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STUDY ON THE INFLUENCE OF PARTICLE SIZES OF WASTE GLASS ON THE PROPERTIES OF FIRED CLAY BRICKS

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Abstract: This study investigate the properties of various sieve fraction of waste glass (WG) on fired clay bricks in order to enhance its service properties for masonry. Green bricks prepared from various sieve fractions were dried in an oven at 110 °C for 12 hours to remove moisture content and fired in a furnace for 4 hours until 1000 °C was attained. They were left to soak for another 4 hours and allowed to cool in the furnace. Samples were tested for firing shrinkage, weight loss, apparent porosity, water absorption, bulk density, compressive strength and modulus of rupture. Property evaluation and compliance level analysis was carried out on the results obtained, to check level of compliance with existing standards. Results revealed that firing shrinkage, weight loss, apparent porosity and water absorption reduced as particle sizes reduced while bulk density, compressive strength and modulus of rupture were enhanced as WG particle sizes reduced. Compliance level table shows that sieve fractions of -150+75 μm (sample C) and -75 μm (sample D) had 100% compliance with all standard used for comparison, while the control sample X (0% additive), (sample A) -850+300 μm and (sample B) -300+150 μm had 50 %, 63 % and 88 % compliance respectively. It was observed that as particles size reduced, the properties of the bricks were enhanced. In conclusion, WG particles size of 150 μm and 75 μm had the optimum impact on the properties of fired clay bricks for construction purpose.
Keywords: waste glass, fired bricks, particle size, compliance level, masonry

1. INTRODUCTION

Industrial revolution is a great thing that has happened in the world. It has brought about production of many goods which have been useful in almost all facets of life, for humans [1]. Other impacts of industrial revolution are in the speed of achieving task and in the production of semi-finished and finished goods from raw material deposits. One of this semi-finished and finished goods are glass products, made from silica sands through industrial processes. As the demand of these glass products rises, more and more of these products are been manufactured daily [1].

These glass products are used directly, like glass plates and cups, or in packaging of other goods like bottles for packaging soft drinks and alcohols. After the consumption of theses drinks, the bottles are no longer needed, hence disposed into bins [2]. Glass cups and plates used in homes when mistakenly broken end up as waste disposed in bins and these waste eventually find their ways to landfills. As these wastes been dumped continuously on landfills continue to take space, thereby constituting nuisance in the environment, since they degrade slowly [3].

One way to reduce this waste glass is by recycling and reusing. A more efficient way of recycling and reusing is adding the waste to clay in the production of fired bricks. This process requires less energy consumption and short processing root. The process of recycling entails collection, sorting, crushing, milling and sieving before adding to clay [4].

Previous studies carried out showed that addition of waste glass to clay bricks contributed to properties of clay bricks. [5], reused waste glass in the production of building bricks. He added WG powder (-21 μm) to clay at varied amount. 0, 2.5, 5 and 10% of WG powder was added to clay and fired the brick samples at 850, 950 and 1050°C. From the result recorded, it was shown that as the content increased from 0 to 10%, porosity, water absorption, firing shrinkage and loss on ignition reduced while bulk density and compressive strength increased. Also, as temperature increased, compaction and compressive strength increased. In another study, [4] added 2 different particle sizes (150 and 600 μm) of waste glass to clay mixes at 0, 10. 20, 30 and 40% by weight and the brick samples were fired at 900, 1000 and 1100°C. The result showed that firing shrinkage, bulk density and compressive strength of the bricks increased while porosity and water absorption reduced as waste glass content and firing temperature increased. It was started clearly that the finer waste glass size (150 μm) had higher compressive strength than that of 600 μm. Conclusion made was that 30 % optimal property was achieved at 30 % content of waste glass and temperature of 1100 °C [4].

This study, investigation the influence of waste glass of different particle sizes on the physical and mechanical properties of fired bricks.

