https://doi.org/10.51459/futajeet.2021.15.1.269

Journal of Engineering and Engineering Technology

INFLUENCE OF WOOD SAW DUST AND WASTE GLASS ADMIXTURE ON SELECTED PROPERTIES OF FIRED CLAY BRICKS FOR MASONRY

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ARTICLE HISTORY

Received: 06-10-20

Accepted: 24-03-21

KEYWORDS:

Fired clay bricks, additives, densification, brittleness and compaction.

ABSTRACT

This study investigated the effect of mahogany wood sawdust (WSD) and waste glass (WG) addition on the properties and cost of producing fired clay bricks for construction of houses. Materials used were clay, WSD and WG. Brick samples were produced in batches and labeled as samples A (with no additives), B, C, D, E, F, G and H. Each sample of B, C, D, E, F, G and H contained 5% fixed amount of WSD, and 10, 15, 20, 25, 30, 35 and 40% of WG respectively. Brick samples produced were tested for apparent porosity, bulk density, compressive and flexural strengths, thermal conductivity and wear. Results obtained showed that as waste glass content increased in the samples, bulk density and compressive strength increased due to enhancement of densification and compaction within the samples. Thermal conductivity also increased as waste glass increased due to reduction in porosity and reduced inter-particle distance. The value of flexural strength increased with WG content but at 35% and 40%, the value reduced. This is as a result of an increase in brittleness as waste glass content increased which increased stress concentration in the samples, hence leading to a reduction in flexural strength. Also, it was observed that the increase in the content of the waste glass led to a reduction in the value of apparent porosity and wear depth due to improved cohesion between particles in the bricks. Comparing results obtained with existing standards and considering the cost of production, 5% WSD and 25% WG addition, with apparent porosity of 26.3 %, compressive strength of 17.5 MPa, thermal conductivity of 0.32 W/mk and wear depth of 1.72 mm is recommended for construction purposes.

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1.0 INTRODUCTION

A continued rise in the cost of building houses, due to rise in the price of Ordinary Portland Cement (OPC) and other building materials resulted in the need to create an alternative to concrete bricks in building houses. Also, the increase in temperature due to climate change creates the need to use insulating bricks for building houses. Most houses in modern days are built with concrete hollow bricks due to a higher strength exhibited by these bricks, compared to clay bricks. But these bricks have poor thermal insulation property which is explained by the heat experienced by inhabitants on sunny days especially in tropical regions of the

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world.

The primary purpose of a building is not only to provide shelter but also thermal comfort for the occupants. Many alternative efforts that are needed to restore thermal comfort when absent in buildings often result into huge energy consumption and carbon emission (Mardiana and Riffat, 2015; Odewole and Folorunso, 2020). Buildings account for a significant percentage of world's energy consumption and also contribute greatly to global carbon emissions. Buildings are responsible for more than 40% of the world's total primary energy consumption as well as over 33% of annual carbon dioxide emissions (Udodiong, 2019). Greenhouse gas emissions arising from energy consumption in buildings significantly exceeds those from transportation and industrial activities; and carbon emission from fossil fuels as well as electricity use in buildings is expected to increase from 8.6 billion tonnes in 2004 to 15.6 billion tonnes in 2030 under a high growth scenario (Odewole and Folorunso, 2020). Also, heating and cooling demands in buildings are responsible for the highest energy consumption percentage (more than 60%), followed by lighting which accounts for 11 to 20% energy demand (Sadiq, 2020 and Rashidi, 2018).

