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Production and characterization of porous insulating fired clay bricks with corn cobs admixture

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Abstract

This research studies physical, mechanical and thermal properties of fired clay bricks. Three different sizes of corn cobs were used as an additional material in production process; large (L) between 2 and 1.7 mm, medium (M) between 1.6 to 1.4 mm and small (S) less than 0.5 mm. Then, they were added into the specimen in an amount of 0, 5, 10, 15, 20, 25 and 30 %wt of the total weight. All samples were fired at 950-1150ºC and were tested by using universal testing machine (UTM), scanning electron microscopy (SEM), specific surface area (BET) and thermal conductivity (heat flow meter). The results indicated that the compressive strength of fired samples clay bricks decreased because of the percentage of corn cobs added in the mixture. However, the specimens with 10 % of large corn cobs which were fired at 1150ºC provided a good result of thermal conductivity. The results also meet the Thai Industrial standard (TIS 77-2545).

Keywords: Thermal conductivity, Porosity, Insulating brick, Ceramic

1. Introduction

Bricks are construction materials which have been used since ancient times as we can see in numerous historic buildings [1]. Nowadays, bricks are still being used for the same purpose [2]. Thermal conductivity of a brick is an important parameter in calculating, designing, and implementation of the building's energy consumption plan which includes heating, ventilation, and air conditioning system (HVAC) [3]. Consequently, the thermal insulation property of building materials which can be found in traditional clay bricks are of paramount importance [4]. Thermal conductivity performance is an important criteria 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 to the other [6]. There are two different thermal conductivity values of these bricks. The first value involves the porous 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 porous. Thus, increasing of the thermal insulation property implies the production of materials with a higher porosity [8-9]. This endeavor focuses on the production of efficient thermal insulation bricks using locally available clay combined with corn cobs admixture .It also focuses on studying of physical, mechanical and thermal properties of the bricks.

2. Materials and methods

2.1 Properties of brick's raw materials

Ko Kha clay (KK) used as raw materials is obtained from Ko Kha district in Lampang province, Thailand. Corn cobs used in this research are agricultural wastes. Chemical analysis and loss on ignition (LOI) of Ko Kha clay and corn cobs carried out prior to characterization by X-ray fluorescence technique (XRF: Megix Pro MUA/USEP T84005, Philips). The chemical composition of both corn cobs and Ko Kha clay is shown in Table 1. The average particle size distribution of Ko Kha clay was analyzed by laser diffraction (Mastersizer S, Melvern Instrument Ltd), as shown in Figure 1. The mineralogical composition of raw brick clay achieved by using an X-ray diffractometer technique (XRD: X' Pert PRO MPD, Philips). The major crystalline phases found in Ko Kha clay consist of Quartz, Muscovite, Hematite and Montmorillonite, as shown in Figure 2. Thermal analysis (TG/DTA: Simultaneous Thermal Analysis - STA 409 EP, NETZSCS) on raw clay is shown in Figure 3: graphs are given [10]. Total weight loss of about 7.5% was observed at 1000°C. The first 1.8% decrease in the mass occurred in between 20 and 200°C due to the evaporation of physical water [2, 6]. The second and third weight losses were observed between 200–450°C and

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Table 1 Chemical composition of Ko Kha clay and corn cob used in the experiments

Sample	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO_2	CaO	MgO	K_2O	Na_2O	LOI
Ko Kha clay	64.23	19.16	5.91	0.83	0.01	0.13	0.52	2.13	0.38	6.39
Corn cob	69.08	1.81	0.64	0.01	0.05	2.61	5.44	12.79	0.03	7.57

