Effects of Additive on the Physical and Thermal Conductivity of Fired Clay Brick

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***Abstract*-This research studies physical, mechanical and thermal properties of fired clay bricks due to the effects of charcoal addition. Thermal performance with the physical, mechanical and microstructures properties were also investigated. All samples were fired at 950 °C. The results indicated that the density of fired clay bricks was reduced by up to 10 wt%, depending on the percentage of charcoal incorporated into the raw materials. Compressive strength of fired clay bricks samples decreased according to the percentage of charcoal included in the mix. When the percentage of charcoal was up to 10 wt%, water absorption and apparent porosity was rapidly increased. It was apparent that as the percentage of charcoal increased in the body, the porosity was clearly observed. From the results, it can be reduced that thermal conductivity decreases with decrease in density and increase in fired clay bricks porosity.**

Keywords- Brick; Porosity; Compressive Strength; Density; Charcoal

I. INTRODUCTION

Bricks are construction materials which have been used since ancient times and currently display different states of deterioration in numerous historic buildings[1]. Nowadays, bricks are still being used for the same purpose[2]. Thermal conductivity of a building material is an important parameter in calculating and designing the HVAC system and implementation including energy consumption of the building[3]. Consequently, the thermal insulation properties of building materials such as traditional clay bricks are of paramount importance[4]. Thermal conductivity performance is an important criterion of building materials because the thermal conductivity influences the selection of building materials in engineering application[5]. The thermal conductivity of a brick is the rate at which a brick conducts heat. Heat losses from building are dependent on the thermal conductivity of materials in the walls and roof. Building bricks must be able to minimize the heat flow from one side of the bricks to the other[6]. There are two 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 rectangular cross-section[7]. These studies point out that the thermal conductivity of bricks is mainly related to their bulk density, so that increasing the thermal insulating properties implies the production of materials with a higher porosity[8]. In this study, charcoal was used as an additive for making clay brick samples.

This paper studies physical, mechanical and thermal properties of fired clay bricks due to the effects of charcoal addition.

II. EXPERIMENTAL

In order to measure the physical and mechanical properties and feasibility of using charcoal material for brick production, the materials and methods are explained in this section.

Charcoal and Hang Dong clay used as raw materials were obtained from Hand Dong district in Chiang Mai province, Thailand. Charcoal used as an organic additive is available in the northern part of Thailand (Fig. 1). The chemical composition of clay body and charcoal was determined by X-ray fluorescence (XRF) that shown in Table 1. While the mineralogical composition of clay body and charcoal were achieved using an X-ray diffractometer (XRD). The major crystalline phase found in charcoal contained quartz and cristobalite, while in Hang Dong clay consisted of quartz, muscovite, kaolinite, alkali-feldspar and hematite. The average particle size distribution of Hang Dong clay was analyzed by diffraction (Mastersizer 2000+Hydro 2000 MU) as shown Table 2. The texture of the fired clay bricks was examined with a light microscopy (Olympus, stemi 2000-C).

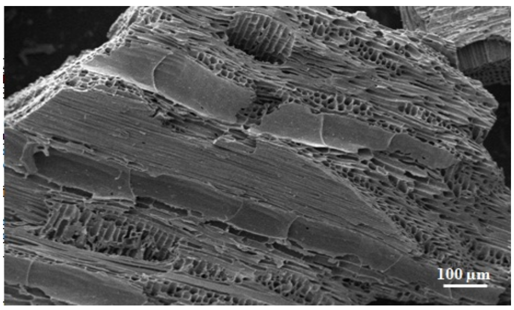


Fig. 1 SEM image of charcoal.

TABLE I CHEMICAL COMPOSITION OF CLAY AND CHARCOAL OBTAINED FROM HANG DONG DISTRICT USED IN THE EXPERIMENT

Constituents	**Hang Dong clay (wt %)**	**Charcoal (wt %)**
SiO_2	59.94	87.92
Al_2O_3	20.84	<0.01
Fe_2O_3	4.90	-
CaO	0.20	0.36
K_2O	2.20	1.58
P_2O_5	-	0.80
TiO_2	0.84	-
MnO	1.60	0.17
LOI (Loss on ignition)	9.30	8.70
Total	99.82	99.84

TABLE II PARTICLE SIZE DISTRIBUTION OF CLAY

Particle size (μm)	**wt%**
0-10	23.70
10-50	47.90
50-100	16.20
100-150	6.10
150-200	3.10
200-300	2.20
300-400	0.80

The thermal conductivity measurement test was conducted according to an adapted experimental procedure of international standards ASTM C177[9]. The thermal conductivity was calculated by using the following equation:

$$\frac{dq}{dA} = k\frac{dT}{dx} \tag{1}$$

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).