Considering the abundance of clay and waste glass in our immediate environment and their low-cost advantage, fired clay bricks were proposed as alternative building bricks (Ivanov, 2018 and Danupon, *et al*., 2008). In an effort to enhance the properties of fired clay bricks, towards meeting the requirement for masonry bricks, additives were mixed to clay during the production process (da Silva *et al* 2019, Folorunso, 2018, Emmanuel, 2008 and Folaranmi, 2009). Some of these additives are wood sawdust (WSD) and waste glass (WG). The addition of WSD increases pores in bricks by burning off when fired at high temperature and thereby improving thermal insulation properties of fired bricks (Folorunso and Akinwande, 2021 and Odewole and Folorunso, 2020). However, the increase in sawdust content reduces bulk density and compressive strength of these bricks because of the light weight of the sawdust (Cultrone, 2020; Folorunso, 2018; Aramide, 2012; Augustine, 2006; Bachir and Halima, 2012 and Emmanuel, 2008). Also, studies carried out in adding waste glass to bricks showed that there was an increase in compressive strength of brick samples as the content of waste glass increased (Chidiac and Federico, 2007 and Hisham, 2016).

Works have been done in using clay bricks as alternative building bricks since clay has good workability, relatively cheap and readily available in our immediate environment, in addition to the fact that the use of clay is cost-effective and energy saving (Fernando *et al.,* 2018; Aeslina *et al*., 2017; Folorunso and Akinwande, 2021). Many researchers have utilized environmental wastes in the production of bricks by adding these wastes to clay. The environmental wastes used include wood saw dust, bamboo ashes, rice husk, charcoal, sludge, waste glass, fly ash, coal mining and petroleum refining wastes (Obidiegwu *et al.*, 2015; Hisham and Samir, 2017; Akinwande, 2020). These wastes were added to improve properties of fired bricks for various applications ranging from masonry to refractory.

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(a) (b) (c)

Figure1: Materials used in the study (a) clay sieved to 150µm (b) WSD sieved to 600µm (c) waste glass sieved to 150µm

This study, therefore, focused on investigating the effect of the addition of these two additives (WSD and WG) on the properties of fired clay bricks with the view to producing insulating bricks with good service properties and at a comparatively reduced cost for masonry purpose.

2.0 MATERIALS AND METHOD

The materials for this work were wood sawdust (WSD), waste glass (WG) and clay obtained from a clay hill in Ijapo Estate, Akure South Local Government, Nigeria. The XRD quantitative analysis of the clay revealed the following: kaolinite – 6.33 %, muscovite/illite – 2.96 %, quartz – 43.82 %, microcline – 29.45 % and plagioclase albite – 17.44 % (Folorunso, 2018)

2.1 Sample Preparation

The fixed amount of WSD (5%) and the varied amount of WG (10 to 40% at 5% interval) were mixed with clay at varied proportions in a mixer. Fixed 5 % WSD was used in order to have a reliable basis for comparing the effects of varied amounts of WG on the fired samples. By sprinkling water into the mix, "wet clay" was produced which was extruded into a mould (170 by 90 by 75mm) in a compression moulding machine with a pressure of 10MPa. The brick samples in the green condition were left in the open at room temperature of 27 °C for 12 hours and oven-dried for 8 hours at 110 °C. The dried samples were fired in an electric oven at 5 °C/min to 800 °C and held for 2 hours in the furnace. The samples were allowed to cool to room temperature in the furnace and brought out for tests. The samples produced with different compositions of WSD and WG are as shown in Table 1.

Two brick samples of each composition were tested and the average value was obtained for each of the properties evaluated in this study.

Table 1: Mix proportions of samples produced.

Samples	Waste glass (%)	Wood sawdust (%)	Clay (%)
A	0	0	100
B	10	5	85
C	15	5	80
D	20	5	75
E	25	5	70
F	30	5	65
G	35	5	60
H	40	5	55

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2.2 Apparent Porosity

Apparent porosity is the ratio of the volume of open pore space in a specimen to the exterior volume. It was measured in line with ASTM C373-88 (ATM, 2006). The brick samples were dried at 110 °C for 12 hours while the dry weight in the air was measured and recorded. The samples were suspended in a container of water, for a period just enough to record the weight (ASTM C373-88; ATM, 2006) The weights of the saturated samples were measured in air and when suspended in water. Apparent porosity is expressed as;

$$\text{Apparent porosity (\%)} = \frac{Ms-Md}{Ms-Mw} \quad (1)$$

Where: M_d is the mass of dried sample when suspended in the air. $M_s$ismass of the saturated sample when suspended in air. M_w is the mass of saturated sample when suspended in water.