2. MATERIALS AND PREPARATION

The materials used include clay and waste glass bottle. The clay was dug form a borrow pit in Ire-Akari community in Akure, Nigeria, while the bottles were bought from a glass shop where glass bottles, cups, plates and other waste glass products collected from landfill were sold for recycling. The clay lump was dried in the sun for 3 days, broken into smaller pieces, followed by crushing and milling in a ball mill and later sieving to different sizes using electric sieve shaker. Clay sieved to -150 µm was used in this study. The waste glass bottles were initially washed, wiped clean, crushed, pulverized and sieved using the same shaker. Four sets of waste glass particles were collected and employed in this study based on sizes; -850+300 µm, -300+150 µm, -150+75 µm and -75 µm.

(a) - 850 +300 µm (b) - 300 + 150 µm (c) - 150 + 75 µm (d) - 75 µm

Figure 1: Particle sizes of waste glass particles employed in this study

Control sample X was produced by adding water to Clay (sieved to -150 µm) and the slurry obtained compacted into a mould of 190 x 60 x 60 mm. Samples A, B, C and D were produced using the same procedure, with the addition of 20% fixed amount of waste glass at different particle sizes of -850+300 µm, -300+150 µm, -150+75 µm and -75 µm respectively. The samples were allowed to settle for 12 hours before been dried in an oven at 105 °C for another 12 hours, to dry out moisture content. The dried samples were then fired in a furnace for 4 hours until 1000 °C was attained and then soaked for another 4 hours before allowing cooling in the furnace. After this, the samples were examined for firing shrinkage, weight loss, apparent porosity, water absorption, bulk density, compressive and modulus of rupture

Table 1: Composition of Samples

Sample	X	A	B	C	D
Clay (%)	100	80	80	80	80
Waste Glass (%)	0	20	20	20	20
Waste glass particle size (µm)	-	-850 +300	-300 +150	- 150 + 75	- 75

3. TEST METHODS

— Particle size analysis of waste glass and clay

The test was carried out in line with [6], using dry sieving method. 17.5Kg of the clay and 8.5Kg of waste glass were introduced into the electric sieve shaker from the top sieve (4750 µm aperture) and the result presented in Table 2.

— Tests carried out on brick samples

≡ Firing shrinkage

Length measurement was taken using venier caliper of precision ± 0.01mm in line with [7]. The samples were dried in the oven at 110 °C for 12 hours and allowed to cool. Dry length of the samples and the length after firing were measured as L_1 and L_2 respectively. Dry shrinkage was evaluated using the expression

$$\text{Firing shrinkage FS} = \frac{L2-L3}{L2} \times 100 \tag{2}$$

≡ Weight loss

In the course of firing, moisture, organic and inorganic content present in bricks burn off, leading to reduction in weight of sample as a result of shrinkage. The weight of sample dried in an oven at 110 °C was measured in air as M_x and the weight after firing was measured as M_y. Weight loss index was evaluated using equation (1)

$$\text{Weight loss} = \frac{Mx-My}{Mx} \times 100 \tag{1}$$

≡ Apparent porosity and water absorption

Apparent porosity was determined as stated in [8]. Bricks samples were oven dried for 12 hours at 105 °C to 110 °C in an oven. Samples were immersed in a beaker of water for 24 hours after which each was wiped and cleaned. Weight of dried sample in air was measured as M_1. The weight of saturated sample in air was measured as M_2 and the mass when suspended in water is M_3. Apparent porosity was evaluated using equation 3

$$\text{Apparent Porosity AP} = \frac{M2-M1}{M2-M3} \times 100 \tag{3}$$

Water absorption was measured in line with [8] and evaluated using the expression in equation (4).

$$\text{Water Absorption} = \frac{M2-M1}{M1} \times 100 \tag{4}$$

≡ **Bulk density**

Samples were dried in the oven at 110 °C for 12 hours, allowed to cool and the mass when suspended in air was measured as M_1. The dried sample was later immersed in water for 24hours to attain saturated. The mass of saturated sample when suspended in air and water was measured and recorded as M_2 and M_3 respectively. Bulk density was evaluated in line with [8] using equation (5)

$$\text{Bulk Density} = \frac{M1}{M2-M3} \tag{5}$$

≡ **Compressive strength**

Dried samples which were dried in oven at 110 °C (for 12hours) were used in evaluating the compressive strength as per [9]. The strength was evaluated as expressed in (6).

