Effect of Waste Glass on Properties of Burnt Clay Bricks

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Abstract

The amount of waste glass found in solid waste is growing enormously as the modernization is growing. Waste glass deposited in landfills can be used in burnt clay bricks to overcome the problems faced by the brick kilns in Pakistan. In Pakistan, most of the bricks kilns are located near the agricultural areas; therefore, agriculture waste can be used as fuel for burning of bricks. This may result in lower strength of bricks due to lower maximum temperature obtained through agricultural waste. However, brick kilns located near cities use coal as fuel for burning of bricks which extracted from mines located thousands of miles away from brick kiln. This will require considerable transportation cost in order to bring this coal fuel for brick burning process in order to achieve higher temperature and consequently higher strength properties of bricks. In this study, glass waste was mixed with clay mixture in order to achieve higher strength properties of bricks prepared with low energy fuel (i.e. agricultural waste). Different proportions of waste glass from 0 to 20% at various temperatures i.e. 900, 950 and 1000 °C (temperature achieved through electrical oven) were investigated for the manufacturing of waste glass-clay bricks in the laboratory. Furthermore, specimens were also prepared in the industrial brick kilns for comparison purposes with the specimens prepared in the laboratory. Both laboratory and industrial brick kiln specimens were tested for their physical and mechanical properties. Results showed that increasing the waste glass content and burning temperature, the compressive and flexural strengths were increased, while the water absorption and weight per unit area were decreased. This study made an effort to investigate the effect of waste glass material in burnt clay bricks leading towards sustainable construction at low production cost.

Key Words: Waste Glass; Bricks; Sustainable Construction.

1. Introduction

Burnt clay brick is one of the oldest building materials and continues to be a most popular and leading construction material because of being cheap, durable and easy to handle and easily available in most parts of Pakistan. Burnt clay bricks are used for building-up exterior and interior walls, partitions, piers, footings, pavements, factories, bridges and other load bearing structures. Clay is the most important raw material used for making these bricks. It is an earthen mineral mass or fragmentary rock capable of mixing with water and forming a plastic viscous mass which has a property of retaining its shape when molded and dried. When such masses are heated to redness, they acquire hardness and strength. This is a result of micro-structural changes in clay materials through its chemical property.

Brick kiln is the place where bricks are burnt for industrial manufacturing. There are approximately 15000 brick kilns in Pakistan, out of which five thousand exists in Punjab province [1]. A kiln usually runs for three to four cycles per year and in each cycle approximately seven million bricks are produced. In Pakistan, bricks are manufactured in kiln known as Fixed Chimney Bull's Trench Kiln. It is a moving fire kiln where fire moves through bricks stacked in annular space formed between outer and inner walls of the kiln.

Several wastes have been used in burnt clay bricks i.e. fly ash, sandy loam, rice husk ash, basalt stone dust etc [2]. These are used not only to modify the shaping, drying and firing behaviour of clay mass, but also to provide help in conserving agricultural land and utilizing waste materials available in large quantities. These wastes should have a desirable level of physical and chemical characteristics so as to modify the behaviour of clay mass within the optimum range without any adverse effect on the performance and durability. Fly ash when added to clay bricks reduces drying shrinkage and develops strength on firing. Sandy loam is effective in controlling the drying behavior of highly plastic soil mass [2]. Rice husk ash controls excessive shrinkage of soils. Basalt stone dust is mixed with soil to modify shaping, drying and firing behavior of bricks [2].

Recent advancements in living standards and development of technology have brought a significant increase in the consumption of glass material. The resulting increase of waste glass requires solution for recycling to be carried out in an economical and feasible manner [3]. Estimates have been made by United Nations that the yearly volume of solid waste disposed in landfills in world is about 200 million tons, of which waste glass was 7% [4]. Rate of solid waste generation in Pakistan was around 20 million tons per year according to 1998 Census. The population of Pakistan for the year 2014 was projected to be 198 million on basis of annual growth rate which was estimated to be 2.61% and the estimated solid waste in 2014 was projected to be about 25 million tons per year, of which 7% was waste glass (approximately 1.8 million tons per year) [5]. Therefore, in this study, an effective way of utilizing that waste glass in burnt clay bricks was investigated.

