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Study of the Effects of Waste Glass Additives on the Properties and Compliance level of Fired Ceramic Masonry Bricks

A. A. Akinwade[1], A.A. Adediran[2,3*], O.A. Balogun[1], B.A. Abel[1], T.P. Daniel[1], R.A. Kazeem[2] and T.M.A. Olayanju[3]

[1]Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, Nigeria.
[2]Department of Mechanical Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria.
[3]Landmark University Waste to Wealth & Energy Initiative Board (LUWWEI), Landmark University, Omu-Aran, Kwara State, Nigeria.
Corresponding Author; adediran.adeolu@lmu.edu.ng, +2348032458545

Abstract-
The current study reports the effects of waste glass additives on the properties and compliance level of fired ceramic masonry bricks. In the course of producing durable bricks for masonry, waste glass powder sieved to 150 µm was added to clay, mixed with water and fired to 1000 °C. The effects of the waste glass addition were investigated by subjecting 242 ceramic bricks produced to physical, mechanical, and thermal tests. Their morphological behaviour was thereafter examined. From the results obtained, the physical and mechanical properties were improved as waste glass content increased in the samples. Values of properties obtained were compared with existing standard values for bricks and it was observed that compliance level at 0% waste glass was 63%, at 10% waste glass addition, it was 75% and at 15% to 40% waste glass addition, compliance was 100%. Therefore, it was concluded that waste glass addition to bricks improved the properties of bricks for construction purpose.

Key words: fired ceramic bricks, compliance level, waste glass, properties, construction.

1. Introduction

Clay is a naturally occurring kind of soil which is sticky when wet and contains different minerals like silica, alumina, iron oxide, magnesia, calcium oxide and other trace minerals. The plastic nature clay exhibits when in contact with water makes it very easy to be moulded into different shapes [1]. Different products have been made using clay and these include products like bricks and pottery including pots, plates and other kitchen wares. Mixture of some additives to clay also resulted into some advance products like ceramic tiles and white wares. Clay is in abundance in Nigeria and all over the world, hence can be regarded as cheap industrial raw material for different uses [1]. Due to its availability and its good work ability, clay is been employed in making fired bricks for houses. In the production of fired masonry ceramic bricks, various additives had been mixed with clay and different properties have been observed in such bricks [1]. Additives added include fly ash [2,3] in the production of flash bricks, industrial sludge in the production of fired bricks [4] and shale in the production of bio-bricks [5]. Others additives include plant sludge and rice husk [6], saw dust [7,8], tobacco [9], polystyrene [10], plastic fiber [11] and recycled paper [12]. These additives produced different results in reduced efflorescence as observed in [2], while in [3], the fly ash was used in producing flash bricks which were noted to be lighter and stronger (in terms of compressive and tensile strengths) than standard clay bricks. Further observation was that, the bricks had

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resistance to salt attach and achieved a bond higher than standard clay bricks. Fly ash is a good additive in production of fired clay bricks. The mixing of wastewater sludge to clay was noted to result in higher shrinkage and water absorption in the bricks produced while pulverized sludge ash produced good bond in bricks [4]. Addition of rice husk, saw dust, tobacco, polystyrene, plastic fiber and recycled paper resulted in higher porosity, lighter weight and increased water absorption. This study investigated the effect of waste glass on properties of fired bricks as an alternative waste, which can be incorporated in fired bricks for masonry application.

