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INVESTIGATION OF WASTES PLASTIC AND GLASS TO ENHANCE PHYSICAL - MECHANICAL PROPERTIES OF FIRED CLAY BRICK

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Abstract

Around the world, large amounts of plastic and glass waste have been collected. This work is given as a way to reduce this material. This paper aims to investigate how fired clay bricks' physical and mechanical properties are affected by plastic/glass (P/G) powder. It is used as a replacement for clay, varying the plastic/glass content 00/20, 05/15, 10/10, 15/05, and 20/00 weight %. The ratio of soil to water remains constant 0.3. The maximum temperature is presented after three fire phases. The temperatures are 300 °C for the first, 600 °C for the second, and 900 °C for the third. Results for the physical properties showed an increase in the water absorption of clay brick specimens as the plastic content increased; in addition, efflorescence was increased with plastic powder. However, the density and firing shrinkage decrease with plastic quantity. Also, the experimental results showed a decrease in water absorption and efflorescence when the glass powder was increased. While the density is higher when glass powder is 20 %. According to the findings on mechanical properties, clay brick samples with higher plastic powder content 20 % displayed a decrease in compressive strength and flexural bending strength, i. e. the mechanical properties (compressive and flexural strengths) are increased with the increased glass powder.

Keywords:

Plastic powder;
Glass powder;
Clay;
Efflorescence;
Compressive strength.

1 Introduction

The increasing levels of chemical pollutants such as carbon dioxide CO_2 and carbon monoxide CO and the increase in the Earth's temperature have become the first worldwide goal for controlling climate change. A protocol to control greenhouse gas emissions has been proposed by some countries. For the period from 2008 to 2012, the 15 member states that made up the European Community in 1997 have a shared reduction target of 8 % in CO_2 emissions compared to 1990 [1]. The bricks must be fired during the production process to achieve strength, and this process uses 24 million tons of coal annually, one of the most polluting resources on earth [2]. Since the bricks are fired at temperatures between 1000 °C and 1400 °C, more fuel must be burned to reach the necessary temperature [3]. Additionally, fired clay bricks have been a common building material since ancient time and can now be found in many historic structures in various stages of deterioration. Nowadays, bricks are still being used for the same purpose [4]. Unfortunately, modern construction requires higher-quality fired brick. Due to the ceramic bond formed during the fusion phase of the silica and alumina components in clay, bricks have been engineered to become stronger, more porous, and more homogeneous [5]. Because of the high bond strength and durability of clay particles produced by the firing process of a wet clay brick [6], silicon dioxide SiO_2 is an important element of clay; it melts due to the high temperature applied during clay brick firing. After cooling, the silicon dioxide produces a strong bond between the clay particles. Using straw fibers, a few study examined into the compressive strength of unfired clay brick units [7]. There is also a study on the effects of limestone powder on the physical-mechanical properties of fired clay bricks [8]. Nowadays, there are numerous industrial wastes such as plastic, glass, and fly ash. To reduce environmental pollution by recycling waste, which benefits both the environment and the economy. The authors of the literature review put out the theory that glass wastes might be employed as a potential fluxing agent to lower the clay bodies' temperature fire. The recycling of used glasses could then be an additional strategy for cutting production costs and energy consumption [9]. In addition, the findings have been reported in higher density, decreased water absorption, and lower drying shrinkage when glass wastes are used in mixtures of specimens [9]. The investigation of the influence of waste glass and plastic on the physical and mechanical properties of fired clay bricks is of particular interest in this study.

Population growth has led to an increase in both the need for and demand for plastic materials. Additionally, in 2010, 192 coastal countries produced an estimated 275 million tons of plastic waste [10]. The environment has been severely harmed by the 12.7 million tons of plastic waste that have been poured into the ocean. For example, in South Africa, of the 59 million tons of general trash produced, 80 % was dumped in landfills, only 12 % was recycled, and the remaining 8 % was left as beach debris [11].

