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Physical property and compressive strength of fired clay bricks incorporated with paper waste

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Abstract

This research is intended to evaluate the effects of paper waste addition on the physical properties and strength of fired clay bricks. Paper waste was mixed with clay in the ratios of 2.5, 5.0, 7.5 and 10 wt%. Green bricks were fired with different variations of temperature from 900-1100°C for1 h in air. Fired bricks were then analyzed for physical and mechanical properties. Porosity was increased with higher paper waste content. An increase in porosity relatedly created lower density and higher shrinkage values. Additionally, porous content in fired clay bricks correlated to the deterioration of the compressive strength, due to the weakness area of defect. However, the highly porous brick presented low thermal conductivity. Therefore, the porous brick from paper residue inclusion presented excellent insulating behavior, while adequate compressive strength could be still be maintained.

1. Introduction

Fired clay bricks have been commonly in building construction for a long time [1]. The advantages of fired clay brick are stability of thermal shrinkage during fluctuation of temperature and high-pressure resistance [2-3]. For these reasons, the quality of bricks has been continually improved for modern construction. Climate change problems are currently documented, which are associates the rise in the average temperature of the Earth's climate system. Therefore, low thermal conductivity of the building materials will be attractively studied in the future. Higher porosity in a fired clay brick structure is a common approach to improve the different temperatures between inside and outside of building constructions because the porous regions can block heat transferring ability [4-5]. Moreover, highly porous brick has a lighter weight [6]. Organic wastes were studied as the pore former in clay brick. Organic waste was eliminated from the brick structure during the firing process, where the remaining voids became the pores. Organic wastes such as grass, rice husk and tobacco are widely modified in the brick industry for saving clay material, increasing porosity and lowering the thermal conductivity of fired clay brick [7-8]. The study on the optimum organic waste addition in clay brick can produce bricks of lower thermal conductivity, which means a lower heat transfer through the walls of building constructions. It was determined that the use of rice husk, jute and limestone in a brick composition that affected lower thermal conductivity in the range of 6-18 wt% [9-12]. Paper sheet has been continually produced worldwide for a variety of uses and is commonly available as waste product. Most grades of the paper consist of organic and inorganic material. The organic portion consists of hemicellulose, cellulose, lignin, and various compound of lignin about 70%. The inorganic portion consists of added material, such as clay, titanium oxide and calcium carbonate about 30 wt% [13]. These organics begin to decompose as carbon residue at about 270-350°C. Paper sheets are a large component of waste after use. Therefore, the use of paper waste has been studied as the possible pore former in fired clay brick production for elimination of paper waste. Sutcu and Akkurt [14] reported that the compressive strength of porous bricks with paper waste additions (<30 wt%) had significantly decreased with higher paper residue, but their thermal conductivity values were improved.

This research focuses on finding the optimum composition of incorporated paper waste in clay brick to for the optimum thermal conductivity and retention of acceptable compressive strength. Effects on physical properties including density, porosity water absorption and shrinkage on compressive strength and thermal conductivity are also explored.

2. Experimental

2.1 Materials and preparation

The selected clay in this research was obtained from the local brick factory in Kalasin Province, Thailand. Mineralogical and chemical compositions of clay were determined by using X-ray diffraction (XRD) and X-ray fluorescence (XRF), respectively. The particle size distribution of the clay was studied

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by laser diffraction techniques. It found the narrow single curve with D [3,4] value of about 12.51 μm. Paper waste was prepared by a paper shredder machine to obtain a width of 5 mm. Paper waste contents were varied at 0, 2.5, 5.0, 7.5 and 10 wt% in clay-based composition. Mixtures were ground by a ball mill process for 30 minutes with 20-25 wt% of water to obtain the continuous plastic flow. The mixtures were then formed into rectangular shapes with a dimension of 140×65×40 mm by use of a handing mold. Green brick samples were dried at room temperature for 24 h, and then over-dried at 110°C for 24 h to remove water from green brick. The dried clay bricks were fired at 900, 1000 and 1100°C for 1 h using a heating rate of 2°C·min^{-1}.

