EFFECT OF FLY ASH CONTENT ON ENGINEERING PROPERTIES OF UNFIRED BUILDING BRICKS

ẢNH HƯỞNG CỦA HÀM LƯỢNG TRO BAY LÊN CÁC ĐẶC TÍNH KỸ THUẬT CỦA GẠCH KHÔNG NUNG

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Abstract - The use of unfired building bricks (UBB) to replace conventional fired clay bricks is an effective way to reduce the negative effects on the environment. Moreover, utilization of fly ash (FA) to partially replace cement in UBB significantly reduces the amount of CO2 emission to the atmosphere. This study investigates the possible application of raw FA from Nghi Son coal power plant in the production of UBB. The FA is used to replace 0%, 15%, 30%, and 50% cement in the brick mixtures. The effect of FA content on engineering properties of the UBB is evaluated. Analysis of cost and the optimal mixture is also conducted. Test results indicate that all of the brick samples have technical properties satisfying the requirements of TCVN 6477-2011. Moreover, this study finds that increasing the amount of FA results in reducing compressive strength, bulk density, and cost, however, increasing the water absorption of brick.

Key words - unfired building bricks; fly ash; compressive strength; water absorption; bulk density.

Tóm tắt - Sử dụng gạch không nung thay thế gạch đất sét nung truyền thống là một giải pháp hữu ích nhằm giảm thiểu các tác hại đến môi trường. Bên cạnh đó, việc sử dụng tro bay thay thế một phần xi măng trong sản xuất gạch không nung góp phần giảm đáng kể lượng CO2 phát thải ra bầu khí quyển. Bài báo này nghiên cứu khả năng ứng dụng tro bay thô của nhà máy nhiệt điện Nghi Sơn trong sản xuất gạch không nung. Hàm lượng tro bay được sử dụng để thay thế 0%, 15%, 30%, và 50% xi măng trong cấp phối gạch. Ảnh hưởng của hàm lượng tro bay lên các đặc tính kỹ thuật của viên gạch được đánh giá. Phân tích chi phí sản xuất và cấp phối tối ưu cũng được thực hiện. Kết quả thí nghiệm cho thấy, tất cả các mẫu gạch đều có các thông số kỹ thuật thỏa mãn theo TCVN 6477-2011. Hơn nữa, nghiên cứu này cũng cho thấy rằng khi hàm lượng tro bay tăng thì cường độ chịu nén, khối lượng thể tích và chi phí giảm, nhưng độ hút nước của gạch tăng.

Từ khóa - gạch không nung; tro bay; cường độ chịu nén; độ hút nước; khối lượng thể tích.

1. Introduction

Brick is one of the important construction and building materials in the world. In Vietnam, the construction industry consumes about 22 billion bricks each year. Most of them are conventional bricks, which are produced from clay with high burning temperature. As estimated by the government, the demand for building brick in 2020 is expected to be 42 billion units. Thus, to produce this large quantity of bricks, an approximate 600 cubic meters of clay, which is equivalent to about 30,000 hectares of the agricultural land are used. Moreover, the production of clay bricks consumes an intensive amount of energy and released a significant quantity of carbon dioxide (CO_2) into the air. Therefore, Vietnam has started to limit the production of conventional fired clay bricks and encouraged people to use unfired building bricks as a method to protect the natural resources and to save the environment. However, most of the unfired bricks are produced using a large amount of ordinary Portland cement. It is well-known that the production of cement consumes significant energy and generates a significant quantity of CO_2 to the atmosphere. Thus, many countries in the world have been using other supplementary cementitious materials as a partial or full replacement of ordinary Portland cement.

In Vietnam and other developing countries, the accumulation of unmanaged industrial waste has been increasing and has an inverse outcome to the environment. Turning such wastes into sustainable construction materials is an effective measure not only for the environment but also for the economic benefit. Fly ash is one kind of such wastes, a byproduct from the thermal power plant that has been widely used as a partial or full replacement for cement in the production of bricks and concrete.

