

EFFECTS OF FLY ASH ADDITION ON THE DURABILITY AND MECHANICAL PERFORMANCE OF FIRED CLAY BRICKS

Anuwat Srisuwan¹, Siwat Lawanwadeekul², Chiawchan Saengthong¹, Siriwan Artbumrung³ and Nonthaphong Phonphuak^{3,*}

Received: January 18, 2021; Revised: February 21, 2021; Accepted: February 27, 2021

Abstract

The main objective of this study was the utilization of fly ash (FH) additive in the fired clay brick mixtures. The effects of FH additions (0, 10, 20, 30, and 40% by weight) incorporated in clay brick compositions on the physical properties and mechanical strength had been investigated. The green clay brick specimens were fired at 800-1,000°C to obtain vitreous phase connection. Behavior of packed particles associated apparent porosity (APP), bulk density (BD) and water absorption (WA) values were reported, which were directly cased in the compressive strength (CS) of the fired specimens. The results showed that the APP and WA values were also decreased, while BD values were improved with an increase in sintering temperatures. The CS of clay brick specimens with 10 and 20 wt% of FH after fired at 1,000°C had higher than of the CS strength standard value as required by ASTM C62-13a. The optimum FH addition in the fired clay bricks at 1,000°C was achieved in 10 wt% FH, which confirmed a partial replacement of additive wastes in making fired clay bricks.

Keywords: Fly ash, porosity, clay brick, mechanical strength

Introduction

Presently, clay bricks are still used all around the world as building materials. Clay bricks have particularly required to have sufficient mechanical-physical properties as well as excellent thermal properties (Muñoz *et al.*, 2013). Thailand has produced clay bricks for construction use from the past old days. The most of the products are produced within the household in the rural area, when mechanization is used in the production

(Phonphuak *et al.*, 2020). Clay bricks should have good properties such as high densification and low porosity that cased a good mechanical strength to endure violent weather and long time without maintenance (Adeola, 1997; Karaman *et al.*, 2006). The use of additives in clay brick production is frequent and depends on the characteristics required (Cultrone *et al.*, 2005). Fly ash (FH) is a by-product of coal combustion to generate electricity. The FH

¹ Faculty of Liberal Art and Science, Sisaket Rajabhat University, Muang, Sisaket 33000, Thailand.

² Faculty of Industrial Technology, Lampang Rajabhat University, Lampang, 52100, Thailand.

³ Department of Industrial Technology, Faculty of Engineering, Rajabhat Maha Sarakham University, Maha Sarakham 44000, Thailand. E-mail: nonthaphong@rmu.ac.th

* Corresponding author

is a solid waste material with varying color gray-black, depending on the volume of unburned carbon (C) and particles. FH can be applied in the production of solid brick, cement, cellular concrete, concrete lightweight construction aggregate, and masonry mortar. In previous studies, many researchers have investigated the use of FH in clay brick mixture (Abbas *et al.*, 2017; Eliche-Quesada *et al.*, 2018; Esmeray and Atis, 2019; Sutcu *et al.*, 2019). Hossain *et al.* (2018) reported fly ash (FH), rice husk ash, and glass cullet as additives in fired building bricks with tests on the physical; mechanical and thermal properties and compared with their respective ASTM standards. It had been attractively studied to apply these wastes in brick construction materials, which had reduced waste and increasing waste value. The dosages of 5-25 wt.% of fly ash, rice husk ash, and glass cullet in mixed clay brick after fired at 800-1,000°C in air atmosphere indicated that the partial replacement of clay body significantly increased the porosity and water absorption of clay bricks, but the thermal conductivity (k) values were improved as 0.67 and 0.95 W/mK.

