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THE USE OF SAWDUST WASTE ON PHYSICAL PROPERTIES AND THERMAL CONDUCTIVITY OF FIRED CLAY BRICK PRODUCTION

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ABSTRACT: In this paper, the effects of incorporation of sawdust waste on the properties of fired clay bricks were investigated. Clay bricks fabricated with 0%, 2.5%, 5%, 7.5%, and 10% by weight of sawdust waste were tested. The clay brick specimens were firing at 900 °C, 1000 °C, and 1100 °C for study the water absorption, bulk density, apparent porosity, compressive strength, and thermal conductivity of the fired clay bricks. The experimental results found that the using of sawdust waste reduced the bulk density and compressive strength of the specimens. It was observed their apparent porosity ratios up to 30% improved with increasing of sawdust waste up to 10% by weight after firing at 900 °C. The compressive strength of bricks specimen with 2.5% by weight of sawdust waste addition and fired at 1100 °C showed a higher than of value strength as required by ASTM C62-13a. In addition, the thermal conductivity of the porous fired clay bricks specimens with 2.5-10% by weight sawdust waste addition produced at 1000 °C compared to the fired clay brick specimens without additive, decreased from 0.47 to 0.22 W/mK. The results thus showed that sawdust waste was a potential material for use as a pore former additive to raw clay-brick production.

Keywords: Physical properties, Clay brick, Pore forming, Thermal insulation, Sawdust waste

1. INTRODUCTION

One of the oldest construction materials is brick, and it continues to be one of the most popular building materials because it is durable, easy to handle, aesthetic in look, and inexpensive. Today, clay bricks are still being used for the same purpose. A fired clay brick should also contain high amount of pores to give it a lighter weight and associated low thermal conductivity [1]-[4]. New construction materials with friendly environment are interested in current research. Therefore, the improvement of fired clay bricks incorporating sawdust waste that is especially the development approach [5]-[6]. For environmental protection and sustainable development, a number of researchers have investigated the use of waste materials to produce clay bricks. A wide variety of waste materials have studied, including sawdust, coal, coke, papermaking sludge, grass and coconut shell, corn cob, rice husk, and inorganic ones are polystyrene, perlite, and dolomite or calcite [7]-[11]. Firing temperature is an important factor in clay brick making industry. It influences the mineralogical, textural and physical formation of clay bricks [12]. The porosity of material is a major factor influencing its thermal conductivity, but no simple relationship can be formulated to cover the complexity of various factors. Air is a very good insulating material so that a highly porous body material will have a lower conductivity than the same material with solid body. The advantage and application of high porosity bricks are the lightweight structure and better thermal insulation [13]-[14]. Sawdust is a waste from the primary wood working and timber industry. As it possesses a firing capacity, it is normally used as a fuel source in the thermal processes (biomass). The main chemical components of sawdust are; C (60.8%), H (5.2%), O (33.8%) and N (0.9%). Dry wood is primarily composed of cellulose, lignin, hemicelluloses, and minor amounts (5-10%) of extraneous materials [8], [15]. The sawdust waste can be incorporated in clay as a pore-forming agent in clay brick technology. Furthermore, such combined products give the fired clay a more porous microstructure. Okunade [16] investigated the use of wood ash and sawdust as admixtures in laterite-clay bricks. Sawdust (for burning out) and wood ash admixtures with ratio of 70:30 by weight laterite-clay were investigated. The admixtures were added in various combinations of proportions by volume (from 0 to 10%). This had resulted in denser products with high compressive strengths (with 0% sawdust and 10% wood ash), high softening coefficient, low water absorption rates, low saturation coefficient, low abrasion index, especially with addition of wood ash admixture solely. Conclusively, the results revealed that wood ash on its own would also result in production of lightweight and more porous products [16]. In this research, the effects due to the use of sawdust waste were investigated in laboratory and the firing behavior, physical properties and thermal conductivity of fired clay bricks were discussed.