2.2 Testing method

Shrinkage values of fired clay brick at 900, 1000 and 1100°C were measured by following the standard of ASTM C326-09 [15]. Physical properties of fired clay brick cosisted of the apparent density, water absorption and porosity, which were determined by the Archimedes method based on ASTM C373-14a [16]. The compressive strength of fired clay brick samples was measured under ASTM C773-88 [17]. The results of physical and compressive strength were the average of 10 samples. The thermal conductivity test of fired clay brick was conducted according to an adapted experimental procedure of ASTM standard C177-97 [18].

3. Results and discussion

XRD pattern of clay is shown in Figure 1. Quartz is indicated the main mineral structure, while the patterns of rutile, hematite and muscovite are the secondary components. In general, quartz has a chemical composition of SiO_2 that corresponded to the XRF result in Table 1. It is observed that SiO_2 presented the principal compound with 67.41 wt%, while CaO, Al_2O_3, Fe_2O_3, CaO, K_2O, TiO_2, MnO and MgO are presented slightly. The loss on ignition (LOI) of Clay was about 4.71 wt%. SEM micrograph (Figure 2) shows the morphology of clay, where it has the polygon shape with a different size in the range of 1-20 μm.

The fractured surface has been studied to observe the porous and densification regions of fired clay bricks. Figure 3a presents the fractured green brick with 2.5 wt% of paper waste that was observed white phase of paper waste. After firing at 900 °C in Figure 3b, these paper waste regions were combusted and then replaced by the porosities. The consideration of the fractured surface of clay brick samples with higher paper waste additions are shown in Figure 3b-3e. It seems that porosity tends to increase with higher paper waste addition. However, only fractured surface results cannot be reliable alone because it only appears from some surface area. It is also confirmed by the results of the physical properties. 8

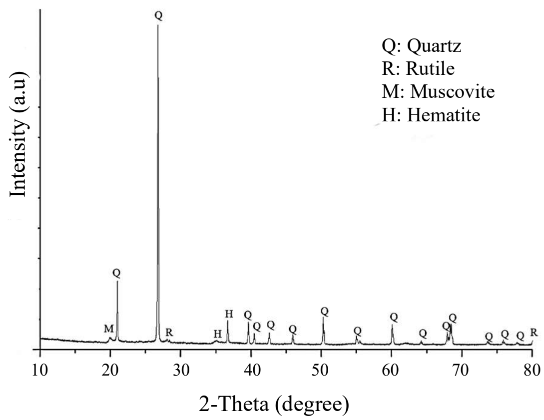

Figure 1. X-ray diffraction patterns of clay.

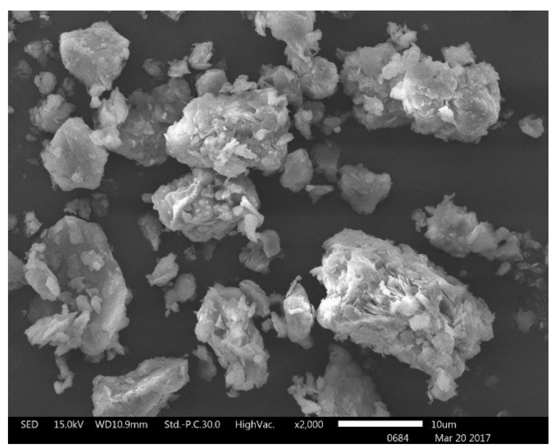

Figure 2. SEM micrograph of clay.

Table 1. Chemical composition of clay.

Compositions											
	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	P_2O_5	TiO_2	MnO	MgO	LOI
Clay	67.41	16.27	3.95	0.39	3.16	-	-	1.82	1.35	0.94	4.71

