ACTA METALLURGICA SLOVACA
2021, VOL. 27, NO. 1, 4-10

RESEARCH PAPER

EXPERIMENTAL STUDY ON THE MECHANICAL BEHAVIOUR OF FIRED SAND-CLAY AND GLASS POWDER-CLAY BRICKS

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Received: 30.07.2020
Accepted: 12.10.2020

ABSTRACT

Mechanical behaviour of fired bricks containing varied amount of fine sand (FS) and waste glass powder (GP) was investigated. FS and GP were added to bricks at varied amount of 0, 5, 10, 15, 20, 25, 30, 35 and 40 wt. %. Firing was done at 1200 ºC and samples produced were evaluated for compressive and flexural strengths while microstructural analyses of 25 wt. % FS and GP-clay bricks were examined. Results showed that compressive strength was highest at 30 wt. % GP for GP-bricks while for FS-clay bricks, compressive strength rose to 11.4 and 12.8, at 35 and 40 wt. % FS addition. Flexural strength for GP-clay and FS-clay bricks peaked at 30 wt. % GP (3.63 MPa) and 40 wt. % FS (2.45) respectively. Flexural modulus increased progressively and exponentially as FS and GP proportion increased. Work done in resisting deformation and deflection during bending reduced with increased amount in both additives. Flexural strain was inversely related to load and stiffness. In conclusion, addition of GP and FS in increasing amount resulted in improved mechanical properties in the bricks. Also, increased proportion of GP and FS was found to improve response to loading in fired bricks.

Keywords: glass; sand; fired bricks; mechanical properties

INTRODUCTION

Ceramics are inorganic materials made of metal and non-metal compounds and are composed of silica, alumina, magnesia, zirconia, and other compounds. Properties of these materials include resistance to corrosion and chemical attack due to their inert nature, poor conduction of heat and electricity and high compressive strength. They are also hard, brittle and heavy with poor tensile properties [1-3]. Fired clay are ceramics which are made hard by firing, while unfired clay ceramics are made hard by sun drying or oven drying. Concrete or cement bricks are a form of ceramic products which are made strong by the addition of cement followed by further curing [4]. Oven drying is done on green ceramic body at 110 ºC for water removal and decomposition of some organic elements present. Firing process involves exposure of ceramic body to high temperature for a period of time to enhance hardness, strength and other properties [5-7]. The process of sintering enhances bond within particles leading to improved properties [8]. Firing of clay is undergone in the production of potteries, wares, roof tiles and bricks. Properties of fired bricks include porosity, shrinkage, density, and strength. Clay in its raw form is porous which affects strength and density in the sense that higher porosity leads to reduced strength [7, 9]. For structural application, reduced porosity in bricks is necessary in order to ensure structural integrity of buildings. Reduced porosity in bricks results in reduced inter particle distance leading to enhanced bond between particles [10]. The process of reducing porosity in fired clay body involves the incorporation of additives like waste glass powder/shavings, eggshell powder, silica nano particles [11] and other additives. Adding of eggshell as bio-fillers to fired clay bricks [12] was noted to produce fired bricks of high compressive strength and hardness, good thermal expansion coefficient and lower water absorption at 25 wt. % eggshell powder addition. Addition of waste glass, was recorded to reduce porosity and water absorption while increased compressive strength was noted, when waste glass powder was added in increasing proportion of 0, 10, 20, 30, and 40 wt.% [13,14]. In this study, waste glass powder and fine sand were added to fired bricks and comparison was made on mechanical behaviour of such bricks at varied proportion addition; for application in masonry.

MATERIAL AND METHODS

Materials Preparation

Materials used include sand, glass bottles and clay. The sand was obtained from a stream; washed and sun dried for 3 days. Clay used was excavated from a depth of 1.5 m in a borrow pit in Aule, Ondo State, Nigeria. Water was added to the clay, stirred and left undisturbed for two days. The water was poured off leaving behind the clay. Fresh water was added, stirred and left undisturbed for another two days and the water was poured off while the left over clay was spread in a cotton material and allowed to sun dry for 7 days. Dried clay lumps were broken into smaller pieces, followed by crushing and milling. Waste glass bottles (bottles of soft drinks and alcoholic drinks) were bought from a shop where waste glass products were sold for recycling. The bottles were washed and sun dried for one day followed by crushing and milling before sieving. The sand, waste glass and milled clay were sieved using an electric sieve shaker (Model RX 29) which top sieve has an aperture of 4750 µm. Clay (sieved to 300 µm), glass powder (GP) and fine sand (FS) which were sieved to -150 µm were collected and used for sample preparation.