2. MATERIALS AND METHODS

2.1 Characterization of Raw Materials

The clay body is taken from one of the local plants. The average particle size distribution of clay body was analyzed by laser diffraction using a Melvern Mastersizer (Melvern Instrument Ltd.). Analysis results revealed that the particle size distribution ranges from 1-100 µm and presented the average particle size with D (4,3) (Volume Mean Diameter) of 14.91 µm (Fig. 1). The mineralogical composition of clay body was achieved using an X-ray diffractometer technique (XRD Panalytical X' Pert PRO MPD, Netherland). The major crystalline phases found in clay body were quartz, muscovite, rutile and hematite (Fig. 2). Chemical analysis of the clay was carried out using X-ray fluorescence (XRF) elemental analysis spectrometer (Horiba Mesa-500 w). Chemical compositions of clay body are given in Table 1.

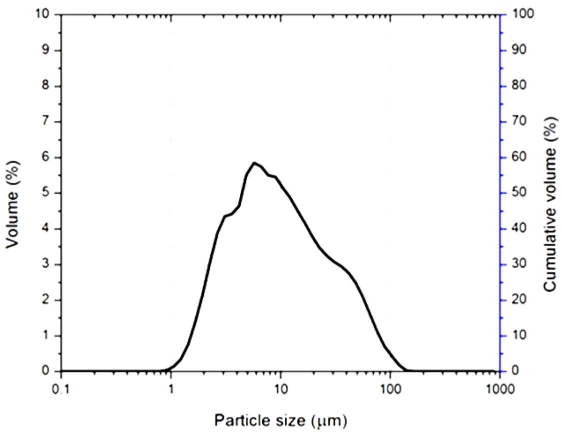

Fig. 1 Particle size distribution of clay body.

2.2 Preparation of Brick Specimens

To determine the extent of the pore-forming effect of the use sawdust waste, additive was dry sieved through No. 45 mesh and finally the sawdust waste particle sizes was obtained in the ranges from 0.5-1.0 mm. Then, it was added in to the raw-brick clay body in different proportions (0, 2.5, 5, 7.5, and 10% by weight), in order to form specimens with internal dimension of 14 cm x 6.5 cm x 4.0 cm and molded with hand. Specimens were dried at 110 °C for 24 hrs, after that fired at 900 °C, 1000 °C and 1100 °C with soaking time for 30 min.

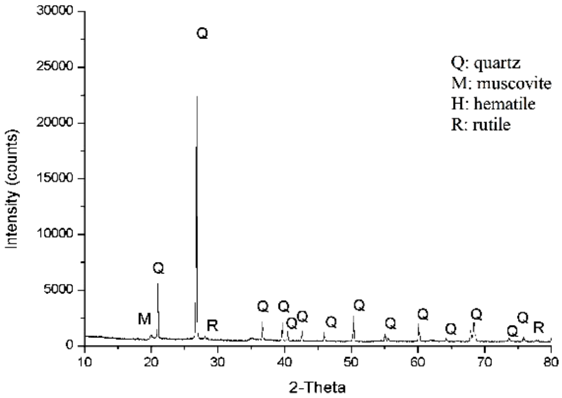

Fig. 2 XRD pattern of clay body.

Table 1 Chemical compositions of clay body.

Oxide content	Clay body (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 (Loss on ignition)	8.74

Fired shrinkage was measured in accordance with the standard ASTM C326-09 [17]. The water absorption, bulk density and apparent porosity of brick specimens were tested using the Archimedes method in accordance with ASTM C373-14a [18]. The mechanical strengths of fired clay bricks were measured using the methods specified in ASTM C773-88 [19] and a digital camera was used to study the surface texture of fired clay bricks. The thermal conductivity measurement test was conducted according to an adapted experimental procedure of international standards ASTM C177-97 [20]. The thermal conductivity was calculated using the following equation:

$$\frac{dq}{dA} = k\frac{dT}{dx} \quad (1)$$

Where q is the rate heat flow in direction normal to surface (W), k is the thermal conductivity (W/m K), A is the surface area (m^2), dT is the temperature difference, the thickness (K) and dx are the distance measured normal to surface (m). Fired brick specimens mixed with an increasing amount of sawdust waste 0%, 2.5%, 5.0%, 7.5%, and 10%. All specimens were fired at 1000 ^oC with a size of 30 cm wide, 30 cm long and 25 mm thick for the measurement of thermal conductivity respectively.

