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Properties of Fired Clay Bricks Mixed with Waste Glass

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This study is to investigate the effect of adding waste glass on the properties of fired clay bricks. Two different particle sizes (smaller than 150 μm and 600 μm) of waste glass are added to clay mixes at contents of 0, 10, 20, 30 and 40% per weight. Brick samples are fired at 900, 1000 and 1100℃ in an electrical furnace for 6 hours, at a heating rate of 5℃/min. The physical and mechanical properties of fired clay bricks are studied. The firing shrinkage, bulk density and compressive strength of the bricks increase as the amount of waste glass content increases and as firing temperature increases. The apparent porosity and water absorption decrease with the increase of the amount of waste glass and firing temperature. The particle size of waste glass powder was very important and had a significant effect on the properties of fired clay bricks; the finer the particle size, the higher the compressive strength. Based on the executed testing program, it is found that the optimal properties of fired bricks are achieved at 30% content of waste glass and a firing temperature of 1100℃. The results also prove that it is possible to make bricks with compressive strength in excess of 95 MPa and water absorption not more than 6%.

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Keywords: Fired clay bricks; waste glass; recycling; firing temperature; physical and mechanical properties.

1. INTRODUCTION

Worldwide, bricks are a major building material and perhaps one of the oldest. The worldwide annual production of bricks is currently about 1391 billion units and the demand for bricks is predicted to be continuously increasing [1]. Clay materials are mostly used for the manufacture of bricks. Waste can be added in order to enhance its properties. Solid waste is of a great concern among governmental agencies, and environmentalist regarding the increasing amounts of waste throughout the world.

One waste material which has a potential as a brick additive is waste glass. It is not biodegradable and therefore it creates a problem for solid waste disposal. The disposal into landfills also does not provide an environment-friendly solution. Hence, the use of waste glass as a construction material is a practical solution to the environmental problems caused by this solid waste.

The United Nations estimates the quantities of solid waste disposed of annually over the world as 200 million tons, 7% of which is made up of glass [2]. In Palestine, this amount approaches 1.2 million tons [3], 4% of which is made up of glass with no recycling activities existing [4].

Recently, many researchers around the world have studied the use of waste glass as an additive in fired clay bricks, tile and stoneware to enhance its properties. Most of their studies focused on using from 5% to 20% of waste glass by weight, and the glass particle sizes ranging from 45 to 600 µm. In all reported test results, shrinkage was found to be increased as waste glass content is increased, as well as with increasing firing temperature [5,6,7,8, 9,10,11, 12,13,14,15,16,17]. Hwang et al. (2006) also indicated that the finer glass (5 µm) exhibited twice the shrinkage of the coarse glass (150 µm) in compositions [10].

In the previous studies, the trend for all results clearly indicates an increase in compressive strength with increasing waste glass contents, especially between 10% and 30% mass [6,8,9,11,15,16,17,18,19,20]. Fired clay bricks with suitable mechanical properties can be obtained at a proper firing temperature by using waste glass content ranging from 15 to 30% by weight of clay [16]. Moreover, (Phonphuak et al., 2015) stated that the use of 10% of waste glass and firing at 900ºC yielded bricks with strengths similar to those of normal clay brick fired at 1000℃ [17]. In other research, Chidiac and Federico [9] indicated that the strength and transport properties of clay bricks were found to improve as a result of the improvement of pore structure when 15% (by weight of clay) of both fine and coarse waste glass was added. Leshina and Pavnev (2002) concluded that the optimum content of glass in a ceramic mixture is from 15–20% [20].