2.3 Bulk density

The bulk density is the weight of the sample in a given volume. The samples used in this test were dried at 110 °C in an oven to allow complete surface dryness and allowed to cool. The weight was measured and recorded. After, the samples were suspended in a container of water, one after the other and the weights, when suspended in water were measured and recorded for each sample. This was followed by complete immersion of the samples in water for 24 hours after which the saturated weight when suspended in air was measured and also recorded. Bulk density was evaluated using the expression

$$\text{Bulk density} = \frac{\text{Md}}{\text{Msat} - \text{M sus}} \quad (2)$$

Where: M_d is mass of dried sample suspended in air. M_{sat} is mass of saturated sample suspended in air. M_{sus} mass of saturated sample suspended in water.

2.4 Compressive strength

Compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. The samples were dried at 110 °C for 12 hours and placed in a compression testing machine with a load of 15 KN applied per minute. The test was carried out in line with ASTM C67 (ASTM, 2003). The samples were positioned between stationary and movable plates of the machine and the load was applied at uniform rate until fracture occurred. The maximum load to failure was recorded noting the cross-sectional area of application of the load.

$$\text{Compression strength} = \frac{Maximum\ load\ to\ failure}{cross\ sectional\ area}\ \text{N/m}^2 \quad (3)$$

2.5 Flexural Strength

The capacity of bricks to resist deformation by bending is the flexural strength. Three-point twisting test was carried out on the samples in line with ASTM C293 (ASTM, 2010). The maximum load applied, the width and the depth of the sample were measured and recorded. Flexural strength was evaluated using the relation

$$F_r = 3Pa/2bd^2 \quad (4)$$

F_r is the flexural strength, b is the width of the sample, d is the depth/height of the sample, and a is the distance between two support.

2.6 Thermal conductivity

This is the degree to which a material conducts heat. The test was carried out according to ASTM C177 (ASTM, 2019). The sample was prepared using a circular-shaped mould. The samples were 25mm in diameter and 4mm

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thick. The test was conducted by hot guided plate method at 29 °C. The samples were placed in between two rods heat source allowing heat to flow through the samples, and the temperatures of the upper and lower surfaces of the samples were measured as heat flowed through the samples.

2.7 Wear Test

Wear is the damage or deterioration sustained from continuous use. Wear test was carried out in line with IS 13801 (IS 13801, 1993) procedure. Samples were dried at 110 °C for 12 hours and weighed. The thickness of the sample was measured and recorded. 20 g of alumina powder was evenly dispersed on the grinding part of the disc in the abrasion testing apparatus. The sample was fixed to the holding device of the apparatus with the surface facing the disc. A load of 30 Kg was used as stipulated in the procedure and a speed of 30 rev/min was applied. The mass of the sample after 220 revs was measured and recorded. The loss in thickness was evaluated using the expression

$$D = \frac{(M1 - M2)}{M1 \; x \; A} \; x \; V \qquad (5)$$

Where: D is the average loss in thickness, M_1 is the initial mass of the specimen, M_2 is the final mass of the specimen, V is the initial volume of the specimen and A is the surface area of the specimen.