2. Experimental Methods

Clay soil used were dug out from borrow pits in two different locations (which are 20 m apart) in Ire-Akari community, Akure, Nigeria. The clay samples were mixed together in equal proportion while the waste glass bottles used were obtained from a waste glass retailer (as shown in Table 1). Clay samples collected were milled and sieved to -150 µm. Clay and waste glass powder sieved to -150 µm were collected and a portion of the two were tested for chemical composition as presented in Table 2. Rectangular bricks samples of 190 x 60 x 60 mm were made by mixing 0, 10, 15, 20, 25, 30 and 40% of waste glass to clay (Table 1), with water addition (water to clay ratio is 0.35 to 0.42) and compacted by a pressure of 10 MPa. The samples were exposed to the atmosphere for 24hours, after which they were dried for 12 hours. Dry samples were fired to 1000 ^{o}C in an electric furnace and allowed to cool in the furnace. Fired samples were examined for firing shrinkage as per [13], apparent porosity and water absorption as per [14], bulk density, percentage weight loss, compressive and flexural strength as stated in [15]. Wear rate was carried out in line with [16] and the effects of waste glass on the properties of fired bricks were investigated. Three samples were used for each composition in conducting the test and the results were recorded and the mean values obtained were used for analysis.

Table 1: Sample designation and description.

Sample Designation	Clay Content	Waste Glass content
A	0	0
B	90	10
C	85	15
D	80	20
E	75	25
F	70	30
G	65	35
H	60	40

Table 2: XRF results of clay and waste glass.

Compounds	Content in Clay	Content in Waste Glass
SiO_2	61.70	71.80
Al_2O_3	22.50	2.20
Fe_2O_3	5.80	0.32
MgO	0.70	1.50
CaO	1.20	8.20

K_2O	Nill	0.57
Na_2O	0.3	8.32
MnO	0.1	0.04
CuO	0.01	0.02
ZnO	0.01	Nill
Other oxides	2.88	4.14
LOI	4.80	2.89

LOI is Loss on Ignition

3. Results and discussion

Firing shrinkage and Percentage weight Loss

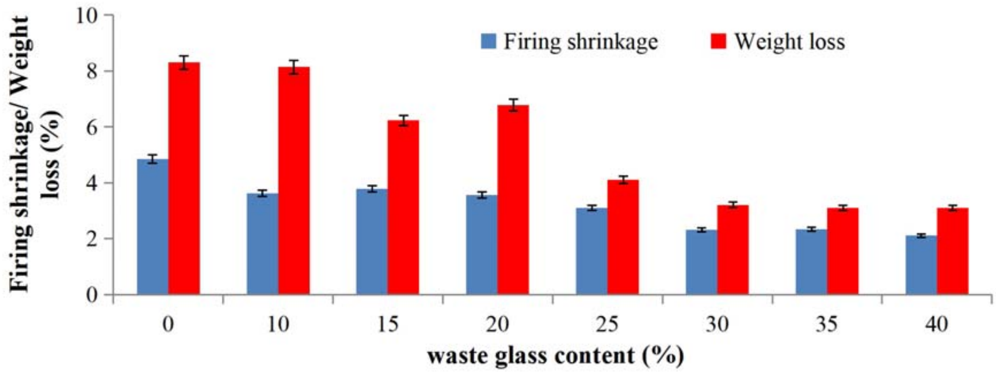

Fig.1: Effect of waste glass addition on firing shrinkage and percentage weight loss.

With increasing volume addition of waste glass, dimensional stability was impacted in the samples resulting to reduction in firing shrinkage as the additives increased (Fig. 1). Loss in weight in fired bricks is explained by shrinkage experienced during firing and loss of volatile and organic content present in the samples. At high temperature glass phase expansion leads to increased compactment, hence with increasing volume of waste glass content there was reduction in weight loss. It is evident that by increasing the volume addition of waste glass resulted to the reduction in firing shrinkage as the additives increases (Fig. 1). The loss in weight in fired bricks is explained by shrinkage experienced during firing and loss of volatile and organic content present in the samples. At high temperature glass phase expansion leads to increased compactment, hence with increasing volume of waste glass content there was reduction in weight loss.