Firing shrinkage, mechanical properties, water absorption (WA) and apparent porosity (AP) properties of fired clay bricks containing waste glass were determined in previous studies. In all reported test results, both WA and AP were found to decrease as glass content is increased, as well as with increased firing temperature [7,10-17,19-22]. Loryuenyong et al. also indicated that water absorption as low as (2-3) % was achieved for bricks containing (15–30) % by weight of glass content and fired at 1100℃. When the glass waste content was 45% by weight, apparent porosity and water absorption was rapidly increased. A preliminary experiment carried out by the same author showed that for smaller particle size of glass, this problem can be avoided [16]. Youssef et al. (1998) recommended the addition of glass at 33.3% by weight and firing at 1100℃ to get 5.6% water absorption for non-glazed floor tiles [19]. But Luz and Ribeiro [13] who used glass particles size less than 40 µm, reached the water absorption values close to 0.0% by using 20% waste glass content and a firing temperature of 1150℃.

The objective of the present work is to focus on enhancing fired clay bricks and to investigate the effect of the addition of waste glass with different amounts (0, 10, 20, 30 and 40%) to the original brick clay on the properties of the fired clay bricks. Firing shrinkage, bulk density, apparent porosity, water absorption, compressive strength, and the effect of waste glass particle size on the properties of the fired body are studied.

The successful use of waste glass will aid in reducing the environmental and health problems related to the disposal of waste glass and the scarcity of land area needed for disposal. Reducing waste is not the only reason to investigate the addition of certain residues into a clay matrix, although traditionally it has been the main purpose of research on this topic. Other reasons may be considered, such as saving energy required in the manufacturing process and reducing the manufacturing cost.

2. MATERIALS AND METHODS

2.1 Raw Materials

All materials used in this study are locally available. Clay is to be used in this investigation with (0%, 10%, 20%, 30%, and 40%) of waste glass powder as a partial replacement for clay. The raw materials were prepared through drying, milling and sieving. Waste glass is prepared in the laboratory to particle sizes smaller than 600 μm. Another particle size (150 μm) of waste glass was prepared to compare with 600 μm (Fig. 1). The particle size distribution test was carried out for both clay and waste glass by using sieve analysis and the hydrometer method. The results of the particle size analysis are shown in Fig. 2.

Fig. 1. Two different waste glass particle sizes (150 μm and 600 μm)

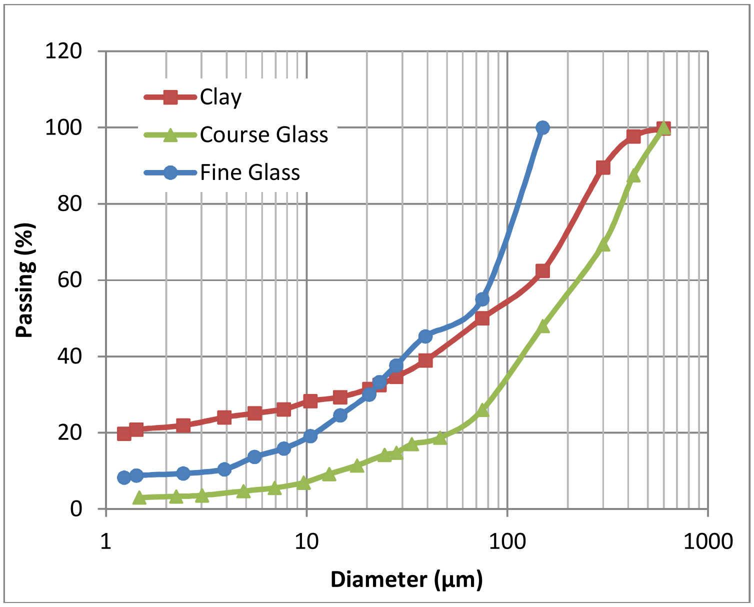

Fig. 2. Particle size distribution curve of the clay and waste glass powder

2.2 Experimental Procedures

In order to obtain comparable results, 19 different groups of samples were prepared depending on the amounts of waste glass added, heating temperature and particles size of waste glass. The mix proportions were prepared based on the dry weights of the materials. Mixture proportions were shown in Table 1. The methodology of manufacturing porous clay bricks was shown in Fig. 3.