3. RESULTS AND DISCUSSION

3.1 Firing Shrinkage

Firing shrinkage of clay bricks occurred due to the loss of water from clay structure during the firing process. Clay particles were then moved closer that affected higher shrinkage [3], [8]. However, the degree of shrinkage could be controlled by firing process. Fig. 3(a) shows the firing shrinkage of clay bricks with sawdust waste additions after fired at 900-1100 ^oC. In firing factor, shrinkage was increased with higher firing temperature because of the elimination of the pores. It was observed that the firing shrinkage tended to increase with increasing amount of sawdust waste in clay mixture at the same temperature. This was explained that carbon phase was eliminated from sawdust residues structure, leading to high driving force to improve surface area during firing process. In general, an increase in firing shrinkage. Generally, good quality of fired clay bricks exhibits shrinkage below 8% [11]. The results showed that the firing shrinkage occurred in the fired clay brick was in the range of 4.27-7.31% and were within the limit of ASTM standard C62-13a. The control samples without any sawdust waste addition had comparable firing shrinkage of 4.72-6.36%.

3.2 Bulk Density

The bulk density of fired clay bricks is an important parameter on the performance of the fired clay bricks. This is beneficial in terms of the reduction of the overall dead load and the improvement of the thermal behavior of structure. As the bulk density of clay bricks decreases, its strength also decreases, while its water absorption increases. In this study, the bulk density of fired clay bricks was inversely proportion to the quantity of sawdust waste added in the mixture. The bulk density of clay bricks was decreased with increasing sawdust waste content in the clay bricks. This behavior was associated some generated pores from sawdust waste combustion could not be eliminated in clay structure. The results indicated that the values of bulk density of specimens containing sawdust waste varied from 1.41 to 1.83 g/cm^3 (Fig. 3b). The bulk density is related to durability and water absorption characteristics of clay bricks. The high bulk density indicated the denseness of the clay brick with usually increased durability and reduced water absorption.

3.3 Water Absorption

The durability of clay brick is related to the water absorption of clay brick. The durability of clay brick can be reduced when the brick absorbs water. It is important that the brick should be dense to reduce water absorption in the brick body [21]. According to Fig. 3c, it could be seen that the water absorption slightly increased when sawdust waste increased in the range of 12.3-22.5%. In the part of different firing temperatures, it was found that water absorption of clay bricks decreased with increasing firing temperature where the bricks got stronger. Reduction in water absorption rate in brick structure associated with an increase in compressive strength [22]-[23]. The control specimens without sawdust waste addition had comparable water absorption of 10.8-14.5%. The results of water absorption normally confirmed with the results of porosity.

3.4 Apparent Porosity

Apparent porosity is an important characteristic of fired clay brick and related to the capacity of water absorption [22]. The high porosity of clay brick affected on the reduction of thermal conductivity that is required for insulating materials**.** The study results that fired clay bricks showed various apparent porosity depending on the amount of sawdust waste addition. The highest porosity was about 32.40% for 10% sawdust waste addition after fired at 900 ^oC. The lowest porosity of 22.80% was obtained in the bricks containing 2.5% sawdust waste and fired at 1100 ^oC, as shown in Fig. 3d. Thus, porosity in fired clay bricks was caused when sawdust waste addition was burnt out during firing process. Therefore, the higher the amount of sawdust waste in clay brick, the higher the open porosity and hence the more porous clay brick as a result.

3.5 Compressive Strength

For the building materials, the compressive strength was considered to be very important [22]. Fig. 4 shows the compressive strength of specimens after fired at 900 °C, 1000 °C, and 1100 °C with different sawdust waste addition.