Sample Preparation

Two groups of samples were prepared: fine sand-clay (FS-clay bricks) samples and glass powder-clay (GP-clay bricks) samples. FS-clay brick samples contained sand at varying proportion of 0, 5, 10, 15, 20, 25, 30, 35 and 40 wt. % of fine sand while GP-clay bricks samples contained the same varying proportion of GP (Table 1). Clay was mixed with water and the additives in a mechanical mixer and the slurry moulded into shape using compression moulding machine at 10 MPa. Water was added during mixture at water to clay ratio of 7:20. The green bricks produced were left undisturbed for 24 hours after which they were oven dried for 12 hours at a temperature of 110 ºC in order to remove moisture and other volatile content. This was followed by firing in an electric furnace at 5 ºC/min until 1200 ºC was attained. The temperature was maintained for 4 hours before allowing samples to cool to room temperature in the furnace. Bricks 150 mm × 150 mm × 150 mm and 400 mm x 100 mm x 100 mm were produced for this study.

Table 1 Composition of samples

FS/GP	0	5	10	15	20	25	30	35	40
Clay	100	95	90	85	80	75	70	65	60

Preliminary test on materials used

Tests were carried out to examine the specific gravity, bulk density and moisture content of sand and clay (in as received condition) as well as glass powder (after sieving) in line with existing procedure stated in Table 2. Sieving was done out on the materials used as per [15,16]. Also, chemical composition of the materials were analysed and the results presented in Table 4.

Tests on brick samples

Compressive strength

Compressive strength test was carried out on each sample to determine its load bearing capacity in line with [17] procedure. The brick samples (150 mm × 150 mm × 150 mm) were initially oven dried at 110 ºC until a constant mass was attained and tested using a universal testing machine (TBTUTM-600). The samples were placed flat horizontally between the plates of the machine and a load of 10 kg/min was applied. The maximum load at failure was recorded and the compressive strength calculated using the expression in Equation 1.

$$\text{Compressive strength (MPa)} = \frac{\text{Maximum load at fracture}}{\text{Cross sectional area}} \quad (1.)$$

Flexural strength

This strength evaluates the ability of bricks to resist deformation by bending and was carried out on samples (400 mm x 100 mm x 100 mm) immediately after cooling to room temperature. The test was done in line with [18] with a loading rate of 15 kg/min and the result evaluated using Equation (2).

$$\text{Flexural strength (MPa)} = 3Fh/2bd^2 \quad (2.)$$

Where F is the maximum load at fracture, h is the length of the support plan/length between supports; b is the width of the sample, d is the thickness/depth of the sample.

RESULTS AND DISCUSSION

Physical properties and chemical composition

Table 2 showed the physical properties of materials used which was in consistent with works reported by [19-21].

Table 2 Physical Properties of Materials Used

Properties	GP	FS	Clay
Specific gravity	2.75	2.67	2.61
Bulk density	2.01 g/cm^3	1.73 g/cm^3	1.58 g/cm^3
Moisture Content	-	4.2%	26.2%
Fineness Modulus	1.27	1.65	1.67

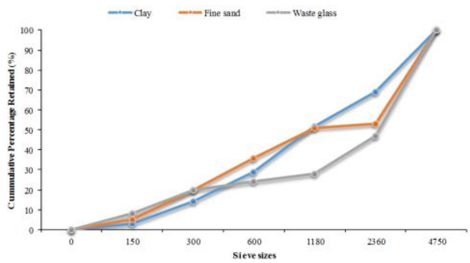

Fig. 1 Particle size distribution of GP, FS and Clay

Table 3 Chemical Composition of materials used (X-ray Fluorescence result)

