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Contributed Paper

Utilization of Sugarcane Bagasse Ash to Improve Properties of Fired Clay Brick

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ABSTRACT

In this paper, the effects of incorporation of sugarcane bagasse ash (SCBA) on the properties of fired clay bricks were investigated. Clay bricks fabricated with 0, 2.5, 5, 7.5 and 10% by weight SCBA were tested. The clay brick specimens were fired at 900, 1000 and 1100 °C to study for water absorption, density, porosity and compressive strength of the brick samples were investigated. The bulk density of the tested specimens varied upon the SCBA dosage level and the dosage level of up to 10 wt.% was found to be satisfactory in this work. This was accompanied by the increases in water absorption and porosity and reduction in compressive strength of samples. The compressive strengths of bricks with 2.5 % SCBA fired at 1000 °C and with 2.5, 5.0 and 7.5 % SCBA fired at 1100 °C were higher than the required strength values as per ASTM C62-13a with beneficial reduced density and increased porosity. The firing shrinkage values were slightly increased with increasing in the SCBA content but were still within limit of the standard requirement. The results thus showed that SCBA was a potential material for use as a pore former additive to raw clay-brick production.

Keywords: sugarcane bagasse ash, clay brick, porosity, compressive strength, durability

1. INTRODUCTION

Bricks are wildly used around the world as construction materials [1]. Nowadays, bricks are still being used for the same purpose [2]. It is important that the quality of clay bricks must be high for use as construction materials in modern construction. Bricks should be homogeneous, hard and has strong bonding from the fusion of materials during firing process [3]. The fired clay brick should also contain high porosity to give lower density and the associated low thermal conductivity. The agricultural wastes such as rice husk, tobacco, sugarcane bagasse, coconut husk, cotton stalk, tea, grass and sawdust are therefore often utilized [4,5]. Using recycling agricultural by-products as performance enhancing additives in the brick industry is quite attractive [6]. Porosity is an important microstructural feature in most natural and man-made materials and often affects significantly the physical properties of these materials such as fluid permeability and thermal conductivity. 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 [7]. The pore system is also important considering the stability of thermal isolation of bricks in humid condition. The higher porosity and mean pore radius was found to decrease the difference between the thermal conductivity measured at 0 and 100% R.H. [8]. The advantage and application of the high porosity brick are the light weight structure and better thermal insulation.

Sugarcane bagasse ash (SCBA) is obtained from the burning of bagasse as a heat source in the sugar industry [9]. The sugarcane bagasse ash contains approximately 62% of silica, and some minor components of alumina, calcium oxide, ferric oxide, and potassium oxide. Quartz and cristobalite are the major crystalline phases found in the sugarcane bagasse ash [10,11]. A number of researchers have investigated the use of sugarcane bagasse ash particularly in ceramics materials, fired clay bricks, cement, mortar and concrete mixtures [12-20]. Faria et al. (2012) investigated the use of sugarcane bagasse ash in the manufacture of clay bricks at temperature of 1000 °C. The results indicated the increase in water absorption and decreases in firing shrinkage and tensile strength of clay bricks with the increasing in the amount of SCBA. The use sugarcane bagasse ash up to 10 wt.% into clay brick body was thus recommended. This ensures that the strength is not severely affected and the use of sugarcane bagasse ash in the brick industry is sustainable and safe [16]. Other researchers also suggested that sugarcane bagasse ash could be used as a raw material for the production of clay bricks [14,16], however, the high firing temperature of 1100 °C adversely affected the strength of bricks [21].

The SCBA contained a high amount of loss on ignition as shown in Table 1. The loss on ignition related mainly to the presence of organic matter (organic carbon). Firing the bricks with SCBA, the organic matter was burnt off leaving the pore in the brick body. This altered the properties of the fired brick containing SCBA. The aim of this study was to determine the feasibility of using the sugarcane bagasse ash (SCBA) as a pore forming additive in making fired clay bricks with firing temperature in the range 900-1100 °C. The effects on the physical properties, mechanical properties and surface morphology of fired clay bricks were discussed.