3.0 RESULTS AND DISCUSSION

The results are as presented below:

3.1 Apparent porosity

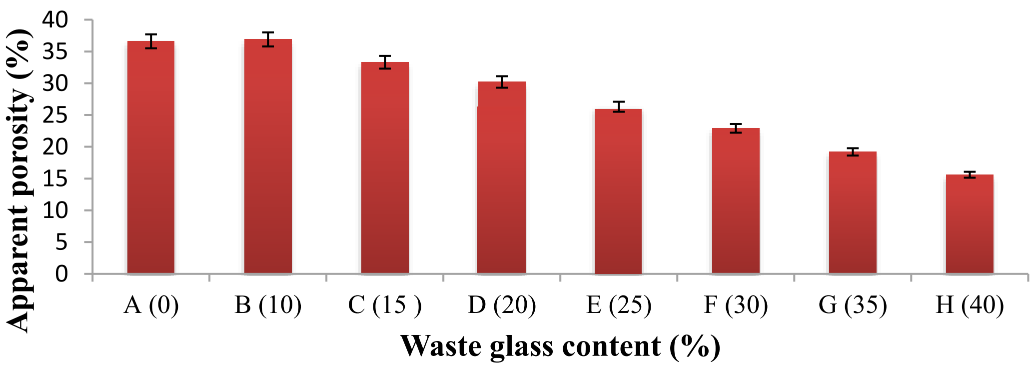

Figure 2: Variation of Apparent Porosity of Samples with Glass Content

Porosity affects bulk density and mechanical properties and the service performance of bricks. Figure 2 shows that as waste glass content increased, porosity initially increased from A to B by 0.82% indicating an increase in the volume of pores from sample A to B. This shows that additional pores were created in sample B confirming that the sawdust had an impact on sample B. As waste glass content increased from 10% in sample B to 40% in sample H, porosity reduced progressively because at high temperature, liquid glass phase reduced inter-particle distances of the samples by adhesion, thereby reducing the size and volumes of pores and hence, reduced porosity.

At 15% addition of WG (sample C), the reduction was by 8.7% showing more impact

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of WG addition on the porosity. The trend continued from 15% WG to 40% WG content, as waste glass content increased. The fine particles of WG contributed to a reduction in porosity, filling up the pores present in the brick despite the presence of 5% wood sawdust. Apparent Porosity values for 25% WG content to 40% WG content fell below 30% porosity required, in line with BS 3921 (BS 3921, 1985) standard for bricks used in masonry.

3.2 Bulk density

As waste glass content increased in the samples (Figure 3), densification increased owing to a higher density of waste glass. Bulk density therefore increased. Firing at high temperature also enhanced compaction within the samples as the formed glass phase reduced pore volumes and enhanced adhesion within the particles. Even in the presence of sawdust in the samples, waste glass still promoted the rise in the bulk density (Aramide, 2012). This can be explained by the 3.37% increment in the bulk density from sample A to B. The increment in the bulk density between samples ranged from 6 to 8% from sample B to H. This implies that the addition of waste glass enhanced the bulk density. Samples C to H met standard requirement of bulk density for bricks used for construction (BS 3921, 1985 and TCVN 1451, 1998).