2. Research Significance and Objectives

Coal is being used as a fuel to burn clay bricks at high temperatures. A huge quantity of coal is extracted from mines and transported to kilns for burning bricks leading to higher cost. Therefore, an alternative material can be used for burning these bricks. In Pakistan, waste corn cobs, wheat hay, rice husk and other agricultural waste are being used as a fuel in brick kilns at various places of Punjab. However, these waste materials result in lower burning temperature and consequently lower brick strength achieved. Therefore, a solution is required to effectively use these agricultural wastes as a fuel rather than costly coal in order to obtain required strength of bricks which is not being achieved with low energy fuels. Waste glass from landfills can be effectively used in the manufacturing of bricks which can improve the strength and durability properties of bricks even burn at low temperature. The main objective of this research program is to investigate the physical and mechanical performance of burnt clay bricks incorporating different contents of waste glass at various burning temperatures.

3. Brick Manufacturing Process

3.1. Raw Materials

In this research, the manufacturing of bricks was carried out in the actual kiln (Fig. 1), known as bhatta locally (Pak Brick Kiln, Lahore), and in laboratory oven under controlled temperature.

The raw materials used for manufacturing glass-clay bricks were clay and waste glass (Fig. 2). Clay used in this research was taken from the kiln on Multan road, 14 km from Lahore, Pakistan. Waste bottled glass was obtained from the local recycling supplier, which was further crushed to powdered form. The chemical properties of clay and waste glass used are shown in Table 1. Figure 3 shows the sieve analysis results of both the clay and waste glass. Results of sieve analysis show that soil particles are well graded and waste glass particles are finer than clay particles.

Figure 1: Pak Bricks Kiln, Multan Road near Lahore, Pakistan

a. Clay used for brick manufacturing

b. Waste glass used for brick manufacturing

Figure 2: Raw materials used for the manufacturing of bricks

3.2. Mixture Proportions

Specimens were prepared with various dosage of waste glass content from 0 to 20%, with 0% waste glass (WG) specimen as the control specimen. Total 30 brick specimens for each waste glass dosage were casted at the kiln site (Pak Bricks Kiln, located on Multan road). The quantities required for casting these specimens are shown in Table 2.

Table 1: Chemical analysis of clay and waste glass

Constituents	Clay (%)	Glass (%)
Muscovite	51	-
Quartz, SiO_2	33	63
Chlorite	10	-
Calcite, $CaCO_3$	5	-
Lime, CaO	0	13
Soluble Sulfates	0.03	-
Soluble Silica	0	-
Chlorides	0.60	0.61
Alkali, Na_2O	0.10	14
pH-Value	8.8	9.8

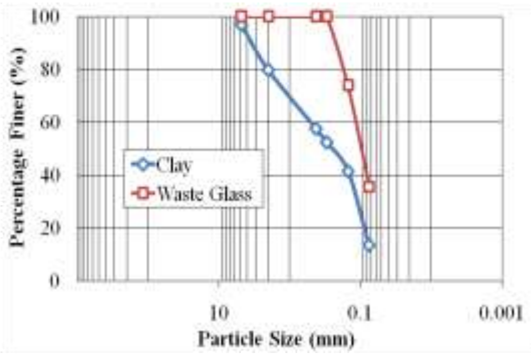

Figure 3: Sieve analysis results of clay and waste glass

3.3. Specimen Preparation

Raw materials were weighed accurately and mixed dry clay with waste glass powder thoroughly (Fig. 4). After manual mixing, water was added till the required workability achieved. It was observed here that upon increasing waste glass content, water requirement for achieving desired workability has reduced because glass has zero water absorption property.

When homogenous mixture was prepared, balls of clay required for one brick casting was prepared which were placed on the area where bricks had to be shaped from the balls. Before pouring the clay ball into brick mold, clay ball was coated with dry sand to avoid sticking of clay to the mold, which may result in early cracks. Then, bricks of size 9×4.5×3 inches were casted. Figure 5 shows the prepared wet bricks.