Constituents	GP (%)	FS (%)	Clay (%)
SiO_2	71.8	78.3	60.1
Al_2O_3	2.5	8.8	25.1
Fe_2O_3	0.9	1.4	7.4
CaO	10.3	2.3	1.1
MgO	2.7	0.2	1.3
Na_2O	6.8	3.3	0.6
Others	3.6	3.0	0.3
Loss on ignition	1.4	2.7	4.1

The specific gravity of GP, FS and Clay used were evaluated to be 2.75, 2.67, and 2.61 respectively while bulk density was obtained as 2.01g/cm^3, 1.73 g/cm^3 and 1.58 g/cm^3. Results of the moisture content showed that clay in its raw state had moisture content of 26.2 wt. %, while fine sand had 4.2 wt. % moisture content. The finest of the materials was GP which had modulus of 1.27 falling in grading zone 2 as per [19]. From the results of the particle size distribution, 68.7 wt. % of GP lie below 300 µm sieve fraction. Based on the result on fineness modulus for FS (Fineness modulus of 1.65), FS falls under the classification of fine sand as per [19]. FS can be classified under grade 2 sand [20] indicating moderate fineness. 45.2 wt. % of the sand was retained below 150 µm. Clay has fine modulus of 1.75, with 46.3 wt. % retained on 150 µm. Table 3 highlights the chemical composition of materials used. Silica content is higher in the materials and from evaluation made 70% of the mix materials has silica content.

Analysis of mechanical behaviour of bricks

Compressive strength of brick samples

The plot showing the effect of compositions on compressive strength of samples is as shown in Fig. 2.

DOI: 10.36547/ams.27.1.622

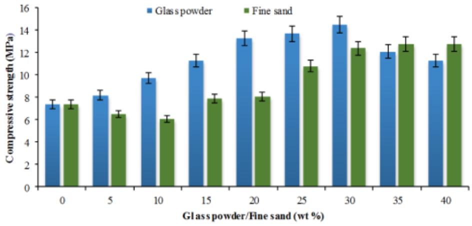

Fig. 2 Effect of compositions on compressive strength of samples

Compressive strength reduced from 7.4 MPa at 0 wt. % FS addition to 6.5 MPa at 5 wt. % FS addition (Fig. 2). It further reduced to 6.1 MPa at 10 wt. % addition which may be due to lower level of bonding between particles. This may be attributed to the lower adhesion between sand and clay particles due to the loose non plastic nature of sand (loose nature) and inability of sand to meet up with initial adequate bonding volume (Vi) for additives in the bricks, leading to lower level of compaction. At ≥15 wt. % FS addition, compressive strength increased progressively. At 25 wt. % content of FS, compressive strength increased by 33.3% to 10.8 MPa, and with further addition, it increased by 14.81% at 30 wt. % content of FS. The value remained constant at 35 and 40 wt. % addition but with reduced increment of 3.2%. Addition of ≥15 wt. % FS to clay resulted in enhancement of compressive strengths owing to ability of sand particles to fill in pores resulting in enhanced fusion and compactment.

At 5 wt. % glass powder (GP) addition, compressive strength rose to 8.2 MPa. As GP proportion increased, compressive strength increased further due to enhanced cohesion and compactment within the clay body. In addition, increased glass phase formed, further compliment the strong bond achieved thereby leading to increase in compressive strength. Compressive strength got to a peak of 14.5 MPa at 30 wt. % GP before declining at 35 wt. % and 40 wt. %. The results obtained in this present study can be compared with results recorded in [13,15] and [22] in terms of proportion of waste glass where maximum compressive strength was attained. According to [15] where 900 °C was employed in firing, maximum compressive strength was attained at 50 wt. % waste glass powder addition, though in present study, maximum strength was recorded at 30 wt. % GP. Authors [23] reported on fired clay samples at 1100 °C and a maximum compressive strength was recorded at 40 wt. % added content of milled glass (sieved to -100 µm) and further addition resulted in reduced strength. However, report from [13] attained maximum compressive strength at 1000 °C for 40 wt. % of waste glass (sieved to -150 µm) while at 1100 °C, maximum compressive strength was attained at 30 wt. % addition of waste glass. Further increase in waste glass content resulted in reduction in compressive strength. As waste glass proportion increased in the samples, there was increased glassy phase. However, as this glass phases expands, brittleness increased [13]. This explains the reduction in compressive strength beyond some certain proportion of waste glass addition. It can be deduced that when attaining ≥30 wt. % of waste glass powder, compressive strength reduces, though depends on firing temperature and sieve fraction of glass powder.