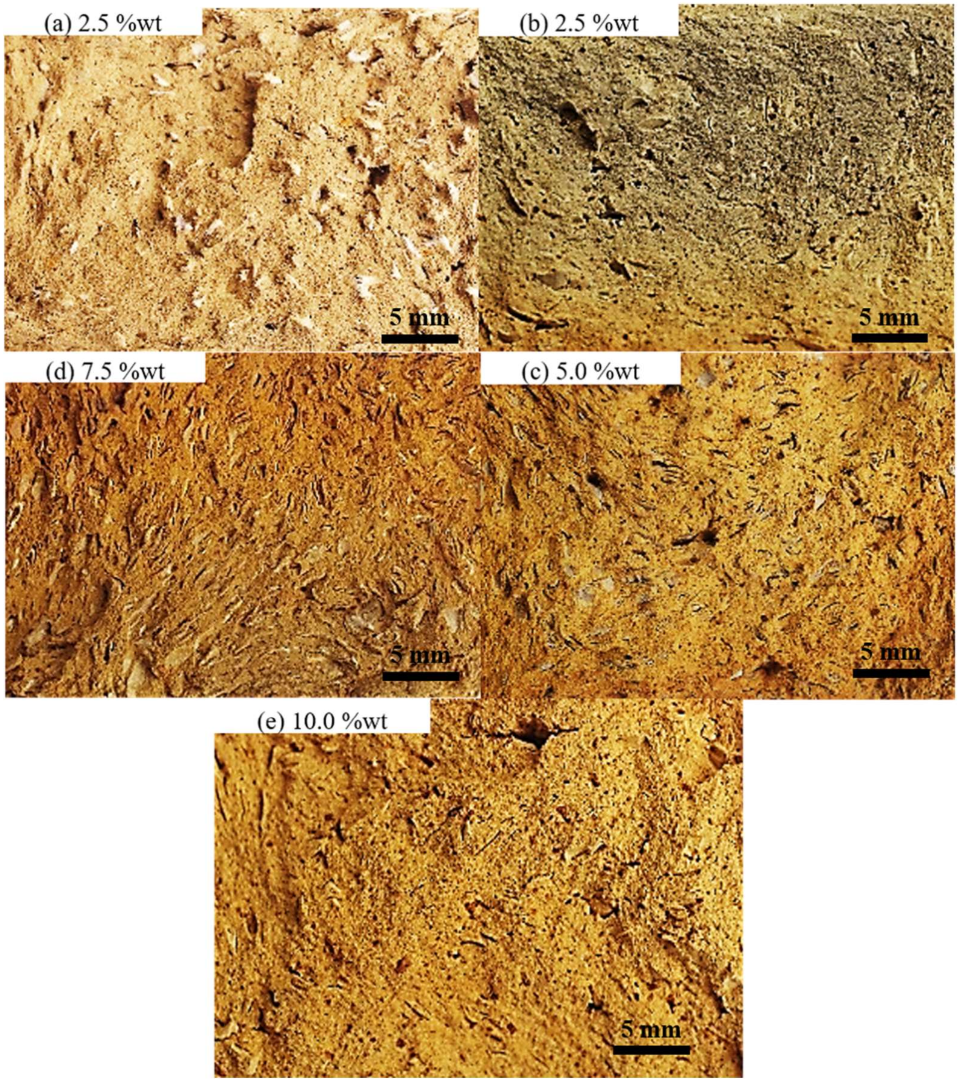

Figure 3. Fractured surface of (a) unfired brick with 2.5 wt% paper waste and (b)-(e) fired brick at 1000°C with different percentage of paper waste.

Figure 4 shows the bulk density of clay bricks with different paper waste additions after being fired at 900-1100°C. The linear graph of fired bricks at 900°C shows that the bulk density value is significantly decreased with increasing paper waste additions. At 1000°C and 1100°C, both graphs tend to be the same, which indicated the deteriorated coordination of particles with higher paper waste additions. It is due to the volatile paper waste. Bulk density of fired bricks are improved with increasing temperature. It can be explained by the fact that clay particles are highly connected to reducing surface area during higher sintering mechanism. The densification of fired brick is therefore increased. The lowest density (1.38 $g \cdot cm^{-3}$) appeared for clay brick with 10 wt% of paper waste after being fired at 900°C. The densification is related to porosity and water absorption of fired clay bricks.

The curves in Figure 5 present the effect of paper addition on porosity of fired clay brick at 900-1100°C. Apparent porosity values are increased continually, when the paper waste is progressively added in brick compositions for fired clay bricks at a similar temperature. As for the effect of higher firing temperatures, apparent porosity is improved obviously because of the sintering mechanism. In general, the porosity is indirectly proportional to the water absorption because porous areas can trap water in the fired clay brick. The water absorption graph of clay bricks at different paper wastes additions after being fired at 900-1100°C is displayed in Figure 6. The 3 curves present the water absorption of bricks with different firing temperatures, while each curve was created from various paper waste additions in the range of 0.0-10.0 wt%. A similar trend of all curves observed that the water absorption is increased with higher paper waste additions. This result corresponds to the porosity because water is infiltrated in the fired clay brick structure by the pores.