Table 2: Mixture proportions and quantities used for casting brick specimens

Specimen	C : WG (% : %)	Clay (Kg)	WG (Kg)	Water (liters)
0% WG	100 : 0	105	0.00	30.00
5% WG	95 : 5	99.75	5.25	28.50
10% WG	90 : 10	94.5	10.50	26.25
15%WG	85 : 15	89.25	15.75	25.50
20% WG	80 : 20	84.00	21.00	24.50
WG = Waste glass; C = Clay				

Figure 4: Mixing of waste glass and clay

Figure 5: Freshly prepared bricks

Freshly casted brick specimens were numbered (Fig. 6) according to the glass content in it to avoid mixing of specimens. After casting, the bricks were left to dry for time till they were hard enough to be handled and picked, this time is usually 1 to 2 days, but since the specimens were casted under a rain protection shed, it took 1 week for the bricks to dry enough to be handled and picked for burning process. After enough drying, bricks were transported to two locations: one for

Figure 6: Brick numbering on wet specimen

burning in actual kiln and others for burning in the oven at controlled temperature.

Table 3: Number of specimens burn in kiln and oven

Specimen	Number of specimens	
	Kiln	Oven
0 % WG	10	20
5% WG	10	20
10% WG	10	20
15% WG	10	20
20% WG	10	20

Figure 7: Brick specimens placed in kiln

Total 50 brick specimens were placed in the kiln for 45 days (Fig. 7). Brick specimens were fired in the kiln for 36 hours. Bricks were removed from the kiln after 45 days (Fig. 8). The remaining 100 specimens were placed in laboratory oven (Fig. 9) at different temperatures (i.e. 900, 950 and 1000 ^oC). The oven temperature was gradually increased to desired burning temperature (900, 950 or 1000 ^oC). The oven was set for 0 to 1 hour at 200^oC, 1 to 2 hours at 500 ^oC, 2 to 36 hours at constant desired temperature (900, 950 or 1000 ^oC). Figure 10 shows the brick specimens after burning in an electric oven after 45 days.

4. Experimental Testing Program

The bricks manufactured in the kiln and electric oven were tested according to ASTM C 67 (Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile) [6]. According to ASTM C 67 recommendation, minimum 10 specimens should be tested for each stack having 1000000 bricks.

Figure 8: Brick specimens removed from kiln

Figure 9: Brick specimens placed in electric oven

Figure 10: Brick specimens removed from electric oven after burning process

Before testing, it should be ensured that the prepared brick specimens were free from dirt or any other materials which were not included in their manufacturing. Afterwards, each tested brick specimens were weighted and their mechanical properties including compressive and flexural strengths were determined. Moreover, water absorption and efflorescence tests were performed in order to evaluate its physical properties.

5. Results and Discussion

5.1. Weight per unit Area

Before weighing, brick specimens were dried at 110 °C for 24 hours and cooled at room temperature (25 °C) for approximately 3 to 5 hours. Afterwards, brick specimens were weighed using weighing balance. Results of weight per unit area of tested brick specimens are shown in Fig. 11.

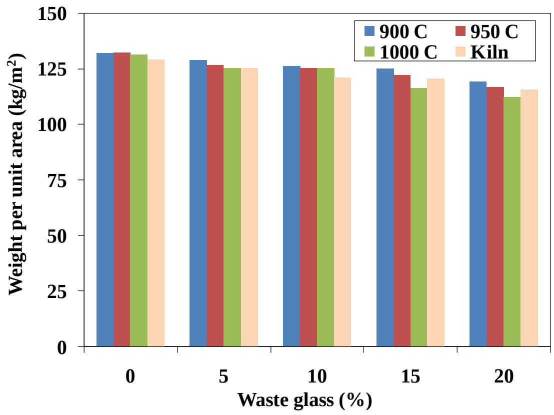

Figure 11: Weight per unit area of brick specimens

It was observed that the weight per unit area of brick samples decreased with increase in waste glass content for both the industrial kiln and laboratory oven burned brick specimens (Fig. 11). For instance, approximately 12% decrease in weight per unit area was observed for bricks specimens incorporating 20% waste glass content at 950 °C compared to that of similar specimen without waste glass addition. This can be attributed to the fact that the unit weight of waste glass powder is considerably lower than the unit weight of clayey soil, which in turn reduces the weight of the burnt brick. Furthermore, as the burning temperature increased, the weight per unit area of the bricks decreased (Fig. 11). This was due to the reduction in moisture content and increase in the glassy phase of brick at higher burning temperature.