Many studies have investigated the use of fly ash as a main cementitious material regard to cement in producing unfired bricks [1-4]. The compressive strength and water absorption of the bricks strongly depend on forming pressure, fly ash content, quality of fly ash, and dimension of bricks. With the use of 10 - 30% fly ash and under forming pressure of 20 MPa, bricks have compressive strength values of 12.8 - 18.3 MPa and water absorption of 13.7 - 19.4% [1]. When fly ash content increases to 50 - 80% and also under varying forming pressure from 0.5 to 30 MPa, the compressive strength of bricks is lower than 10 MPa and the water absorption of bricks is higher than 32.8% [2]. With the use of 90 - 100% fly ash and forming pressure of 26 MPa, Chindaprasirt and Pimraksa [3] indicated that the bricks had the excellent compressive strength of higher than 47 MPa and water absorption of lower than 19.5%. Kumar [4] investigated the use of 60 - 90% fly ash in making unfired bricks. It is noted that bricks in Kumar's study were produced by compaction on a vibration table. Test results showed that the compressive strength of the bricks was lower than 8 MPa, and water absorption of bricks was higher than 28.9%. The compaction by a vibration table was not as effective as compaction by pressure.

In order to increase the efficiency of fly ash, alkali-activator was used in some studies [5-8] to activate the pozzolanic reaction of fly ash. The use of a combination of fly ash and ground rice husk ash with alkali-activator resulted in good performance of bricks with compressive strength higher than 20 MPa and water absorption lower than 16% [5]. It is noted that the forming pressure of 35 MPa is applied in this study. Freidin [6] examined the use of fly ash and bottom ash in manufacturing unfired building bricks under forming pressure of 4 MPa. The produced bricks had compressive strength of 3.5 - 20 MPa and water absorption of 5.8 - 38.4%. The use of 100% fly ash under forming pressure of 30 MPa was studied by Arioz et al. [7]. The use of fly ash-red mud mixture to produce unfired bricks resulted in compressive strength of higher than 16 MPa and water absorption of lower than 7% [8].

The use of blended fly ash and other cementitious materials as a binder material for preparing brick samples was examined in some studies [9-11]. With the use of 5 - 15% cement as binder substitution, 85 - 95% of remaining binder were fly ash and rice husk ash, the compressive strength of bricks was higher than 13 MPa and water absorption was lower than 16% [9]. These bricks were formed by the pressure of 35 MPa. With the use of fly ash, slag, and cement as binder, the bricks had a compressive strength of 14.3 MPa and water absorption of 16.5 % [10]. In that research, the cement content was only 3% of total binder and forming pressure was from 10 to 25 MPa. Shakir et al. [11] investigated the use of 10 - 15% cement and 0 - 40% fly ash in total amount of the brick. Test results indicated that all the bricks had a compressive strength of higher than 6.2 MPa and water absorption of lower than 19.1%.

The use of fly ash in unfired building bricks is popular in the world. However, the application of low-quality fly ash with a high loss on ignition, greater than 6% as required by ASTM C618 [12], in the production of unfired building bricks under low forming pressure (lower than 10 MPa) is absent from the literature. Therefore, the objective of this study is to investigate the possibility to use raw fly ash with low quality in the production of unfired building bricks. The fly ash used has the loss on ignition of 15.7%, which is much greater than the requirement of ASTM C618 [12]. The brick was formed under a low forming pressure of 5 MPa. The effect of fly ash content on engineering properties of the unfired building bricks is investigated in the present study.

2. Materials and experimental program

2.1. Materials

The unfired building bricks are made from cement, fly ash, chippings, and water. The cement used in this study is Nghi Son type-PC40. Fly ash is taken from Nghi Son thermal power plant. The physical and chemical properties of both cement and fly ash are given in Table 1. The sum of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3) is greater than 70%, thus this fly ash is classified as class-F according to ASTM C618 [12]. It is noted that the loss on ignition of this fly ash is 15.75%, which is much higher than the upper limit of 6% as suggested by ASTM C618 [12]. Chippings is a by-product from the stone crushing process produced during quarrying activity, with the maximum size of 5 mm, density of 2.65 T/m^3, fineness modulus of 3.54, and moisture content of 0.5%. Figure 1 shows the gradation curve of the chippings used in this study.