Table 1. Chemical compositions of the clay and SCBA.

Oxide	Clay (wt.%)	SCBA (wt. %)
SiO_2	58.76	88.03
Al_2O_3	21.34	2.31
Fe_2O_3	5.10	3.67
CaO	0.21	2.55
K_2O	3.10	0.32
Na_2O	-	0.28
P_2O_5	-	-
TiO_2	0.93	-
MnO	1.18	-
MgO	-	-
LOI (Loss on ignition)	8.74	10.57

2. MATERIALS AND METHODS

2.1 Characterization of Raw Materials

Raw clay used in this study was obtained from the local brick plant in Maha Sarakham province, Thailand. Chemical analysis of the clay was carried out using X-ray fluorescence (XRF) elemental analysis spectrometer (Horiba Mesa-500 w). Chemical compositions of raw clay and sugarcane bagasse ash (SCBA) are given in Table 1. The mineralogical compositions of clay and sugarcane bagasse ash were obtained using X-ray powder diffraction (XRD Panalytical X' Pert PRO MPD, Netherland). The XRD pattern of clay showed quartz as the main component with small amounts of muscovite, hematite and rutile (Figure 1) where in SCBA the main phase consisted of quartz and cristobalite as shown in Figure 2. The particle size distribution of raw clay was analyzed by diffraction using Mastersizer, Melvern Instrument Ltd. as shown in Figure 3. The results showed the particle size distribution in the range of 1-200 μm with D [4, 3] of 14.91 μm. The raw clay is dark in color and its particle size distribution can give good compactness which results in low porosity.

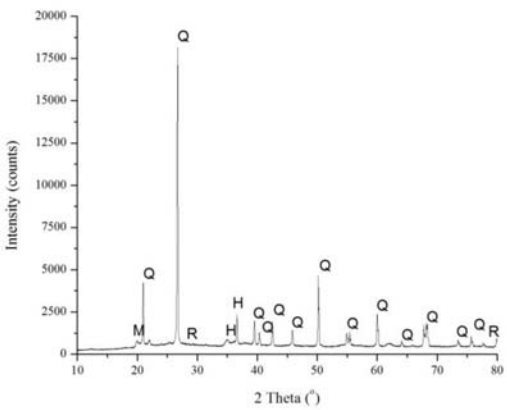

Figure 1. X-ray diffractrogram of the clay (Q : quartz, M : muscovite, R : rutile, H : hematite).

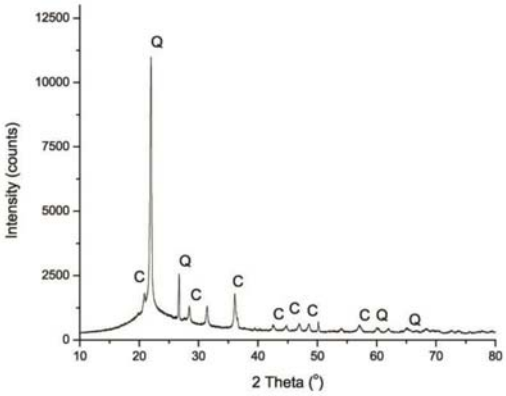

Figure 2. X-ray diffractrogram of SCBA (Q : quartz and C : cristobalite).

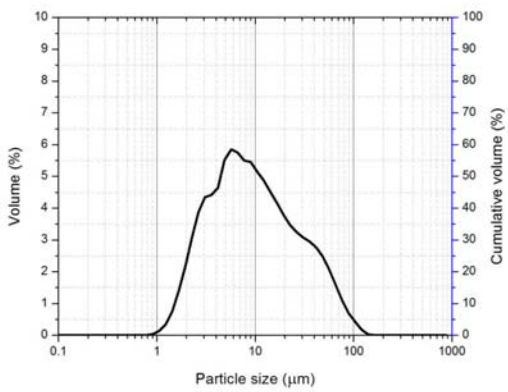

Figure 3. Particle size distribution of clay.