Apparent porosity and Water absorption

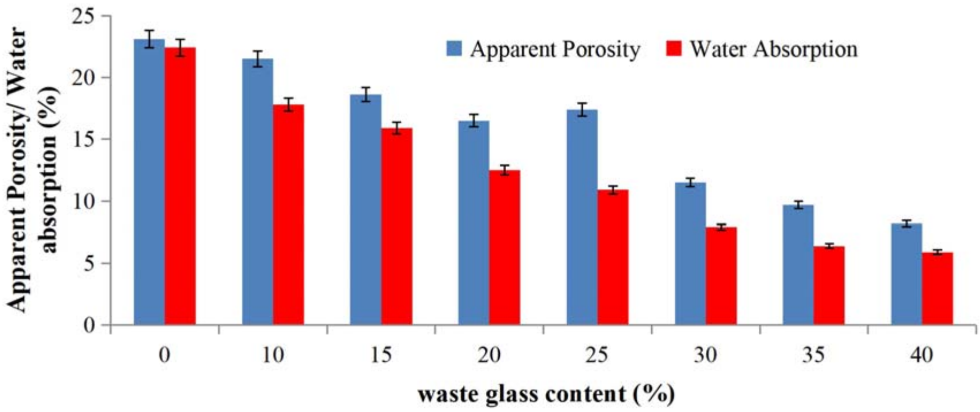

Fig. 2: Effects of waste glass addition on apparent porosity and water absorption.

Waste glass presence in the bricks samples reduced porosity due to in filling of available pores in the bricks. This enhanced compactment leading to reduction in porosity. During sintering, densification was enhanced which further reduced volume of pores. At high temperature, vitrification was enhanced leading to further fusing of the particles, hence, porosity was reduced. Similarly, as porosity reduced, water absorption in the samples reduced with increasing waste glass content. Apparent porosity reduced from 23.1% with no waste glass content to 8.1% at 40% waste glass content, porosity reduced with increasing amount of waste glass, which also reflected in water absorption capacity as it reduced from 22.4% (0% waste glass) to 5.9% (40% waste glass).

Bulk Density

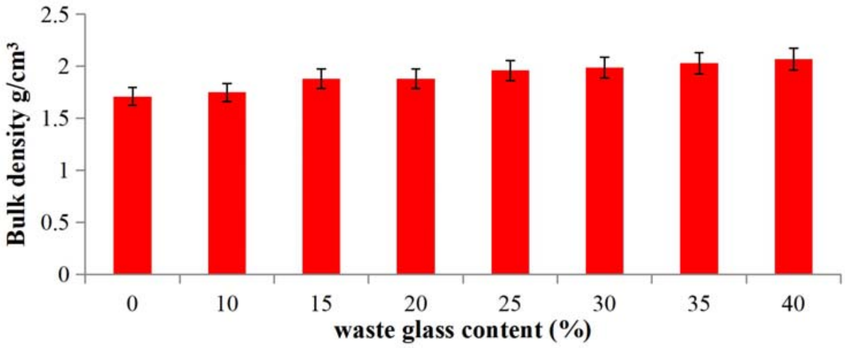

Fig. 3: Effects of waste glass addition on bulk density.

The purpose of adding waste glass to clay is to improve the properties of fired clay produced during firing. Reduced porosity results into compaction and densification in the samples. At high sintering temperature, vitrification process leads to further densification and compaction resulting into increased cohesion within the particles. As waste glass content increased in the bricks, bulk density increased gradually from 1.71g/cm^3 (0% waste glass) to 2.07g/cm^3 at 40% waste glass addition (Fig. 3).