In this study, clay soil mixing was replaced with various percentages of plastic/glass P/G (00/20, 05/15, 10/10, and 20/00 %) that were moistened with water. The samples of clay brick units were aged for 30 days at room temperature. After preparing samples for one day, the molds were taken out. The temperatures used to fire each specimen were 300, 600, and 900 °C. Between 300 and 600 °C are used for preheating, 900 °C is used for firing, and 0 °C is used for cooling.

There are four parts to this work. The first part is the introduction.

The second part contains the tools and methods used in the experimental study to examine unfired and fired specimens. The third one summarizes the findings and goes through different observations and comments that support the conclusions. The work's conclusions are presented in the final part.

2 Materials and methods

2.1 Dry clay soil

Approximately 1.5 meters in depth of dry clay soil from Maysan city in southern Iraq was used in this investigation (Ebttirah region). Fig. 1 shows how soil samples were collected, ground into fine granules, and sieved via a 2.36 mm sieve.

Fig. 1: Dry clay soil sample.

2.2 Plastic waste

Everybody in the world currently uses plastic, which is a highly common substance. These days, plastic is the material of choice for reusable items because it is lightweight and flexible. Covers, bottles, and food packaging are frequently made of plastic. The main issue with plastic is that it breaks down. Polymer compounds, which are used to make plastic, are not biodegradable. This means that when plastic is embedded in the ground, it won't decompose. After use, this material degrades and pollutes the air and land. The authors present plastic powder as a substitute for clay soil in order to investigate the effect on the physical and mechanical properties of fired clay bricks. See Fig. 2.

Fig. 2: Plastic powder (PS) sample.

2.3 Glass powder

Glass waste is produced in large quantities each year but is frequently dumped in landfills. Despite the fact that recycling waste glass for the manufacturing of new glass goods has many benefits for the preservation of natural raw materials, a substantial amount of waste glass cannot be recycled and is instead deposited into open landfills due to impurities and the related recycling costs [12]. According to reports, the European Union (EU) produces about 0.9 million tons of waste glass annually [13]. Glass waste is one material that is used in the production of ceramic products. It was discovered that adding 10 % waste glass to ceramic products improved their apparent density, apparent porosity, water absorption, and loss to fire [14]. In this study, glass powder is replaced with clay soil to investigate the effect on the physical and mechanical properties of fired clay bricks. See Fig. 3.

Fig. 3: Glass powder sample.

2.4 Water

Tap water was used in the mixing and absorption of the clay brick units.

2.5 Mixing and fabrication of bricks

Five different mixtures were produced for the lab experiments. The characteristics of mixes are shown in Table 1. To compare the effects of five different Plastic/Glass (P/G) percentages 00/20, 05/15, 10/10, 15/05, and 20/00 %, the water to soil (W/S) ratio in the mixes was held constant 0.3. In a steel pan of the mixer, the dry soil and *P/G* content were mixed for two to three minutes. To produce more homogeneous mixtures, water was added to the mixes as the mixer was running. Then, the mixes were put into a steel mold that had the following dimensions: 3*4*8.5 cm. Steel molds were lubricated to prevent clay from sticking to the walls of the molds.

The mixture proportions listed in Table 1 were used to fill the steel mold. Ten clay brick samples of each P/G percentage were constructed for physical and mechanical tests. Fig. 4 demonstrates that clay brick samples were created for all mixtures. The specimen was 4 cm thick before the pressure load. All samples had a thickness of 3 cm after being subjected to a 15 MPa compressive stress in a steel mold for one minute.

Then, the clay brick specimens were removed from the mold. The clay brick displayed no evidence of deterioration throughout the demolding procedure. All clay brick units underwent a 24-hour curing process at room temperature. Clay brick samples were then allowed to air dry for 30 days at 30 - 37 °C.

All of the samples were then fired three phases of temperature 300, 600, and 900 °C in a furnace with a maximum temperature of 1200 °C. The phases are made up of three durations: the first preheats for 65 minutes between 300 and 600 °C, the second fires for 30 minutes at 900 °C, and the third cools for 60 minutes. The creation of the burned clay specimens was done in accordance with ASTM C67-03 [15] standards, see Fig. 5

Table 1: Mixtures proportions for all P/G percentages as replacement clay.

