IMPROVEMENT OF THERMAL INSULATING PROPERTIES AND POROSITY OF FIRED CLAY BRICKS WITH ADDITION OF AGRICULTURAL WASTES

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Abstract

This paper studies fired clay bricks mixed with different agricultural wastes such as grass (GA), coconut husk (CH), and sugarcane bagasse (SB) as porous additives in brick production. The agricultural wastes were added to the clay mixture in the compositions of 0, 2.5, 5, and 7.5 wt%. Mixed clay bricks were fired at 1000°C for 1 h and were then studied for their physical and mechanical properties. The pore shapes of the fired bricks were examined by SEM micrograph. The porosity was linearly generated with a higher waste content. An increase of the porosity was significantly related to an increasing shrinkage and water absorption, while the bulk density was decreased. The compressive strength value of the fired clay bricks tended to decrease according to the percentage of agricultural waste included in the mixture. From the physical properties' results, the thermal conductivity varied from 0.45 W/m K to 0.21 W/m K depending on the GA, CH, and SB contents (2.5-7.5%). Conclusively, the results revealed that the agricultural wastes could be used advantageously in the improvement of the thermal insulation properties and low dead load in building materials.

Keywords: **Porosity, thermal conductivity, agricultural wastes, clay brick, compressive strength**

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Introduction

Bricks are widely used around the world as construction materials. As urbanization expands, demand for bricks gradually increases (Phonphuak and Thiansem, 2012). Bricks are especially required to have adequate physical and mechanical properties as well as a good insulation behavior (Muñoz *et al*., 2014). Agricultural wastes are used for animal feed, fertilizer, and fuel for energy production, but little work has been carried out to develop the utilization of these wastes in the production of building materials (Demir, 2006). The major quantities of wastes generated from agricultural sources are sugarcane bagasse, rice husk, jute fiber, coconut husk, cotton stalk, tea waste, palm oil waste, grass, sawdust, etc. Reuse of such wastes as sustainable construction materials appears to be a viable solution not only for pollution problems but also for the problem of land-fill and the high cost of building materials (Madurwar *et al*., 2013). Using renewable agricultural byproducts and waste materials as performance enhancing additives in the brick industry has been gaining more and more ground recently. The additives, mixed into the clay brick, are burnt out during the firing process producing extra energy, and decreasing the total energy need of the industrial furnace (Bánhidi and Gömze, 2008). For environmental protection and sustainable development, many researchers have studied the utilization of agricultural waste materials as additives to clay bricks. A wide variety of waste materials have been studied, including tobacco residues, sawdust, grass, processed tea waste, sunflower seed shell, and spent grains from the brewing industry which can be used as pore-forming additives in the production of fired clay bricks (Russ *et al*., 2005; Demir, 2008; Bánhidi and Gömze, 2008; Zhang, 2013; Phonphuak and Chindaprasirt, 2015; Eliche-Quesada and Leite-Costa, 2016). Wastes of an organic nature were added to increase the porosity and insulation ability of the products, while improving the mechanical strength of the matrix by introducing combustion energy (Arsenocić *et al*., 2015). The porosity of the brick depends directly on the mineralogical composition of the raw material and firing temperature but, generally, bricks fired at high temperatures are more vitreous and undergo the greatest changes in size and porosity (Cultrone and Sebastián, 2009). A way to reduce thermal conductivity would be to create cavities within the structure, thus increasing the porosity and allowing more air to be contained within so that thermal conductivity would fall (Bories *et al*., 2014). Thus, the main objective of this study is to investigate the effects of agricultural waste additives on the porosity and thermal conductivity properties of fired clay bricks.

Materials and Method

The clay used in this study was obtained from one of the local brick plants. Chemical analyses of the clay were carried out using the X-ray fluorescence technique (Mesa-500W Series, Horiba Ltd., Kyoto, Japan). The mineralogical composition of the clay was achieved using an X-ray diffractometer (XRD) (X'Pert PRO MPD, Philips, Amsterdam, Netherlands). The average particle size distribution of the clay was analyzed by diffraction (Mastersizer 2000 + Hydro 2000 MU, Malvern Instrument Ltd., Malvern, UK).