In a conclusion, the waste materials can be utilized in making clay brick to economic and sustainable building materials. The present work aimed to determine the influence of the incorporation of fly ash (FH) on the technological properties of resulting clay bricks were studied

Materials and Methods

In this study, the clay used from the local clay bricks making in Maha Sarakham Province, Thailand. FH obtained from a coal power plant in Mae Mo District, Lampang Province, Thailand. Chemical elements of raw-materials were measured by using XRF; Horiba Mesa-500w. The phase analysis of raw-materials was performed by XRD; Philips Co., Eindhoven, Netherlands. Particle distribution values of clay and FH were measured by laser diffraction (Mastersizer 2000+Hydro 2000). The microstructures analysis of clay and FH were examined and analyzed using a scanning electron microscope (SEM: LEO 1460 VP, Zeiss).

The bricks specimen mixture without and four kinds of adding amounts of FH at 10, 20, 30, and 40

wt.% were introduced in the mixtures of raw-clay as shown in Table 1.

Each series of specimens was mixed for 30 min in a ceramic grinding balls-milling to get homogeneous mixing. Each series was then mixed with the addition of 20-40% water to supplement the plastic mixing condition of the mixture. The rectangle mold dimension of 50×95×30 mm was applied to extrusion process. Green clay brick specimens were dried at room temperature for 3 days, and followed at 110±5°C for else 24 h. Strength development of brick specimens were design in three firing temperatures as 800°C, 900°C, and 1,000°C in an electrical-furnace for 4 h, with a heating rate of 2°C/min (45 min soaking time).

The physical performance of prepared such as WA-water absorption, BD-bulk density, and APP-apparent porosity of clay bricks was assessed following the standard of ASTM C373-14a, (2014). Linear firing shrinkage (LS) were tested with standard test method according to ASTM C326-09, (2014). The mechanical property of clay brick specimens was conducted by measured tests the methods in (ASTM C773-88, 2011).

Results and Discussion

The chemical composition of clay and FH was presented in Table 2. The major chemical components of clay are silica (SiO₂), alumina (Al₂O₃), ferric oxide (Fe₂O₃), potassium oxide (K₂O), manganese oxide (MnO) with slight components of titanium dioxide (TiO₂), and calcium oxide (CaO). The FH powder includes large dosages of silica, iron oxide, calcium oxide, and also minor alumina, potassium oxide, sodium oxide, titanium dioxide, and manganese oxide. Total weight loss (LOI) was observed at 1000°C of clay and FH to estimate organic matter or carbonate content in the raw

Table 1. Mixing ratios of clay bricks

Samples	(wt%)	
	Clay	Fly ash (FH)
Control	100	0
1	90	10
2	80	20
3	70	30
4	60	40

Table 2. The chemical composition of clay and FH

	Compositions (wt%)										
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	K ₂ O	Na ₂ O	P ₂ O ₅	TiO ₂	MnO	MgO	LOI
Clay	60.75	23.35	4.85	0.94	2.16	-	-	0.85	2.34	-	4.76
Fly ash	25.67	8.52	28.17	29.64	2.77	0.19	-	0.69	0.22	-	1.74

materials. It was seen that organic matter in clay, which had higher than FH. Although high organic matter in clay implied about the good adhesion behavior, however black coring effect must be observed after firing process.

The particle-size distribution measurement was analyzed due to identifying the size of clay and FH powder, as shown in Figure 1. The particle-size curve of clay presented only one peak distribution with the average particle size $D[4,3]$ about 14.91 μm . Particle-size curve of FH indicated in two peaks size distribution. The average particle size $D[4,3]$ of FH was about 36.22 μm . It could be presented that average particle sizes of clay and FH were small that had good water infiltration. Therefore, it was a suitable plasticity for clay brick forming process.

The XRD pattern were obtained with a Bruker D8 Advance diffraction (Cu $K\alpha$ radiation), patterns were recorded in 2θ between 10 to 80° with a step interval of $0.04^\circ 2\theta$ and counting time of 1 sec per step. In the identification phase of clay and FH powder, the results indicated that the main crystalline phase found in clay (Figure 2(a)) was SiO_2 : quartz, $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$: kaolinite, $\text{KAl}_2(\text{AlSi}_3\text{O}_{10})$: muscovite and Fe_2O_3 : hematite. Whereas FH is an amorphous silica phase is shown in (Figure 2(b)).