2.2 Preparation of Specimens

The amounts of SCBA used in fabricating the samples were 0, 2.5, 5, 7.5 and 10%. The clay and SCBA were mixed using ball mill to obtain homogenous mixture. Water content of 20-25% was added to the mixture during ball milling to obtain a good plastic condition. Clay brick specimens with sizes of 14 cm × 6.5 cm × 4.0 cm were molded with hand. The samples were dried at 110 °C for 24 h and then fired at three different temperatures; 900, 1000 and 1100 °C using a heating rate of 2 °C/min and soaking time of 30 min.

2.3 Characterization

The linear shrinkage was measured in accordance with the standard ASTM C326-09 [22]. The water absorption, bulk density and apparent porosity of brick samples were tested using the Archimedes method in accordance with ASTM C373-14a [23] and a digital camera was used to study the surface texture. The mechanical strengths of fired clay bricks were measured using the methods specified in ASTM C773-88 [24]. The X-ray diffraction analysis (XRD) of unfired clay brick and the 5% SCBA fired clay bricks at temperatures of 900, 1000 and 1100 °C were also performed.

3. Results and Discussion

3.1 Firing Shrinkage

The linear shrinkage occurred due to the lost of water from clay bodies during firing. When the clay body lost some water and the solid particles moved closer, shrinkage of clay brick resulted [2,25,26]. As expected, in this study the firing shrinkage increased with increasing firing temperatures from 900 to 1100 °C. Also, there was an indication that the linear shrinkage increased with increasing amount of SCBA in the clay mixture (Figure 4a). Shrinkage in shaping clay bricks occurs due to the leaving of water from the clay body. In other words, when the reduction of water between clay particles occurs, particles come closer and shrinkage starts. To minimize shrinkage, firing temperature which is an important parameter affecting the degree of shrinkage must be controlled during the firing process [4]. In general, an increase in the temperature results in an increase in shrinkage. Normally, a good quality of bricks exhibits shrinkage below 8% [27]. This influenced the burning characteristics of clay brick. With increased SCBA content and reduced amount of clay. Similar finding of increase of shrinkage with increased firing temperature has been reported [21]. The linear shrinkages of SCBA specimens were in the range of 4.36-7.15% and were within the limit of ASTM standard C62-13a. The control specimens without any SCBA addition had comparable firing shrinkage of 4.72%- 6.36%. The lower shrinkage was due to the increase in the SCBA content.

3.2 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 [28]. It is important that the brick should be dense to reduce the water absorption in the brick body. From Figure 4b, it could be seen that the water absorption slightly increased with increasing amount of SCBA and the values were in the range of 13.1-22.7%. In general, water absorption of clay bricks decreased with increasing sintering temperature where the bricks got stronger. The increase in water absorption would cause clay bricks to be undesirable and could weaken the wall strength [29]. However, 2.5 and 5% of SCBA only slightly increased the water absorption values and thus caused minimal adverse effect on the brick properties. For example, at 1100 °C, the water absorption values of the brick were 11.0, 13.0 and 14.5 for 0, 2.5 and 5.0 % SCBA, respectively. The incorporation of 2.5% SCBA resulted in the reduction in porosity compared with that of the 0% SCBA brick (Figure 4c). This was associated with less water leaving for 2.5% SCBA and conformed with the reduction of shrinkage (Figure 4a). The results of water absorption normally conformed with the results of porosity. In this case, there is an increase in water absorption with the use of 2.5% SCBA for all firing temperatures (Figure 4b). This was probably due to the hand-shaping of brick using rather wet clay mixture. The SCBA particles could orient themselves such that the continuous pores were formed and this resulted in the increased water absorptions.