5.2. Water Absorption

Brick specimens were submerged in water at room temperature for 24 hours (Fig. 12). Afterwards, specimens were removed and cleaned with damp cloth in order to remove excess water from surface and then weigh them. Water absorption of each specimen can be calculated as follows:

$$\text{Water absorption} = \frac{100(W_s - W_d)}{W_d} \qquad (1)$$

where, W_d and W_s are the dry and saturated weights of the brick specimen, respectively.

Figure 12: Brick specimens during water absorption test

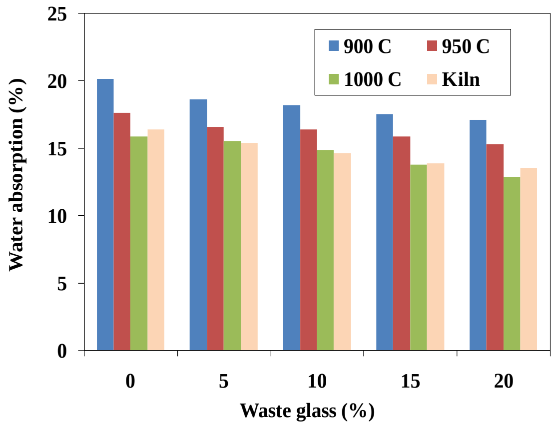

Figure 13: Water absorption results of brick specimens

Figure 13 shows the water absorption results for various waste glass content at different burning temperature and kiln burned specimens. The water absorption capacity of brick specimens decreased with higher content of waste glass for both laboratory burned and industrial kiln burned brick specimens. This was due to zero water absorption capacity of glass material.

Moreover, it was observed that the increase in burning temperature decreased the water absorption capacity (Fig. 13). This was mainly attributed to increased compactness of particles due to vitrification of bricks and partial glassification of clay leading to reduce the water absorption of glass-clay bricks.

5.3. Efflorescence

Brick specimens were immersed in 25 mm deep water in a non-corrosive container (Fig. 14). After 7 days, specimens were taken out from the container and dried. Each brick specimens was visually examined for any signs of efflorescence and reported. Furthermore, the percentage of area affected by efflorescence was also calculated and reported as shown in Table 4.

Figure 14: Brick specimens immersed in water for efflorescence testing

Figure 15: Efflorescence observed on brick specimens after 45 days

No efflorescence was observed on any sample after 7 days. Therefore, test was continued for a longer period. After 45 days, some signs of efflorescence was observed (Fig. 15). Table 4 shows the results of efflorescence observed on brick specimens after 45 days.

It was observed that the efflorescence in brick specimens increased with higher content of waste glass (Table 4). This can be attributed to the fact that the waste glasses used in this study were obtained from recycling, which contained various salt content leading to increased efflorescence.

Furthermore, with an increase in the burning temperature, a decrease in efflorescence was observed. This decrease was due to the increased vitrification leading to more dense micro-structure and decreased porosity which did not allow the water to penetrate and create efflorescence issue.

It was also observed from the results that the brick specimens burned at brick kiln showed much more efflorescence as compared to those burned in the laboratory oven. This was due to the following reason: The coal burnt in brick kilns contains sulfur in the form of iron pyrites or marcasite and free sulfur. When the coal is burned, the iron sulfide is oxidized and sulfur dioxide gas is released. Sulfur dioxide passes through the kiln along with other gases and reacts with water vapors to form sulfuric acid. Then, sulfuric acid reacts with carbonates and other calcium salts in clay brick to form calcium sulfate i.e. gypsum leading more efflorescence of brick specimens burned in brick kiln than those burned in laboratory oven.

Table 4: Efflorescence results after 45 days

Waste glass content (%)	Burning source	Effloresced Area (%)
0	Brick Kiln	5
5		7
10		10
15		13
20		18
0	Oven at 900 °C	4
5		6
10		8
15		10
20		15
0	Oven at 950 °C	3
5		4
10		5
15		7
20		10
0	Oven at 1000 °C	2
5		3
10		4
15		6
20		8

5.4. Compressive Strength

The test specimens were capped with gypsum on their opposite bearing sides as shown in Fig. 16 in order to get a smooth contact for uniform application of load.

Bricks were dried for 24 hours in order to hardened the capped material. Afterwards, specimens were placed inside the machine and a uniform incremental load was applied (Fig. 17).

