Clay bricks prepared with sugarcane bagasse and rice husk ash – A sustainable solution

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Abstract: This study aims to characterize the clay bricks produced by the addition of the two agricultural waste materials i.e. sugarcane bagasse and rice husk ash. Disposing off these waste materials is a very challenging task and is a hazard to environment. The sugarcane bagasse and rice husk ash were collected locally from the cities of Peshawar and Wazirabad, respectively. These were mixed with the clay for brick manufacturing in three different proportions i.e. 5, 10 and 15% by weight of clay. Mechanical i.e. compressive strength and modulus of rupture and durability properties i.e. water absorption; freeze-thaw and sulphate resistance of these bricks were evaluated. Test results indicated that the sulphate attack resistance and efflorescence of clay bricks incorporating sugarcane bagasse and rice husk ash have been increased significantly. However, no significant effect on mechanical properties was observed. Furthermore, the additions of wastes have reduced the unit weight of bricks which decrease the overall weight of the structure leading to economical construction. Therefore, it can be concluded that the addition of waste materials in brick manufacturing can minimize the environmental burden leading towards more economical and sustainable construction.

1 Introduction

Clay products (burnt clay bricks or blocks) are one of the oldest materials used in the construction activities. Bricks/blocks are prepared after burning the clay in a kiln. Raw materials and production method play an important role in developing brick properties. Bond development between the clay particles occur through firing process. Silica (SiO₂) is considered as the main constituent of clay that helps in bond development. Generally different fluxing agents are added in clay to lower down the melting temperature. Fluxing agent helps to achieve required brick properties at lower temperature, leading to fuel saving.

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Production and consumption of burnt clay bricks is still common in many parts of the world. China is considered as the top country in brick production [1]. Similarly, India with annual 180 billion tons of brick production is the second largest brick producing country [2]. Extensive utilization of natural resources like clay has caused an alarming situation [3-5]. Moreover, day by day increasing waste generation is also causing environmental problems. Therefore, researchers are focused to develop new construction materials by utilizing waste products in construction. Waste material consumption will not only reduce the environmental burden but also lead towards an economical and sustainable solution.

Different waste materials have been investigated in the production of bricks with improved performance. Waste glass, fly ash, agricultural and industrial wastes was used effectively in the production of burnt clay bricks [6]. Utilization of waste glass in clay bricks can improve the strength and porosity [7-8]. Similarly, utilization of fly ash in brick production was very effective. Improved strength and water absorption was observed in case of fly ash bricks. Furthermore, utilization of fly ash is environment friendly leading towards green construction [9-10]. Utilization of marble powder in burnt clay bricks can be very helpful in controlling the environment pollution and air borne diseases. Marble powder replacement 15-20% by weight of clay was found effective in brick production [11].

Pakistan is an agricultural country producing approximately one million rice husk annually [12]. This husk is used as a fuel source in brick and paper industry. As a result of combustion, rice husk ash (RHA) is obtained. Similarly, Pakistan produces around 50 million tons of sugarcane annually [13]. Bagasse is obtained after utilization sugarcane in sugar production. Bagasse is also consumed as fuel source and as a result sugarcane bagasse ash (SBA) is produced. There is no proper mechanism for the disposal of these ashes. As a result, environmental pollution is increasing by these wastes. Different researchers have studied the utilization of RHA and SBA in clay bricks [1, 14-17]. Lighter bricks with improved thermal conductivity can be prepared by using agro wastes in brick production [18-19].

In this study clay bricks have been prepared after incorporating RHA and SBA in different proportion (5%, 10%, 15% by weight of clay). Burnt clay bricks were prepared in brick kiln on a massive scale. The utilization of these waste will be helpful in saving the natural resources along with economical and sustainable construction.

2 Materials and methods

Clay was attained from a brick kiln in Pakistan. Similarly, RHA and SBA were obtained from a sugar milland industrial brick kiln located in Pakistan respectively. Firstly, RHA and SBA were added and mixed manually (Fig. 1(a)) with clay in different proportions presented in Table 1. Afterwards, mixture was prepared by adding water (Fig. 1(b)) and allowed for 3 hours to attain homogeneity. Molds (228x114x76 mm) were then filled with clay lumps to prepare the bricks. Bricks were first dried in the sun for 10 days (Fig. 2(a)) and then burnt in a kiln for 36 hours at approximately 800°C. Brick specimens were removed after 45 days from the kiln (Fig. 2(b)).

Raw materials' properties were studied by chemical analysis, particle size distribution and specific gravity. X-ray fluorescence (XRF) and X-ray diffraction analysis (XRD) were performed to determine the chemical composition. Particle size distribution and specific gravity of raw materials were determined in accordance with ASTM D422 (Standard test method for particle-size analysis of soils) and ASTM D854 (Standard test methods for specific gravity of soil solids by water pycnometer), respectively.