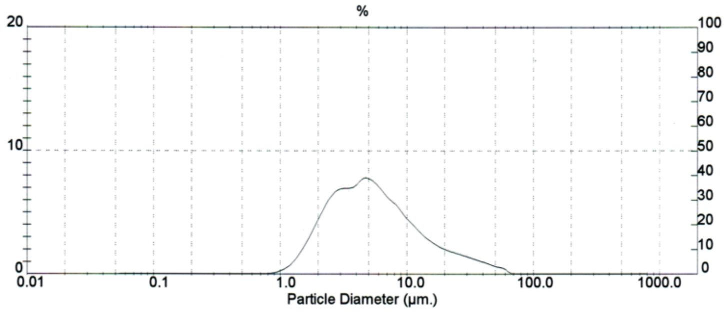

Figure 1 Particle size distribution of Ko Kha clay

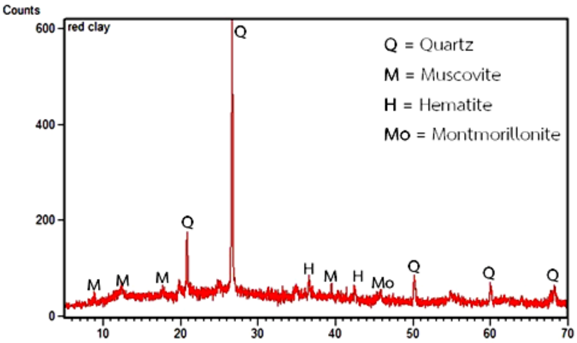

Figure 2 X-ray diffraction patterns Ko Kha clay used in experiments

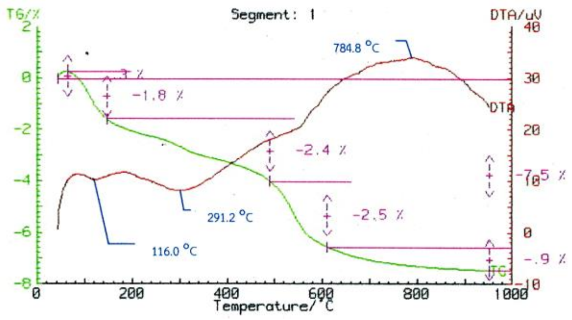

Figure 3 Thermal analysis (TG/DTA) on Ko Kha clay

450–650°C which may be due to the burning of organic matter and removal of chemical water. The larger weight loss was detected in between 650 and 750°C and smaller reaction at about 750–1000°C.

2.2 Preparation of brick samples and sintering procedure

In order to determine the extent of the pore forming effects by corn cob, corn cob additive were dry sieved and separated into three different sizes; large (L) between 2 and 1.7 mm, medium (M) between 1.6 to 1.4 mm and small (S) less than 0.5 mm. Then prepared corn cobs were added into raw clay brick with seven different percentages: 0, 5, 10, 15, 20, 25 and 30 %wt. After that, the specimens were formed by extruding for the perforated rectangular shaped (190 mm ×90 mm ×65 mm). Each group of green specimens was fired at five different temperatures: 950, 1000, 1050, 1100 and 1150°C with two hours soaking time in gas kiln furnace. The specimens were naturally cooled down to room temperature in the furnace.

2.3 Testing method for the physical and mechanical properties of fired brick

In this study, the test method was carried out in accordance with the standard of Thai Industrial Standard (TIS 77-2545) to determine the total linear shrinkage, water absorption and compressive strength [11]. The method based on ASTM C373-88 (2002) was used to determine the bulk density, and apparent porosity [12].

The thermal conductivity measurement test was conducted by following an adapted experimental procedure of international standards ASTM C177 [13]. The thermal conductivity was calculated by using the following equation:

$$\frac{dQ}{dA} = k\frac{dT}{dx}$$

When Q is the rate of heat flowing in normal direction to surface (W), k is the thermal conductivity (W/m K), A is the surface area (m^2), dT is the temperature difference, and dx is the measured normal distance to surface (m).

