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Effects of charcoal on physical and mechanical properties of fired test briquettes

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ABSTRACT: Organic combustible additives are frequently used to generate porosity in fired clay bricks. This study aims to investigate the effects of charcoal addition to fired test briquettes on their compressive strength, water absorption, apparent porosity, bulk density, and apparent density. The test results indicate that the amount of charcoal additive and the firing temperature are the key factors determining properties of the test fired briquettes. The study shows that low-density, porous, and lightweight briquettes can be made from Hang Dong clay mixed with charcoal additive.

KEYWORDS: lightweight bricks, porosity, water absorption

INTRODUCTION

Bricks can be sun-dried or fired in a furnace at a temperature ranging from 900–1200 °C[1,2]. However, fired bricks are usually stronger than sun-dried bricks, especially if they are made of clay or clayey materials[3]. Bricks can be divided into various groups according to their main mineral composition, namely silica, zirconia, alumina, mullite, magnesite, and dolomite bricks[4].

Bricks become homogeneous, harder and stronger due to the ceramic bond from the fusion phase of the silica and alumina clay constituents[5]. Brick properties are affected as a result of physical, chemical, and mineralogical alteration. Besides brick cracks, compressive strength and water absorption are two major physical properties of bricks that are potential predictors of their ability to sustain weathering effects reasonably well without cracking[6]. The main factors involved in manufacturing bricks are the type of raw material used and the firing temperatures, both of which affect the final product[1]. Additives are frequently used in brick production and the selection of additives depends on the characteristics required such as insulation. One way to increase the insulation capacity of bricks is to generate porosity in the clay body. Combustible, organic types of pore-forming additives are most frequently used for this purpose[7]. Organic pore formers are generally cheaper than inorganic ones and also have the advantage of ensuring a heat contribution to the firing furnace. Inorganic pore formers cause less environmental problems but they may change the plasticity of the clay system negatively and increase the amount of water needed to maintain an acceptable plasticity[8]. Organic product residues are extensively used as a pore former in the brick industry[9]. Attempts have been made to incorporate waste in the production of bricks, for example, rubber, limestone dust, wood sawdust, processed waste tea, fly ash, and sludge[10]. In this study, charcoal was used as an additive for making clay briquette specimens. Charcoal, a form of amorphous carbon, is produced when wood, peat, bones, cellulose, or other carbonaceous substances are heated with little or no air present. As a result, a very porous residue of microcrystalline graphite remains. Charcoal is a fuel and have been used in blast furnaces until the advent of coke[11]. The purpose of this study is to investigate the effects of charcoal addition on the properties of the briquette specimens. Different amounts of charcoal (0%, 2.5%, 5.0%, 7.5%, and 10% by weight) were added to original briquette specimens and fired at temperatures ranging from 900 to 1100 °C. The microstructural changes in the fired test briquettes were investigated using scanning electron microscope (SEM). The basic physical and mechanical properties of briquette specimens including compressive strength, water absorption, apparent porosity, bulk density, and apparent density were examined and assessed.

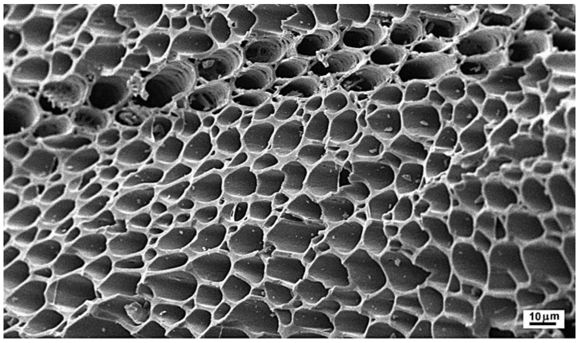

Fig. 1 SEM micrograph of charcoal.

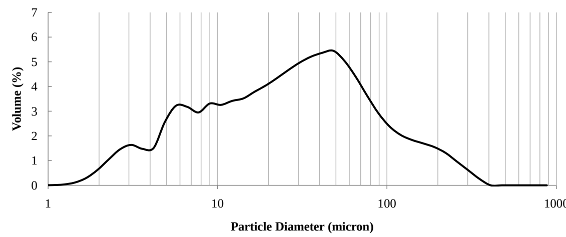

Fig. 2 Particle size distribution of Hang Dong clay.

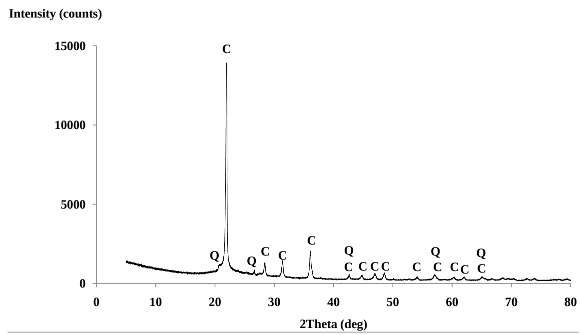

Fig. 3 X-ray diffraction patterns of charcoal (C=cristobalite and Q=quartz).