Figure 3 present the SEM-micrographs of clay and FH revealed. Their particle of clay (Figure 3(a)) is different in size and agglomerated. For FH is various particle size spherical in shape (Figure 3(b)).

The standard of clay brick further examined agreeable to the order of linear shrinkage. Besides, sintering is another important characteristic affecting the degree of linear shrinkage. Ordinarily, a fired clay brick must be a shrinkage of less than 8%

(Weng *et al.*, 2003; Karaman *et al.*, 2008; Phonphuak and Thiansem, 2012; Phonphuak *et al.*, 2016; Phonphuak, 2017; Njindam *et al.*, 2018). The variation of LS of the clay bricks as a function of temperatures and FH content of the ratio is shown in (Figure 4(a)). This observation is a result of clay bricks were fired at a temperature of 800°C to $1,000^\circ\text{C}$. It was observed that the LS increased with increasing sintering temperature. The LS values of the clay bricks were in the range of 3.51-4.23%. While the reference bricks without any FH additive had equal LS was 3.42-4.18%. The property of the clay bricks in WA was adjacently related to the APP of the clay bodies (Cultrone *et al.*, 2005; Kazmi *et al.*, 2016; Phonphuak and Chindaprasirt, 2018). It is explained that porous is the hole to absorb the water. Thus, the sample had high porosity that could absorb high water value. From (Figure 4(b)) WA of clay bricks decrease with an increase in sintering temperature. However, the dosage of FH added increases the WA rate in a linear manner. Increasing WA causes clay bricks to adhere to each other and this weakens the wall strength. Hence, the resistance of clay bricks against frost also increases with decreasing WA. The study showed that the WA of clay bricks fired at temperatures of 800°C to $1,000^\circ\text{C}$ was in the range of 14.5-24.4%. The results of APP (Figure 4(c)) indicated that the highest porosity was 35.4% fired at 800°C (addition FH at 40 wt%), and the lowest porosity was 21.3% fired at $1,000^\circ\text{C}$ (addition FH at 10 wt%). Whereas, the reference bricks without any FH addition had comparable WA and APP fired at 800 - $1,000^\circ\text{C}$ between 12.3%-14.5% and 22.6%-23.2%, respectively. This result showed that a high percentage of FH in clay bricks caused high porosity in specimens (Singh *et al.*, 2016). Porosity in brick