3. Results and discussion

The results of the physical and mechanical properties of additive samples: large, medium and small corn cobs after firing test were summarized in Table 2-4. The investigated topics that reported in this paper are firing shrinkage, bulk density, apparent porosity, water absorption, compressive strength, pore size analysis, thermal conductivity, and microstructure analysis verification. The samples were formed from Ko Kha clay with the average particle size distribution of 1–100 μm, D[4,2] was 7.76 μm, and corn cob with three different sizes. The results revealed that corn cob sizes did not significantly affected the conditions of the physical and mechanical properties of fire clay bricks.

3.1. Effects of corn cob addition on physical and mechanical properties

3.1.1. Firing shrinkage

In general, shrinkage occurs in shaping clay bricks due to the evaporation of water from clay body. In other words, when water between clay particles reduce, 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, 9]. An increasing in the temperature results in an increase in shrinkage. In this study, the samples were fired at the temperatures between 950 and 1150°C. The results indicated that shrinkage occurred in the sample fired by briquettes was in the range of 9.42 - 21.72% as shown in Table 2-4. the percentage of shrinkage rises with increase in the amounts of corn cob addition.

3.1.2 Bulk density apparent porosity and water absorption

The density of clay bricks depend on several factors which are the specific gravity of the raw material used, the process of manufacturing and the degree of firing temperature [4]. If the density of the clay brick decreases, the strength of the clay bricks would decrease but the water absorption would increase. In this study, the bulk density of fired test briquettes was inversely proportional to the quantity of corn cob added. The bulk densities of specimens decreased when increase the amounts of corn cob from 0%wt to 30%wt, but the bulk densities of specimens increased when firing temperature rise. The results show that bulk density in the ranges of 0.97–2.01 g/cm^3 (Table 2-4). The bulk density is related to compressive strength and water absorption of bricks.

The apparent porosity was directly proportional to the water absorption. Therefore, similar trends were observed in apparent porosity and water absorption. The study has shown that the apparent porosity depending on the amount of corn cob added. The highest porosity was 51.63% with 30%wt of large corn cob additive, and the lowest 8.12% with 5%wt of small corn cob additive. This result revealed that the higher percentage of corn cob addition was added in specimens, the higher porosity in specimens is (Table 2-4). Thus, the porosity in fired test briquettes was caused when corn cob additive was burn out during firing process.

Water absorption is an important factor for the durability of clay bricks. When water infiltrates bricks, it decreases the durability of bricks. Thus, the internal structure of bricks must be dense enough to void the intrusion of water. To increase density and decrease water absorption of bricks, the firing temperature must be raised. In this study, the amount and size of corn cobs added into the samples that were fired at lower temperature (950°C) increased the water absorption rate in a linear manner. On the contrary, when testing the samples with higher amounts and smaller sizes of corn cobs additive by firing at a high temperature (1150°C), the water absorption of fired samples decreased. According to Table 2-4, the water absorption of the samples after fired at the temperatures between 950 and 1150 °C is in the range of 0.31–72.84%. The standard criteria of TIS 77-2545 determined that good quality bricks should not have water absorption rate higher than 20%.

3.1.3. Compressive strength

The compressive strength is a mechanical property used in clay brick specifications. It has assumed great importance for two reasons. Firstly, with a higher compressive strength, other properties like flexure, resistance to abrasion, etc., are also improved. Secondly, while other properties are relatively difficult to evaluate, the compressive strength is easy to determine [9, 14]. The compressive strength test is

Table 2 Average physical and mechanical properties values of the specimens produced under different firing temperatures and varying corn cobs large size (L) concentrations (fired at the temperatures between 950 and 1150°C).