In order to determine the extent of the pore-forming effect on the samples from the 3 residues - grass (GA), coconut husk (CH), and sugarcane bagasse (SB), - several different amounts of the residues (0, 2.5, 5, and 7.5 wt%) for each batch of the samples were mixed in a porcelain ball mill to ensure homogenous mixing. Then, 20-25 wt% of water was added and mixed to obtain a plastic form. Soft-mud rectangular clay bricks with dimensions of 140 mm × 65 mm × 40 mm were formed using a brick hand mold. The clay brick samples were air-dried at room temperature (25-30°C) for 24 h, and then oven dried at 110±5°C for another 24 h. The dried samples were fired at 1000°C for 1 h.

The firing shrinkage was determined by measurement of a specimen's length before and after firing. The linear drying shrinkage and total linear shrinkage were tested and compared to the length before shrinkage in accordance with ASTM standard C326-09 (2014). The Archimedes method based on ASTM standard C373-14a (2014) was used to determine the water absorption, bulk density, apparent density, and apparent porosity. The compressive strengths of the samples were measured in accordance with ASTM standard C773-88 (2011). Thermal conductivity measurement test was conducted according to an adapted experimental procedure of ASTM standard C177-97 (2000).

Results and Discussion

Characterization and Particle Size

The chemical compositions of the clay and RH are presented in Table 1. The clay was composed of the main oxide compounds of SiO_2 and Al_2O_3, while the fluxing agents of Fe_2O_3 and K_2O were indicated at about 5.10 wt% and 3.10 wt%, respectively. Loss on ignition (LOI) of the clay bodies upon heating at 1000°C appeared at about 8.74 wt%. The XRD patterns of the clay are shown in Figure 1. It was found that the clay structure had the main phase of quartz and small peak patterns of muscovite and rutile. However, hematite phases did not appear due to the low iron content. The particle size distribution of the clay powder is presented in Figure 2. The particle size was distributed in the range of 1-200 µm with D (Demir, 2006; Madurwar *et al.*, 2013) of 7.12 µm. The wastes' additions were cut with a cutting machine to obtain a shorter length than 5 mm.

Microstructure and Physical Properties of Fired Clay Brick Samples

The microstructures of the unfired bricks with the different additions of the wastes are presented in Figure 3. The unfired clay bricks with grass (GA), coconut husk (CH), and

Table 1. Chemical composition of the clay used in the experiments

Composition	Clay (wt%)
SiO_2	58.76
Al_2O_3	21.34
Fe_2O_3	5.10
CaO	0.21
K_2O	3.10
Na_2O	-
P_2O_5	-
TiO_2	0.93
MnO	1.18
MgO	-
LOI*	8.74

** LOI (Loss on ignition)*

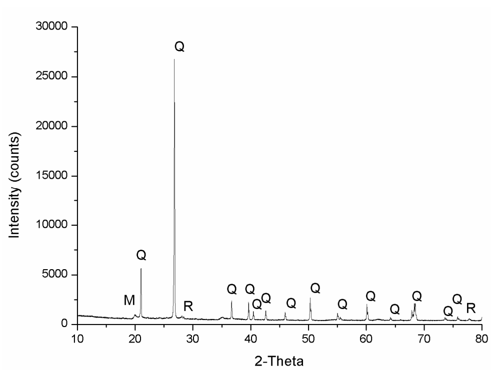

Figure 1. XRD patterns of clay material (Q = quartz, M = muscovite, R = rutile)

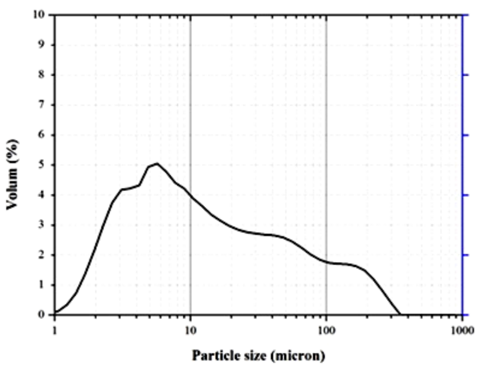

Figure 2. Particle size distribution of the clay

sugarcane bagasse (SB) additives are shown as molded clay bricks before firing (Figures 3(a)-(i)).