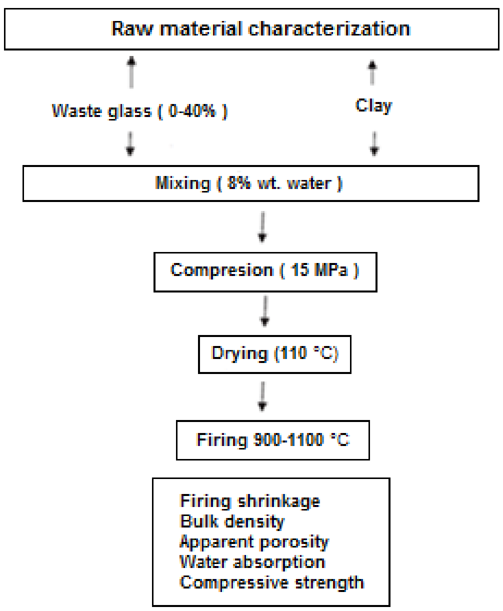

Fig. 3. Methodology for manufacturing clay bricks

Solid brick clay samples were produced using pilot laboratory procedures and equipment. The raw materials were mechanically mixed for 5 minutes for uniform consistency. After dry mixing, water of about 8% of total weight was sprayed on the dry mixtures for the production of semi-dry molded brick samples. Test specimens with a dimension 215mm (L)×102.5 mm (W)×65 mm(H) were prepared in laboratory type moulds. A hydraulic press was used to make the bricks by compressed it to a pressure of 15 MPa. The shaped samples were then cured under laboratory conditions (21℃) for 24 hours. Samples were then dried in an oven and maintained at 45℃ for 6 hours and then at 110℃ for 24 hours. The dried samples were fired at 900, 1000 and 1100℃ in an electrical furnace at a heating rate of 2.5℃/min until 650℃, and then 5℃/min until 900℃, 1000℃ and 1100℃. The time taken to reach the required temperature was about 5 to 6 hours and the specimens were kept at this temperature for 1 hour to achieve better strength. The samples were naturally cooled down in the furnace. There were 19 groups of samples and with 3 samples for compressive strength test and other 3 samples for the rest of tests, this leads to 19 × 3 × 2 = 114 brick samples. These brick samples were prepared for testing purposes (Fig. 4).

2.3 Testing Method for the Physical and Mechanical Properties

The brick samples were tested for water absorption, bulk density, apparent porosity, firing shrinkage and compressive strength, to determine their quality. Linear shrinkage was

Table 1. The brick mixtures prepared from the raw materials

Firing temperature (℃)	Group name	Clay (wt.%)	Waste Glass (wt.%)
900	A1	100	0
	B1	90	10
	C1	80	20
	D1	70	30
	E1	60	40
1000	A2	100	0
	B2	90	10 (Coarse and fine glass)
	C2	80	20 (Coarse and fine glass)
	D2	70	30 (Coarse and fine glass)
	E2	60	40 (Coarse and fine glass)
1100	A3	100	0
	B3	90	10
	C3	80	20
	D3	70	30
	E3	60	40

obtained according to the standard ASTM C326 [23]. The bulk density, Water absorption, and apparent porosity were measured according to Archimedes method described in standard ASTM C373 [24]. The compressive strength was measured for brick samples according to ASTM C67 [25].

3. TEST RESULTS AND DISCUSSION

At least 3 samples were used for each test for all of the groups listed previously in Table 1 and the mean values are presented and discussed in this section. The investigated physical and mechanical properties are bulk density, apparent porosity, water absorption, firing shrinkage and compressive strength are shown in the Table 2.

