EFFECT OF FLY ASH ON THE MECHANICAL PROPERTIES OF MORTAR

ẢNH HƯỞNG CỦA TRO BAY ĐẾN ĐẶC TÍNH CƠ HỌC CỦA VỮA

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Abstract - Class F fly ash is used to replace the OPC on the mass basis of the total cementitious material (CM) at the replacement portion of 0%, 10%, 20% and 40% while the water and CM ratio is constant at 0.4. The flexural and compressive strengths of all mixes are determined up to 90 days. The results show that within the range of investigation, the fly ash improves the consistence of fresh mortar but reduces both flexural and compressive strengths of mortar at early age depending on the replacement portions. At 90 days, the 10%FA flexural strength gained is equal to the control sample strength while the flexural strengths of 20% FA and 40% FA continue to develop to the strength of the control sample. At 28 days, the compressive strength of 10% FA is higher than that of the control samples and the compressive strength of 20% FA, 40% FA is nearly the same as the control samples at 90 days. Both flexural and compressive strengths of 40% FA will be gained with long term curing in water, and should be investigated in further research. The relationship between compressive strength and flexural strength regardless of fly ash content is almost fit with some previous researches.

Key words - mortar; fly ash; compressive strength; flexural strength; consistence

Tóm tắt - Tro bay loại F thay thế xi măng theo tỉ lệ khối lượng chất kết dính là 0%, 10%, 20% và 40% trong khi tỉ lệ nước và chất kết dính không đổi 0,4. Cường độ chịu uốn và nén của vữa được xác định đến 90 ngày. Kết quả cho thấy tro bay tăng độ linh động hỗn hợp vữa, nhưng giảm cường độ chịu uốn và nén của vữa ở giai đoạn đầu tùy theo tỉ lệ thay thế xi măng. Tuy nhiên, tại 90 ngày, 10% tro bay thay thế có cường độ chịu uốn gần bằng mẫu đối chứng không có tro bay trong khi cường độ chịu uốn của mẫu 20% và 40% tro bay tiếp tục phát triển khi dưỡng hộ trong nước. Tại thời điểm 28 ngày, cường độ chịu nén của mẫu 10% tro bay thay thế xi măng cao hơn mẫu đối chứng và cường độ chịu nén mẫu 20% và 40% tro bay gần bằng mẫu đối chứng tại 90 ngày. Mối quan hệ giữa cường độ chịu uốn và nén của vữa tro bay gần giống với xu hướng của các nghiên cứu trước đó.

Từ khóa - vữa; tro bay; cường độ chịu nén; cường độ chịu uốn; độ linh động

1. Introduction

The environmental impact of using concrete, the most commonly used construction material worldwide, is being debated along with its constituent materials in research and industry spheres. Fly ash, being a by-product of coal fired electricity generation can potentially provide future solutions to problems faced on building and infrastructure projects when applied and used properly.

The potential for using fly ash as a supplementary cementitious material in concrete has been known almost since the start of the last century [1]. Fly ash has been successfully used in cement concrete and as component of Portland pozzolana cement/ blended cement for more than 50 years. There are some structures in which fly ash has been used [2]. Fly ash concrete was used in Prudential Building, the first tallest building in Chicago after World War II. About 60,000 cum of fly ash concrete with an estimated saving of 3,000 tonne of OPC were used in Lednock Dam construction in the UK during the year 1955. The use of fly ash as a supplementary cementitious material (SCM) in concrete is well recognised for its economic and performance advantages including improved workability, mix efficiency and durability. Fly ash is also widely recognised, used and specified in standards covering SCMs [3] and General Purpose and Blended Cements [4]. More recently, the focus for the use of fly ash in concrete has shifted to quantifying benefits offered in enhancing concrete sustainability [5]. Fly ash can directly contribute to sustainable development whilst maintaining other criteria including engineering design aspects, constructional aspects; and economic advantages [6].

There have been many researches about the influence of fly ash on the mechanical properties of mortar. It has been found that the compressive strength of mortars with fly ash replacement is affected by the hydration reaction, packing effect, and pozzolanic reaction [7]. It has been widely reported that the fineness of fly ash has an important role to play on the development of strength [7, 8]. Different treatments like sieving, magnetic extraction, grinding and mechanical separation can be used to modify the properties of fly ash in order to improve the compressive strength and microstructural properties of fly ash mortars [9, 10,11].

This paper aims to investigate the effect of class F fly ash from Northern Vietnam on the development of flexural strength and compressive strength of mortar.