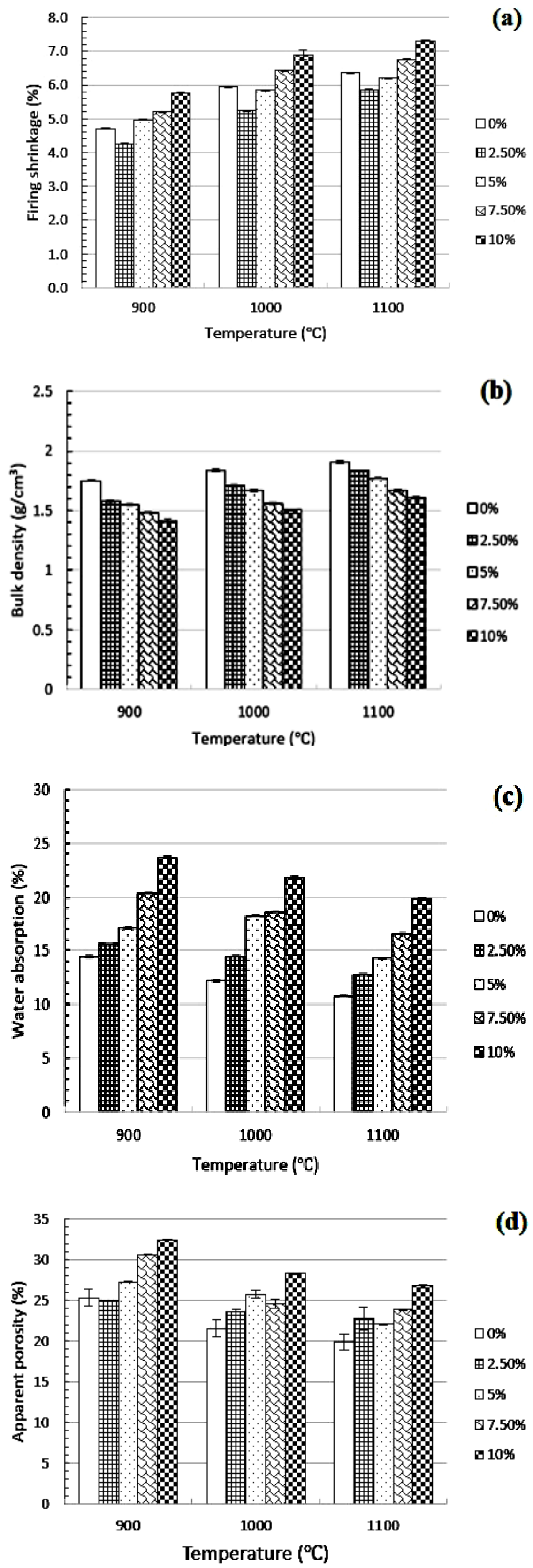

Fig. 3 Physical properties of clay brick fired at 900 to 1100 ºC: (a) firing shrinkage, (b) bulk density, (c) water absorption and (d) apparent porosity.

The results found that the compressive strength of the clay bricks decreased with an increase in the sawdust waste amount, due to the reduction in density and increase in porosity.

However, the compressive strength can be increased by an increasing in the firing temperatures, due to an increase in density and reduction in porosity. To increase in firing temperature from 1000 to 1100 °C substantially increases the compressive strength of fired clay bricks. The compressive strength values varied in the ranges of 4.35-18.2 MPa for samples were added sawdust waste ratios ranging from 2.5 to 10 wt.%. The specimen was give the most satisfactory results is a mixture ratio of 2.5% by weight and fired at 1100 ºC. The compressive strength was obtained from this condition is 18.2 MPa that are adequate when compared to the ASTM C62-13a, as required 17.2 MPa [24].

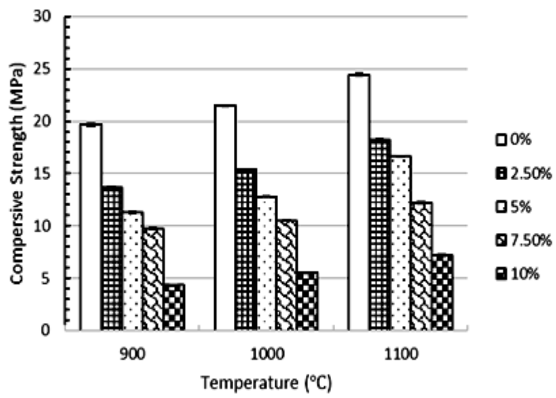

Fig. 4 Compressive strength of fired clay bricks.