Table 1. *Physical and chemical properties of cement and FA*

Items		Cement	Fly ash
Physical properties	Specific gravity	3.12	2.16
Chemical composition (wt.%)	SiO_2	22.38	48.38
	Al_2O_3	5.31	20.42
	Fe_2O_3	4.03	4.79
	CaO	55.93	2.80
	MgO	2.80	1.41
	Others	4.45	4.28
	Loss on ignition	1.98	15.76

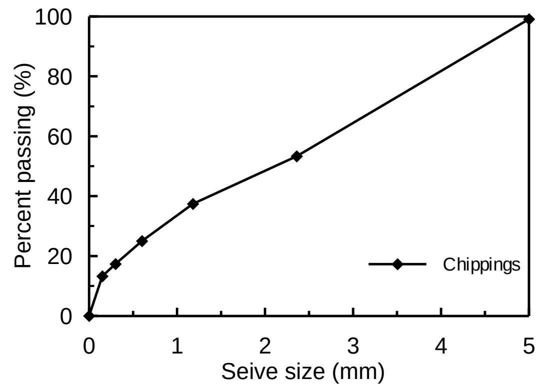

Figure 1. *Gradation curve of chippings*

2.2. Preparation of unfired building brick samples

Bricks are designed with two different water-to-binder ratios of 0.5 and 0.6, denoted as M50 and M60, respectively. The fly ash is used to replace 0%, 15%, 30%, and 50% cement. The number 0, 15, 30, and 50 after M50 and M60 denotes the percentage of fly ash to replace cement in these mixtures. The ingredient proportions of all brick mixtures are shown in Table 2.

Brick samples with the size of 220×105×65 mm are produced under forming pressure of around 5 MPa in a steel mold. The use of raw fly ash of low quality and low forming pressure to manufacture unfired building bricks is investigated in this study.

Table 2. *Unfired brick mixture proportions*

Mixture	Ingredient proportions (kg/m^3)			
	Cement	FA	Chippings	Water
M50-0	440.0	0	1693.3	220.0
M50-15	370.5	65.4	1677.5	218.0
M50-30	302.3	129.6	1662.0	215.9
M50-50	213.3	213.3	1641.8	213.3
M60-0	366.7	0	1755.6	220.0
M60-15	309.2	54.6	1741.9	218.3
M60-30	252.7	108.3	1728.5	216.6
M60-50	178.7	178.7	1710.9	214.4

2.3. Test programs

The unfired building brick samples are checked for dimensions and visible defects, compressive strength, water absorption, and bulk density in accordance with TCVN 6477-2011 [13]. Additionally, an analysis of cost and the optimal mixture is also performed. The compressive strength of bricks is measured at 3, 7, 14, and 28 days, while other properties are measured at 28 days. The reported values that are presented herein are the average values of three samples.

3. Results and discussion

3.1. Dimensions and visible defects

Table 3 and 4 show the dimensions and visible defects of brick samples, respectively. As a result, both dimensions and visible defects of all of the brick samples conform to TCVN 6477-2011 [13]. The slight difference in dimensions (± 1mm) compared with standard dimensions is due to the deformation of the steel mold under forming pressure during the manufacturing process of brick samples. No any visible defect of brick samples is observed. The brick samples exhibit a consistency of shape and dimensions without visible defects.

Table 3. *Dimensions of brick samples*

Dimension	Measured dimension (mm)	Allowable error (mm)
Width	105 ± 1	± 2
Length	220 ± 1	± 2
Height	65 ± 1	± 3

Table 4. *Visible defects of brick samples*

Type of visible defects	Allowable level	Visible defects of brick samples
The curvature of the surface of brick (mm), no more than	3	No
The number of edges and corner cracks with the depth of 5 ± 10 mm and the length of 10 ± 15 mm, no more than	4	No
The number of cracks through the thickness pulling to a width that not exceeding 20 mm, no more than	1	No

3.2. Compressive strength

The compressive strength development of brick samples prepared with different water-to-binder ratios of 0.5 and 0.6 are shown in Figures 2 and 3, respectively. The brick samples with a water-to-binder ratio of 0.5 have higher compressive strength than that of the samples with a water-to-binder ratio of 0.6. This phenomenon is due to the lower water-to-binder ratio associated with the greater amount of cement. Thus, the products of cement hydration reaction are main carriers of strength in the unfired building bricks.

The replacement of cement by fly ash shows a negative effect on the compressive strength of brick samples. At 28 days, the compressive strength values of M50-0, M50-15, M50-30, and M50-50 are 57.8, 43.3, 36.8, and 29.7 MPa, respectively. It means that using fly ash to replace 15%, 30%, and 50% amount of cement in the brick mixtures results in an approximate 25%, 36%, and 49% reduction of brick strength in comparison with the fly ash-free bricks, respectively. For brick mixtures with a water-to-binder ratio of 0.6, the compressive strength values of brick samples with 0%, 15%, 30%, and 50% fly ash are 45.7, 27.3, 19.6 and 16.5 MPa, respectively. Similar to M50 mixtures, the replacement of 15%, 30% and 50% cement by fly ash causes an approximate 40%, 57%, and 64% reduction in strength of bricks as compared with the no fly ash bricks, respectively. This reduction in brick strength is mainly due to the slow pozzolanic reaction of low-quality fly ash [14]. However, all fly ash brick samples have compressive strength values of higher than 16 MPa, which is much higher than the required strength for a building brick [13].