Compressive Strength and Flexural Strength

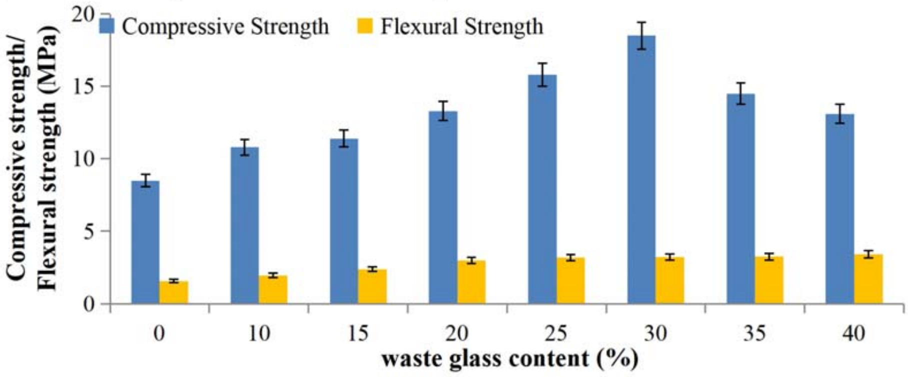

Fig 4: Effect of waste glass addition on compressive and flexural strength.

With increased amount of waste glass content, compressive strength increased gradually from 8.5 MPa to 18.5 MPa (Table 1 and Fig. 4) as a result of reduced interparticle distance and reduced volume of pores within the bricks. At high temperature, there was increased glass phase volume, which further reduced volume of pores, hence leading to enhanced compaction. At 30% waste glass content compressive strength rose to a peak of 18.5 MPa but fell at 35% waste glass addition, also fell a bit further when waste glass increased to 40%. This is due to increase in volume of brittle glassy phase formed during sintering. In the case of flexural strength, the value rose from 1.54 MPa to a peak of 2.41 MPa at 40% waste glass addition.

Wear Rate

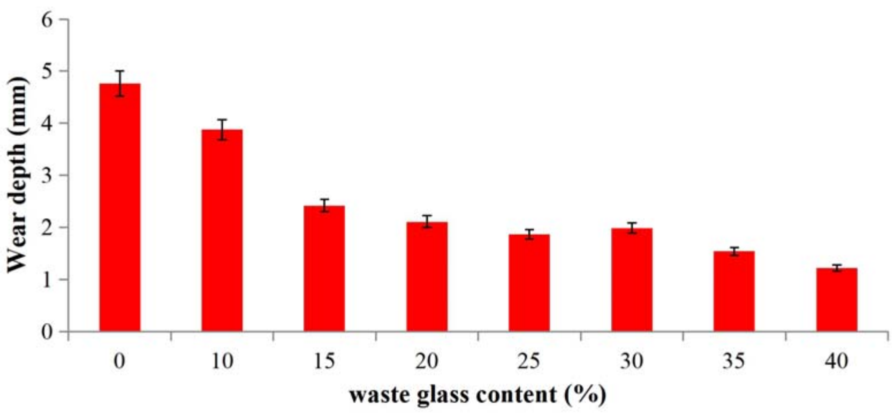

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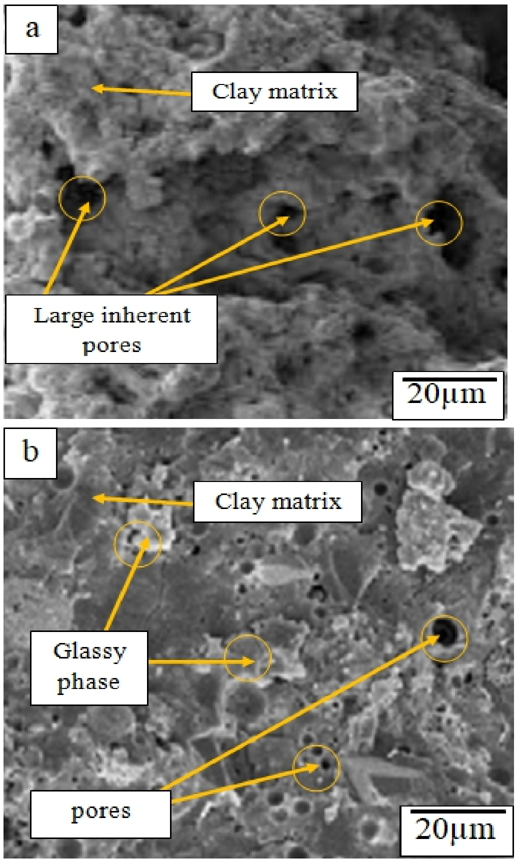
Fig 5: Effect of waste glass addition on wear rate.