3.6 Thermal Conductivity of Fired Clay Bricks

The thermal conductivity was analyzed only for specimens that have been fired at 1000 °C. Fig. 5 presents the thermal conductivity of fired clay bricks were added sawdust waste of 0 to 10% by weight and fired at 1000 °C. The results indicated that the specimens with a higher percentages of sawdust waste induced low thermal conductivity. Especially, a mixture ratio of 10% wt.% gives the lowest thermal conductivity. This results, it could be explained that the thermal conductivity is related to the density and porosity in the fired clay bricks (i.e., the thermal conductivity decreased with a decrease in the density and an increase in the porosity). It was shown that the thermal conductivity is directly proportional to the density and inverse with the porosity of the fired clay bricks. An understanding of the heat conduction process involves the porosity that occurs in clay bricks, which directly relates to the density.

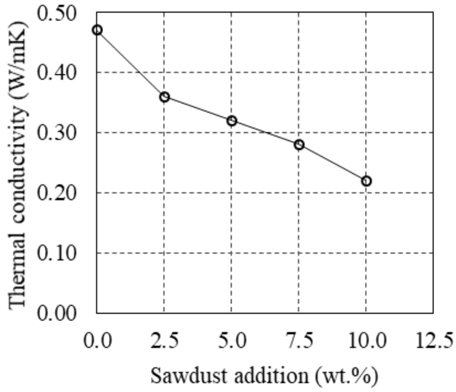

Fig. 5 Thermal conductivity of fired clay bricks at 1000 °C

3.7 Surface Texture of Fired Clay Bricks

Surface texture of fired clay bricks with different sawdust waste addition are presented in Fig. 6 (cross-sectional view). The fired clay bricks specimens contained the sawdust mixture will appear the visible pores that can be seen after firing at various temperatures. This results illustrated the effect of mixing sawdust waste in the texture of fired clay bricks, it affects to the water absorption, porosity, and density of the fired clay bricks. The fired clay bricks with high content of sawdust waste also showed high level of visible pores. In addition, the firing method, the chemical composition of clay and the firing temperature also affected with the color of fired clay bricks. The color of fired clay bricks also became darker with the increasing firing temperature. In our study, the bricks fired at high temperature (1000 and 1100 °C) were reddish-brown caused of iron oxide.

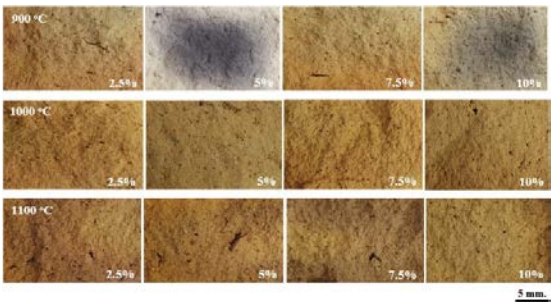

Fig. 6 Surface texture of fired clay bricks specimens fired at 900 to 1100 °C with different percentages of sawdust waste.

4. CONCLUSION

In conclusion, the results showed that sawdust waste could be used as pore forming additive in making fired clay bricks. The results show that the addition of sawdust waste affects to the physical, mechanical, and thermal properties. The sawdust waste-clay bricks with a higher sawdust waste content displayed an increase in firing shrinkage, water absorption, and porosity. But it can be reduced by using a higher firing temperature in the case of water absorption and porosity, whereas the shrinkage is still increase. The density and compressive strength of the clay bricks decreased with an increase in the sawdust waste addition and it can be increase by using a higher firing temperature. However, good compressive strength of clay bricks received for this study and accordance with the ASTM standart (requirement of 17.2 MPa), is a mixture ratio of 2.5 wt.% of sawdust waste and fired at 1100 °C (18.2 MPa). While the thermal conductivity of the clay bricks tended to decrease with an increase the sawdust waste addition. The thermal conductivity varied from 0.47 to 0.22 W/mK for the clay bricks with added the sawdust waste of 2.5-10% by weight and fired at 1000 °C when compared to the clay bricks specimen without addition. This result was due to the higher porosity, resulting in decrease of heat conductivity.

5. ACKNOWLEDGMENTS

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