MATERIALS AND METHODS

Properties of briquette raw material

In this study, clay used as raw material for test briquettes was obtained from Hang Dong district in Chiang Mai province, Thailand. Charcoal used as an organic additive is available in the northern part of Thailand. Local people make charcoal by burning woods with little air present and use it in their daily routine as fuel (Fig. 1). Chemical analysis of the clay briquette specimens was carried out prior to characterization by X-ray fluorescence technique (Horiba Mesa-500 w). The chemical composition of Hang Dong clay was SiO_2 (59.49%), 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%), and LOI (9.30%; LOI at 1000 °C was obtained using TGA). The particle size distribution of Hang Dong clay was analysed by diffraction (Mastersizer, Melvern Instrument Ltd), as shown (Fig. 2). The mineralogical composition of Hang Dong clay and charcoal were achieved using an X-ray diffractometer (Panalytical X' Pert PRO MPD, Netherlands). The major crystalline phase found in charcoal contained quartz and cristobalite (Fig. 3), while in Hang Dong clay consisted of quartz, muscovite, kaolinite, alkali-feldspar, and haematite (Fig. 4). Microstructures of the briquette specimens were examined using scanning electron microscope (SEM - JEOL JSE-5410 LV).

Preparation of test specimens

In order to determine the extent of the pore-forming effects of charcoal additive, certain charcoal particles in the range size 2–3 mm (size 1), 1–2 mm (size 2) to less than 0.5 mm (size 3) were used. They were added into raw briquette clay and divided into five different specimens mixed with increasing charcoal particles (0%, 2.5%, 5.0%, 7.5%, and 10%). Each specimen was mixed in a porcelain ball mill in order to ensure homogeneous mixing. Then, each briquette was formed (mixed with about 20–30% water to plastic condition to obtain the desired shape), into soft-mud rectangle-shaped specimens with an internal dimension of 5.0 cm $\times$ 9.5 cm $\times$ 3.0 cm using briquette specimens hand-moulding. Specimens 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 specimen was fired at four elevated temperatures: 900, 950, 1000, and 1100 °C with 2 h soaking time in a gas kiln furnace.

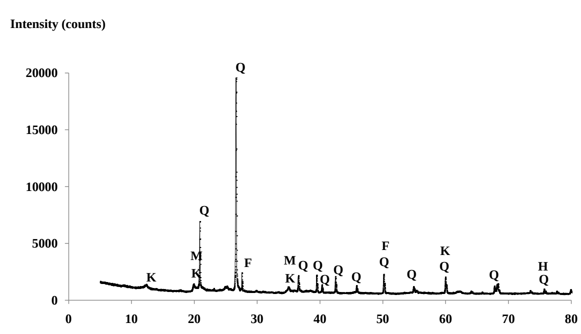

Fig. 4 X-ray diffraction patterns of Hang Dong clay (Q=quartz, M=muscovite, K=kaolinite, F=alkali-feldspar and H=haematite).

The specimens were naturally cooled down to room temperature in the furnace.

Testing method for the physical and mechanical properties of specimens

Shrinkage was determined by directly measuring the length of a specimen before and after firing at 900–1100 °C. The linear drying shrinkage and total linear shrinkage of the specimens as a percentage of plastic length, were determined following ASTM standard C326-82 (2002)[12].

Physical and mechanical properties such as compressive strength, water absorption, bulk density, apparent density, and apparent porosity of specimens were assessed in accordance with the standard of American society for testing and materials C773-88[13] and C373-88[14].