Flexural strength

Representative plot showing the effect of compositions on flexural strength of samples is shown in Fig 3.

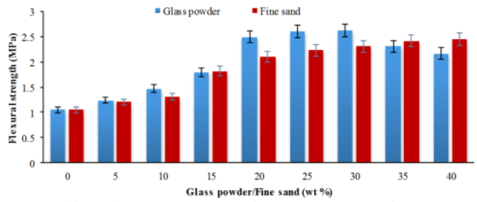

Fig. 3 Effect of compositions on flexural strength of samples

From Fig. 3, flexural strength increased progressively from 1.05 MPa at 0 wt. % of FS addition to 2.45 MPa at 35 and 40 wt. % of FS due to strong bond between sand-clay particles as a result of enhanced fusion. For samples with GP addition, flexural strength climaxed at 30 wt. % GP (2.63 MPa) and at further addition of GP, the strength declined in value due to the brittle glassy nature exhibited in bricks. Samples containing between 20 to 40 wt. % of both sand and glass powder met standard [24,25] for masonry bricks.

Flexural modulus and strain

Further analysis involves evaluation of flexural modulus. The deflection exhibited during the test for flexural strength was measured and recorded and the flexural strain evaluated using Equation (3).

$$\text{Flexural strain } (\alpha) = 6dt/L^2 \qquad (3.)$$

Where d was the recorded deflection (mm), t was thickness of sample and L is the distance between two supports. Flexural Modulus (GPa) was evaluated as flexural strength divided by flexural strain, while work done in resisting deformation during deflection (Nm) was evaluated by multiplying maximum load at failure (N) by deflection (mm).

Table 4 shows the average deflection, work done and flexural Modulus for Fine Sand (FS). Table 5 shows the average deflection, work done and flexural Modulus for Glass Powder (GP).

Table 4 Average deflection, work done and flexural Modulus for Fine Sand (FS)

Fine sand (wt. %)	Maximum load at Failure (N)	Average deflection (mm)	Flexural Strength (FS) (MPa)	Flexural Stiffness (x 10^{-3} N/m)	Flexural strain (α)	Work done (x 10^{-3} Nm)	Flexural Modulus (GPa)
0	17.96	0.80	1.05	22.45	0.0120	14.37	0.0875
5	20.69	0.62	1.21	33.37	0.0093	12.83	0.1300
10	22.40	0.44	1.31	50.90	0.0066	9.86	0.1985
15	31.12	0.35	1.82	88.91	0.0053	10.90	0.3434
20	35.91	0.31	2.10	115.84	0.0047	11.13	0.4468
25	38.13	0.22	2.23	173.32	0.0033	8.39	0.6758
30	39.50	0.14	2.31	282.14	0.0021	5.53	1.1000
35	41.38	0.09	2.42	459.78	0.0014	3.72	1.7285
40	41.90	0.07	2.45	598.57	0.0011	2.93	2.2273

Table 5 Average deflection, work done and flexural Modulus for Glass Powder (GP)

Glass Powder (wt. %)	Maximum Load at Failure (N)	Average deflection (mm)	Flexural Strength (FS) (MPa)	Flexural Stiffness (x 10^{3} N/m)	Flexural strain (α)	Work done (x 10^{-3} Nm)	Flexural Modulus (GPa)
0	17.96	0.71	1.05	25.30	0.0110	12.75	0.0955
5	21.20	0.54	1.24	39.26	0.0081	11.45	0.1296
10	25.14	0.42	1.47	59.86	0.0063	10.56	0.2333
15	30.61	0.28	1.79	109.32	0.0041	8.57	0.4366
20	42.75	0.22	2.50	194.32	0.0033	9.41	0.7576
25	44.63	0.12	2.61	371.92	0.0018	5.36	1.4500
30	44.97	0.06	2.63	749.50	0.0009	2.70	2.9222
35	39.50	0.04	2.31	987.50	0.0006	1.58	3.8500
40	37.11	0.03	2.17	1237.00	0.0004	1.11	5.4250

Effects of composition on flexural modulus and flexural stiffness of samples

Representative trend showing variations in Flexural modulus Fig 4(a) and flexural stiffness Fig 4(b) at increasing Glass powder and Fine sand content.