ID Specimens	W/S	P/G [%]	P/G [kg/m^3]	Soil [kg/m^3]
P/G 00/20 %	0.3	00/20	0/520	2080
P/G 05/15 %	0.3	05/15	130/390	2080
P/G 10/10 %	0.3	10/10	260/260	2080
P/G 15/05 %	0.3	15/05	390/130	2080
P/G 20/00 %	0.3	20/00	520/00	2080

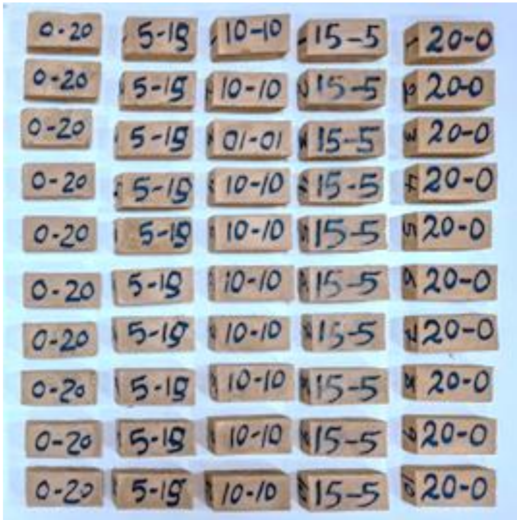

Fig. 4: Clay brick specimens for all percentages P/G, 00/20, 05/15, 10/10, 15/05 and 20/00 %.

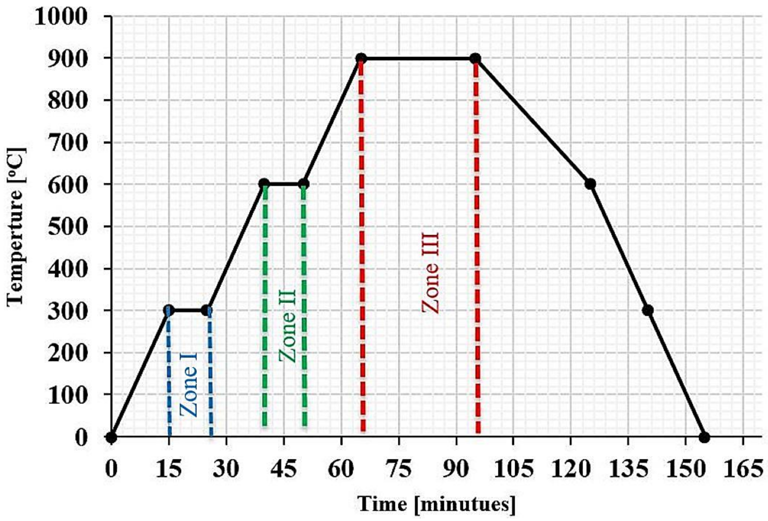

Fig. 5: Variations in temperature and time while clay brick samples are being fired.

3 Results and discussion

Experimental results show that the presence of Plastic/Glass has a considerable impact on the physical and mechanical characteristics of fired clay bricks, especially their absorption, efflorescence, density, firing shrinkage, compressive and flexural strengths. The specific attributes are covered in detail below.

3.1 Water absorption

Clay bricks' ability to absorb water is a key determinant of their durability. According to Demir, when leakage occurs in a brick, its durability is reduced [16]. A fired clay brick's interior structure must therefore be sufficiently dense to prevent water penetration. High temperatures and high glass powder percentages were used to produce high density clay bricks and reduce water absorption; such as, the water absorption of clay brick samples with a P/G of 05/15 % was reported at 9%, and this value was increased by 17 % for samples with a P/G of 20/00 %.

The apparent porosity is inversely correlated with water absorption. Similar findings in water absorption and apparent porosity were reported by Eliche-Quesada et al. [17].