RESULTS

The effects of the addition of different charcoal percentages on properties of test fired briquettes are summarized in Table 1. The quality of fired briquette specimens was further investigated according to the degree of firing shrinkage. Normally, a fired clay brick with a high quality exhibits shrinkage below 8%[15]. The firing temperature is another important parameter affecting the degree of shrinkage. Generally, increasing the temperature results in an increase in shrinkage[15]. The firing shrinkage in all charcoal bearing mixture (measured at 950 °C) increased with increasing charcoal ratios (Table 1). The test results indicated that the amount of charcoal additive and firing temperature were the key factors determining the quality of test fired briquettes. In terms of density, an increase in the amount of charcoal caused a reduction in the clay body density and increase in porosity of the specimens. The charcoal additives in the specimens were burnt out through the process of firing leaving abundant pores in clay bricks[16]. Accordingly, the quality of the test fired briquettes in water absorption was closely related to the porosity of the fired clay bodies. The water absorption for fired briquette specimens fired at 950 °C was in the range of 18% to 40% (Table 1). Thus water absorption was directly proportional to apparent porosity. The highest apparent water porosity was 53% (10% of charcoal additive size 1) and the lowest 31% (2.5% of charcoal additive size 3) suggesting that high percentage of charcoal in the specimens caused an increase in porosity. Furthermore, the water absorption of porous fired clay bodies is indicative of the quantum of overall apparent porosity. Thus porosity in fired briquette specimens occurred as charcoal additive was burned out during firing and this agrees with literature[17]. However, the density of clay bricks depends on several factors such as the specific gravity of clay, method of manufacture, and degree of burning. The bulk density of fired briquette specimens was inversely proportional to the quantity of charcoal added in the mixture. The bulk density of fired briquette specimens decreased with an increase in the amount of charcoal additives from 2.5% to 10%. These resulted in the bulk density ranging from 1.17 to 1.68 g/cm^3. The apparent density decreased with charcoal addition according to the control mix. The apparent density of fired briquette specimens varied from 1.87 to 2.30 g/cm^3 at 950 °C. Compressive strength, the most important test for assuring the engineering quality of a building material[15], greatly depended on the amount of charcoal in the fired briquette specimens

Table 1 Effect of charcoal size and proportion on the physical and mechanical properties of fired briquette specimens (fired at 950 °C).

Properties	Size	Proportion (% by weight)				
		0%	2.5%	5.0%	7.5%	10%
Firing		2.15	–	–	–	–
shrinkage	1*	–	2.10	2.21	2.37	2.45
(%)	2**	–	2.16	2.18	2.24	2.36
	3***	–	2.47	2.70	2.81	2.88
Water		17.2	–	–	–	–
absorption	1	–	21.8	27.8	34.8	40.7
(%)	2	–	19.2	22.6	29.9	35.7
	3	–	18.3	20.0	24.3	33.2
Bulk		1.80	–	–	–	–
density	1	–	1.61	1.50	1.37	1.17
(g/cm^3)	2	–	1.65	1.58	1.52	1.42
	3	–	1.68	1.63	1.57	1.49
Apparent		29.0	–	–	–	–
porosity	1	–	35.3	38.3	47.2	53.9
(%)	2	–	33.8	35.5	46.0	48.8
	3	–	31.5	35.1	38.9	46.6
Apparent		2.58	–	–	–	–
density	1	–	2.19	2.07	1.95	1.87
(g/cm^3)	2	–	2.24	2.14	2.01	1.91
	3	–	2.30	2.24	2.13	2.07
Compressive		152.7	–	–	–	–
strength	1	–	77.8	77.4	47.7	29.0
(kg/cm^2)	2	–	107.0	64.7	41.9	73.8
	3	–	143.5	90.6	85.7	78.6

* Charcoal size 1 (2–3 mm),
** Charcoal size 2 (1–2 mm),
*** Charcoal size 3 less than (0.5 mm)

and the firing temperature. In addition, compressive strength of clay briquette specimens decreased with an increase in the proportions of charcoal as well as the firing temperature (Table 1). An increase in compressive strength was due to a decrease in porosity and an increase in bulk density with an increasing temperature. The test results showed that the highest compressive strength was 143 kg/cm^2 (charcoal size 3, 2.5%) and the lowest 29 kg/cm^2 (charcoal size 1, 10%).

Microstructure of the test fired briquettes

The morphological characteristics of fired briquette specimens are shown in Fig. 5 (a)–(d). Original Hang Dong fired briquette specimens (a), a specimen with the charcoal particles in the range size 2–3 mm (size 1, b), 1–2 mm (size 2, c) to less than 0.5 mm (size 3, d). The structure of clay specimens had an influence on the values of water absorption. The fired briquette specimens with the addition of fine charcoal exhibited the lowest water absorption capacity, which could be explained by the least porosity. Fig. 6 (a)–(e) shows SEM images of fired test briquettes with 0, 2.5, 5.0, 7.5, and 10% charcoal additive, respectively. Fig. 6 (a)–(e) shows local vitrification in the fired briquette specimens. The fired briquette specimens with charcoal additive had larger pores than their counterparts without charcoal additive when fired at 950 °C. This