Mechanical and durability properties like unit weight, compressive strength, modulus of rupture, water absorption, initial rate of absorption and efflorescence were determined in accordance with ASTM C67 (Standard test methods for sampling and testing brick and structural clay tile). However, ASTM C20 (Standard test methods for apparent porosity, water

absorption, apparent specific gravity, and bulk density of burned refractory brick and shapes by boiling water) was used to determine the apparent porosity of brick specimens.

Table 1. Mixture proportions of raw materials.

Brick series	Clay (%)	RHA (%)	SBA (%)
C	100	-	-
RHA5	95	5	-
RHA10	90	10	-
RHA15	85	15	-
SBA5	95	-	5
SBA10	90	-	10
SBA15	85	-	15

Fig. 1. Preparation of mixture for brick production.

Fig. 2. Drying and burning process of brick production.

3 Results and discussion

3.1 Properties of raw materials

Table 2 shows the chemical composition of raw materials. It was observed that silica and alumina were the main skeleton components of clay. Presence of silica within the range of 50-60% makes it suitable for brick production [6]. Moreover, the amount of fluxing agents (K_2O , CaO , MgO , Fe_2O_3 and TiO_2) and calcium oxide in clay was greater than 6% and 9%. Therefore, it can be classified as low refractory calcareous clay [20]. Silica was also found as the main chemical component of RHA and SBA. Other oxides like alumina, iron oxide, calcium oxide and magnesium oxide were found in small amount.

Table 2. Chemical and physical properties of the raw materials.

Components	Clay	RHA	SBA
SiO ₂ (%)	57.05	77.21	87.97
Al ₂ O ₃ (%)	11.91	6.87	1.84
Fe ₂ O ₃ (%)	4.96	4.69	2.65
CaO (%)	8.98	3.65	2.65
MgO (%)	2.52	1.45	0.72
TiO ₂ (%)	0.68	-	-
P ₂ O ₅ (%)	0.14	-	-
SO ₃ (%)	-	0.37	0.15
MnO (%)	0.08	-	-
Na ₂ O (%)	1.86	1.24	0.28
K ₂ O (%)	2.21	2.59	0.32
LOI (%)	9.59	4.71	10.45
pH	8.55	-	-
Unit Weight (kg/m ³)	1120	550.54	258.6
Specific Gravity	2.24	2.11	1.96

Loss on ignition (LOI) was observed higher for SBA (10.45%)as compared to clay (9.59%) and RHA (4.71%). It may be related to the combustion of carbonates and unburnt particles.

Figure 3-5 shows the x-ray diffraction (XRD) scans of clay, RHA and SBA Quartz was observed as the major mineral present in the clay along with cinnabar, halite, alumina, calcite, fluorite and hematite minerals in minor amount. Furthermore, RHA and SBA were also found comprised of the quartz (SiO₂). Other minerals present in RHA were hematite, calcite and fluorite. Whereas, SBA comprised of calcite, corundum, hematite, fluorite, halite and bornite minerals in minor amount.

Fig. 3. XRD pattern of clay.

Fig. 4. XRD pattern of RHA.

Fig. 5. XRD pattern of SBA.

Figure 6 shows the particle size distribution curves of raw materials. It was observed that a wide range of sizes were present in the raw materials. Major amount of clay particle sizes was observed within the sand and silt size. However, particles of RHA and SBA were observed mostly within the sand and silt sizes, respectively. As far as, specific gravity is concerned. Clay (2.24%) showed a higher specific gravity than RHA (2.11%) and SBA (1.96%), which indicated the production of lighter bricks by incorporating these wastes.

Fig. 6. Particle size distribution for RHA, SBA and clay.

Table 3. Particle size distribution analysis of raw materials used.

Particle content	Raw materials		
	Soil (%)	RHA (%)	SBA (%)
Gravel	0	0	0
Sand	58.29	73.38	25.47
Silt	40.46	25.12	73.03
Clay	1.25	1.50	1.50

3.2 Mechanical and durability properties

3.2.1 Weight per unit area

Results of weight per unit area are shown in figure 7. It was observed that lighter bricks can be produced after incorporating RHA and SBA in clay bricks. Lighter bricks up to 15% and

4% were prepared after incorporating 15% of SBA and RHA in replacement of clay, respectively. Lesser unit weight of RHA (550.54 Kg/m³) and SBA (258.6 kg/m³) as compared to clay (1120 kg/m³) was considered responsible for lighter weight bricks. Light weight bricks can be very helpful in earthquake affected areas and can be economical by reducing the transportation cost.

Fig. 7. Effect of RHA and SBA wastes on weight per unit area of bricks.

3.2.2 Compressive strength

Figure 8 showed the compressive strength results of clay bricks incorporating RHA and SBA. It was observed that with waste addition strength of burnt clay bricks were reduced. For instance, decrease of 14% in compressive strength was observed after incorporating 5% of SBA by clay weight in brick specimens. 50% reduction in compressive strength was observed with 15% SBA replacement with clay. Addition of RHA also showed a similar reduction in strength. Increase in porosity was considered as the main reason of strength reduction. Brick specimens showed compressive strength of 6.62 and 7.18 MPa after incorporating 5% of RHA and SBA, respectively, which satisfied the Building Code of Pakistan 2007 requirement for minimum compressive strength.