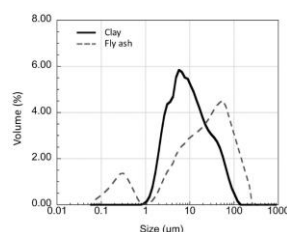


Figure 1. Particle-size curves of clay and FH

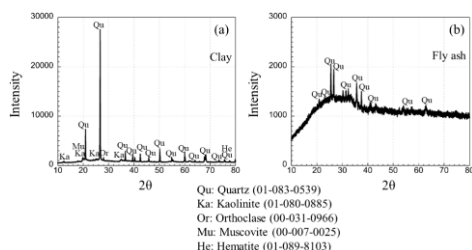


Figure 2. XRD phase identifies (a) clay and (b) FH

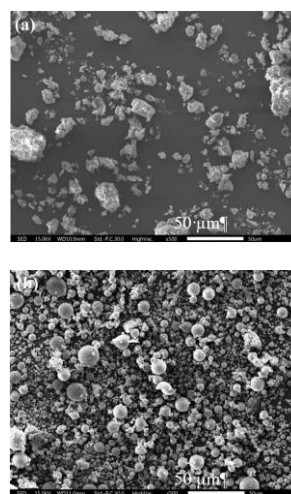


Figure 3. Morphology of raw materials: (a) clay and (b) FH

affected on good and inferior. It could absorb thermal conductivity to reduce indoor temperature. In contrast, it was affected on low compressive strength value. Especially, the WA of porous fired clay bodies is indicative of whole apparent porosity. For ASTM C62-13a, (2013), standard SW grade bricks must be absorption lower than 17%. Fired clay brick specimens with the required WA of firing temperature 900°C and 1000°C of FH additions 10 to 20 wt. %. In general, the BD of fired clay bricks on several factors which are such as specific gravity (sg) of raw materials, the manufacturing process, and thermal performance (Weng *et al.*, 2003). The BD of bricks was inversely proportional to the quantity of FH added to the mixture. If pores, voids, and cavity are reduced, the density and strength of clay brick increase, and the WA decreases (Sutcu *et al.*, 2019). The BD of bricks decreased with an

increase in the dosage of FH from 10 to 40 wt%. BD of bricks increased with an increase in sintering. As shown in (Figure 4(d)), the result revealed that the BD of clay bricks containing FH was in the ranges of 1.67 to 1.95 g/cm³.

The CS of clay brick is the final significant engineering indicator for construction materials. For the ASTM C62-13a, (2013), the strength of brick must be 17.2 MPa. In this research, the result shows that the CS greatly dependent on the dosage of FH addition in the clay brick specimens and the sintering temperature (Dondi *et al.*, 2002; Sarkar *et al.*, 2007).

Figure 5 shows the results of CS indicated that the clay brick specimens decreased with an increase in the dosage of FH additions in the clay brick specimens. An increase in CS was due to a decrease in APP with an increasing sintering temperature. The results showed that the CS values vary between 9.8 MPa to 18.3 MPa. When FH additions increased from 10-40 wt% and sintering temperature at 800°C to 1,000°C. Nevertheless, the CS of clay brick specimens with 10 wt% and 20 wt% FH additions and sintering temperature at 1,000°C were the strength higher than of standard. On the other hand, the reference group fired clay bricks without any FH

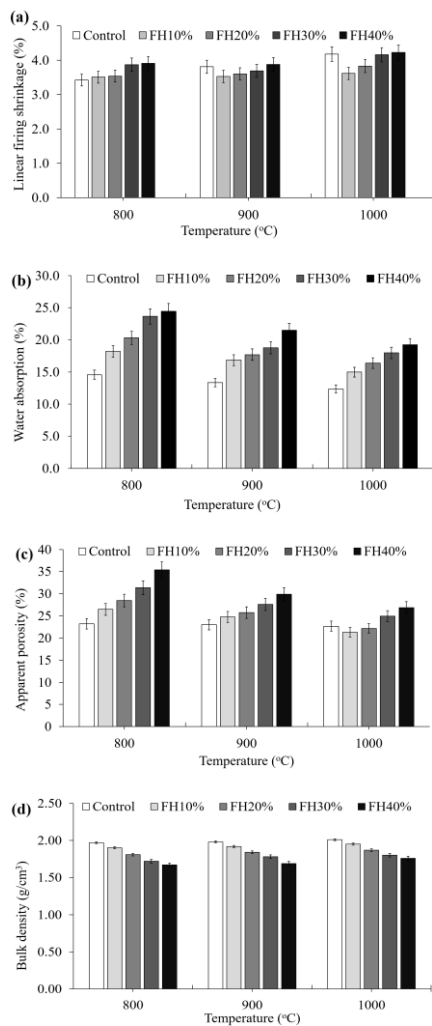


Figure 4. Effects of FH additions on the physical properties of specimens: (a) LS; (b) WA; (c) APP and (d) BD