2. Experimental programme

2.1. Materials

Table 1. *Chemical composition and physical properties of fly ash*

Fineness (%)	21.5 (>45 μm)
Loss on ignition LOI (%)	5.83
Moisture (%)	0.04
SiO_2 (%)	58.9
Fe_2O_3 (%)	5.75
Al_2O_3(%)	23.9
SO_3(%)	0.03

The materials used in this study are those commercial available in Vietnam. The ordinary Portland cement used is obtained from Song Gianh Company. The fine aggregates are locally natural sand. Fly ash is obtained from power station in the Northern Vietnam. The properties of fly ash are shown in Table 1. In according to ASTM C618, $SiO_2+Al_2O_3+Fe_2O_3=88.55 \geq 70\%$, so this type of fly ash is classified as class F.

2.2. Mix proportion and sample

The mix compositions of all mixes are presented in Table 2. Four mixes are cast and cured in water. For M2, M3, M4 the OPC is replaced by 10%, 20%, 40% FA (by weight) respectively, while mix M1 is the control mix without fly ash. For each mix, 15 prism dimensions of 40x40x160 mm are cast for determination of flexural and compressive strengths at 1day, 7 days, 28 days, 56 days and 90 days. After bending test for determination of flexural strength, the two halves of each prism are used to determine the compressive strength in accordance with BS EN 196-1: 2005.

***Table 2**. The mixture proportions of mortar*

ID	W/CM	W/C	OPC (kg)	Fly ash (FA) (kg)	Sand (kg)	Water (kg)	Diam- -eter of mortar (mm)
M1 (0%FA)	0.4	0.40	10	0	10	4	166
M2 (10%FA)	0.4	0.44	9	1	10	4	192
M3 (20%FA)	0.4	0.50	8	2	10	4	202
M4 (40%FA)	0.4	0.66	6	4	10	4	205

2.3. Consistence of fresh mortar

The consistence of fresh mortar is determined by flow table test in accordance with BS EN 1015-3:1999. The mortar is filled into the mould after mixing in two layers, each layer being compacted by 10 short strokes of the tamper to ensure uniform filling of the mould. During filling, hold the mould firmly on the disc, using one hand. Skim off the excess mortar with a palette knife and wipe the free area of disc clean and dry, being especially careful to remove any water from around the bottom edge of the mould. After approximately 15s, slowly raise the mould vertically and spread out the mortar on the disc by jolting the flow table 15 times at a constant frequency of approximately one per second. The diameters of the mortar in two directions at right angles to one another are measured by using calipers. The mean value is calculated and presented in Table 2.

2.4. Flexural and compressive strengths of mortar samples

The flexural strength and compressive strengths are determined in accordance with BS EN 196-1: 2005. The three points bending is used to determine the flexural strengths as shown in Figure 1. Two halves of broken prisms are used to determine the compressive strengths of mortar as shown in Figure 2.

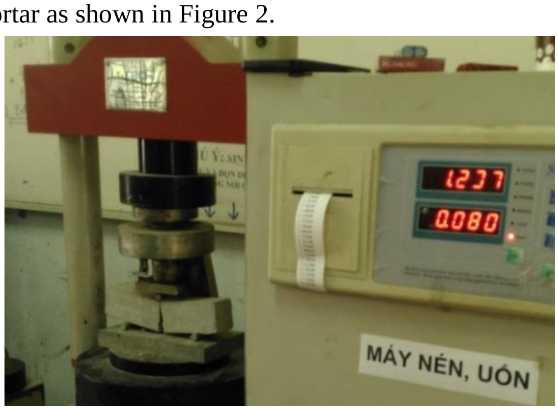

***Figure 1.** Flexural strength test of mortar*

***Figure 2.** Compressive strength tests of mortar*

3. Results and discussion

3.1. Consistence of fresh mortar

The consistence of fresh mortar is determined by the diameter of mortar of flow table test as shown in Table 2. It is clear that fly ash contributes to the increase of workability by the increasing of diameter of mortar. The diameter of mortar increases from 166 mm to 192 mm to 202 mm to 205 mm when fly ash is used to replace OPC by 0%, 10%, 20% and 40% respectively. Therefore, FA is considered to absorb water less than OPC.

3.2. Flexural strength development

The flexural strengths and flexural strength activity indexes of all samples are shown in Table 3 and plotted in Figures 3 and 4. The flexural strength activity index is defined as the ratio (in percent) of flexural strengths of the FA replacement samples to the corresponding control samples (0%FA).