Shrinkage of the clay bricks occurs due to the evaporation of water in the clay structure during the firing process. In other words, when the water between the particles leaves, the particles come closer together and shrinkage occurs (Weng *et al*., 2003; Karaman *et al*., 2006; Eliche-Quesada *et al*., 2011). The quality of fired clay bricks can be further assured according to the degree of firing shrinkage. Normally, a good brick exhibits a shrinkage below 8% (Benlalla *et al*., 2015). In this study, the fired clay bricks were fired at 1000°C. The percentage of shrinkage increases with the increasing addition of GA, CH, and SB (2.5-7.5%), as shown in Figure 4. The results indicated that the shrinkage occurred in the fired clay bricks in the range of 5.16-6.52% (GA), 5.44-6.26% (CH), and 4.66-5.66% (SB), whereas the control fired clay bricks without any waste addition had a comparable firing shrinkage of 5.94%. This is explained by the particles being able to be conveniently transferred to the reduced surface area in the firing process due to the appearance of pores replacing the agricultural waste.

The bulk density of fired clay bricks depends on several factors which are the specific gravity of the raw material, the method of manufacture, and the firing temperature. In this study, the bulk density of the fired clay bricks was inversely proportional to the quantity of the GA, CH, and SB wastes added into the mixture, as shown in Figure 5. The bulk density of the samples decreased with an increase in the amounts of GA, CH, and SB ranging from 2.5-7.5%. The bulk density values appeared in the range of 1.35-1.75

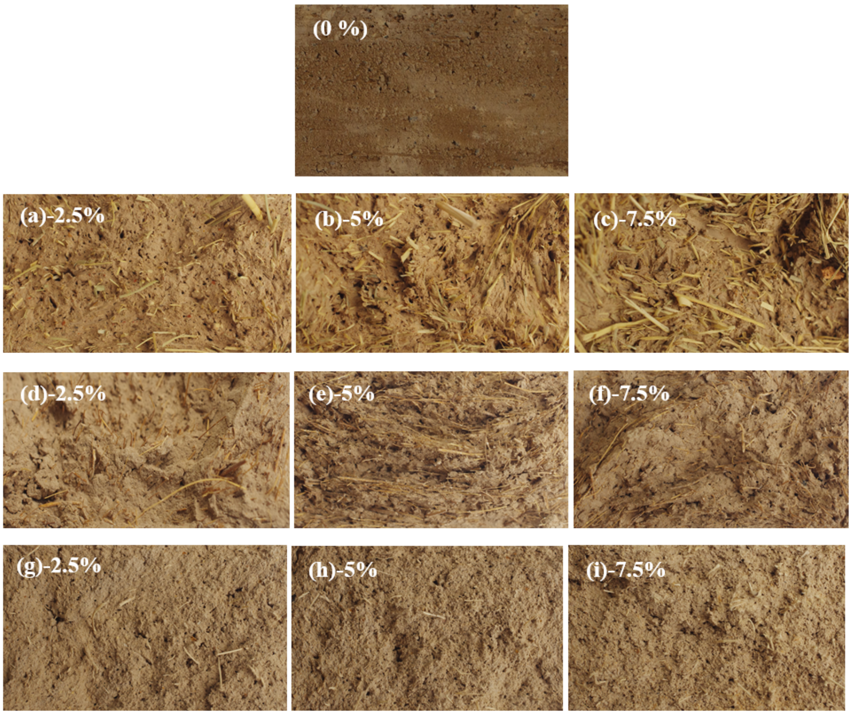

Figure 3. Microstructures of unfired clay bricks with different percentages of grass (GA) (a, b, c); coconut husk (CH) (d, e, f); and sugarcane bagasse (SB) (g, h, i)

g/cm^3, while the bulk density of the bricks without waste addition was 1.82 g/cm^3. The bulk density is related to the durability and water absorption of the clay bricks.

Water absorption is an important factor for the durability of clay bricks. When water infiltrates bricks, it decreases the durability of the bricks (Demir, 2009; Phonphuak *et al.*, 2016). Thus, the internal structure of the brick must be sufficiently dense to void the intrusion of water. Low values imply good resistance to the natural environment and acceptable permeability of bricks (Aouba *et al.*, 2016). Figure 6 shows the water absorption of the fired clay bricks incorporating GA, CH, and SB. It was observed that the water absorption increased with the higher percentages of GA, CH, and SB. For instance, the mixture incorporating 7.5% of GA, CH, and SB showed that the water absorption values were about 27.40%, 19.80%, and 23.10%, respectively. These water absorption values were higher than the fired clay bricks without any waste addition (12.20%). The addition of waste increased the porosity of the fired clay bricks. However, this effect is expected, since