3.1 Firing Shrinkage

Generally, bricks must have a firing linear shrinkage lower than 8% in order to retain good mechanical performance [22]. As shown in Table 2, the firing shrinkage increases with increasing firing temperature and also increases with increasing the amount of waste glass. Small amount of waste glass additives causes positive shrinkage, representing water evaporating

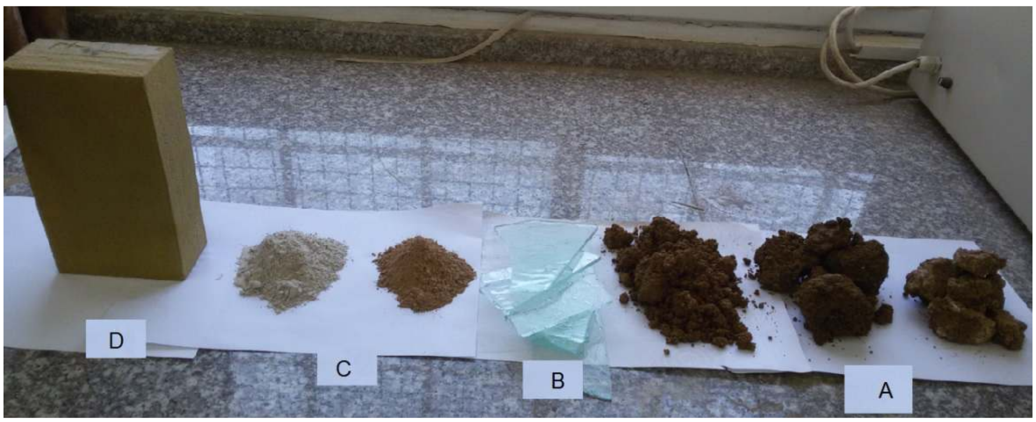

Fig. 4. A) Clay, B) Waste glass, C) Clay and Waste glass powdered, D) Fired clay brick

Table 2. Mean values of the physical and mechanical properties of the samples for coarse glass (600 µm glass)

Properties name	Firing temperature (℃)	Waste glass %				
		0%	10%	20%	30%	40%
Firing shrinkage (%)	900℃	0.51	0.69	0.71	0.78	0.81
	1000℃	0.64	0.84	1.01	1.32	1.67
	1100℃	1.03	2.88	4.55	6.19	-5.20
Bulk density (g/cm3)	900℃	1.80	1.81	1.81	1.82	1.82
	1000℃	1.81	1.84	1.85	1.86	1.87
	1100℃	1.89	1.94	1.96	1.97	1.64
Water absorption (%)	900℃	16.24	15.38	14.77	13.94	1 3.73
	1000℃	15.63	13.53	12.75	11.44	10.86
	1100℃	13.45	10.29	8.31	5.93	4.83
Apparent porosity (%)	900℃	33.67	30.76	29.41	27.6	2 7.38
	1000℃	31.26	27.39	25.53	22.86	21.70
	1100℃	25.23	19.96	16.29	11.53	7.90
Compressive strength (MPa)	900℃	18.61	22.91	20.41	21.91	17.88
	1000℃	21.33	30.67	32.34	42.75	43.17
	1100℃	28.82	47.45	77.75	96.37	55.98

out of the system then ceramic particles fuse together leading to greater proximity and thus enhancing linear shrinkage. The addition of a large amount of waste glass decreases the firing shrinkage of the bricks. It is observed that large amount of coarse waste glass induces negative shrinkage, i.e. an expansion of the material. This is evident in sample E3 which has 40% by wt. of coarse waste glass and fired at 1100℃ , where the value of shrinkage in this case is equal to -5.20 (Fig. 5). This may be attributed to glassy phase (glass particles were likely to be forced out toward the surfaces of all bricks), where they formed or accumulated into larger particles. This phenomenon is more pronounced whenever the firing temperature increased because of the coarse glass particles will move with difficulty through a few narrow paths toward the surface. This is causing bubbles protruding from the exterior bricks. Some bubbles that are trapped in the specimens cause expansion.