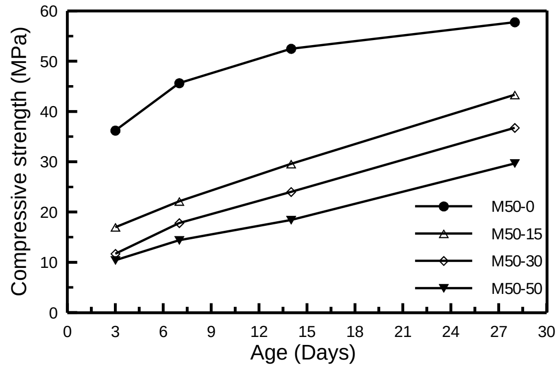

Figure 2. *Compressive strength development of M50 mixtures with different fly ash replacement levels*

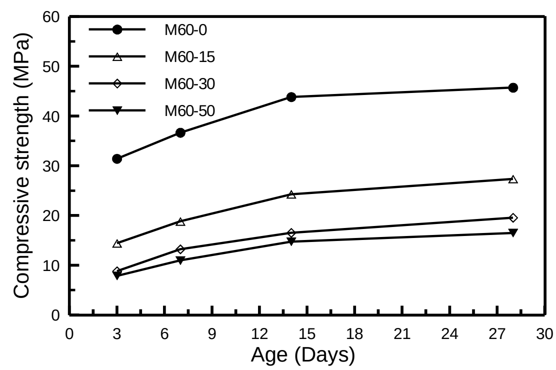

Figure 3. *Compressive strength development of M60 mixtures with different fly ash replacement levels*

3.3. Water absorption

Figure 4 shows the effect of fly ash on the water absorption level of the unfired building bricks. The water absorption of the brick samples ranges from 4.9% to 8.2%. These values are lower than 14%, which is the maximum level stipulated by TCVN 6477-2011 [13]. The brick mixtures with a water-to-binder ratio of 0.5 (M50 group) have lower water absorption than corresponding brick mixtures with water water-to-binder ratio of 0.6 (M60 group). Because the amount of cement in M50 mixtures is higher than that in M60 mixtures (see Table 2), the hydration rate of the M50 mixtures is higher, contributing to a denser structure and thus a lower water absorption level of bricks as compared with the M60 mixtures [15]. In addition, Figure 4 clearly shows that the water absorption of bricks increases significantly with increasing fly ash content. At 50% fly ash content, the water absorption levels of the M50 and M60 mixtures are 31% and 52% greater than the control mixtures without fly ash, respectively. As aforementioned, the fly ash used in this study has a low quality with the high loss on ignition that is due to the amount of unburned carbon. The high water demand of unburned carbon leads to increasing the water absorption of fly ash bricks [16]. However, all brick mixtures register the water absorption levels of lower than 14%, satisfying the requirement of TCVN 6477-2011 [13]. This indicates that the raw fly ash of low quality can be used to replace up to 50% cement in the brick mixtures.

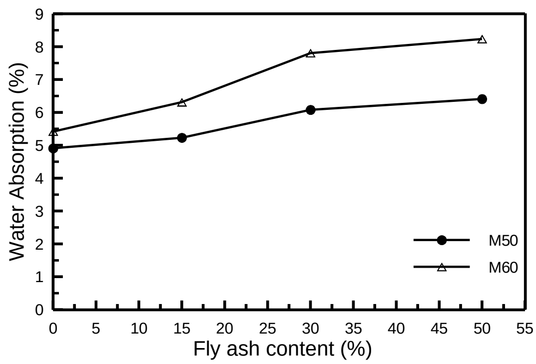

Figure 4. *Effect of fly ash content on the water absorption capacity of brick samples*

3.4. Bulk density

The bulk density is defined as the mass of brick divided by its volume. This is an important property of building bricks. If the bulk density of building bricks is high, the required construction cost of foundation is high too. The low bulk density is associated with light-weight building bricks. However, the bulk density of a brick sample is often directly proportional to its compressive strength and opposite to its water absorption capacity. As shown in Figures 5, the bulk density of bricks decreases with increasing the fly ash content. The brick samples with 15%, 30%, and 50% fly ash have average bulk density values of 9.6%, 11.7%, and 13.0% lower than the fly ash-free bricks, respectively. This is mainly due to the much lower specific gravity of fly ash as compared with that of cement (see Table 1). Moreover, the addition of fly ash of low quality results in the slow reaction, introducing more voids/ pores within the brick structure, and thus reducing the bulk density of brick samples [14].

