al*., 2008; Yami & Umaru, 2007; Zakin, 2001; Wattanasiriwech & Wattanasiriwech, 2019).

Evidently therefore, all the blends of Ugwuoba clay with sugarcane bagasse ash and corncob ash manifested reasonable refractoriness with the 10%SBA and 20%CCA having refractoriness values close to that of the Ugwuoba clay. The advantage of this is that the blending of these organic wastes with the clay will improve the environment, increase wealth creation and job opportunities through recycling of these wastes.

CONCLUSION

It can be concluded from the research findings that Ugwuoba Clay is suitable for refractory bricks production based on the values of the its chemical composition and the values of shrinkages, apparent porosities, water absorption coefficients, apparent densities, bulk densities and moduli of rupture of the various blends with bagasse and corncob ash. Significantly, the 10%SBA and 20%CCA were adjudged the best under the prevailing circumstances but in comparative terms, the 10%SBA performed much better than the 20%CCA.

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