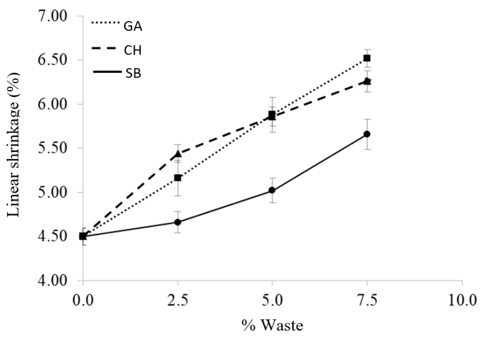

Figure 4. Linear shrinkage of mixed clays with different wastes after firing at 1000°C

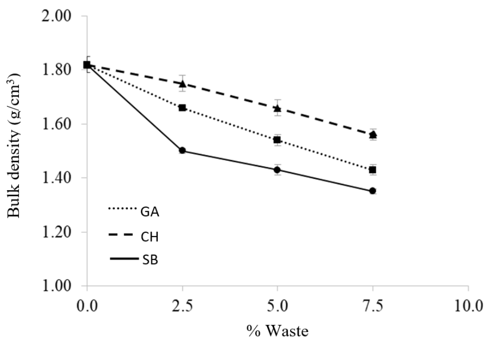

Figure 5. Bulk density of mixed clays with different wastes after firing at 1000°C

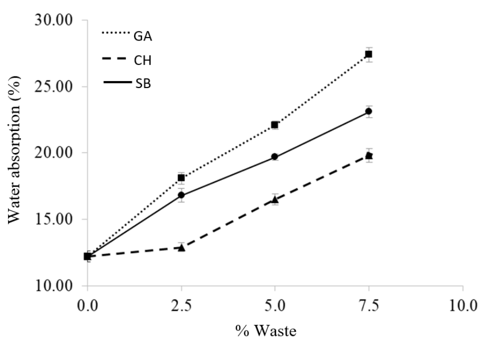

Figure 6. Water absorption of mixed clays with different wastes after firing at 1000°C

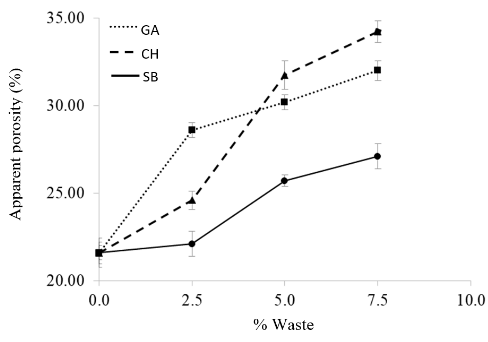

Figure 7. Apparent porosity of mixed clays with different wastes after firing at 1000°C

the organic matter of the waste residues was eliminated during the firing process, leading to the increase in the open porosity of the fired clay bricks (Eliche-Quesada *et al*., 2012).

Water absorption directly corresponds to apparent porosity because the water must be trapped in the porous regions. Therefore, similar trends were observed in water absorption and apparent porosity (Eliche-Quesada *et al*., 2011). The study showed that the apparent porosity of the fired clay bricks depended on the amount of the addition of GA, CH, and SB. Figure 7 shows the porosity results for the fired clay bricks samples incorporating GA, CH, and SB. It was observed that the control samples have the least porosity at 21.60%, whereas the GA, CH, and SB 7.5% samples have the highest porosity values at 32%, 34%, and 27.10%, respectively. This result revealed that the higher the percentage of waste added into the samples, the higher the porosity that occurred in the samples. Thus, the porosity in the fired clay bricks was caused when waste additives were burnt during the firing process.

According to ASTM standard C62-13a (2013), grade MW and SW bricks must have an average maximum absorption of 20.0% and 17.0%, respectively. Hence, the higher values of water absorption measured in this study are indicative of high porosity brought on by the incorporation of GA, CH, and SB. Water absorption was approximately 27.40% and 1.90% for the brick samples incorporating 2.5-7.5% of GA, CH, and SB respectively, and the increase in the pores in all the samples is linear with an increased water absorption and the decrease of the density. It can be concluded that the fired clay bricks incorporating lower contents of GA, CH, and SB (i.e. 2.5%) were within the specified limits of water absorption.