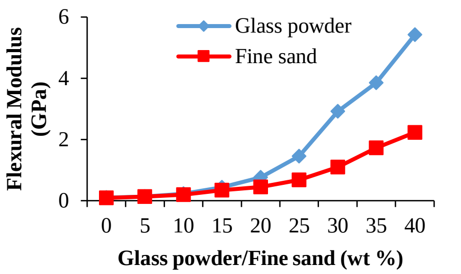

Fig. 4 (a) Showing Flexural modulus

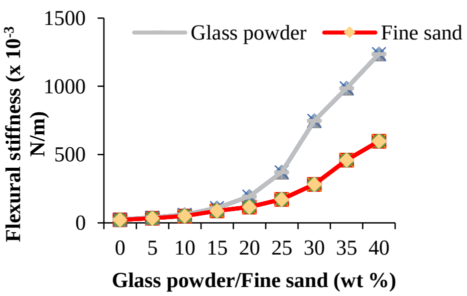

Fig.4 (b) Showing Flexural stiffness

As glass powder and sand content increased, flexural modulus increased (Fig. 4a), average deflection decreased leading to continuous decrease in strain. This resulted into progressive increase in flexural modulus, indicating increase in stiffness as glass powder and sand content amount increased. The strong bond formed between particles of clay and fine sand amounted to increased stiffness and rigidity. Increased compactment and strong adhesion between GP-clay bricks particles further enhanced resistance to bending in samples with GP. The strong glassy phase formed in samples containing GP further enhanced the resistance to deflection in GP-clay bricks samples, leading to high degree of flexural modulus compared with FS-clay samples. Flexural moduli for both samples (GP-clay and FS-clay bricks) were almost the same from 0 wt. % of to 15 wt. % addition of the additives. However, at 20% addition, the difference was becoming clearer. Between 20 wt. % and 25 wt. % addition of GP, there was a large increment of almost 91% in flexural modulus of GP-clay bricks compared to 51% in FS-clay bricks. As the content of the additives increased to 30, 35 and 40 wt. %, progressive increase in flexural modulus was 101%, 32% and 41% respectively for GP-Clay bricks, while in the case of FS-clay bricks, the progressive increase was 62%, 32% and 26% respectively. The flexural modulus- curve was exponential and progressive for GP-clay bricks and FS-clay bricks. Percentage increment of flexural modulus, in GP-clay was much higher than that of FS-sand, as a result of increased strong glass phase formed in the samples as GP content increased, which further complemented the bond formed between GP and clay particles. From the Fig. 4a, addition of ≥ 25% of both additives resulted in significant resistance to bending in bricks. Flexural stiffness (Fig. 4b) also followed the same trend for both FS and GP-clay bricks in that at 20 wt. % content of the additives, stiffness increased exponentially.

Effect of composition on work done during bending

Fig. 5 shows the downward movement of the work done in resisting deflection at maximum load application for both GP-clay and FS-clay bricks. This is attributed to increased resistance to deflection in the samples as content of both GP and FS were increasing. The additives were effective in the reduction of work done in resisting deflection. Work done in GP-clay bricks is lower than that of FS-clay bricks except at 10 wt. % of the additives where it's vice versa. This implies that as additives increased in the sample, the work done against load applied in causing deflection reduced, indicating high resistance to deflection. Comparing the two forms of bricks, work done against load in GP-clay bricks is lower than that of FS-clay bricks for each mix proportion (except for 10 wt. %), indicating, there is higher resistance to load in GP-clay bricks than in FS-clay bricks.