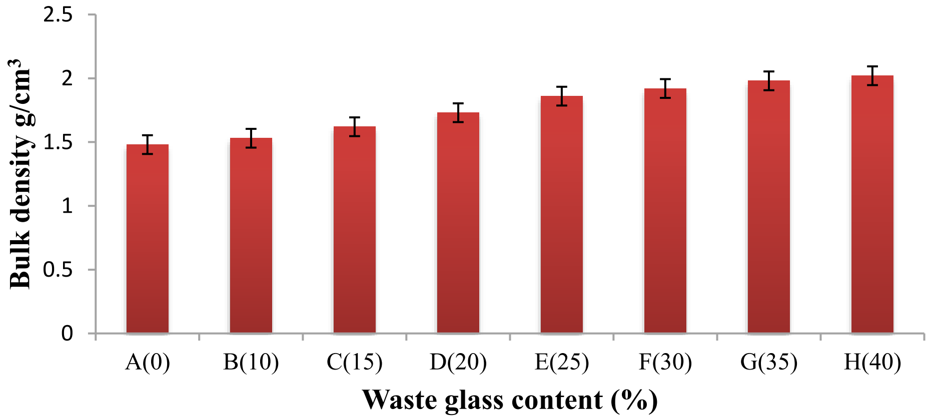

Figure 3: Variation of Bulk Density of Samples with Glass Content

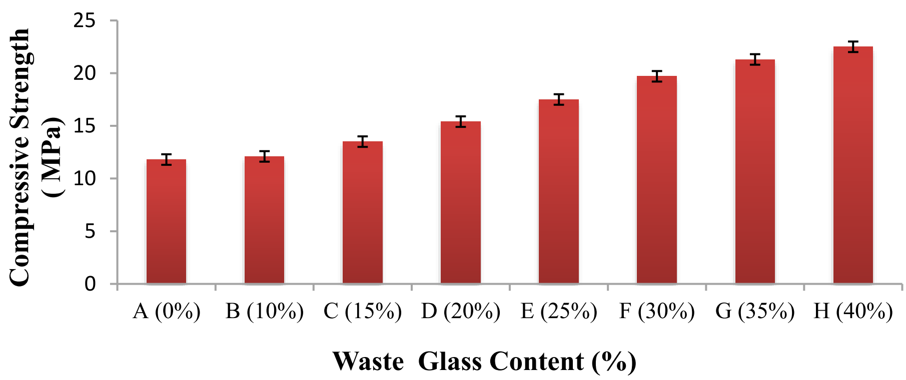

Figure 4: Variation of Compressive Strength of Samples with Glass Content

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3.3 Compressive strength

From Figure 4, the compressive strength increased as waste glass content increased even with 5% by weight of saw dust. The addition of waste glass contributed to densification and compaction. Glassy phase formed during firing increased as waste glass content increased, which resulted in the closing of the internal pores. The area fraction and inter-particle compactness of the waste glass in the brick is directly proportional to the wt% of the waste glass. Therefore, the compactly arranged WG particles offered resistance to dislocation motion under compressive loading process and hence, contributed to the increase in strength of bricks. It was observed that bulk density and compressive strength increased from 0% WG to 40% WG indicating a direct link between the two properties. On addition of 10% WG, the compressive strength rose by 2.5% from sample A to B while in the case of sample D, with 20% WG content, there was an increment of 11%. This implies that at 10% WG, the sawdust still had greater influence in affecting the strength. But from 15% of WG upwards, the influence of WG was more pronounced as the strength continued to rise progressively. All samples met Nigerian Industrial Standard of 2.5MPa (NIS 87, 2000) for construction, British standard of 5MPa (BS 3921, 1985) and Malaysian standard of 5.2MPa (MS 76, 1972), while samples D to H met ASTM 62 standard of 15.2MPa (ASTM, 2001 and 2003) for load-bearing bricks used in moderate weather condition.

3.4 Flexural Strength

The flexural strength (Figure 5) increased from 1.84 MPa for control at 0% WG content to 4.32 MPa at 30% WG content, showing that as waste glass content increased the strength increased. However, at 35% and 40% waste glass content in sample G and H respectively, flexural strengths reduced owing to the brittleness of glass content. So, as glass phase increased in the sample, stress concentration induced by the particles increased, hence residual stress in the brick samples increased which in turn increased brittleness. AS3710 stipulated a minimum of 2MPa for flexural strength of bricks for masonry work (AS 3700, 2001). Therefore, all bricks samples investigated in this work met the standard except for samples A and B.