***Table 3.** Flexural strengths and strength development index of mortar samples*

ID	Flexural strength (MPa) – (Flexural strength activity index)				
	1 day	7 days	28 days	56 days	90 days
M1 (0%FA)	4.20 (100)	5.49 (100)	6.15 (100)	6.35 (100)	6.45 (100)
M2 (10%FA)	3.22 (77)	5.11 (93)	5.58 (91)	5.88 (93)	6.30 (98)
M3 (20%FA)	2.28 (54)	4.33 (79)	4.70 (76)	5.31 (84)	5.53 (86)
M4 (40%FA)	1.25 (30)	2.32 (42)	4.48 (73)	5.40 (85)	5.66 (88)

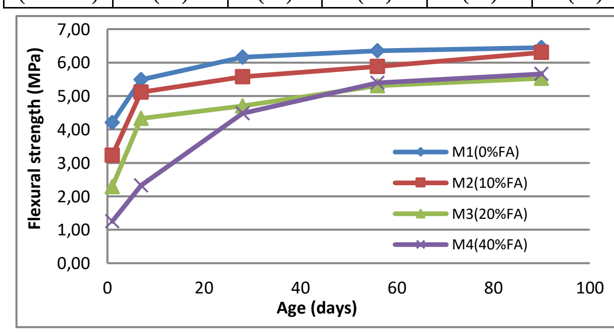

***Figure 3.** Flexural strengths of mortar*

Figure 3 shows the development of flexural strengths of all fly ash replacement samples (M2, M3, M4) and control sample (M1). The flexural strength of fly ash replacement samples decrease when FA is used to replace the OPC at 10%, 20% and 40% up to 90 days. At 90 days the flexural strengths of 10%FA replacement gained is nearly the same as the flexural strength of the control sample, 6.45MPa and 6.3MPa for the control and 10%FA respectively. The flexural strength of the control sample at the ages of 1 day, 7 days, 28 days, 56 days and 90 days are 4.2MPa, 5.49MPa, 6.15MPa, 6.35MPa. It looks like that the flexural strengths of the control sample are kept remaining the same after 28 days. The flexural strengths of 10%FA continue developing slowly after 28 days, they are 5.58MPa, 5.88MPa and 6.3MPa at the age of 28days, 56 days and 90 days respectively. Similarly the flexural strengths of 20%FA and 40%FA continue to develop after 28 days and are predicted to gain the higher value than the flexural strength of the control sample with long term curing in water

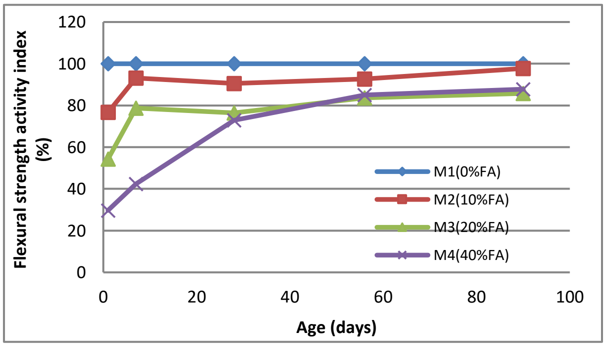

Figure 4. *Relationship between the flexural strength activity index of fly ash mortar and curing age*

Figure 4 shows that the flexural strength activity indexes of fly ash replacements increase with the curing ages. The flexural strength development index of 10%FA increases very slowly from 91% at 28 days to 98% at 90 days. The flexural strength development index of 20% also increases slowly from 76% at 28 days to 86% at 90 days. For 40%FA replacement the flexural strength development indexes increase dramatically from 30% at 1 day to 73% at 28 days to 88% at 90 days. Therefore, it can be seen that the rate of development of flexural strength of FA samples is higher than the control samples with long term curing in water.

3.3. Compressive strength development

The compressive strengths and compressive strength activity indexes of all samples are shown in Table 4 and plotted in Figures 5, 6. The compressive strength activity index is defined as the ratio (in percent) of compressive strengths of the FA replacement samples to the corresponding control samples (0%FA).

Table 4. *Compressive strength of all samples*

ID	Compressive strength (MPa)-(Compressive strength activity index)				
	1 day	7 days	28 days	56 days	90 days
M1 (0%FA)	17.52 (100)	39.52 (100)	46.89 (100)	51.06 (100)	52.65 (100)
M2 (10%FA)	11.81 (67)	32.57 (82)	49.59 (106)	50.28 (98)	53.26 (101)
M3 (20%FA)	13.97 (80)	26.27 (66)	42.58 (91)	47.94 (94)	52.09 (99)
M4 (40%FA)	2.16 (12)	11.09 28)	24.84 (53)	32.19 (63)	40.26 (76)

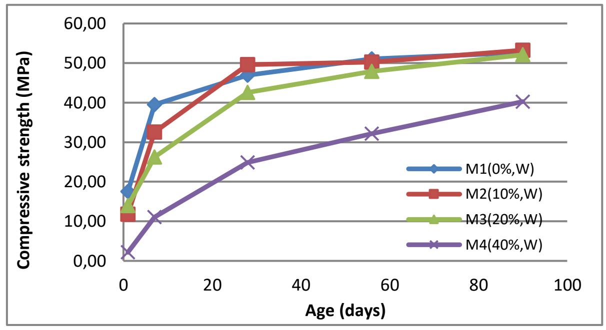

Figure 5. *Compressive strengths of mortar*

Figure 5 shows the development of compressive strength of all mortar samples cured in water. At early age, before 28 days, the FA contributes to the reduction in compressive strength of mortar, the higher percentage of FA replacement the higher reduction in compressive strength. However at 28 days, the compressive strength of 10%FA samples increases to the value higher than that of the control samples (0%FA). Similarly it can be seen that the compressive strength of 20%FA developes with the time of curing in water and gains to the close compressive strength of the control samples and 10%FA at 90 days. The flexural strength of 40%FA samples developes with the time and is predicted to develop with the long term curing in water (after 90 days).