The crystal structure of the brick will change during the fire process, and clay particles typically pack more firmly, increasing the density of the brick. Three levels of fire temperature are shown in this work: the first is 300 °C for 10 minutes, the second is 600 °C for 10 minutes, and the third is 900 °C for 30 minutes. When the waste glass samples were exposed to high temperatures, the glass particles melted, which contributed to an increase in the density of clay bricks. As for the increase in plastic waste, the authors have noticed an increase in water absorption. The implication of this during firing is that most of the plastic melts at a high temperature, which creates voids inside the brick structures. During the absorption test, the void must be left behind after cooling and filled with water. The maximum values for clay bricks' water absorption percentage in accordance with Iraqi Standards (IQS 25-1988) are shown in Table 2 [18].

The absorption-Plastic/Glass relation is depicted in Fig. 6. The lowest water absorption rate was found in clay brick samples that included no plastic at all 18.8 %, indicating Type A. In contrast, clay bricks containing 20 % plastic absorbed water at a rate of 22.19 %, indicating Type B.

In general, it was found that the amount of plastic in the clay brick samples caused an increase in water absorption. To put it another way, as more glass powder is produced, it absorbs less water, as shown in Fig. 6.

Table 2: Maximum clay brick water absorption limits in accordance with Iraqi Standards, IQS 25-1988.

Clay brick class	**Maximum limits of water absorption [%]**	
	One unit	**Average of 10 units**
A	22	20
B	26	24
C	28	26

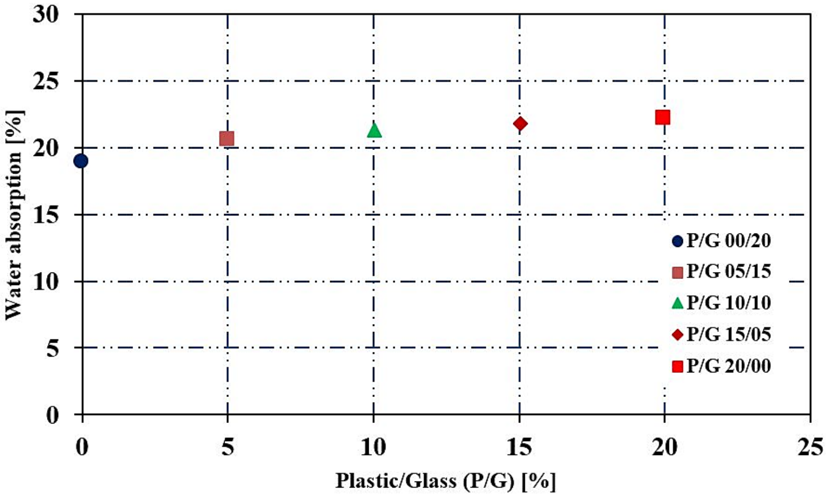

Fig. 6: Water absorption-Plastic/Glass relationship.

3.2 Efflorescence of clay brick

Salt efflorescence, a common surface problem on clay brick, mortar, and concrete facades, is the formation of salt crystals on a surface brought on by the evaporation of water from the slats. It usually entails white salt deposits that are water soluble, like sodium chloride or alkali sulfates that typically appear soon after the facade is built.

The percentage of an area that was affected by efflorescence for clay brick specimens that included plastic powder. It was found that adding plastic powder caused an increase in efflorescence. For example, only 9.6 % of the surface area of bricks containing 5 % of plastic powder exhibited efflorescence, compared to 4.1 % for the control bricks devoid of plastic powder. The efflorescence was then 36 % for the specimens containing plastic powder with 20 %. While this relationship is contrary, i.e., the efflorescence area decreased with the incorporation of glass powder. This test complies with ASTM C67-03 [15] standards, see Fig. 7. Glass powder melts at 900 °C, filling the pores and reducing water absorption. It has an impact on the porosity of the materials. On the other hand, when porosity grew, water was absorbed more readily, resulting in more efflorescence. Vračević, Martina, et al. noticed an increase in the amount of free calcium oxide CaO associated with efflorescence [19]. A previous study showed the calcium oxide value of glass materials is less than that of clay [20]. As a result, when a portion of the clay was replaced with glass powder, the CaO value decreased, which lowered efflorescence.