3.3 Apparent Porosity

Apparent porosity of fired clay brick is related to the capacity of water absorption [26]. The high porosity of clay brick is beneficial in terms of thermal properties i.e. brick with high porosity level has low thermal conductivity and is good for the insulating properties. The results in this work indicated that the apparent porosity depended on the amount of SCBA in the clay brick. The highest porosity of 30.12% was obtained in the fired clay brick containing 7.5% SCBA and fired at 900 °C. The lowest porosity of 20.0% was obtained in the bricks containing 0 and 2.5% SCBA and fired at 1100 °C (as shown in Figure 4c). This indicated that high SCBA content led to high porosity of the fired clay bricks increased due to the burning out of SCBA during firing process. Therefore, the higher the amount of SCBA in clay brick, the higher the open porosity and hence the more porous clay brick as a result.

3.4 Bulk Density

The bulk density of brick is an important parameter on the performance of the fired clay bricks. The low-density brick results in the low dead load of the structure as well as provides a reduced thermal conductivity of the brick. This is beneficial in terms of reduction of the overall dead load and the improvement of thermal behavior of structure. The bulk density of clay bricks (Figure 4d) decreased with increasing SCBA content in the clay bricks. This trend was expected and it was associated with the open porosity brought by the combustion of SCBA. The results indicated that the values of bulk density of samples containing SCBA varied from 1.47 to 1.95 g/cm^3. It was evident that the bulk density controlled the 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.

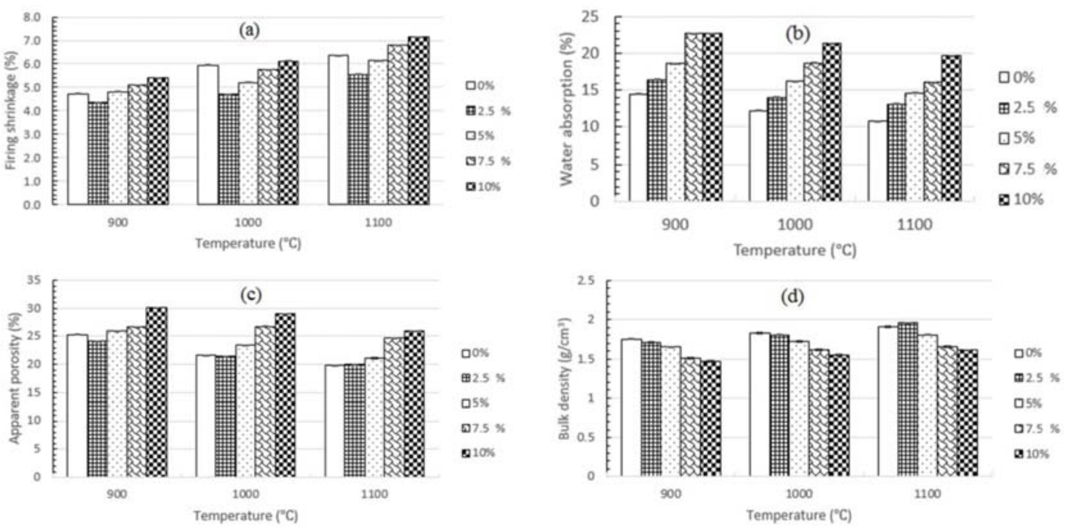

Figure 4. Physical properties of specimens with 0 to 10 wt.% SCBA fired from 900-1100 °C: (a) firing shrinkage, (b) water absorption, (c) apparent porosity and (d) bulk density.

3.5 Compressive Strength

Strength is one of the most important parameter for the quality of construction materials [30,31]. According to ASTM C62-13a [32], the Grade MW bricks must have minimum compressive strength of 17.2 MPa. In this study, the compressive strength of samples fired at 900 - 1100 °C depended on the SCBA content in the clay bricks. With increasing firing temperature, the strength of the bricks increased due to a decrease in porosity and an increase in density. The results showed that the compressive strengths of the samples varied from 10.53 to 24.47 MPa with corresponding 2.5 to 10 wt.% SCBA. The results in figure 5 showed that bricks with 2.5 % SCBA fired at 1000 °C had adequate strength of 19.5 MPa compared to 17.2 MPa as required by ASTM standard [32]. At the firing temperature of 1100 °C, bricks with 2.5, 5.0 and7.5% SCBA had adequate strengths of 22.5, 20.5 and 17.7 MPa.