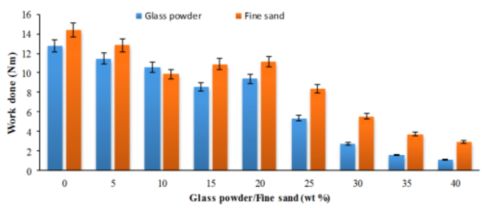

Fig. 5 Variation in work done in bricks during bending test

Flexural strain against maximum load at failure for brick samples

The strain-load curve in Fig. 6(a) shows the decrease in strain at failure as maximum load increased. For load between 18 N and 42 N, the strain ranged between 0.004 and 0.011 for FS-clay bricks. At higher FS proportion of ≥ 25 wt. %, increment

DOI: 10.36547/ams.27.1.622

in load applied was lower compared to compositions below 30 wt. % which also resulted into lower reduction in strain experienced at ≥ 25 wt. % FS addition owing to increased compactment in the samples. As load applied lied between 17 and 45 N, strain at failure was reducing (Fig. 6(b)). There was a 20% reduction in strain between 15 wt. % of GP and 20 wt. % of GP with a corresponding 4.4% increase in load to failure. At ≥ 20 wt. % GP, there was shrinkage in strain which resulted into corresponding lower percentage increase in maximum load to fracture for samples.

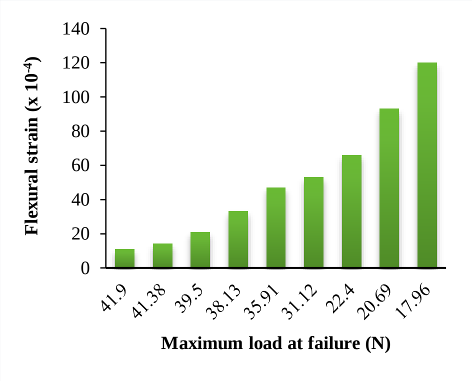

Fig. 6 (a) Plot showing the curve of strain at failure against maximum load at failure for FS-clay bricks

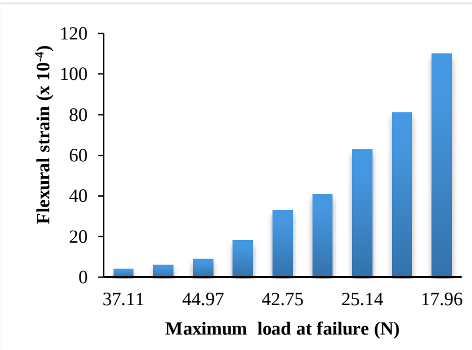

Fig. 6 (b) Plot showing the curve of strain at failure against maximum load at failure for GP-clay bricks

Generally, with increased load, strain at fracture reduced for both forms of bricks, due to reduced work done in resisting deflection as FS and GP contents increased in the samples. In Fig. 6b, highest load was recorded at 30 wt. % of GP with a resulting strain of 0.009. At 35 and 40 wt. % of GP, strain further reduced to 0.006 and 0.004 respectively, which was a further reduction of 33.3 and 55.6 % respectively, owing to higher value of stiffness.

Flexural strain against stiffness for brick samples

The representative plots showing the flexural strain against flexural stiffness for FS-clay bricks and GP bricks are as shown in Fig. 7 (a) and (b) respectively.

From Fig. 7 (a) and (b), flexural strain reduced with increased stiffness for both type of bricks. This is due to increased strength induced as composition of FS and GP increased in samples. Flexural strain was higher in FS-clay bricks than GP-clay bricks, while flexural stiffness was higher in GP-bricks than FS bricks. This can be attributed to the fineness of GP, with fineness modulus of 1.50, which is lower than that of sand (fineness modulus of 2.26). A finer particle of additive contributes to strength improvement in bricks [13].