$$\text{Compressive Strength} = \frac{\text{Maximum Load at fracture}}{\text{Cross sectional area}} \tag{6}$$

≡ **Modulus of rupture**

The test was carried out in line with [10] (three point loading) using the expression

$$MOR = 1.5Fl/wd^2 \tag{7}$$

MOR is Modulus of Rupture, F is Maximum load applied, l is span length, w is width if sample and d is depth of sample

4. RESULTS AND DISCUSSION

— **Particle size analysis**

After sieving of the clay and waste glass, aggregate particles on each sieve were collected and weighed. Figure 2 shows the particle size distribution of the clay and glass particles. Particle size distribution analysis was carried out using dry sieving method as per [6]. From the distribution shown in table 2, 97 % and 92 % of waste glass and clay were collected below 1180 µm and used for the sample preparation. This shows that the particles were fine.

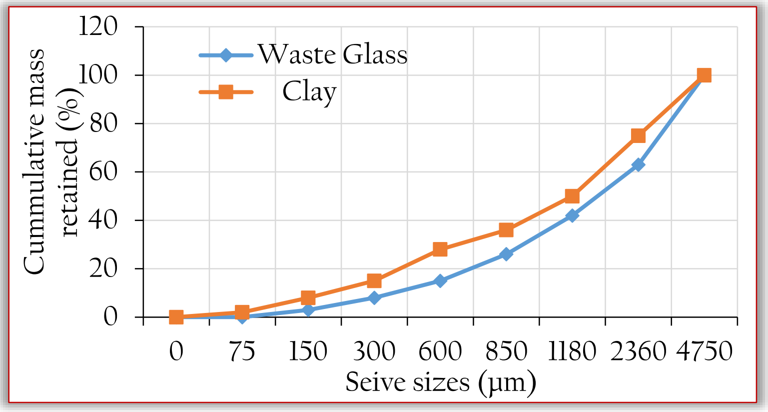

Figure 2: Particle Size Distribution of waste glass and clay

Table 2: Particle Size Distribution Table

Sieve no	Sieve diameter(µm)	% mass passing		% mass retained		Cumulative % retained	
		WG	Clay	WG	Clay	WG	Clay
4	4750	100	100	0	0	0	0
8	2360	100	98	0	2	0	2
16	1180	97	92	3	6	3	8
20	850	92	85	5	7	8	15
30	600	85	72	7	13	15	28
50	300	74	64	11	8	26	36
100	150	58	50	16	14	42	50
200	75	37	25	21	25	63	75
Pan	------	-	-	37	25	100	100

— **Properties of brick samples**

Table 3 : Values of Properties

Samples	Firing shrinkage (%)	Loss in weight (%)	Apparent porosity (%)	Water absorption (%)	Bulk density (g/cm³)	Compressive strength (MPa)	Modulus of rupture (MPa)
X	2.43	7.5	23.5	21.2	1.41	6.81	1.51
A	2.12	6.7	20.1	18.7	1.52	8.24	2.11
B	1.13	5.3	18.3	16.4	1.61	9.59	2.45
C	0.94	4.1	15.4	13.7	1.73	10.24	2.65
D	0.87	3.3	11.2	10.5	1.87	11.30	2.73

≡ **Effect of particle sizes on the firing shrinkage of fired Bricks**

Figure 3 shows the value for linear shrinkage. It was observed that sizes of particles reduced, shrinkage reduced. Pores in the bricks are filled with WG particles hence reduced the volume of pores. During sintering, the amorphous glass phase is formed which reduced the porosity and the distance between the particles thereby enhancing cohesion within the particles. Loss of moisture content and compactment during sintering led to the shrinkage.