The wear rate displayed in Figure 5 reduced as waste glass content increased in the samples, showing that as waste glass content increased hardness and wear resistance increased, due to enhanced cohesion within particles as a result of reduced interparticle distance and presence of strong glass phase.

Microstructural behaviour



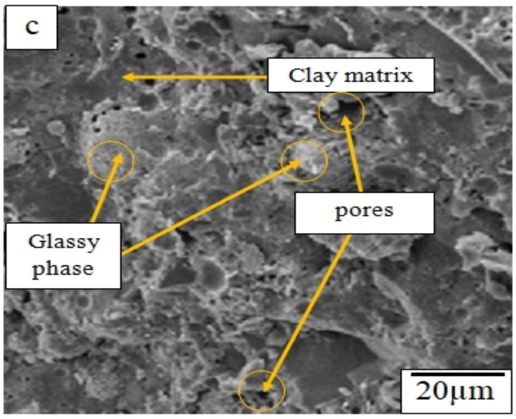


Fig. 6: SEM images of samples containing (a) 0 wt. % (b) 25 wt. % (c) 35 wt. % WGP.

Representative morphological images showing the features of selected samples produced are as displayed in Figure 6. It is noted that the images show a large amount of pores present within the clay matrix. Also, as observed in Fig. 6 (b), the surface morphology of sample E (25% WG) showed a reduced pore volume compared with sample A (0% WG content). It is evident that better property behaviour was noticed in 25% WG content relative to sample A with 0% WG. Similarly, Fig. 6c shows a further reduction in pores, this is likely to be responsible for lower porosity and water absorption in sample E containing 35 wt. % WG. The glassy phase can be observed in both Fig. 6b and 6c, which contributed to further reduction of pores and enhanced mechanical properties. The consequence of these improvements reflected in increased compliance level of samples with increasing WG content.

Property Evaluation

Table 3: Property evaluation of brick samples.

			Various content of waste glass (%)							
Properties	**Standard Value**	**Source**	**Control X (0% WG)**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
Firing Shrinkage	< 8 %	[17]	1	1	1	1	1	1	1	1
Weight loss index	< 15%	[18]	1	1	1	1	1	1	1	1
Apparent Porosity	< 30 %	[19]	1	1	1	1	1	1	1	1
Water Absorption	< 18 %	[15]	0	1	1	1	1	1	1	1
Wear depth	< 3mm	[20]	0	0	1	1	1	1	1	1
Bulk density	>1.6 g/cm^3	[21]	1	1	1	1	1	1	1	1
Compressive Strength	>5 MPa	[19]	1	1	1	1	1	1	1	1
Flexural	>2MPa	[22]	0	0	1	1	1	1	1	1

Strength								
Total Value	5	6	8	8	8	8	8	8

Table 4: Compliance level of samples.

Waste glass (%)	**0**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
Compliance (%)	63	75	100	100	100	100	100	100

The values obtained for the properties of samples were compared with existing standards (Table 1 and 2) in other to bench mark the findings from the current study. It is evident that the compliance level was calculated as ratio of total value for each sample. The results showed that the compliance level gave a total expected value of 7.

4. Conclusions

In this study, we report that waste glass powder of particle size ~150 µm was added to clay in other to investigate the effects on the properties of fired ceramic bricks. A comparison was done with existing standard in order to access the compliance level with those standards. It was concluded that;

1. addition of waste glass improved the properties of fired bricks produced,
2. increase in amount of waste glass content increased the compliance level of bricks produced when compared with existing standard values for masonry;
3. ≥15% by weight of waste glass can be employed in the production of masonry bricks for low rise building.

Therefore, waste glass addition to bricks is useful in obtaining better performance for masonry works and can be encouraged. In recommendation, the properties obtained in this study can be evaluated for further studies.

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