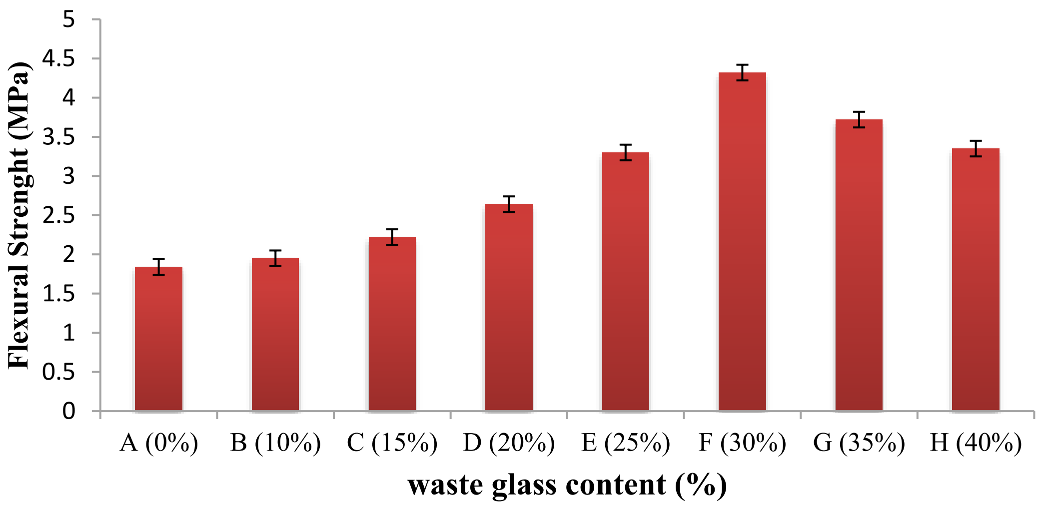

Figure 5: Variation of Flexural Strength of Samples with Glass Content

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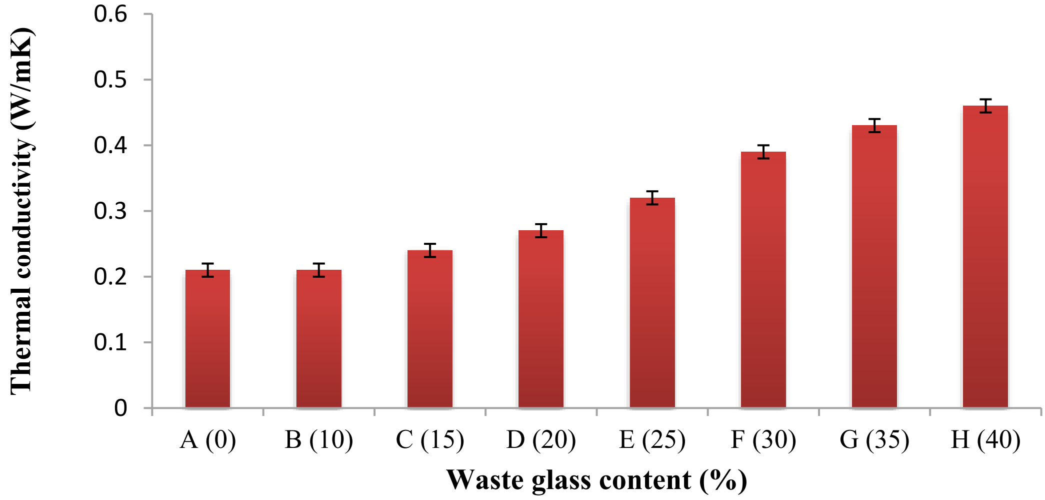

Figure 6: Variation of Thermal Conductivity of Samples with Glass Content

3.5 Thermal conductivity

The original intention of adding a 5% fixed amount of sawdust to the samples even as waste glass content was increasing in the samples, was to investigate its effect on thermal conductivity. This was done with the aim of producing insulating bricks for building houses, for the purpose of reducing the effect of hot weather on inhabitants of such buildings. Insulation reduces unwanted heat gain and decreases the energy demand of heating and cooling. The thermal conductivity of fired clay bricks (Masonry bricks) is in the range of 0.4 to 0.7 $Wm^{-1}K^{-1}$ (Dondi *et. al,* 2004 and Garcia 2010), while ASTM C177 (ASTM, 2019) gave a value between 0.4 to 0.6 $Wm^{-1}K^{-1}$.