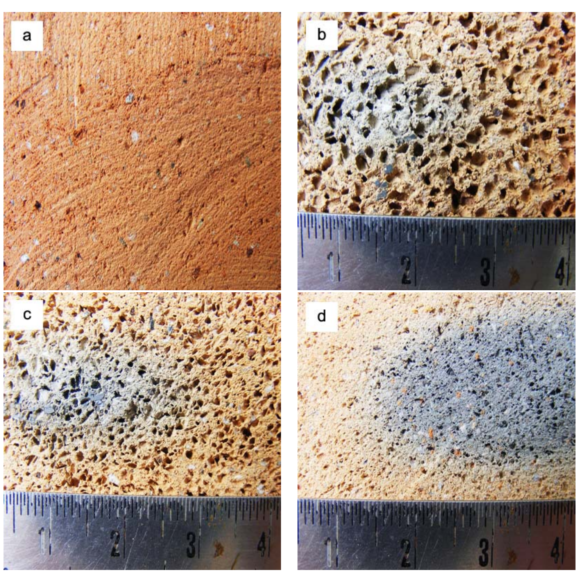

Fig. 5 Surface texture of fired briquette specimens were fired at 950 °C (a) original Hang Dong clay, (b) mixed with charcoal size 1 (2–3 mm), (c) mixed with charcoal size 2 (1–2 mm) and (d) mixed with charcoal size 3 (less than 0.5 mm).

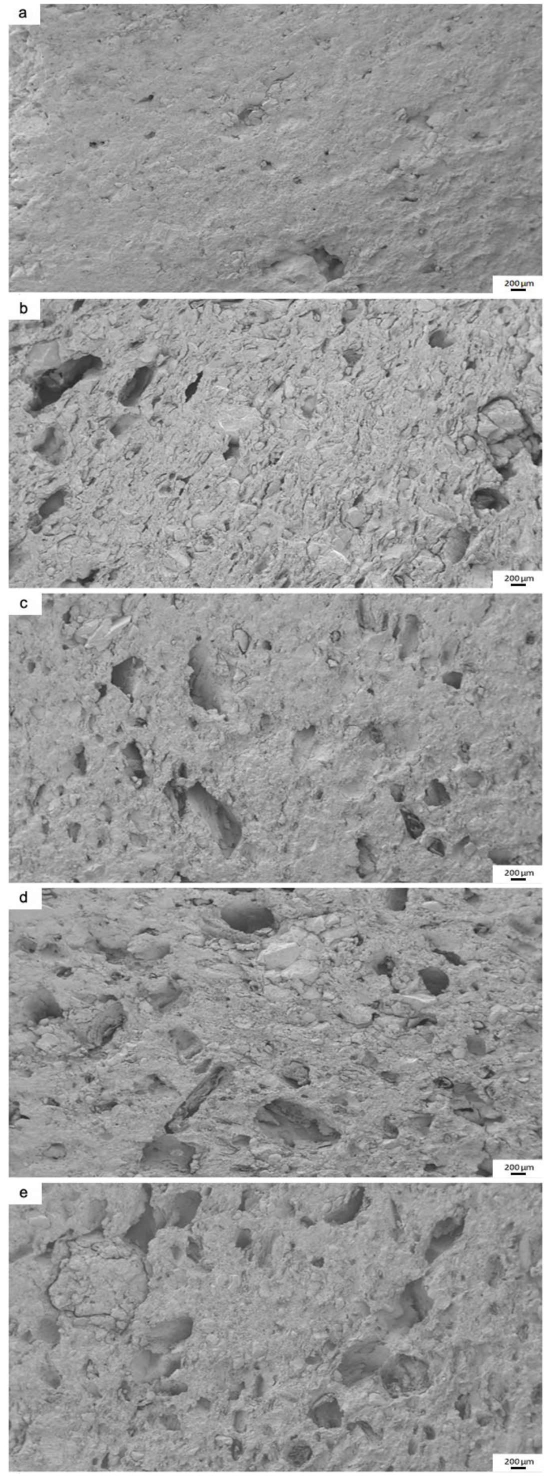

Fig. 6 SEM photomicrographs of specimens with various amounts of charcoal size 3 were fired at 950 °C. (a) original Hang Dong fired briquette specimens, (b) with 2.5%, (c) 5.0%, (d) 7.5% and (e) 10% charcoal.

was due to the burning out of charcoal additives.

CONCLUSIONS

The present study confirms that local raw materials, clay and charcoal, can be used to produce clay bricks at the bench scale only. The addition of charcoal is mainly designed to produce lightweight and more porous fired briquette specimens. Firing clay briquettes specimens at 950 °C and increasing the content of the charcoal addition lead to an increase in the shrinkage and water absorption. The values of bulk density, apparent density, and compressive strength of specimens decreased with an increase in the amount of charcoal. Firing time is shorter as the amount of charcoal is elevated. The most appropriate firing temperature for test fired briquettes is 950 °C because they are more durable, porous and stronger than current commercial bricks. Thus charcoal could be used as a pore former additive in clay body. We conclude that charcoal is regarded as an appropriate additive to raw materials used in producing lightweight fired clay briquettes. Further studies are needed to expand the results by using brick size as specimens in order to draw conclusion for manufacturing commercial bricks.

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