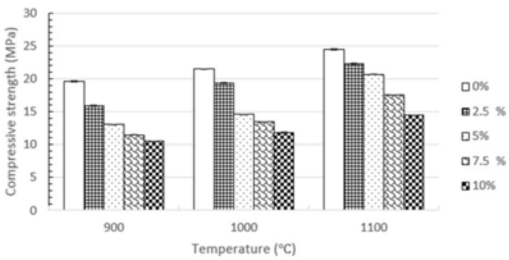

Figure 5. Mechanical strengths of the fired clay bricks.

3.6 Surface Texture of Fired Clay Brick

Figure 6 shows the surface texture of the fired clay bricks with 2.5, 5, 7.5 and 10 wt.% SCBA. The fired clay bricks samples with SCBA contained visible pores when fired from 900 to1100 °C. The results revealed the effect of mixing SCBA on the fired clay brick specimens which can be seen in the cross-section a view. The results correlated well with the water absorption, porosity and density of the brick. The bricks with high content of SCBA also showed high level of visible pores. Beside the firing method, the chemical composition of clay and the firing temperature also affected with the color of bricks. The color of 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. This reddish-brown color indicating the dense and strong bricks, which according to the observed lower absorption values and higher compressive strength.

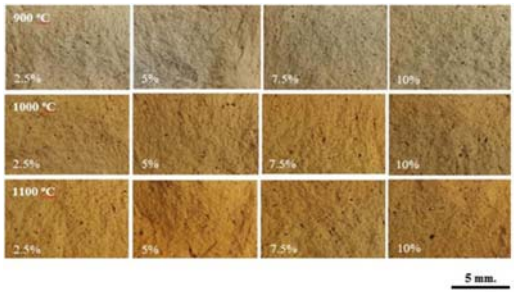

Figure 6. Surface texture of clay bricks fired at 900 to 1100 °C with different percentages of SCBA.

The XRD patterns of unfired and fired clay bricks with different firing temperatures are presented in Figure 7. For unfired brick, quartz is the main phase with some minor phases of hematite, muscovite and rutile. The rutile phase was depleted after firing. From Figure 7, the anorthite phase was present in the 5 % SCBA bricks with high firing temperatures of 1000 and 1100 °C. This suggested that the anorthite phase was formed for the high firing temperatures.

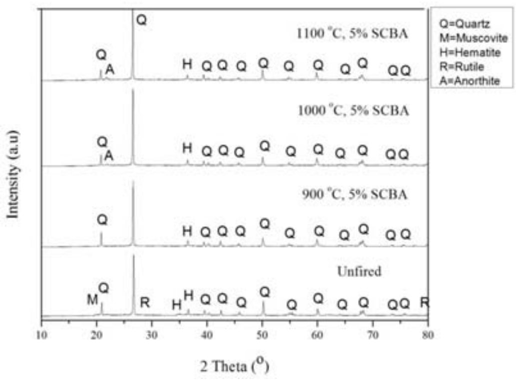

Figure 7. X-ray diffraction of unfired clay brick and 5% SCBA fired clay bricks fired at 900-1100 °C.

4. Conclusions

In conclusion, the results showed that SCBA could be used as pore forming additive in making fired clay bricks. The results indicated that the addition of SCBA does have a reduction effect on compressive strength. However, good strength bricks which meet the ASTM strength requirement of 17.2 MPa could be obtained with 2.5 % SCBA fired at 1000 °C and 2.5, 5.0 and 7.5% SCBA fired at 1100 °C. The SCBA-clay bricks had lower density due to the pore forming characteristics of SCBA when compared to the control bricks without SCBA. The reduced density was the added beneficial property of fired clay and lightweight bricks.

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