		Percent corn cobs additions by weight						
Properties	***Temperatures (°C)***	***none***	***5%***	***10%***	***15%***	***20%***	***25%***	***30%***
Firing shrinkage (%)	950	9.42	10.91	13.80	14.67	12.48	11.68	12.71
	1000	9.90	12.22	11.50	13.23	12.20	14.79	13.75
	1050	13.33	11.10	14.76	15.10	15.80	17.37	15.80
	1100	15.42	11.43	16.54	18.85	15.34	16.99	16.12
	1150	16.35	17.79	18.79	20.27	17.57	20.32	17.18
Bulk density (g/cm^3)	950	1.77	1.61	1.52	1.32	1.27	1.02	0.97
	1000	1.80	1.77	1.48	1.18	1.24	1.08	1.01
	1050	1.82	1.73	1.57	1.38	1.28	1.12	1.13
	1100	1.85	1.84	1.67	1.45	1.30	1.17	1.19
	1150	1.99	1.95	1.71	1.58	1.30	1.29	1.22
Apparent porosity (%)	950	27.56	30.12	32.17	33.82	37.43	44.07	51.63
	1000	23.82	29.63	31.95	30.77	34.57	38.51	43.75
	1050	20.14	21.70	22.53	27.98	32.73	35.09	40.74
	1100	17.28	20.28	20.24	26.96	35.65	33.90	41.13
	1150	10.24	16.64	19.81	24.96	35.43	30.82	35.13
Water absorption (%)	950	18.11	21.07	30.47	39.94	51.85	62.00	72.84
	1000	12.84	25.34	36.49	47.33	41.72	53.02	61.09
	1050	8.27	20.18	27.00	36.57	42.23	55.19	58.11
	1100	3.45	10.43	19.29	30.32	36.68	47.52	51.30
	1150	0.31	7.64	16.46	25.09	31.32	43.06	49.50
Compressive strength (MPa)	950	19.87	7.33	4.43	4.50	2.80	2.30	1.73
	1000	23.45	11.28	9.72	6.13	5.07	4.81	3.74
	1050	25.94	18.50	17.60	10.96	10.44	6.52	5.50
	1100	56.61	40.83	38.51	25.33	13.18	9.46	7.58
	1150	67.46	51.58	45.09	30.16	21.56	13.59	8.63

Table 3 Average physical and mechanical properties values of the specimens produced under different firing temperatures and varying corn cobs medium size (M) concentrations (fired at the temperatures between 950 and 1150°C).

		Percent corn cobs additions by weight					
Properties	***Temperatures (°C)***	***5%***	***10%***	***15%***	***20%***	***25%***	***30%***
Firing shrinkage (%)	950	10.98	10.49	13.56	11.30	13.42	10.34
	1000	13.33	13.79	14.79	13.97	11.09	11.30
	1050	13.79	13.79	14.55	14.33	13.79	14.16
	1100	15.86	14.54	15.92	14.92	16.95	16.58
	1150	16.31	15.80	17.20	16.84	17.93	16.93
Bulk density (g/cm^3)	950	1.77	1.53	1.69	1.43	1.05	1.07
	1000	1.84	1.70	1.54	1.44	1.23	1.12
	1050	1.90	1.74	1.57	1.45	1.31	1.21
	1100	1.96	1.77	1.60	1.47	1.30	1.28
	1150	2.01	1.84	1.63	1.51	1.44	1.33
Apparent porosity (%)	950	20.18	23.59	25.93	27.82	43.69	45.83
	1000	15.98	17.85	20.13	24.75	31.60	38.98
	1050	11.48	17.55	18.17	24.79	28.18	36.48
	1100	13.89	14.44	16.12	24.36	30.11	34.28
	1150	10.50	15.91	15.58	22.41	27.85	35.99
Water absorption (%)	950	19.98	26.21	26.25	31.95	58.96	57.10
	1000	19.70	22.17	24.35	31.22	58.04	55.35
	1050	16.53	18.47	23.45	31.16	47.03	47.54
	1100	16.86	21.67	18.68	25.19	36.18	35.86
	1150	15.30	19.89	21.47	24.12	36.10	39.60
Compressive strength (MPa)	950	11.60	9.57	6.37	4.33	2.63	1.80
	1000	18.55	17.49	10.81	6.70	5.38	3.96
	1050	20.28	17.92	16.43	11.85	8.68	6.22
	1100	48.43	40.61	30.90	27.40	20.83	17.57
	1150	59.06	50.55	33.91	29.18	19.58	18.52

Table 4 Average physical and mechanical properties values of the specimens produced under different firing temperatures and varying corn cobs small size (S) concentrations (fired at the temperatures between 950 and 1150°C).