Firing shrinkage for control sample X (0% WG additive) is 2.43%, on addition of 20% WG additive of size -850 + 300 µm, the shrinkage reduced to 2.12% which represents 12.8% reduction. The shrinkage further rose progressively with reduction in particles sizes at -300 + 150 µm, -150 + 75 µm and -75 µm respectively. From result obtained, it can be deduced that as particle sizes of waste glass reduced, higher dimensional stability was impacted on the samples tested. In line with [11], all samples met standard value of below 8 %. This finding is in tandem with [12] however study of [13] revealed increase in length shrinkage as waste glass size reduced, further confirmed by [14].

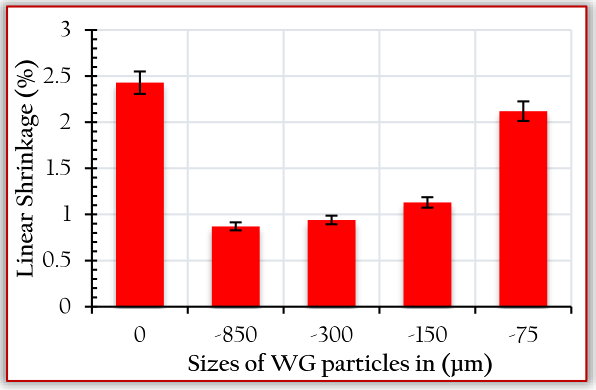

Figure 3: Effect of particle sizes on the Firing shrinkage of Fired Bricks

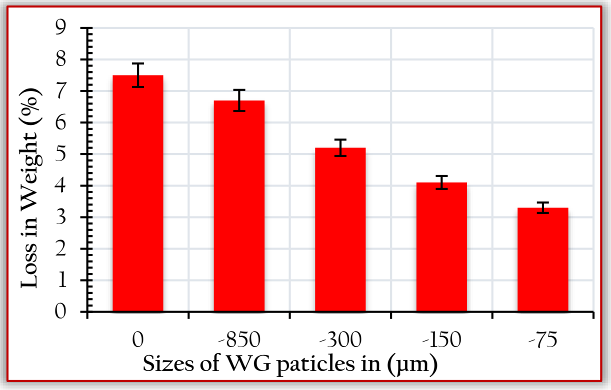

Figure 4: Effect of particle sizes on the weight loss of fired bricks

≡ **Effect of particle sizes on the percentage weight loss**

Due to shrinkage and loss of moisture and volatile content during sintering, volume shrinkage of the bricks occur leading to loss in weight. Weight loss on firing was evaluated as the weight loss between drying at 110ºC and firing at 1000ºC. There was reduction in weight loss percent as shrinkage reduced from control sample X to sample D (figure 4). This indicates that as WG particle sizes reduced, weight loss reduced due to compactment, as a result of the filling of the pores by WG particles. The weight loss index for control sample X (with no additives) was 7.5 %. Samples A, B, C D with different particles size reduction had weight loss of 6.7 %, 5.3 %, 4.1 %, and 3.3 % respectively, amounting to 10.7 %, 29.3 %, 45.3 % and 56 % respective reduction from the value of X. This indicates that there was stability in weight as particle sizes reduced as a result of enhanced densification and compactment which was also promoted by the finesses of the particles. In line with [15], all samples standard value of ‹15 %. Submission of [16] showed that linear shrinkage was greater at finest size than the coarse particles corroborating this study.

≡ **Effect of particle sizes on the apparent porosity and water absorption**

Porosity is a measure of volume of pores present in a bulky sample. Addition of waste glass particles resulted in reduced volume of pores. During sintering, compactment and vitrification occurred which enhanced densification, hence, resulting in reduction in porosity. As porosity reduced, water entry into the bricks reduced leading to decrease in water absorption. Porosity and water absorption as indicated in Table 3 and in figure 5, is lowest at -75µm, having values of 11.2 % and 10.5 % respectively and highest for control sample X, with values of 23.5 % and 21.2% respectively. From the results, it can be deduced that there is inverse relationship between porosity, water absorption and seizes of waste glass particles added.