In order to determine the extent of the pore-forming effects of the charcoal, the particle size of charcoal additive was obtained by dry sieving through No. 45 mesh. It was added into raw brick clay and divided into, four different samples mixed with increasing amount of charcoal (0%, 2.5%, 5.0% and 10% by weight). Also, Archimedes method based on ASTM C373-88 was used to determine the water absorption, apparent porosity and bulk density. The compressive strength of fired clay bricks was measured according to the standard of ASTM C377-88[10, 11]. Green bodies brick with the dimensions of 16.0 cm x 6.5 cm x 4.0 cm. Samples were air dried at room temperature for 24 hrs, and then over dried at 110 ± 5 ^oC. And fired clay bricks samples with the size of 30 cm wide x 30 cm long and 25 mm. thick for the measurement of thermal conductivity respectively. Then, each group of green samples was fired at 950 ^oC with two hours soaking time in gas kiln furnace.

III. RESULTS AND DISCUSSIONS

Experimental results of the samples fired at 950 ^oC are given Table 3. The density of clay brick depends on specific gravity of the raw material used, method of manufacturing and degree of burning[12]. In this study, the bulk density of clay brick samples decreased with an increase in the amount of charcoal from 0% to 10%. As a result, they caused bulk density in the ranges of 1.49-1.80 g/cm^3 (Table 3). Water absorption is an important factor affecting the durability of clay brick. When water absorption infiltrates the bricks, it decreases the durability of bricks[13]. The charcoal additions in the sample were burnt out through the process of firing leaving abundant pores in clay bricks[14]. Accordingly, the quality of the samples in water absorption was closely related to the porosity of the fired clay bodies. The Thailand standard TISI-77 requires the maximum water absorption of 25% as a standard for masonry bricks[15]. According toTable. 3, in this study the water absorption of clay bricks fired at the temperature 950 ^oC was in the range of 17.18-33.21%.

TABLE III MEASURED VALUES OF THE CLAY BRICK SAMPLES FIRED AT 950 °C

Properties	Percent charcoal additions by weight			
	0%	2.5%	5.0%	10%
Bulk density (g/cm^3)	1.80	1.68	1.63	1.49
Water absorption (%)	17.18	18.27	19.98	33.21
Apparent porosity (%)	28.96	31.45	35.14	46.85
Compressive strength (kg/cm^2)	152.66	143.45	90.57	78.59
Thermal conductivity (W/m.K)	0.270	0.262	0.252	0.216

Another important factor of water absorption of bricks is the amount and size of apparent porosity of bricks. In other words, the capacity of water absorption is directly proportional to the amount and size of apparent porosity[16]. The higher number and the larger size of porosity the bricks have, the more water absorption of the bricks can achieve. Therefore, in this study, similar trends were observed in water absorption and apparent porosity. Apparent porosity and water absorption values were increased with increase charcoal addition while the bulk densities were significantly reduced. The porosity in clay brick samples was caused when charcoal was burning out during firing process. As a result, this study yields findings that the highest apparent porosity was 46.85% (10% of charcoal addition) and the lowest 28.96% without any charcoal addition at the temperature 950 °C firing process (Table 3). The most important test for assuring the engineering quality of building material is the compressive strength of the material[16]. According to the TISI-77 standard, the compressive strength of bricks must be 35 kg/cm^2. In this study, the compressive strength of brick samples with 0 - 10% addition of charcoal and 950 °C firing process was in the ranges of 78.59-152.66 kg/cm^2 (Table 3). However, an increase in the charcoal addition and porosity content can affect the compressive strength of clay bricks. It was found that the compressive strength of brick samples varied depending on the amount of charcoal addition and temperature of firing process. That is the compressive strength decreased with an increase in the porosity due to higher amount of charcoal addition and the lower temperature firing process.

The thermal conductivity analysis was performed on test fired clay bricks mixed with charcoal 0%, 2.5%, 5.0% and 10% by weight and fired at 950 °C. The thermal conductivity was calculated by using the Equation (1).

The relation between thermal conductivity and porosity of the clay bricks with charcoal addition could be observed in Table 3. It is evident that increasing the percentage of charcoal caused more porosity. The burning out of charcoal in the body during the firing process caused the porosity in fired clay bricks. The results show that higher percentages of charcoal induce low thermal conductivity to the samples. This is as a result of the increase of air volume obtained by the burning of the charcoal, 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 reduced that thermal conductivity decreases with decrease in density and increase in fired clay bricks porosity. As a result, the thermal conductivity values vary with porosity as shown in Fig. 2.