3.2 Bulk Density

The bulk density is related to durability and water absorption of clay bricks. Density of fired clay brick depends on specific gravity of the raw material, method of manufacturing and degree of burning. As shown in Table 2 with increasing temperature, the density of fired clay brick increases, its strength also increases, while its water absorption and apparent porosity decreases. The bulk density of fired clay bricks is directly proportional to the firing temperature and the added amount of waste glass. The result shows that the bulk density of fired clay brick samples with (0%) waste glass and fired at 1000℃ is 1.81 g/cm3 while at 1100℃ is 1.89 g/cm3. The difference between the two values is about 0.08 g/cm3 which corresponds to 4.1%. As the firing temperature increases, the bulk density increases. This is possible due to increased consolidation or vitrification between particles in the body with increasing temperatures. The bulk density of fired clay bricks also increases with an increase in the amount of waste glass. The bulk density of fired clay bricks fired at 900℃ varies from 1.80 g/cm3 to 1.82 g/cm3. The effect is more pronounced for clay bricks fired at 1000℃, which vary from 1.81 g/cm3 to 1.87 g/cm3. Results show an improvement in bulk density that increases with an increasing the amount of waste glass. For a firing temperature of 1100℃, the bulk density of fired clay bricks varies from 1.89 g/cm3 to 1.97 g/cm3, a slight increase is observed, then the bulk density tends to decrease to 1.64 g/cm3 for more than 30% coarse waste glass contents. As a result, it may be concluded that the addition of waste glass at relatively low temperature densifies the mixture. At higher temperatures, bloating presumably decreases the bulk density as the amount of coarse waste glass grows larger.

3.3 Water Absorption and Apparent Porosity

Water absorption is an important factor for the durability of clay bricks. When water infiltrates a brick, it decreases its durability. Thus, the internal structure of the brick must be dense enough to void leaking of water. To increase density and decrease water absorption of clay bricks, the firing temperature must be raised. Table 2 shows that the highest water absorption value is seen in (A1) which has the highest porosity. The lowest water absorption value was obtained for fired clay bricks (E3) which has the lowest porosity. As understood here, there is a close relationship between water absorption and apparent porosity of bricks. The relation has almost a constant slope with a clear trend of

Fig. 5. Negative firing shrinkage fired clay brick with 40% waste glass and firing at 1100℃

much lower water absorption and apparent porosity with increasing percentages of waste glass. For clay brick samples fired at 900℃, the waste glass particles fuse with the clay bodies and this contribute to the densification of the clay brick. Generally, the water absorption values decrease with increasing firing temperature, and also decrease with increasing amounts of waste glass in the mixtures. The water absorption of clay bricks fired at the temperatures between 900 and 1100℃ are in the range of 16.24% to 4.83%. Thus, the samples are found to be within ASTM C62 specifications (17% for Grade SW) [26].

3.4 Compressive Strength

The compressive strength is the most important index for assuring the engineering quality of a building material, because with a higher compressive strength, other properties also improved. The results in Table 2 indicate that the compressive strength of fired clay bricks depends greatly on the amount of waste glass addition as well as firing temperature. The addition of waste glass considerably contribute to consolidation or vitrification and enhance the strength development by closing the internal pores with glassy phase. Table 2 shows three curves fitted for the data of compressive strength. For the samples fired at 900℃, an initial increase in strength as waste glass is added. The value rises from 18.61 MPa to 22.91 MPa as 10% waste glass is added. Table 2 also shows the value of apparent porosity drops to an almost constant value over 20% waste glass addition. This means that the increase in compressive strength at that low firing temperature is mainly due to reduction in porosity. At 1000℃ there is a gradual increase in strength from 21.33 MPa (0% waste glass) to 43.17 MPa (40% waste glass addition) in harmony with the decrease in apparent porosity observed. Although the amount of waste glass addition reaches 40%, there is a tendency for the compressive strength to reach a nearly fixed value. This may be due to the effect of the low strength of the glassy phase formed as its amount increases. This effect is more pronounced for the sample fired at 1100℃ which reaches a peak in compressive strength at 30% of coarse waste glass addition, followed by a serious decrease in the compressive strength. In view of porosity results, it is clear that as the percentage glassy phase largely increases (at 1100℃), the reduction in apparent porosity does not play significant role in sustaining high values of strength. The optimum compressive strength is 96.37 MPa for bricks containing 30.% of glass and fired at 1100ºC. The result show that the bricks were very porous if a significant amount of coarse wasted glasses was added (>30% wt. glass). For the reference brick E3, the bricks were irregular in shape with a thin layer of melted glass coated on the surfaces. This led to decrease in compressive strength but an increase in water absorption. This result agrees with Loryuenyong et al. on firing at 1100℃ of such mixtures [16].