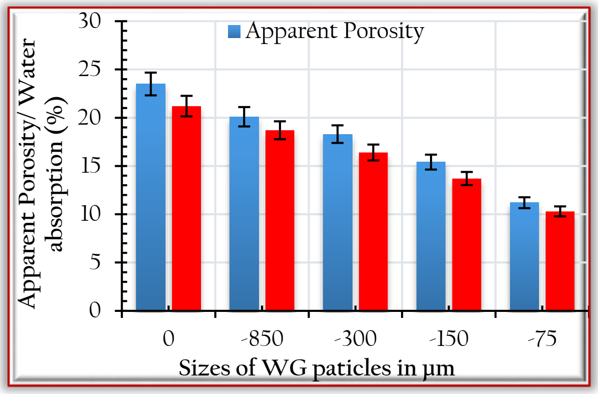

Figure 5: Effect of particle sizes on the Apparent Porosity and Water Absorption

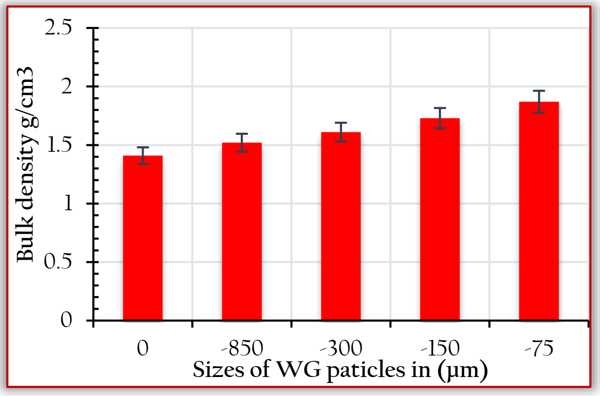

Figure 6: Effect of particle sizes on the Bulk Density

As reported in this investigation, findings of [14] showed reduction in water absorption with finer particle sizes and this is linked to reduction in porosity as particle sizes reduced. Similarly, [12] showed reduction in water absorption as particle sizes reduced from coarse to fine. Submission of [16] revealed reduction in water absorption with higher particle size contrary to findings presented in this study. For water absorption, samples B, C and D containing WG with particle sizes of -300 + 150 µm, -150 + 75 µm and - 75 µm respectively met [11] standard value of < 15 %, while samples A, B, C and D had below 20 % for load bearing bricks as per [17]. For porosity, all samples had below 30 % as per [18] value.

≡ **Effect of particle sizes on bulk density**

The relationship between bulk density and sizes of the waste glass included can be analysed using figure 6. The addition of the waste glass during sample production contributed to densification which was further enhanced during sintering and firing. As the sizes reduced, bulk density increased as a result of increase in volume of particles present in the samples. Bulk density increased from 1.41 g/cm³ in control sample X with no additive present to 1.87 g/cm³ containing - 75 µm, an increment of 33 %. The relationship between bulk density and particle size is inverse. Just as expressed in present work, bulk density was highest on incorporation of the finest particle size of waste glass in [16]. Samples B, C and D had values above 1.6g/cm³ as per [19] standard value for bricks.

≡ **Effect of particle sizes on compressive strength and modulus of rupture**

Figure 7 shows relationship between compressive strength, Modulus of Rupture and particle sizes. As compaction was enhanced, compressive strength was increased from 6.81 MPa in control sample X to 11.3 MPa in sample D. As particle sizes reduced, compressive strength was enhanced. The compressive strength between sample X and sample A was an increase of 21 % while there was an increase of 40.8 % between control X and B. There was an increase of 50.4 % when comparing sample X and C and in the case of sample X and D, the difference was 66%. All samples can be used for low rise building as per [20]. Similarly, as particle sizes reduced, Modulus of Rupture increased from 1.51 MPa in sample X to 2.73 MPa in sample D, an increment of 80.7 %. Samples A, B, C and D complied with [21], for modulus of rupture of brick samples while sample A has below standard value. Corroborative finding was highlighted in [16] [Mao] as compressive strength increased with finer particle size ascribable to enhanced compactment and bonding. Likewise, [14] showcased the same observation as compressive strength rose with finer sizes of waste glass particle sizes. [4,12, 13].