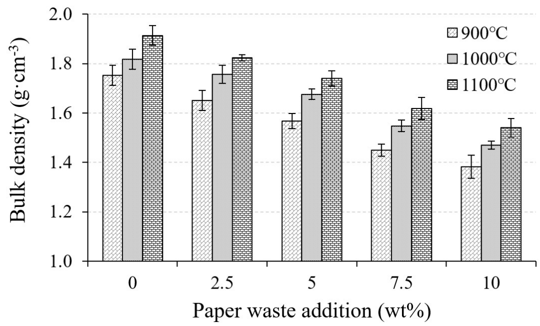

Figure 4. Apparent density values of fired clay bricks at 900-1100°C with 0 to 10 wt% of paper waste additions.

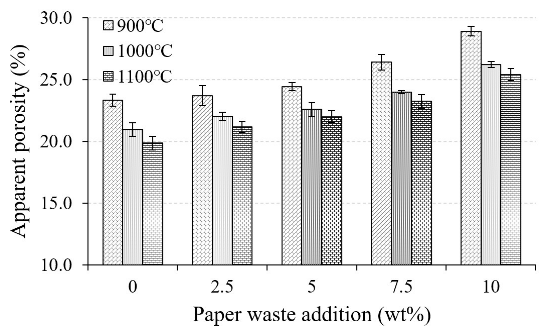

Figure 5. Apparent porosity values of fired clay bricks at 900-1100°C with 0 to 10 wt% of paper waste additions.

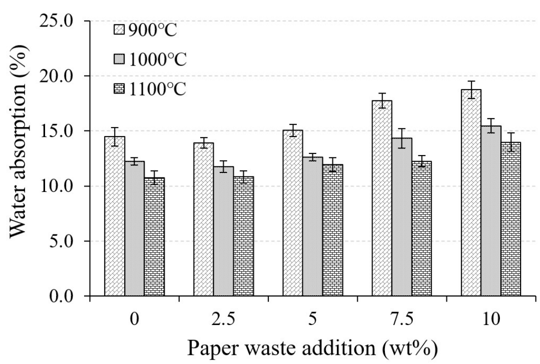

Figure 6. Water absorption values of fired clay bricks at 900-1100°C with 0 to 10 wt.% of paper waste additions.

In fired clay brick fabrication, linear shrinkage values are an important factor due to the contraction of brick samples after the firing process. The shrinkage of fired bricks can be applied about the size of mold design for reducing discrepancy from engineering tolerance after the firing process. A general clay brick should have a shrinkage after firing process less than 8% [19]. Figure 7 shows the linear shrinkage values of fired clay brick with different paper waste addition percentages. The trend of linear shrinkage of clay bricks is higher with increasing paper waste addition for all sintering temperatures. Moreover, an increase of sintering temperature affected greater shrinkage value. Linear shrinkage values of all bricks are in the range of 4.5-7.5%, which are the optimum values for fired clay brick.

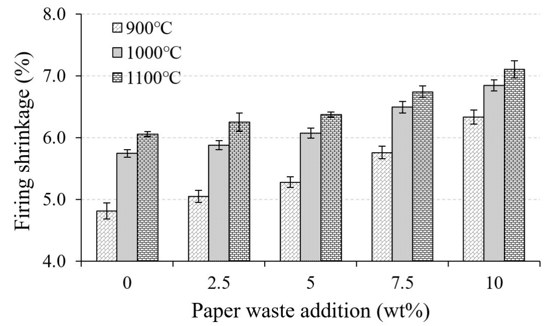

Figure 7. Linear shrinkage values of fired clay bricks at 900-1100°C with 0 to 10 wt% of paper waste additions.

Bricks are mainly used in construction, so it has a good compressive strength to support the construction weight [20]. The effects of the paper waste additions and firing temperatures on compressive strength values is show in Figure 8. It is revealed that the compressive strength values are degraded with increasing paper waste additions, while higher firing temperature affects to improve the compressive strength. The decrease in the compressive strength of fired bricks can be explained by the cause of the porous defect in a brick structure. The pore defect is weak bond compaction, where it is more easily broken. According to ASTM C62-13a (2013), the minimum standard compressive strength of fired bricks is about 17.2 MPa. For this research, it is found that the compressive strength values of bricks with 0.0-5.0 wt% of paper waste additions after being fired at 900-1000°C and 0.0-7.5 wt% fired at 1100°C are higher than that of standard value. The maximum compressive strength (28.5 MPa) is obtained in the fired clay brick without paper waste addition after being fired at 1100°C.