In Figure 6, it was observed that as glass content increased, thermal conductivity increased. Thermal conductivity remained constant for sample 0 and 10% by weight WG (0.21W/mK), while it continued to rise as waste glass content increased from 15% WG. The rise is as a result of a decrease in inter-particle distance caused by a reduction in volume and size of pores, which enables particles in the clay body to easily vibrate and transmit energy. All bricks in this study fell below 0.6W/mK conductivity (ASTM, 2019).

3.6 Wear depth

Figure 7 shows the variation in the wear depth for each sample. As waste glass content increased, wear rate reduced progressively in the samples. The reduction in wear rate indicates an increase in wear resistance of bricks. The addition of waste glass improved the adhesion of particles thereby enhancing hardness in the samples which improved the wear resistance. Sample H with the lowest wear depth of 1.25mm has the highest wear resistance while sample A with the highest wear depth of 3.51mm has the lowest wear resistance. TS 2824 (TS 2824 EN 1338, 2002) permitted not more than 3mm, for wear depth of bricks for masonry bricks. So samples with 15 % WG and more meet the requirement.

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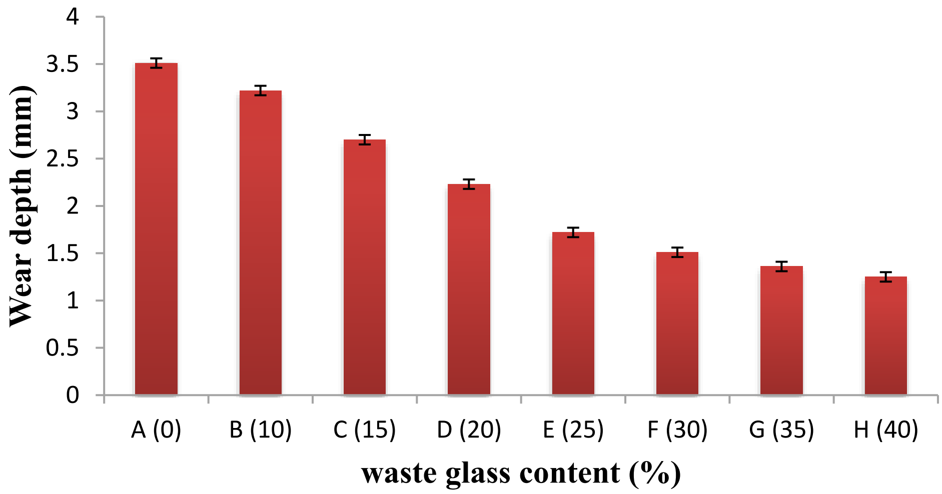

Figure 7: Variation of Wear Depth of Samples with Glass Content

Table 2: Properties Evaluation Table for Brick samples

Properties	Samples								
	Standard values	A	B	C	D	E	F	G	H
Apparent Porosity	Below 30%	0	0	0	0	1	1	1	1
Bulk density	Above $1.6g/cm^3$	0	0	1	1	1	1	1	1
Compressive strength	2.5 to 5.2MPa for low rise building	1	1	1	1	1	1	1	1
Compressive strength	15.2MPa for load bearing	0	0	0	1	1	1	1	1
Flexural strength	2MPa	1	1	1	1	1	1	1	1
Thermal conductivity	Below 0.6W/mK	1	1	1	1	1	1	1	1
Wear depth	Below 3mm	0	0	1	1	1	1	1	1
Total value		3	3	5	6	7	7	7	7

3.7 Properties Evaluation of Brick samples

From Table 2, Symbol “0” implies the sample does not meet the required standard value for the property evaluated while symbol “1” implies the sample meets the standard.