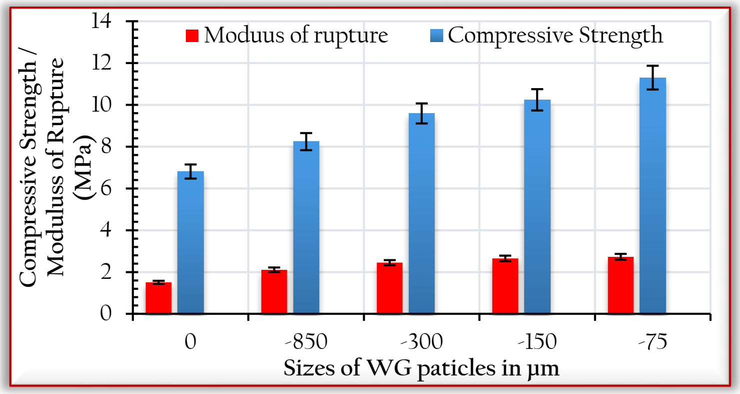

Figure 7: Effect of particle sizes on the Compressive Strength and Modulus of rupture

— **Effect of WG particle sizes on the properties of brick samples: Property Evaluation Table**

Property of each sample was evaluated by comparing the values obtained for each property with the existing standard value as indicated in the sources (Table 4).

Table 4: Property Evaluation Table

Samples (containing 20 % WG at different particle sizes)							
Properties	Standard Value	Source	Control X (0% WG)	A (-850 + 300 µm)	B (-300 + 150 µm)	C (-150 + 75 µm)	D (-75 µm)
Firing Shrinkage	< 8 %	CNS 1127 [11]	1	1	1	1	1
Weight loss index	< 15% (0.15)	TS 704 [15]	1	1	1	1	1
Apparent Porosity	< 30 %	BS 3921 [18]	1	1	1	1	1
Water Absorption	< 18 %	TS 704 [15]	0	0	1	1	1
Water Absorption	< 15 %	CNS 1127 [11]	0	0	0	1	1
Bulk density	>1.6 g/cm³	TCVN 1451:1998 [19]	0	0	1	1	1
Compressive Strength	>5 MPa	BS 3921[18]	1	1	1	1	1
Flexural Strength	>2MPa	AS 3700 [21]	0	1	1	1	1
Total Value			4	5	7	8	8

1 was used in the table when a sample met the standard value for the property considered while 0 was used when the standard value was not met. For instance, in the case of firing shrinkage, all samples met [11] value of ‹ 8%, therefore, 1 was used under each sample, In the case of water absorption, samples B, C and D met the standard value (‹ 18%) as per [15], 1 was used under sample B, C and D while 0 was used for sample A and B. This process was followed until the table was completed and the values were summed up to obtain total value under each sample.

Compliance level of each sample was evaluated by obtaining the ratio of total value obtained for each sample to the expected total value of 8, since 8 standards were considered in this study (Table 5). Samples C and D had compliance of 100% indicating that particle sizes of -150 µm were efficient in improving properties of fired bricks.

$$\text{Compliance Level} = \frac{\text{Total Value}}{\text{Total expected Value}} \times 100$$

Table 5: Compliance Level Table for Samples

Samples (particle sizes)	X (0% WG)	A (-850 + 300 µm)	B (-300 + 150 µm)	C (-150 + 75 µm)	D (-75 µm)
Compliance Level	50	63	88	100	100