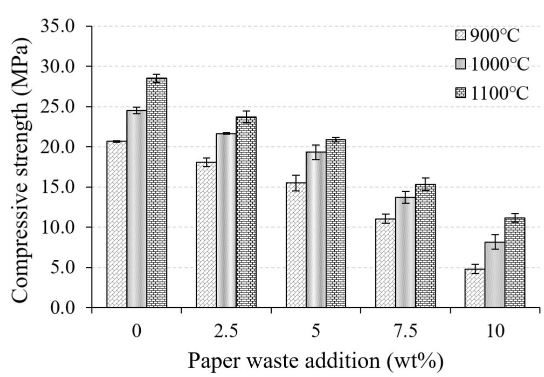

Figure 8. Compressive strength of fired clay bricks at 900-1100°C with 0 to 10 wt% of paper waste additions.

Thermal conductivity is used to describe heat transfer in materials. Less conductivity is more desirable. From global warming problems, clay brick development focuses on the higher insulation properties that are associated with the pores in the structure. It is well known that porous defects have a high insulated area, so porosity can reduce the thermal conductivity of fired clay brick. Figure 9 presents the thermal conductivity of clay brick with various paper waste additions after being fired at 1000°C. It is seen that the thermal conductivity values are improved with increasing paper waste content. This effect is directly related to porosity. Although the pores in the brick structure is a cause of the deteriorated strength, it can result in improved thermal conductivity (insulating) properties of fired brick. Fired clay bricks with 0.0-5.0 wt% of paper waste addition after fired at 900-1000°C and 0.0-7.5 wt% fired at 1100°C provide the compressive strength within the standard, while their thermal conductivity is improved. Therefore, these bricks are a potential manufacturing approach to be developed in real products.

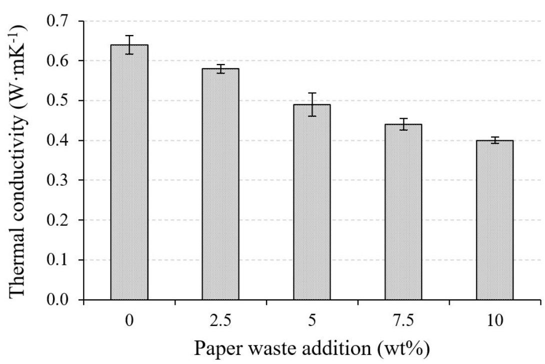

Figure 9. Thermal conductivity of fired clay bricks at 1000°C with 0 to 10 wt% of paper waste additions.

4. Conclusions

Physical properties and compressive strength were studied in this work to consider the feasibility of fired clay bricks with paper waste additions. The clay bricks were produced by incorporating 0-10 wt% of paper and were then fired at 900-1100°C. Densification values of fired clay bricks were decreased, while porosity and water absorption values were increased with increasing paper waste additions. These results corresponded to the burning-out of paper waste after the firing process. Results indicated that the paper wastes could be easily utilized as pore-forming additives into brick bodies. Linear firing shrinkage of the clay bricks varied from 4.5 to 7.5% increasing relatively linearly as the paper waste content and firing temperature increased. From physical property results, paper waste was confirmed as the pore former. The higher porosity with paper waste addition was slightly affected on the diminished compressive strength. However, the compressive strength of samples with 2.5-10 wt% of paper waste addition fired at 900-1000°C and 5-10 wt% fired at 1100°C present higher than the minimum requirements of standard fired brick (ASTM C62-13a). Moreover, fired bricks with paper waste addition still obtained the better thermal conductivity values (lower conductivity) than the bricks without paper waste addition. Conclusively, all results revealed that the paper waste could be used as the pore former addition in fired clay bricks. Higher porous regions caused lower compressive strength but strength values were still acceptable in the standard. The thermal conductivity of bricks was decreased with higher paper waste additions.

5. Acknowledgements

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