3.5 The Effect of the Glass Particle Size

Table 3 and Fig. 6 show that a progressive increase in the proportion of fines in the sample results in a progressive increase in the compressive strength. The results show that the compressive strength of fired clay brick sample with the addition of waste glass particle sizes smaller than 150 µm (D2) at 1000℃ is 65.81 MPa while for brick (D2) with addition of waste glass particle size smaller than 600 µm is 43.17 MPa. The difference between two values is about 22.64 MPa which corresponds to 52.4% increase. This may be due to the bricks became more homogeneous and forming new multi smooth paths during glassy phase.

Table 3. Compressive strength for bricks at different glass particle size

Waste glass %	Compressive strength (MPa) at 1000℃	
	Coarse glass (600 µm glass)	Fine glass (150 µm glass)
10	30.67	38.11
20	32.34	44.84
30	42.75	53.25
40	43.17	65.81

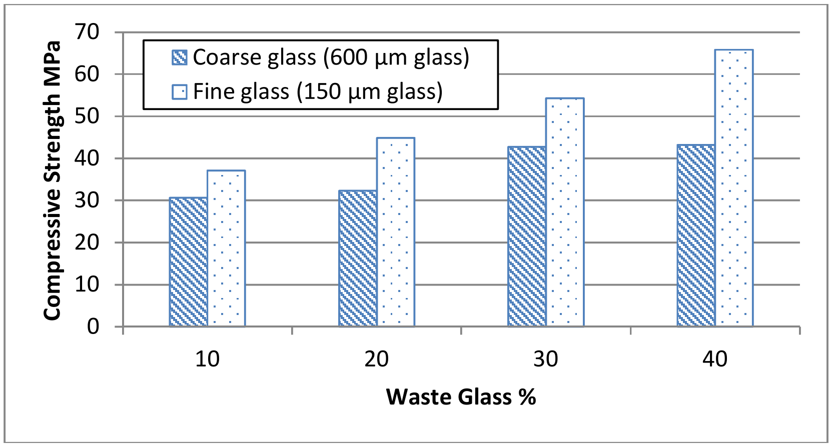

Fig. 6. Compressive strength for bricks at different glass particle size

4. CONCLUSIONS

Brick samples are heated to temperatures which varied between 900 and 1100℃ for 6 hours, with a heating rate of 2.5℃/min until 650℃, and then 5℃/min until 900℃, 1000℃ and 1100℃. The conclusions derived from the aforementioned experiments are as follows.

1. The firing shrinkage, bulk density and compressive strength of the fired clay bricks increased with increasing amount of waste glass content up to 30% and firing temperature up to 1100℃.
2. There was a close relationship between water absorption and apparent porosity of the fired clay bricks and both decreased with increases amount of waste glass content up to 30% and firing temperature up to 1100℃.
3. In this research and for coarse glass only, the optimal amount of waste glass that can be mixed with clay to produce good quality bricks was 30% by weight and the optimal heating temperature for overall properties was 1100℃.
4. The particle size of waste glass powder was very important and had a significant effect on the properties of fired clay brick; the finer was the particle size, the higher was the compressive strength.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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