5. MICROSTRUCTURAL ANALYSIS

Qualitative assessment of the microstructure of fired samples reveal distinct properties. Fig. 8a and 8b are images of fired samples doped with waste glass of particle sizes -850 +300 µm and -300 + 150 µm. Glassy phase is identified to be distributed within clay matrix depicting fusing of the particles together hereby effectuating improved properties as compared with control sample with 0 wt. % waste glass. Fig. 8c and 8d are SEM images of samples doped with -150 +75 µm and – 75 µm waste glass respectively. Similar to Fig 8a and 8b, the glassy phase was evenly distributed within the matrix and this time with refinement of the matrix owing to finer particle size of the waste glass and this cumulated into much improved properties of samples as compared to the ones doped with particles sizes of -850 +300 µm and -300 + 150 µm. This achievement of refinement in samples containing finer sizes of -150 +75 µm and – 75 µm is hereby linked to superior properties exhibited, consequence of which was reflected in the 100 % compliance of .

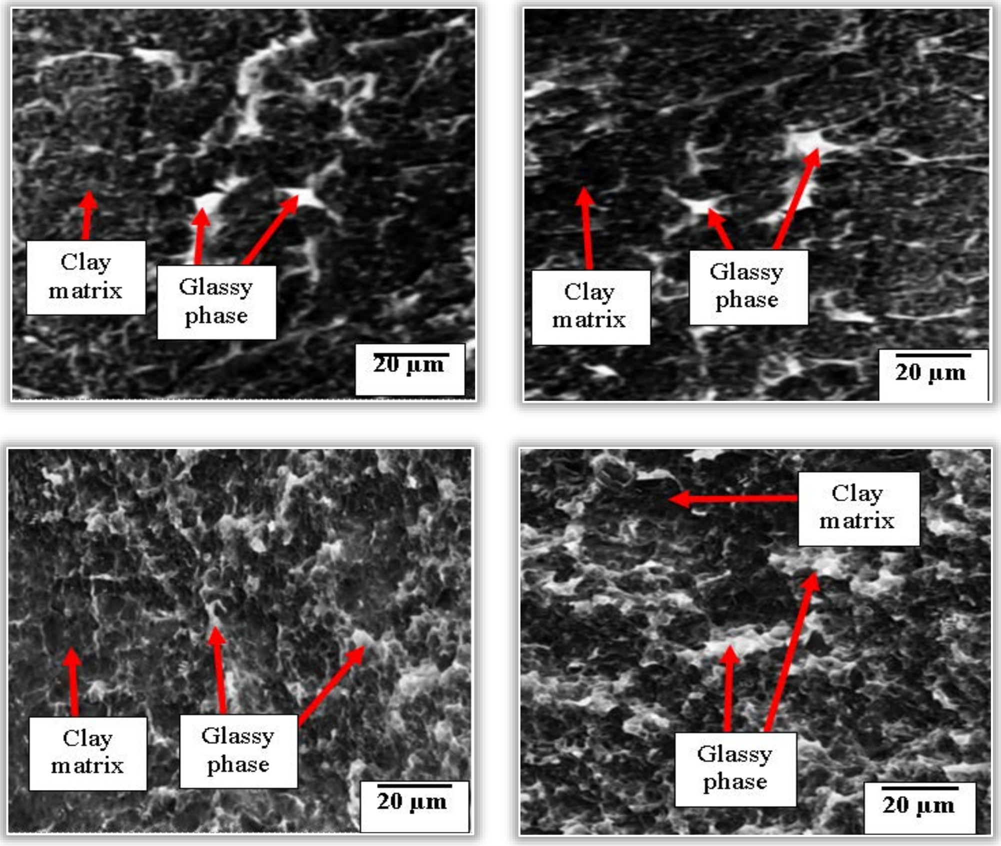

Figure 8: Microstructural analysis

From the result obtained and the analysis carried out in this study, it can be concluded that 20% waste glass addition at varied particle sizes produced different properties in fired brick samples. As particle sizes reduced, properties in brick samples were enhanced which reflected in the compliance level from 50 % in sample X without additives to 63 % sample A (- 850 + 300 μm), 88 % in sample B (- 300 + 150 μm) and 100% in sample C (-150 + 75 μm) and D (-75 μm). Particle sizes below 150 μm for waste glass are effective in producing improved properties in fired bricks.

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