Fig. 8. Compressive strength of bricks incorporating RHA and SBA.

3.2.3 Modulus of rupture

Figure 9 showed that the modulus of rupture reduced after addition of SBA and RHA in burnt clay bricks. 15% replacement of SBA with clay showed minimum flexural strength of burnt clay brick i.e., 0.67 MPa. Similar, decrease in strength was also observed with RHA addition. Reduction in strength was related to increased porosity with waste. However, all the brick specimens satisfied the minimum permissible limit for modulus of rupture i.e., 0.65 MPa according to ASTM C 67 [10].

Fig. 9. Effect of RHA and SBA wastes on modulus of rupture of bricks

3.2.4 Apparent porosity

Porosity is the property of burnt clay bricks, which is related to the durability [21]. Apparent porosity results of burnt clay bricks incorporating RHA and SBA are shown in figure 10. It was observed that porosity of brick specimens increased with waste addition. Least porosity of 36% was observed for control specimens. However, higher porosity of 44% was observed after incorporating 15% of SBA in burnt clay bricks. Similarly, 4% increase in porosity was observed, when RHA addition was increased from 5% to 15% by weight of clay in the mixture. Change in size and number of pores could be the possible reason of increased porosity [22]. Bricks with higher porosity are usually considered lighter having good thermal properties [23].

3.2.5 Water absorption

Water absorption of burnt clay bricks incorporating RHA and SBA was presented in Figure 11. It was observed that with addition of SBA and RHA wastes, water absorption of burnt clay bricks increased. For instance, 24% of absorption was observed after incorporating 10% of SBA, however brick specimens without SBA showed 17% of absorption. Increased absorption with waste addition could be related to increased porosity. Lesser absorption was observed for bricks incorporating RHA as compared to bricks with SBA. Porous nature of SBA was considered responsible for such a behaviour [24]. Water absorption results of burnt clay bricks are also consistent with porosity results. Small amount of waste addition (i.e., 5%) showed water absorption less than 22%. Therefore, these bricks can be used in moderate weathering resistant environment effectively according to ASTM C62 (Standard specification for building brick solid masonry units made from clay or shale).

Fig. 10. Effect of RHA and SBA wastes on apparent porosity results of bricks.

Fig. 11. Water absorption of brick specimens incorporating RHA and SBA.

3.2.6 Initial rate of absorption

Water absorbed during one minute through the brick surface is termed as initial rate of absorption (IRA) (ASTM C67 2003). Bond between brick and mortar is greatly affected by IRA. Results of IRA are shown in figure 12. It was observed that IRA increased with incorporation of RHA and SBA in burnt clay bricks. For instance, IRA value of 0.78 g/cm²/min was observed with mixture incorporating 15% of SBA by clay weight. However, control brick showed 0.46 g/cm²/min of absorption. Higher IRA was observed for SBA addition as compared to RHA, which is related to the porosity [25]. All the results of IRA were observed higher than 0.15 g/cm²/min, therefore these bricks should be wetted before masonry works for proper bond with mortar (ASTM C62 2013).

Fig. 12. Initial rate of absorption of brick specimens incorporating waste.

3.2.7 Efflorescence

Control specimens were observed with slight efflorescence i.e., 5% of the surface area after 7 days. However, brick specimens incorporating RHA and SBA showed no efflorescence. To study the efflorescence for a longer time, brick specimens were kept in efflorescence conditions for 45 days. Control specimens showed minor efflorescence i.e., 10% of the surface area, however brick specimens incorporating RHA and SBA showed no efflorescence after 45 days. Generally, amount of calcium oxide (CaO) is considered responsible for causing efflorescence [20]. Addition of RHA and SBA being silica rich waste materials, reduced the quantity of calcium oxide in burnt clay bricks, therefore improved the efflorescence resistance of bricks.

4 Conclusions

Agriculture waste (RHA and SBA) utilization in burnt clay bricks is an effective way of disposal of waste materials leading to sustainable construction. Lighter bricks can be produced after addition of RHA and SBA in burnt clay bricks. Lighter bricks are helpful in achieving economy during construction. Brick specimens after incorporating RHA and SBA showed less compressive and flexural strength. An addition of 5% of waste in burnt clay bricks satisfied the Building Code of Pakistan requirement for minimum compressive strength. Similarly, all the bricks fulfilled ASTM C 67 requirement for flexural strength.

Furthermore, porosity, water absorption and initial rate of absorption was increased with the addition of waste in burnt clay bricks. High porosity is usually related with good insulation properties. Burnt clay bricks with 5% waste addition can be used in moderate weather according to water absorption results. Efflorescence results were also encouraging. Based on the study, it can be concluded that bricks incorporating RHA and SBA up to 5% can be effectively used for construction purposes leading to sustainable construction.

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