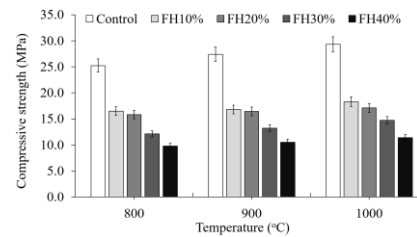


Figure 5. Effects of FH additions on the CS

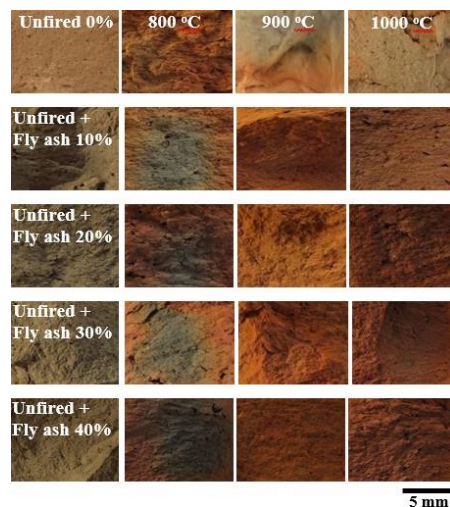


Figure 6. Fractured surface of the specimens

addition fired at 800°C to 1,000°C, showed a CS of 25.2-29.3 MPa respectively.

As seen from Figure 6, shows the photos of the fracture surface texture of the unfired brick, reference bricks, and bricks sintering temperature at 800°C to 1,000°C and different amounts of added FH 0-40 wt%. The photos show that as FH dosage increases, the micro-pores of the clay bricks also increase. This is the key factor in manipulating FH dosage in addition to the clay body and temperatures of the firing process to control WA that can affect CS and BD.

Conclusions

The key findings of using FH in clay brick following conclusions were researched:

1. The FH additions increased the porosity and the decreased BD of specimens. However, an increase in the BD with increasing sintering temperature.
2. WA value increase as the FH addition amount increases, while an increase in the sintering temperature causes a decrease in the WA and APP.
3. The CS of the specimens is decreased by the addition of the FH. However, the lowest CS standard in ASTM C62-13a, the strength was 17.2 MPa. In this research, for sintering at 1,000°C, the CS of fired clay bricks with 10 and 20 wt. % of FH addition was also acceptable at 18.3 and 17.1 MPa.
4. The addition of FH is economically recommended in the existing clay bricks manufacturing plants which use such as clay compositions. Besides, the FH can be considered as a likely additive to raw-materials used in the making of clay bricks.

Acknowledgments

This work was supported by Rajabhat Maha Sarakham University.

