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Using charcoal to increase properties and durability of fired test briquettes

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ABSTRACT

The clay composite and production process of fired clay bricks are essential for the sustainability of clay bricks. The aim of this study was to investigate the physical and mechanical properties of fired test briquettes due to the effects of charcoal addition and firing temperature. Their characteristics were carried out with the determination by TGA/SDTA, XRF, XRD and SEM. The study yielded findings, namely, test briquettes consisting of 2.5% of charcoal additive with sizes less than 0.5 mm mixed with Hang Dong clay specimen and fired at 950 °C achieved the most desirable mechanical and physical properties of fired test briquettes because fired test briquettes were more durable, porous and stronger when compared with current commercial brick specimens that were tested. Thus, charcoal could be used as a pore former in clay body. Conclusively, the results revealed that charcoal could be regarded as a potential addition to raw materials used in the manufacturing of lightweight fired clay bricks.

1. Introduction

Clay bricks, which are a kind of a crystalline ceramic, are one of the oldest known building materials and dated back to the early civilizations [1]. Today, bricks are still being used for the same purpose. As urbanization expands, demand for bricks gradually increases [2]. However, the higher quality of fired bricks is essential for modern construction. Several studies have reported that bricks have been designed to become homogeneous, harder, stronger and porous due to the ceramic bond from the fusion phase of the silica and alumina clay constituents [3]. Most frequent used pore formers in clay brick manufacturing can be classified into two groups: organic and inorganic pore generators [4]. For organic generators, they are sawdust, coal, coke, papermaking sludge, grass and rice husk, and inorganic ones are polystyrene, perlite and dolomite or calcite. In this study, charcoal is used as a pore forming agent for several reasons. Charcoal is locally produced from shrubs and twigs eliminated from fruit plantations in the northern part of Thailand. Although charcoal production is an energy requiring process, when charcoal is used as an additive to clay, it can help save energy in brick production. Other pore forming agents such as waste from processed waste coffee beans and sawdust have been tested and investigated. The studies yielded unsatisfactory results because the strength of bricks was inconsistent and low due to large pores.

Thus these combustible materials including charcoal are used as pore forming agents in the production of light weight bricks. They also make fired bricks become an insulating material thereby saving energy. Due to the fact that energy consumption in the early part of the firing process is reduced, the large amount of energy is generated by the combustion of the pore forming. Thus it results in considerable savings in fuel [5]. Firing temperature is an important factor in clay brick making industry. It influences the mineralogical, textural and physical formation of clay bricks. The density, water absorption, strength and linear shrinkage properties are directly affected by firing temperature especially at vitrification point [6]. Fired clay brick manufacturing is one of the possible ways to dispose of organic and inorganic waste because, an organic waste additive is burnt out, and it causes porosity in the structure in brick production [7]. In this study, charcoal was used as an additive for making clay brick specimens. Charcoal is a form of amorphous carbon. It is produced when wood, peat, bones, cellulose, or other carbonaceous substances are heated with little or no air present. As a result, a highly porous residue of microcrystalline graphite remains. Charcoal is a fuel and it had been used in blast furnaces until coke was introduced and replaced it [8]. The main objective of the study was to investigate the feasibility of using charcoal as additive to clay body. The effects of firing temperature and the charcoal content in the clay mixture were discussed in terms of physical–mechanical properties and microstructure.

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2. Materials and methods

2.1. Properties of brick raw materials

Charcoal and Hang Dong clay (HD) used as raw materials were obtained from Hang Dong district in Chiang Mai province, Thailand. The charcoal used in this research is a form of amorphous carbon and highly porous residue of microcrystalline graphite remains (Fig. 1). Chemical analysis and loss on ignition (LOI) of HD clay were carried out prior to characterization by X-ray fluorescence technique (XRF: Mesa-500W, Horiba, Japan). The chemical composition of Hang Dong clay is given in Table 1. The average particle size distribution of Hang Dong clay was analyzed by diffraction (Mastersizer 2000 + Hydro2000 MU, Melvern Instrument Ltd., UK), as shown in Fig. 2. The mineralogical composition of raw brick clay and charcoal were achieved using an X-ray diffractometer technique (XRD: X' Pert PRO MPD, Philips, Netherland). The major crystalline phase found in charcoal contained quartz and cristobalite (Fig. 3a and b), while Hang Dong clay were quartz, muscovite, kaolinite, feldspar and hematite. Microstructures of the fired clay bricks were examined using SEM (JEOL JSE-5410 LV) and a TGA/SDTA (851^e STAR^e Thermobalance, Mettler Toledo, Switzerland). Coefficients of expansion (COE), of fired clay brick were measured as a function of temperature using a dilatometer (DIL 420 C, Netzsch, Germany). COE was calculated between 25 and 575 °C by using the following equation [9]:

$$COE = \Delta L/(L_0 \cdot \Delta T) \quad (1)$$

where ΔL = the dimension change of fired clay brick, L_0 = the original dimension of fired clay brick and ΔT = the temperature change.