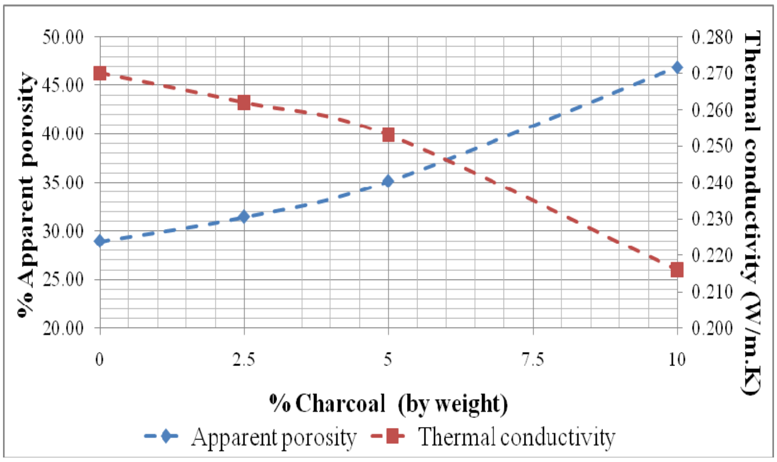
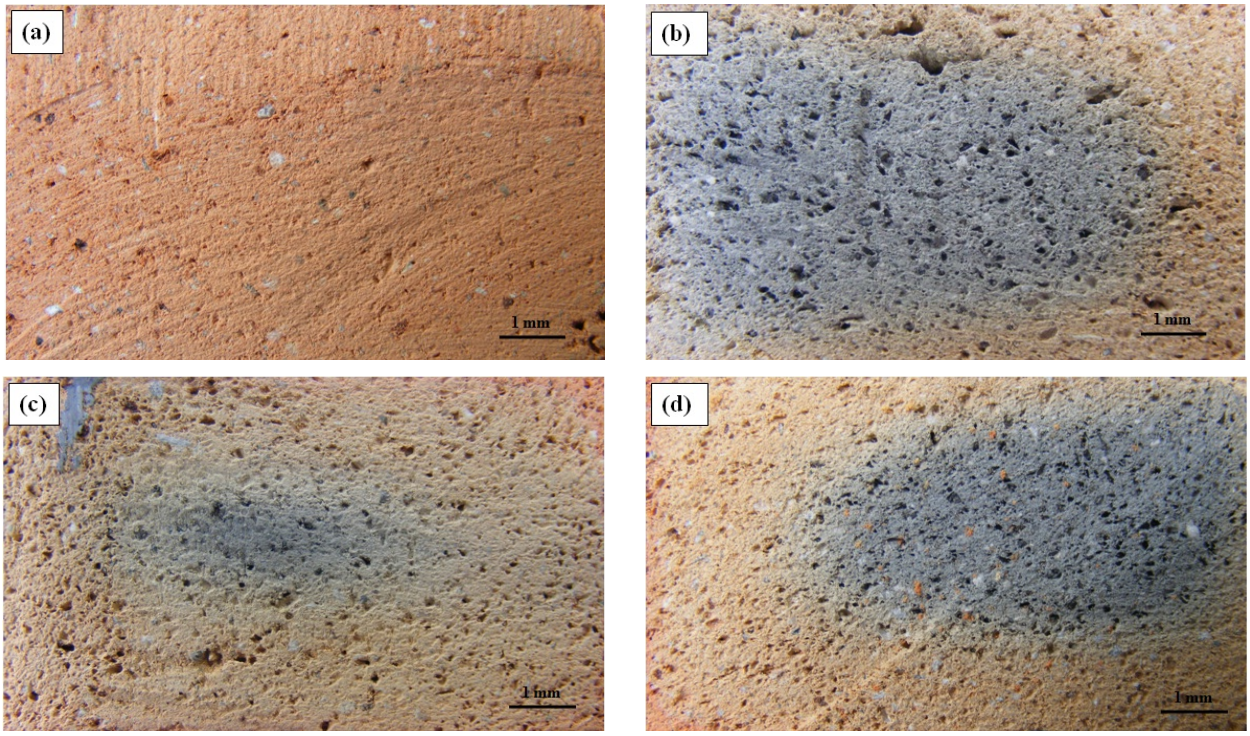


Fig. 2 Relation between thermal conductivity (k) and apparent porosity (%).

Figs. 3 (a)-(d). show the microstructure of the fracture surface of fired clay bricks samples with different charcoal contents and fired at 950°C. The images illustrate when charcoal contents increase, the micro-pores of the samples also increase. This is the main factor in manipulating charcoal content addition to the clay body and temperature of firing process to control water absorption that can affect compressive strength (Table 3). However, when the amounts of charcoal increased and the test bricks were fired, they also increased the size and amount of micropores. Thus, their compressive strength was reduced because compressive strength would be increased when there were a decrease in porosity and an increase in bulk density with increasing firing temperature[2].



Figs. 3 Surface texture of samples with various charcoal additions which were fired at 950 ^{o}C (a) 0 wt %, (b) 2.5 wt %, (c) 5.0 wt % and (d) 10 wt %.

IV. CONCLUSIONS

The characteristics and analysis of physical and mechanical properties of charcoal addition to clay content for the production of clay bricks are reported. The main goal of the addition of charcoal in clay body is to produce lightweight and more porous fired clay bricks. An increase in the content of charcoal addition leads to an increase in the water absorption and apparent porosity. While the value of bulk density and compressive strength of sample varied with the amount of charcoal. The more percentage of charcoal is added to clay body and the higher temperature is firing, the more compressive the strength is and the less water absorption of the fired bricks becomes. The reason for this is that during the burning out of charcoal in the body, the porosity occurred and the pores were open and continuous. As a result, the thermal conductivity decreases with decrease in density and increase in fired clay bricks porosity. The charcoal content significantly influenced the effective thermal conductivity of fired clay bricks. Conclusively, this study yields findings namely: charcoal could be regarded as a potential addition to raw materials used in the manufacturing of lightweight fired clay bricks.

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