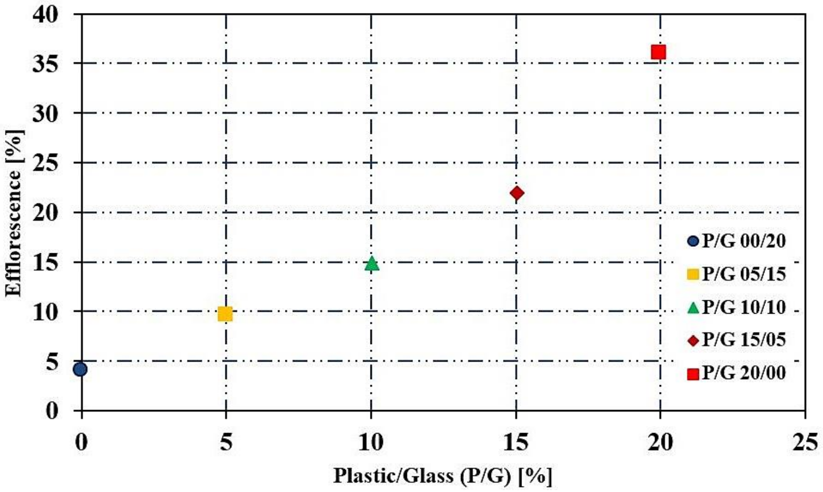

Fig. 7: Efflorescence- Plastic/Glass relationship.

3.3 Clay brick density

The relation between clay brick samples densities and Plastic/Glass percentages is depicted in Fig. 8. By dividing a specimen's mass by its calculated volume, the density of the sample was computed. The density of clay brick is influenced by the raw material's specific gravity, the manufacturing method, and the degree of fire. The density decreased with increasing plastic powder content, according to the experimental results. A 05/15% P/G replacement for the clay, for example, resulted in 3.4 % lighter specimens than a 00/20 % P/G replacement. On the other hand, it can be seen that the densities are decreased by 3.4 %, 7.2 %, 14.7 %, and 21.5 %, with the values of P/G being 05/15 %, 10/10 %, 15/05 %, and 20/00 %, respectively. At 800 °C or higher, the glass powder melts and fills the pores in the clay structure, resulting in a higher density of bricks, i.e., specimens with 20 % glass powder produce fewer voids in the specimen, influencing its weight. In a literature review, it was observed that waste glass powder added to clay creates bricks with a higher bulk density [21].

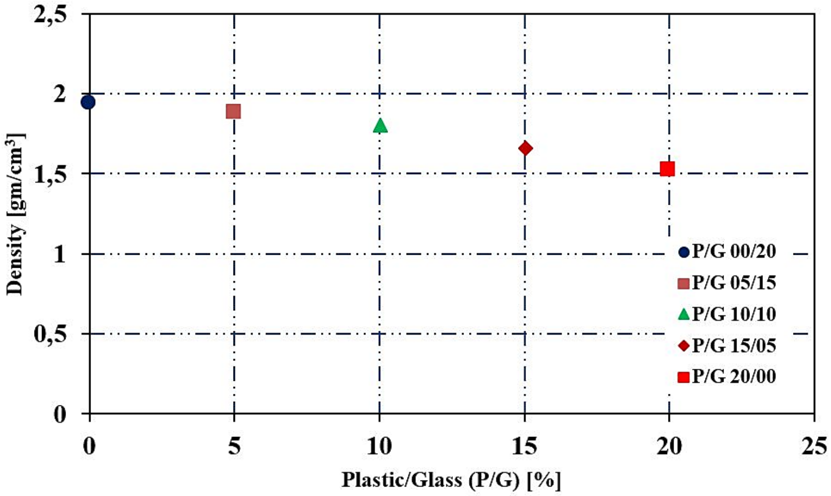

Fig. 8: Density- Plastic/Glass relationship.