2.2. Preparation of test briquettes

In order to determine the extent of the pore-forming effects of charcoal, charcoal additive was dry sieved step by step through meshes No. 35, 40 and 45 and finally the charcoal particle sizes obtained were less than 0.5 mm. Then charcoal additive was added into raw brick clay and divided into five different batches of specimens mixed with 5 different percentages of charcoal additives: 0%, 2.5%, 5.0%, 7.5% and 10%. Each batch of specimens was mixed in a porcelain ball mill in order to ensure homogenous mixing. Then, each was mixed with 20–30% of water to enhance plastic condition of mixture in order to obtain the desired shape when it was formed with brick hand molding into soft-mud rectangular test briquettes whose internal dimension was 5.0 cm × 9.5 cm × 3.0 cm. The test briquettes were air dried at room temperature for 24 h, and then over dried at 110 ± 5 °C for another 24 h to remove water content. Then, each group of green specimens was fired at four different temperatures: 900, 950, 1000 and 1100 °C with 2 h soaking time in gas kiln furnace. The specimens were naturally cooled down to room temperature in the furnace.

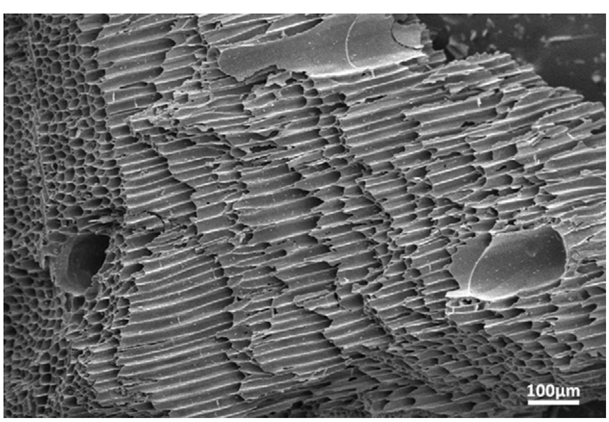

Fig. 1. SEM micrograph of charcoal.

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

Composition	Wt.%
SiO_2	59.94
Al_2O_3	20.84
Fe_2O_3	4.90
CaO	0.20
K_2O	2.20
TiO_2	0.84
Mn_2O_3	1.60
LOI*	9.30
Total	99.82

* LOI (loss on ignition).

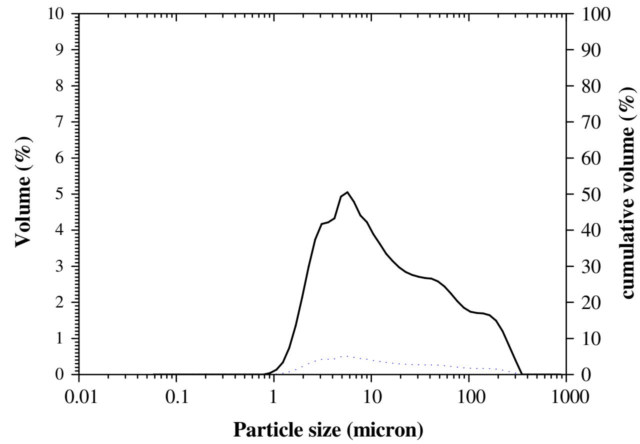

Fig. 2. Particle size distribution of Hang Dong clay.

2.3. Testing method for the physical and mechanical properties of fired test briquettes

In this study, the shrinkage of fired test briquettes was determined by direct measurement of a specimen length before and after firing at 900–1100 °C. The linear drying shrinkage and total linear shrinkage of fired test briquettes were measured and compared to the length of green test briquettes before firing in accord with the standard of ASTM C362-82 (2002) [10].

Archimedes method based on ASTM C373-88 (2002) was used to determine the water absorption, bulk density, apparent density and apparent porosity [11]. The compressive strength, of fired test briquettes was measured in accord with the standard of ASTM C773-88 (2002) [12].

3. Results and discussion

The results of the properties of five batches of fired test briquettes are summarized in Table 2. The physical and mechanical properties investigated and reported are firing shrinkage, water absorption, bulk density, apparent porosity, apparent density, compressive strength, thermal behaviors, and microstructure analysis vitrification. The fired test briquettes were formed from HD clay with the average particle size distribution of 1–200 µm, D [4,3] was 7 µm while charcoal particle sizes were less than 0.5 mm.

3.1. Effects of charcoal addition on properties of fired test briquettes

3.1.1. Firing shrinkage

In general, shrinkage used in shaping clay bricks occurs due to the leaving of water from clay body. In other words, when water between clay particles leaves, particles come closer and shrinkage occurs. To minimize shrinkage, firing temperature which is an important parameter affecting the degree of shrinkage must be controlled during the firing process [4]. An increase in the temperature results in an increase in shrinkage. Normally, a good quality of bricks exhibits a shrinkage below 8% [14]. In this study, test briquettes were fired at the temperatures between 900 and 1100 °C. The results indicated that shrinkage occurred in the test fired briquettes was in the range of 2.00–4.47%. As shown in Table 2, the percentage of shrinkage rises with an increase in the amounts of charcoal addition.

3.1.2. Density of fired test briquettes

The density of clay bricks depends on several factors which are specific gravity of the raw material used, method of manufacturing