Experimental results (Fig. 18) showed that the compressive strength of tested specimens was

Figure 16: Brick specimens capped with gypsum

highly dependent on the waste glass content and burning temperatures.

Figure 17: Compression testing of brick specimens

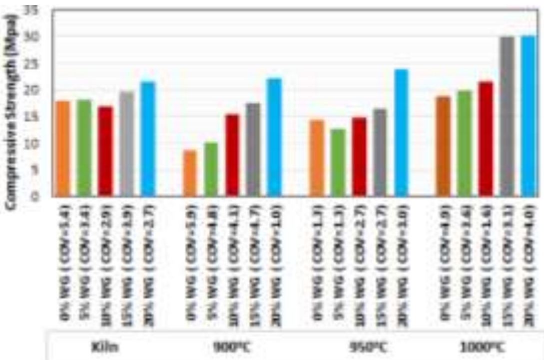

Figure 18: Compression strength results of brick specimens at various burning temperatures

5.5. Flexural Strength

Figure 19 shows the flexural strength performance of brick specimens. Brick specimen was placed on two supports of approximately 1 inch span.

Load at a rate of 8 kN/min was applied at the mid span of brick specimen until failure of the specimen into two pieces (Fig. 20). The modulus of rupture (S) for brick specimen can be calculated as follows:

$$S = \frac{3W\left(\frac{l}{2}-x\right)}{bd^2} \quad (2)$$

Where, W is the failure load, l is the distance between support, x is the distance from mid span of specimen to failure plane, b and d are the width and depth of brick specimen.

Figure 19: Flexural testing of brick specimen

Figure 20: Failure of brick specimen during flexural testing

Figure 21 shows the modulus of rupture of tested brick specimens incorporating various waste glass contents at different burning temperatures. Each flexural strength result reported in Fig. 21 is the average of values obtained on three like brick specimens with a co-efficient of variance (COV) between 1.9% to 5.8%. It was observed that the flexural strength of brick specimen increased at higher temperature of burning. For instance, a 52% increase in modulus of rupture was observed for brick specimen incorporating 10% waste glass content at 1000 °C burning temperature compared to that of similar specimen at 900 °C. This can be attributed to increased vitrification of bricks at higher burning temperature leading to denser structure and consequently higher flexural properties.

Furthermore, as the waste glass content increased, the flexural strength of brick specimens was increased for both the oven burned and kiln burned specimens. For example, a 47% increase in modulus of rupture was observed for brick specimens incorporating 15% waste glass content at 900 °C compared to that of the similar specimen with 5% waste glass content. The increase glass content actually fills the pores inside the clay mixture due to its finer nature leading to denser micro-structure and increased flexural strength. Similar results were also reported in previous studies [7, 11].

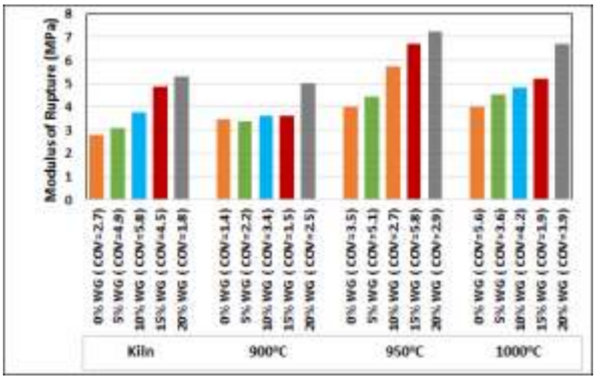

Figure 21: Flexural strength results of brick specimens

Conclusions

In this research, waste glass was incorporated in the burnt clay bricks to investigate its effects on mechanical and physical properties of burnt clay bricks. The purpose of this research was to use waste glass effectively in burnt clay bricks and reduce the environmental waste leading to protecting and preserving environment. Furthermore, waste glass clay bricks at various burning temperature was investigated. Following specific conclusions can be drawn from this study:

1. It was observed that the compressive and flexural strength properties of clay brick increased with higher content of waste glass used. Furthermore, increased burning temperature led to increased strength properties.

2. The water absorption capacity and efflorescence of clay bricks were decreased with increased content of waste glass at higher burning temperature.

3. Brick specimens burned in industrial kiln exhibited similar trend for increased waste glass content like the laboratory burned specimens.

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