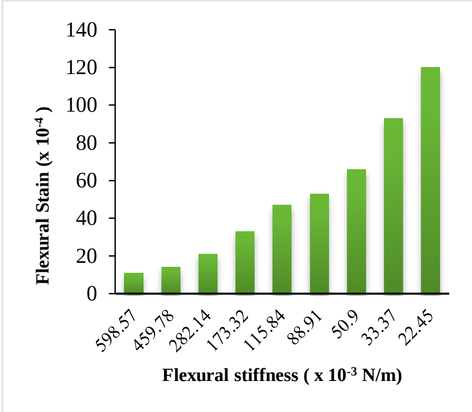

Fig. 7 (a) Plot of flexural strain against flexural stiffness for FS-clay bricks

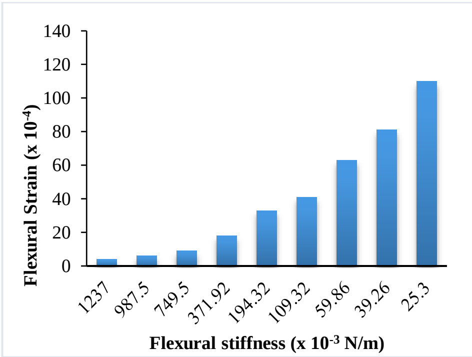

Fig. 7 (b) Plot of flexural strain against flexural stiffness for GP-clay bricks

Microstructural response

The representative morphological images for samples at 0 wt.% FS/GP, 25 wt.% FS and 25 wt.% GP are as shown in Fig. 8(a), (b) and (c) respectively.

Fig 8 (a) highlights the SEM image of brick sample with 0% GP/FS addition. Large amount of pores are observed when compared with bricks containing FS and GP. This explains the reason for lower compressive and flexural strength in sample with 0% GP/FS-clay bricks when compared with 25 wt. % FS-clay bricks and 25 wt. % GP-clay bricks. Fig. 8(b) shows image of 25 wt. % of FS-Clay bricks with few pores present. The sand particles infused into the clay leading to reduction of pores. This explains reason for higher strength in FS-bricks when compared with 0 wt. % GP/FS sample. In the case of 25 wt. % GP addition (Fig. 8c), porosity reduced and there is presence of glass luster as a result of glassy phase formed. The bond between GP and clay particles and the strong glassy

DOI: 10.36547/ams.27.1.622

phase resulted into improved and higher strength in GP-bricks than FS-bricks.

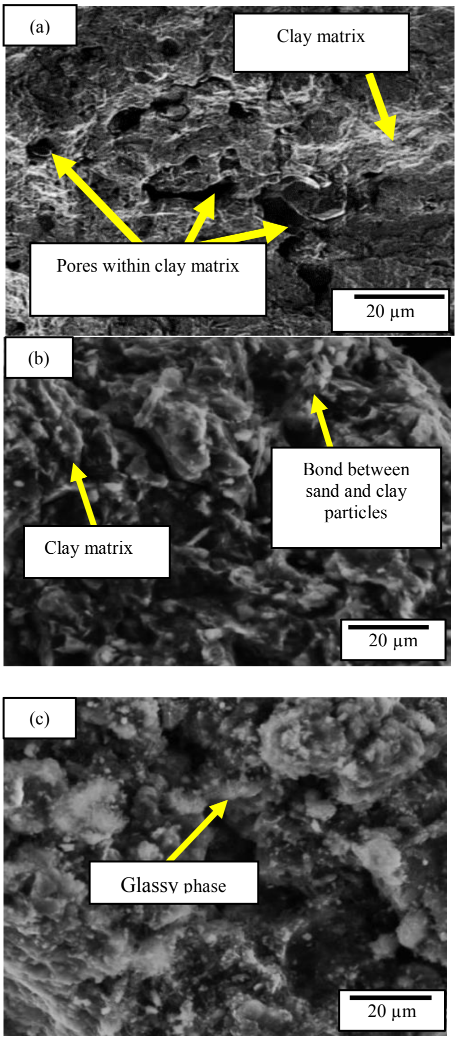

Fig. 8 Showing the SEM images of samples at (a) 0 wt.% FS/GP (b) 25 wt.% FS (c) 25 wt.% GP

CONCLUSIONS

Fine sand and glass powder were added to fired bricks at varied proportion of 5 wt. % to 40 wt. %, and it was concluded that the incorporation of the two additives enhanced the compressive and flexural strengths, and mechanical response to loading. Addition of glass powder up to 30 wt. % gave maximum compressive and flexural strengths; further addition may result in reduction in the strengths. Addition of fine sand sieved to -150 µm at ≥ 15 wt. %, improved mechanical properties of fired bricks at increased proportion. Therefore, addition of glass powder and sand can improve properties of fired bricks for structural application, though glass powder proved to be more effective.

ACKNOWLEDGMENTS

Authors are grateful for the support from Landmark University Centre for Research, Innovation and Discoveries (LUCRID) through Industry, Innovation and Infrastructures, SDGs 9 Group.

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