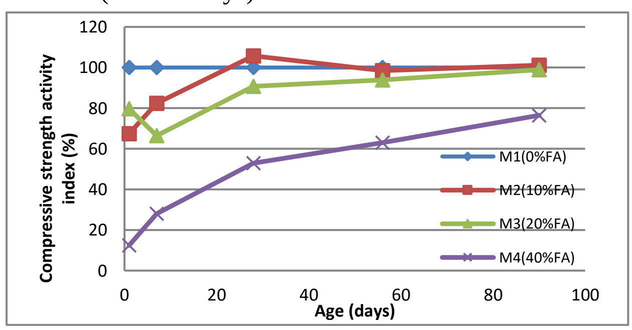

Figure 6. *Relationship between the compressive strength activity index of fly ash mortar and curing age*

Figure 6 shows that the compressive strength activity indexes of fly ash mortar samples generally increase with the age of curing. The increase of compressive strength activity index of 10%FA and 20%FA is slower than that of the 40%FA.

The compressive strength activity indexes of 10%FA are 67%, 82%, 106%, 98%, 101% at the ages of 1 day, 7 days, 28 days, 56 days and 90 days respectively. The compressive strength activity indexes of 20%FA are 80%, 66%, 91%, 94%, 99% at the ages of 1 day, 7 days, 28 days, 56 days and 90 days respectively. Although the compressive strength activity indexes of 40%FA are less than those of 10%FA, 20%FA, the compressive strength activity indexes of 40%FA increase quickly from 12% at 1 day to 53% at 28 days to 76% at 90 days. It means that the compressive strength development of fly ash mortar depends on the fly ash content, as the higher fly ash content the less compressive strength activity indexes up to 90 days, but is expected to gain the higher compressive strength activity indexes with long term curing age.

3.4. Relationship between flexural strength and compressive strength

The relationships between flexural strength and compressive strengths of all mixes are plotted in Figure 7. Some previous researches have proposed the relationships between flexural strengths (modulus of ruptures) and compressive strengths which are also plotted in Figure 7. It can be seen clearly that the relationships between compressive strength and flexural strength of mortar regardless of fly ash contents are almost fit with the previous researches except for the ACI 1995. The proposed equation for the relationship of compressive strength and flexural strength will be developed in future research with more data collected.

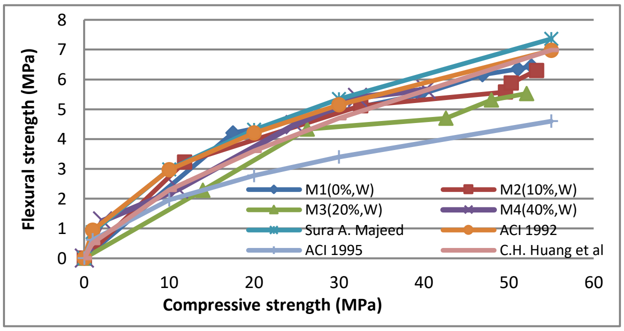

Figure 7. *Relationship between flexural strength and compressive strength*

4. Conclusion

Based on the results reported in this paper, the following conclusions can be made:

- Fly ash can be used to replace OPC for mortar, contributing to the sustainable construction material development.
- Fly ash contributes to improving the workability of fresh mortar as the fly ash consumes less water than OPC.
- At early age the fly ash reduces the flexural strength of mortar. At 90 ages of curing in water, the flexural strength of 10%FA gained is equal to the value close to the flexural strength of the control sample while the flexural strengths of 20%FA and 40%FA continue to develop to the closer value of the control sample.
- At early age the compressive strength of FA sample is less than that of the control samples. However at 28 days, the compressive strength of 10%FA is higher than that of the control samples and the compressive strength of 20%FA is nearly the same as the control samples at 90 days.
- Although high volume fly ash at 40% replacement has less compressive strength than that of the others, the compressive strength of 40%FA replacement is predicted to continue to develop after 90 days.
- The higher content of fly ash the less strength activity indexes at early age, but the higher rate increase of strength activity indexes.
- The relationship between compressive strength and flexural strength regardless of fly ash content are almost fit with some previous researches

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