3.4 Firing shrinkage

According to ASTM C326-03 [22], linear shrinkage was calculated by measuring the volume of the brick sample before and after burning throughout the entire process. A contributing component in fire shrinkage is the loss of water between clay particles, which results in a tighter packing of clay particles and subsequent shrinkage. The percentage firing shrinkage is computed using the following formula:

$$\textit{Firing shrinkage}\ [\%] = \frac{Vd - Vf}{Vd} \times 100, \tag{1}$$

where Vd is volume of the air-dried sample, Vf is volume of the fired sample. All dimensions in millimetres.

The five groups of samples that were assessed in this experiment are depicted in Fig. 9 as they shrink following burning. The mean of the shrinkage values of 3 samples is represented by each point on the graph, along with the variation range.

The results did, however, show a consistent decline in firing intensity. The findings unmistakably demonstrated that the firing shrinkage ranged between 1.99 and 9.67 % for P/G contents of 00/20 and 20/00 %, respectively. On the other hand, the shrinkage was decreased when the glass powder content was increased. This result is accepted by some authors [9]. While the firing shrinkage was increased with the plastic powder. The shrinkage results presented were good (less than 8 %) for the P/G quantities of 00/20, 05/15, and 10/10 %. Previous research found that fired clay specimens with a high amount of glass powder had lower water absorption and higher density, implying less firing shrinkage.

In addition, as the proportion of plastic powder in clay brick specimens increased, shrinkage was seen to increase. This indicates that the waste materials in the clay bricks responded to the firing by melting and expanding the holes in the clay components as the moisture evaporates, raising the likelihood that the particles would fuse together. Finally, the size of the finished bricks after fire is impacted by this activity.

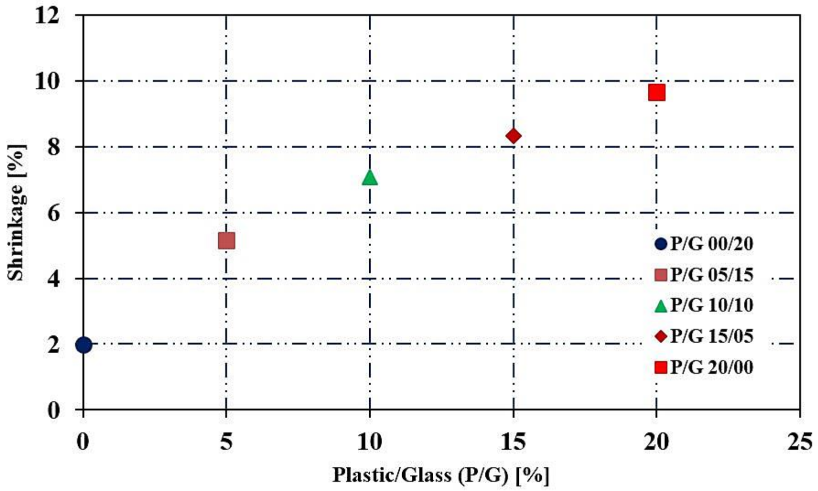

Fig. 9: Shrinkage- Plastic/Glass relationship.

3.5 Compressive strength

When bricks are used to build various constructions, they mainly experience compression. According to ASTM C67-03 [15] standards, Fig. 10 shows the compressive test set-up. Fig. 11 illustrates the results of the compressive strength values determined from the test samples. The clay bricks containing plastic powder P/G demonstrated poorer compressive strength values in the range of 7.04 to 0.961 MPa, compared to the specimens without plastic powder (P/G equals 00/20 %) that obtained a compressive strength of 10.09 MPa. On the other hand, as shown in Fig. 10, the compressive strength increases as the glass powder replacement level for clay increases. The average compressive strength values are inversely correlated to the amount of plastic and directly proportional to the amount of glass powder, meaning that the compressive strength is significantly raised with glass powder and lowered with plastic. The samples with the 05/15 % P/G have a 30 % loss in strength; additionally, the dropping is 90 % for the clay brick with the 20/00 % P/G. Chidiac and Federico [23] discovered similar increases in compressive strength with waste glass addition. In general, the overall porosity and the distribution of pore sizes are significant factors for compressive strength [24]. By adding glass powder to fired clay bricks, interior pores can be filled with a glassy phase, increasing strength.