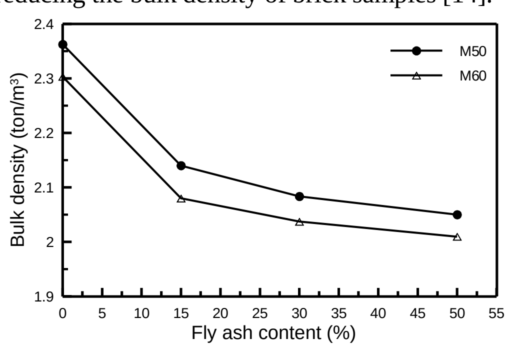

Figure 5. *Effect of fly ash content on the bulk density of brick samples*

3.5. Cost estimation

To assess the economic efficiency of using fly ash in producing unfired building bricks, the estimation for the cost of each brick sample is calculated and shown in Table 5. It is noted that the cost estimation given in Table 4 only includes material cost and it is conducted based on the unit price of construction materials announced by the Thanh Hoa Department of Construction in the first quarter of 2017. As can be seen from Table 5, bricks containing more fly ash register a lower cost. Fly ash is considered as a solid waste material that needs to be treated. Therefore, its price is much lower than that of the other ingredients in the brick mixture. The M60-50 brick mixture has the lowest cost of 507 VND per each unit, which is competitive with the current brick price in the market. Table 5 also demonstrates that the incorporation of fly ash as a cement substitution in the brick mixtures achieves a cost effectiveness in brick manufacturing.

Table 5. *Cost estimation for a brick*

Mixture	**Cost for each material used in brick mixtures (10^3 VND)**				**Total material cost for a brick (VND)**
	Cement	FA	Chippings	Water	
M50-0	539.9	0.0	79.1	3.0	934
M50-15	454.6	13.1	78.4	3.0	824
M50-30	370.9	25.9	77.6	3.0	717
M50-50	261.7	42.7	76.7	3.0	577
M60-0	449.9	0.0	82.0	3.0	803
M60-15	379.4	10.9	81.4	3.0	713
M60-30	310.1	21.7	80.7	3.0	624
M60-50	219.2	35.7	79.9	3.0	507

Note: Cement Nghi Son PC40: 1227 VND/kg, Fly ash: 200 VND/kg, Chippings: 1238000 VND/m^3, water: 13860 VND/m^3.

3.6. Analysis for optimal mixture

The optimal mixture is a mixture that satisfies both technical properties as required by TCVN 6477-2011 [13] and cost effectiveness. For a building brick, the required compressive strength is not as high as concrete, normally around 7.5 MPa because the columns and beams are the main loading carriers of the building. In most of the cases, the light-weight brick is preferred in order to save the foundation construction cost. Besides the technical properties, the brick price is a very important factor to decide that bricks can be sold on the market. Based on the above analyses, the brick samples are produced with using a water-to-binder ratio of 0.6 and 50% fly ash is the optimal mixture (M60-50), which can be suggested for massive manufacture. This brick mixture has a compressive strength value of 16.5 MPa, water absorption of 8.2%, bulk density of 2.0 ton/m^3, and a unit cost of 507 VND.

4. Conclusions

This paper examines the possible application of raw fly ash of low quality in the production of unfired building bricks. The effect of fly content on properties of the bricks is investigated. Based on the above experimental results, the main conclusions are summarized as follows:

1) All of the unfired building brick samples produced in this study have technical properties satisfying the requirements stipulated by TCVN 6477-2011.

2) The water absorption capacity of brick increases with fly ash replacement level, while its compressive strength and bulk density decrease.

3) Increasing the replacement level of cement by fly ash results in reducing of brick cost. For economic reason,

the mixture M60-50 is chosen as optimal mixture with the lowest cost.

4) The use of raw fly ash in the production of unfired building brick is an effective way to solve the problems related to the disposal of solid waste materials and to protect the environment for sustainable development.

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