The compressive strength is a mechanical property used in clay brick specifications. It has assumed great importance for 2 reasons. Firstly, with a higher compressive strength, other properties like flexure and resistance to abrasion are also improved. Secondly, while other properties are relatively difficult to evaluate, the compressive strength is easy to determine. The compressive strength of clay brick is the most important engineering quality index for construction materials (Weng *et al*., 2003; Karaman *et al*., 2008; Okunade, 2008; Phonphuak *et al*., 2016). The compressive strengths of the samples are shown in Figure 8. For the control fired clay bricks without any waste addition and fired at 1000°C, the value of the compressive strength was 21.5 MPa. An increase in the waste addition and porosity content can affect the compressive strength of clay bricks. In this study, the results indicated that the strength of fired clay bricks greatly depended on the amount of the added GA, CH, and SB. The results of the compressive strength (Figure 8) indicated that the compressive strength of the fired clay bricks decreased with the increasing additive amounts. The results revealed that the compressive strengths were in the ranges of 3.18 to 9.84 MPa (GA), 3.30 to 10.4 MPa (CH), and 2.98 to 7.96 MPa (SB). The compressive strength decreased with an increase in the porosity due to the higher amount of waste addition (Figure 8). According to ASTM specification C62-13a (2013), the grade MW bricks must have an average minimum compressive strength of 17.2 MPa. In our study, the compressive strength of samples with 2.5-7.5%, GA, CH, and SB addition were lower than that of MW brick. However, Gencel (2015) reported that

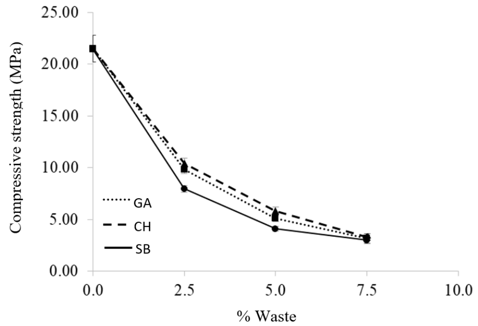

Figure 8. Compressive strength of mixed clays with different wastes after firing at 1000°C

the bricks must have a minimum compressive strength of 7 MPa according to the Turkish and corresponding European standards (TS EN 771-1). It is also believed that some brick with low waste addition tends to improve over time.

Figure 9 shows images of cross-sections of fired clay bricks with 0-7.5%, GA, CH, and SB, respectively. The fired clay brick samples with waste additives had more pores than their counterparts without waste additives when fired at 1000ºC. The images show that as the GA, CH, and SB contents increased, the micro-pores of the samples also increased. This corresponded with the reduction in density and compressive strength, which resulted in increasing water absorption. The results of the effect of mixing with waste additions on the fired clay brick samples can be seen in the cross-sectional views.

Thermal conductivity is an important criterion for building materials because the thermal conductivity influences the selection of building materials in engineering applications (Phonphuak, 2013). The bulk density and porosity are the major factors governing thermal conductivity (Aouba *et al.*, 2016). There are 2 different thermal conductivity values of these bricks. The first value involves the bulk of the material constituting the walls while the second involves thermal conductivity of the entire product consisting of large vertical holes of a rectangular cross-section (Sutcu and Akkurt, 2009). The thermal conductivity test results of the fired clay brick samples are presented in Figure 10. It is evident that increasing the percentage of GA, CH, and SB caused more porosity. The burning out of the waste