		Percent corn cobs additions by weight					
Properties	***Temperatures (°C)***	***5%***	***10%***	***15%***	***20%***	***25%***	***30%***
Firing shrinkage (%)	950	10.93	9.91	11.90	11.73	10.95	10.32
	1000	11.46	11.28	11.90	12.85	12.28	16.52
	1050	14.79	16.62	14.26	17.29	17.00	19.04
	1100	16.10	16.57	16.14	18.03	18.56	20.80
	1150	17.37	18.2	19.24	19.18	19.61	21.72
Bulk density (g/cm^3)	950	1.64	1.39	1.28	1.08	1.08	0.96
	1000	1.64	1.41	1.31	1.19	1.09	1.07
	1050	1.86	1.63	1.41	1.38	1.27	1.18
	1100	1.94	1.69	1.50	1.40	1.31	1.27
	1150	1.98	1.83	1.61	1.44	1.39	1.33
Apparent porosity (%)	950	26.18	29.64	30.32	35.47	45.87	51.17
	1000	25.07	30.60	33.58	37.34	40.76	49.61
	1050	13.20	18.87	28.14	27.45	31.43	35.68
	1100	11.28	16.79	23.50	26.89	30.36	35.07
	1150	8.12	14.47	21.68	23.22	25.90	33.37
Water absorption (%)	950	19.95	31.75	34.11	51.14	59.50	67.05
	1000	21.75	34.67	40.17	47.63	57.23	60.13
	1050	10.06	21.96	34.22	36.55	42.44	47.32
	1100	8.67	17.42	23.54	29.13	37.37	38.07
	1150	4.22	15.11	19.77	28.31	34.95	37.20
Compressive strength (MPa)	950	16.37	12.67	6.97	4.70	2.73	2.23
	1000	23.94	21.51	18.19	12.99	7.75	5.28
	1050	25.04	20.91	19.95	14.29	8.03	7.26
	1100	51.86	42.55	35.89	29.35	26.82	19.27
	1150	63.59	54.09	36.07	30.88	22.04	20.55