Fig. 10: Set-up of compressive test.

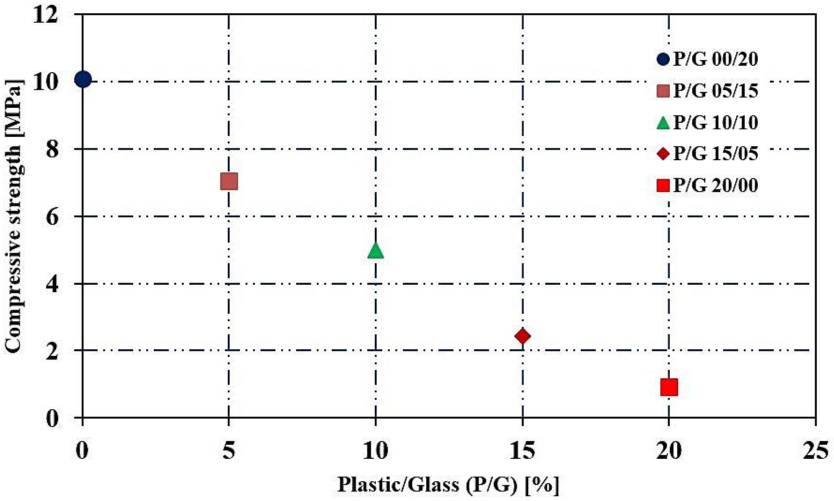

Fig. 11: Compressive strength- Plastic/Glass relationship.

3.6 Flexural strength

This test was conducted in accordance with ASTM C67-03 [25], Fig. 12 refers to set-up of flexural test for the brick specimen and as can be shown in Fig. 13 for the experimental results of flexural strength for all amounts of plastic/glass powder P/G. Each flexural strength result presented in figure 10 is the average value determined from three comparable brick specimens. Flexural strength was found to be higher when the plastic quantity was zero, i.e., P/G was 00/20. While the clay brick specimens showed a minimum flexural strength value with higher plastic content, i.e., P/G is 20/00 %. Flexural strength continuously decreases as the quantity of plastic powder increases. P/G is 05/15 % for samples with 5 % plastic powder, which results in a 34 % decrease, while P/G is 20/00 % for specimens with 20 % plastic powder, which results in a 95 % decrease.

In general, the experimental results showed that the flexural strength increased as the quantity of glass powder in brick units increased, whereas the flexural strength reduced in specimens with plastic powder. For a 15 % substitution of recycled glass powder for clay, Loryuenyong et al. [25] also saw a 50 % rise in the bricks' rupture modulus. Flexural strength is greatly affected by the voids in fired clay bricks [14]. The flexural strength of brick specimens will increase as the number of voids decreases. Bricks with glass powder added had less porosity, which improved their flexural strength.

Fig. 12: Set-up of flexural test.