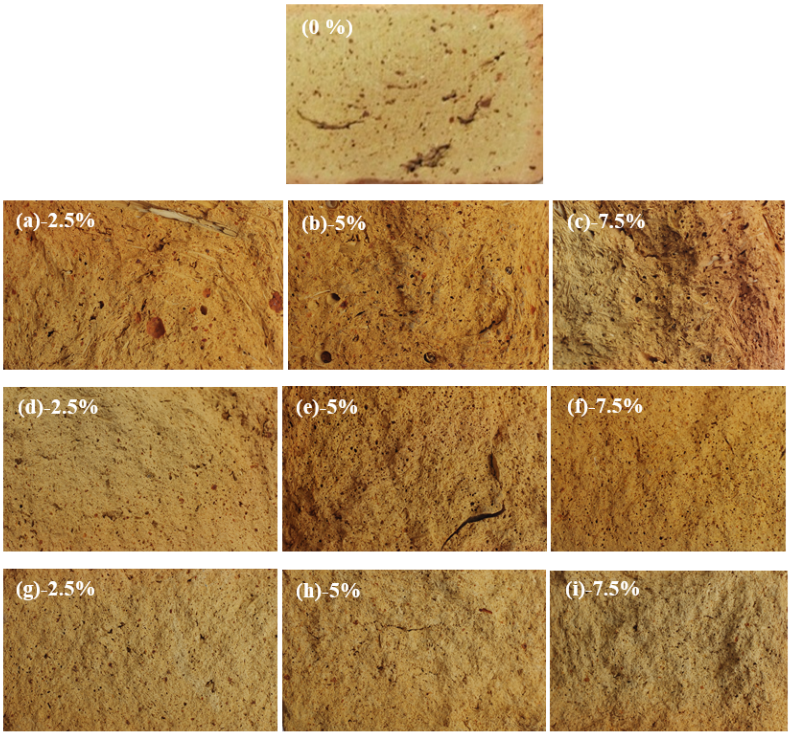

Figure 9. Photographs of clay bricks fired at 1,000oC with different percentages of grass (GA) (a, b, c); coconut husk (CH) (d, e, f); and sugarcane bagasse (SB) (g, h, i)

additions in the body during the firing process caused the porosity in the fired clay bricks. The results show that higher percentages of GA, CH, and SB induced low thermal conductivity in the samples. This is as a result of the increased air volume obtained by the burning of the GA, CH, and SB, a process which leads to pores forming within the samples to make them poor thermal conductors and, hence, good backup insulators. From the results, it can be concluded that thermal conductivity decreases with the decrease in density and increase in the fired clay bricks' porosity. The highest thermal conductivity value was obtained at 0.63 W/m K for the control fired clay bricks without any waste addition. Thermal conductivity of the fired clay bricks decreases from 0.36 W/m K to 0.21 W/m K, (GA addition 2.5-7.5%), while for the CH addition (2.5-7.5%) the decrease was 0.41 W/m K to 0.27 W/m K, and for the SB addition (2.5-7.5%) it was 0.45 W/m K to 0.29.

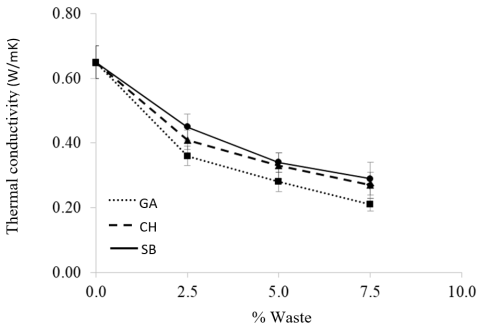

Figure 10. Thermal conductivity of mixed clays with different wastes

Conclusions

In this study, the properties of fired clay bricks incorporating grass (GA), coconut husk (CH), and sugarcane bagasse (SB) wastes as raw materials in the manufacture were investigated. The fired clay bricks were produced by incorporating 0-7.5% GA, CH, and SB by weight. The characteristics and analysis of the physical-mechanical properties and thermal conductivity of the GA, CH, and SB additives to the clay content for the production of fired clay bricks are reported. The total linear firing shrinkage of the clay bricks varied from 5.16% to 6.52%, increasing relatively linearly as the GA, CH, and SB content increased. The bulk density decreased from 1.75 to 1.35 g/cm^3 when the waste content was increased from 2.5% to 7.5% by weight. This is compared to the density of 1.82 g/cm^3 for the control clay bricks without any waste additive. Water absorption increased from 12.90% to 27.40% as the GA, CH, and SB content was increased to 7.5%. Furthermore, it was observed that the porosity increased with the increasing amount of GA, CH, and SB leading to an increase in water absorption. Fired clay bricks incorporating 7.5% of GA, CH, and SB showed apparent porosity less than approximately 32%, 34%, and 27% respectively. The compressive strength of the fired clay bricks decreased with increased proportions of GA, CH, and SB from 2.5% to 7.5% by weight. However, the clay brick samples incorporating 2.5% by clay weight of GA, CH, and SB showed the highest compressive strength of 9.84 MPa, 10.4 Mpa, and 7.96 Mpa, respectively. The thermal conductivity of fired clay bricks is strongly related to the porosity of the bricks. Their thermal conductivities varied from 0.45 W/m K to 0.21 W/m K depending on their GA, CH, and SB content (2.5-7.5%), respectively. Results indicated that the agricultural wastes could be easily utilized as pore-forming additives into brick bodies. Conclusively, the results revealed that the agricultural wastes could be advantageously used in the improvement of the thermal insulation properties, while the compressive strength was low for the construction of buildings. However, the development of the bricks in this work was to increase the value of the scientific quality and importance to the field of construction and civil engineering concerning the added benefit of waste utilization.

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