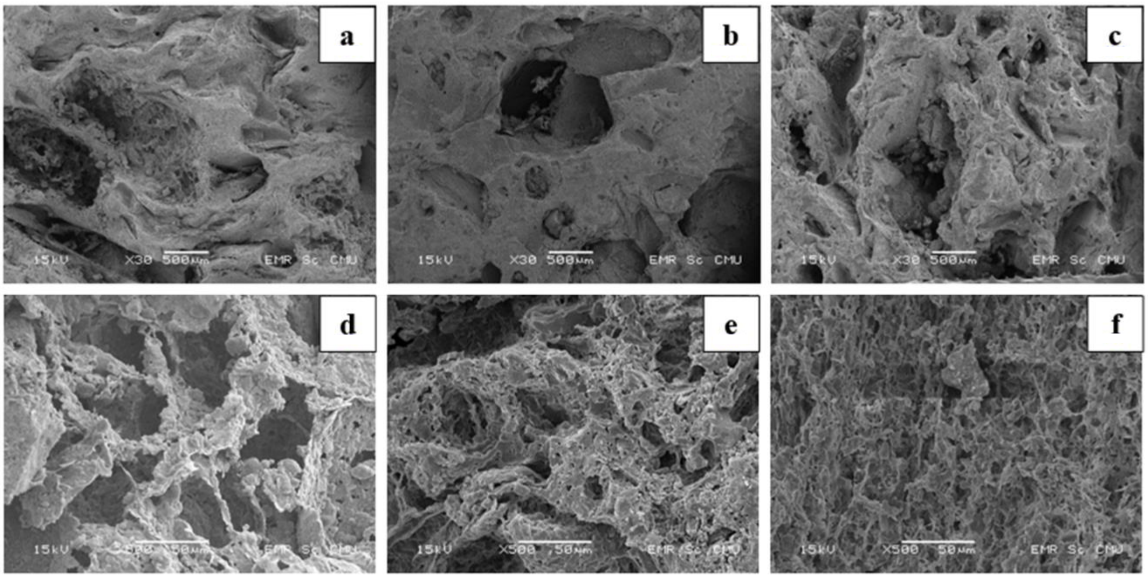

Figure 4 Surface texture of samples fired at 1150°C (a) 10% large corn cobs at 30x magnification (b) 10% medium corn cobs at 30x magnification (c) 10% small corn cobs at 30x magnification (d) 10% large corn cobs at 500x magnification (e) 10% medium corn cobs at 500x magnification (f) 10% small corn cobs at 500x magnification

the most important test for assuring the engineering quality of a building material [15]. In this study the result indicated that the strength of the samples greatly depended on the amount of additive corn cobs and the firing temperature. The results of compressive strength (Table 2-4) indicated that the compressive strength of fired samples increased when the firing temperature rise. An increase in compressive strength was due to a decrease in porosity and an increasing temperature. The results revealed that the compressive strength was in the ranges from 1.73 to 67.46 MPa when corn cobs addition varied from 0%wt to 30%wt and firing temperatures from 900 to 1150°C (Table 2-4). Some bricks meet the criteria of the TIS 77-2545 that defined values no lower than 17 Mpa. In the Table 2-4, it was found that the compressive strengths of clay brick at 0-5% corn cobs and 1150°C are very high (59-67 MPa).Thus, the phase of Mullite is created, and the particles sizes are moved closer together[7]. Generally, in traditional ceramic system, the strength properties decrease as the porosity increases [7, 10].

3.2 Thermal conductivity and pore size analysis

The thermal conductivity and pore size analysis used for selecting the specimens, which added 10 %wt of corn cobs in different sizes for the physical and mechanical properties are in line with Thai Industrial Standard (TIS 77-2545).
The relation between thermal conductivity and porosity of the clay bricks added with corn cobs could be observed in Table 5. There is an evident that increasing in the size of corn cobs caused large porosity. The burning of corn cobs in the body during the firing process caused the porosity in fire clay bricks. The results show that large size of corn cobs induces low thermal conductivity of the samples. This is a result of the increased of air volume obtained by the burning of the corn cobs. This process leads to pores forming within the samples which make them to be less thermal conductors and become good backup insulators. From the results, it can be concluded that thermal conductivity can be decreases by increasing the size of corn cobs in fire clay bricks.

3.3 Microstructure analysis vitrification of fired test samples

The SEM results of the vitrification specimens at 1150°C and different sizes of corn cobs at 10% were shown in Figure 4 a-f. The images show that as size contents increase, the micropores of the specimens also increase. This is the main reason of an increase in water absorption. Thus, when the firing temperature increased the water absorption of the specimens decreased. However, compressive strength was reduced when the amounts of corn cobs increased because the compressive strength directly relates to a decrease in porosity and an increase in firing temperature [2, 15].

4. Conclusions

The characteristics and analysis of physical and mechanical properties of corn cobs added to raw materials for the production of clay bricks were reported. The main goal for adding corn cobs into clay body is to produce porous insulating, fire clay bricks. The increasing amount of corn cobs added into clay bricks leads to an increase in the water absorption of brick. However the values of compressive strength of samples decreased when the amount of additional corn cobs increased and the temperature was higher. The reason is that during the burning process, the porosity occurred and the pores continued bigger as the burning proceed. As a result, the size of additional corn cobs significantly affected the conditions of the thermal conductivity of fire clay bricks. Conclusively, this study yields findings namely: The addition of corn cobs in raw materials can produce porous, insulating, fire clay bricks.

5. Acknowledgements

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