References

- Abbas, S., Saleem, M.A., Kazmi, S.M.S., and Munir, M.J. (2017). Production of sustainable clay bricks using waste fly ash: Mechanical and durability properties. *J. Build. Eng.*, 14:7-14.
- Adeola, J.O. (1977). A Review of masonry block/brick types used for building in Nigeria, [M. Eng. thesis]. University of Benin.
- ASTM C326-09. (2014). Standard Test Method for Drying and Firing Shrinkages of Ceramic Whiteware Clays. ASTM International. West Conshohocken, PA, ASTM Book of Standards Vol. 15.02.
- ASTM C373-14a. (2014). Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products, Ceramic Tiles, and Glass Tiles. ASTM International. West Conshohocken, PA. ASTM Book of Standards Vol. 15.02.
- ASTM C62-13a. (2013). Standard Specification for Building Brick (Solid Masonry Units Made From Clay or Shale). ASTM International, West Conshohocken, PA, ASTM Book of Standards Vol. 04.05.
- ASTM C773-88. (2011). Standard Test Method for Compressive (Crushing) Strength of Fired Whiteware Materials. ASTM International. West Conshohocken, PA, ASTM Book of Standards Vol. 15.02.
- Cultrone, G., Sebastián, E., and De La Torre, M.J. (2005). Mineralogical and physical behavior of solid bricks with additives. *Construct. Build. Mater.*, 19:39-48.
- Dondi, M., Guarini, G., Raimondo, M., and Venturi, I. (2002). Orimulsion fly ash in clay bricks-part 1: composition and thermal behavior of ash. *J. Eur. Ceram. Soc.*, 22:1,729-1,735.
- Eliche-Quesada, D., Sandalio Pérez, J.A., Martínez-Martínez, S., Pérez- Villarejo, L., and Sánchez-Soto, P.J. (2018). Investigation of use coal fly ash in eco-friendly construction materials: fired clay bricks and silicacalcareous non fired bricks. *Ceram. Int.*, 44:4,400-4,412.
- Esmeray, E. and Atis, M. (2019). Utilization of sewage sludge, oven slag and fly ash in clay brick. *Constr. Build. Mater.*, 194:110-121.
- Hossain, S.K.S., Mathur, L., Majhi, M.R., and Roy, P.K. (2018). Manufacturing of green building brick: recycling of waste for construction purpose. *J. Mater Cycles. Waste. Manage.*, 21:281-292.
- Karaman, S., Gunal, H., and Ersahin, S. (2006). Assessment of clay brick compressive strength using quantitative values of colour components. *Construct Build Mater.*, 20:348-354.
- Karaman, S., Gunal, H., and Ersahin, S. (2008). Quantitative analysis of pumice effect on some physical and mechanical properties of clay bricks. *Appl. Clay Sci.*, 8(7):1,340-1,345.
- Kazmi, S.M.S., Abbas, S., Saleem, M.A., Munir, M.J., and Khitab, A. (2016) Manufacturing of sustainable clay brick: Utilization of waste sugarcane bagasse and rice husk ashes. *Const. Build. Mat.*, 120:29-41.
- Muñoz, P., Juárez, M.C., Morales, M.P., and Mendiál, M.A. (2013). Improving the thermal transmittance of single-brick walls built of clay bricks lightened with paper pulp. *Energ. Build.*, 59:171-180.
- Njindam, O.R., Njoya, D., Mache, J.R., Mouafon, M., Messan, A., and Njopwouo, D. (2018). Effect of glass powder on the technological properties and microstructure of clay mixture for porcelain stoneware tiles manufacture. *Constr. Build. Mater.*, 170:512-519.
- Phonphuak, N., Kanyakam, S., and Chindaprasirt, P. (2016). Utilization of waste glass to enhance physical-mechanical properties of fired clay brick. *J. Clean. Prod.*, 112:3,057-3,062.
- Phonphuak, N. (2017). Application of Dry Grass for Clay Brick Manufacturing. *Key. Eng. Mater.*, 757:35-39.
- Phonphuak, N. and Chindaprasirt, P. (2018). Utilization of sugarcane bagasse ash to improve properties of fired clay brick. *Chiang Mai J. Sci.*, 45(4):1,855-1,862.
- Phonphuak, N. and Thiansem, S. (2012). Using charcoal to increase properties and durability of fired test briquettes. *Constr Build Mater.*, 29:612-618.
- Phonphuak, N., Teerakun, M., Srisuwan, A., Ruenruangrit, P., and Saraphirom, P. (2020). The use of sawdust waste on physical properties and thermal conductivity of fired clay brick production. *Int. J. GEOMATE.*, 18(69):24-29.

- Sarkar, R., Singh, H., and Das, S.K. (2007). Effect of addition of pond ash and fly ash on properties of ash-clay burnt bricks. *Waste. Manage. Res.*, 25:566-571.
- Singh, H., Brar, G.S., and Mudaha, G.S. (2016). Evaluation of characteristics of fly ash-reinforce clay bricks as building material. *J. Build. Phys.*, p. 1-14.
- Sutcu, M., Erdogmus, E., Gencel, O., Gholampour, A., Atan, E., and Ozbakkaloglu, T. (2019). Recycling of bottom ash and fly ash wastes in eco- friendly clay brick production. *J. Clean. Prod.*, 233:753-764.
- Weng, C.H., Lin, D.F., and Chiang, P.C. (2003). Utilization of sludge as brick materials. *Adv. Environ. Res.*, 7:679-685.