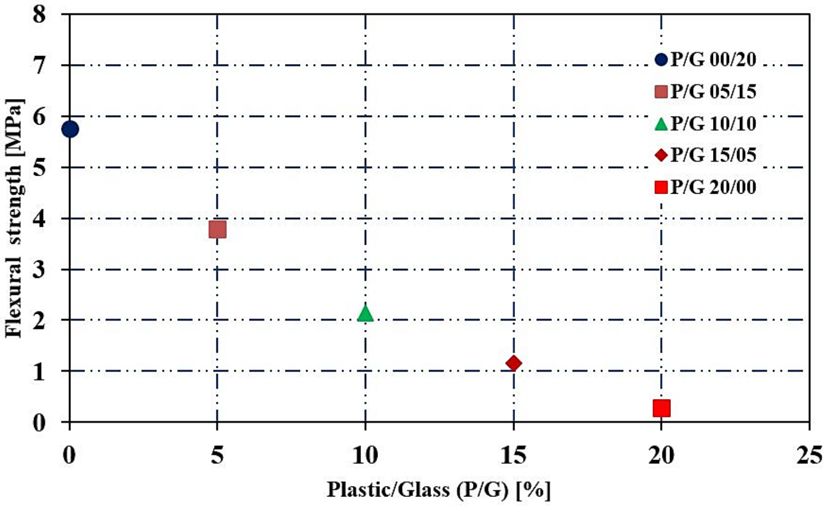

Fig. 13: Flexural Strength- Plastic/Glass relationship.

The following equation represents the flexural strength or modulus of rapture for clay brick specimens. Fig. 14 displays a sample of a clay brick.

$$\text{Flexural strength (modulus of rupture)} = \frac{3F \cdot L}{2b \cdot d^2}, \tag{2}$$

where *F* - failure load in [N], *L* - distance between supports, *B* - width of sample, *D* - thickness of sample. All dimensions in millimetres.

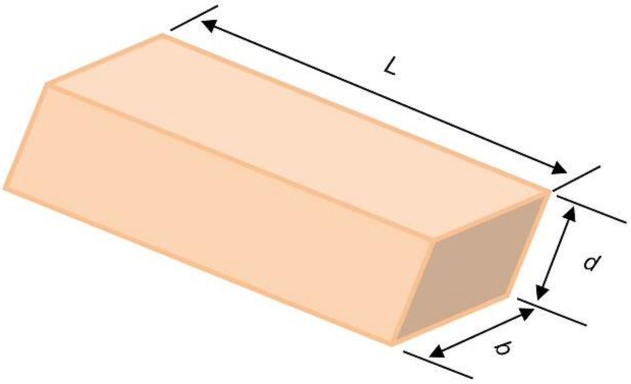

Fig. 14: Clay brick sample.

4 Conclusions

The following were emphasized by the experimental findings on burnt clay brick materials using clay raw materials instead of Plastic/Glass powder P/G:

1) By substituting a sufficient quantity of glass powder for clay when making fired clay bricks, the water absorption of clay brick samples can be gradually improved. Water absorption is reduced by 16 - 9 % when glass powder is used to partially replace clay in the range of 5 - 15 % by weight of clay and increased by 9 - 17 % with increased use of plastic powder in 5 - 20 % clay brick samples.

2) The addition of plastic powder as a replacement for clay resulted in an increase in the efflorescence of clay brick units, i.e., because plastic powder is in the range of 0 - 20 % by weight of clay, the efflorescence value increased from 4.1 to 36 %. However, as the amount of glass powder increases, the efflorescence decreases.

3) The density of fired clay brick specimens was observed to be improved with the addition of glass powder. A glass powder with a density ranging from 1.654 to 1.939 g/cm3 has a range of 5 to 20 %. While the results showed an opposing relationship with the plastic powder.

4) When clay brick samples contain 20 % plastic powder, firing shrinkage is higher, while it is lower when the plastic powder content is 0 %.

5) The compressive strength of clay brick units containing plastic powder 20 % was lower than that of samples containing plastic powder 0 %, i.e., 0.916 MPa for clay bricks containing plastic powder 20 % and 10.09 MPa for samples containing plastic powder 0 %. While the results show an increase in compressive strength with the inclusion of glass powder.

6) Incorporation of plastic powder in flexural strength, reduced the flexural strength of clay brick units with plastic powder, and the highest reduction up to 95 % was found to be in clay brick samples with a 20 % plastic powder replacement percentage. But there are increased values of flexural strength with the glass powder.

7) Clay brick specimens can be used to construct exterior and interior walls, partitions, piers, footings, and other load-bearing structures by replacing the soil with plastic/glass.

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