Sample E was the most preferred of the samples analyzed because it met all the required standards and it contained the additives in the least proportion; 25% WG, which ultimately was the most cost-effective of all the samples that met the standard.

3.8 Morphological Analysis

From Figure 8, Plate (a) shows the SEM image of sample A with no additives. The image

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revealed large amounts of pores while Plate (b) shows the morphology of selected sample E (5% WSD and 25% WG) with reduced pore volume compared to sample A (0% WSD and 0% WG content). The reduced pores, as shown in Plate (b) led to significant reduction in the inter-particle distances and better adhesion between the clay particles and those of the glass, by forming a strong glassy phase. These revelations explain the reason the sample with additive (25 % WG) possesses better property behavior than in sample A with 0% WG.

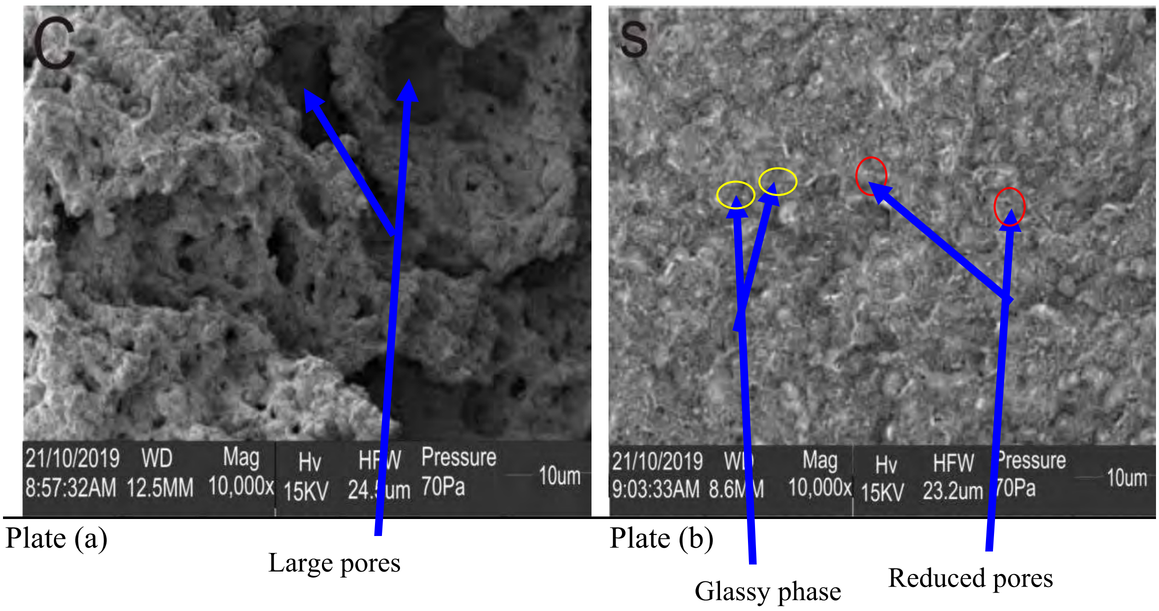

Figure 8:SEM images of control sample A (a) and selected sample E (b) at 10000X

4.0 CONCLUSION

From the results analyzed for various tests, it can be concluded that the addition of WSD and WG to Ijapo clay produced bricks with the optimum mechanical and thermal properties suitable for masonry, at a moderate cost. An increased amount of the waste glass enhanced the properties of these bricks. From the property evaluation carried out on the samples; comparing values obtained with existing standard values, it is concluded that brick samples E (5% WSD and 25% WG), F (5% WSD and 30% WG), G (5% WSD and 35% WG) and H (5% WSD and 40% WG) are fit as insulating bricks for construction purposes but E is selected as the best, putting the cost of production into consideration.

Acknowledgment

The authors expressed gratitude to the staff of the Metallurgical and Materials Engineering Department, The Federal University of Technology, Akure, Nigeria, for their moral supports.

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