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Use of finely ground fly ash as mineral admixture in blended portland cement production

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KEYWORDS

Ground fly ash
Admixture
Blended portland cement
Properties
Fineness

ABSTRACT

Fly ash is an active mineral admixture used commonly in the production of blended Portland cement. Fly ash improves many important properties of cement and cement concrete: increasing late compressive strength, increasing sulfate resistance, reducing heat of hydration, reducing alkali-silica reaction and reducing water permeability. However, the current use of original fly ash has a disadvantage that it reduces the early compressive strength of cement, which limits the amount of fly ash blended into the cement. Theoretically, increasing fly ash fineness would increase the reactivity of fly ash. Therefore, the objective of this study was to evaluate the possibility of using finely ground fly ash as a mineral admixture in the production of blended Portland cement through determining the effect of original fly ash (Blaine fineness of 2600 cm^2/g) and finely ground fly ash (Blaine fineness of 5000 cm^2/g and 6500 cm^2/g) on some properties of Portland cement. The investigated cement properties include water of consistency, setting time, and compressive strength at ages of 1, 3, 7, 28 days. The results show that, increasing the fineness of fly ash increased the water of consistency and setting time of the cement, but the increases were small. Increasing the fineness of fly ash significantly increased both early and late compressive strength of the cement. Therefore, finely ground fly ash can be used to minimize the disadvantage of fly ash, thereby allowing the use of higher fly ash content in production blended Portland cement.

1. Introduction

Fly ash is the flue gas dust in the form of fine particles obtained from the combustion of coal fuel in coal-fired power plants [1]. Fly ash exists mainly in the amorphous phase, and its chemical composition mainly includes SiO_2, Al_2O_3 and Fe_2O_3 [2].

In 2020, Vietnam had 25 thermal power plants that released more than 13 million tons of coal ash, of which fly ash accounts for 80-85% [3]. The amount of coal ash stored in storage yards of thermal power plants was 47.65 million tons. The total amount of coal ash that had been used up to the year 2020 was 34.5 million tons. Since the amount of coal ash used annually is still modest compared to the amount released, the amount of coal ash stored in storage yards is increasing over the years. This has many potential risks to the environment. Therefore, Vietnamese government has issued many policies to promote the use of coal ash as construction materials.

These days, in Vietnam one of important applications of coal ash in general and fly ash in particular is as an active mineral admixture in blended Portland cement production [3]. Up to the year 2020, the amount of coal ash had been used in cement production was 24 million tons. When being added into Portland cement, fly ash exhibits pozzolanic properties, SiO_2 in fly ash reacts with $Ca(OH)_2$ released from the hydration of Portland cement to form C-S-H [4]. Fly ash reduces pore size in cement matrix and the transition zone between cement paste and aggregate [5,6]. Fly ash improves many important properties of cement and cement concrete: increasing late compressive strength, increasing sulfate resistance, reducing heat of hydration, reducing alkali-silica reaction, and reducing chloride permeability [7]. Therefore, the increasing use of fly ash in blended Portland cement production not only reduces the amount of fly ash left, reducing its impact on the environment but also helps to improve the quality of cement.

However, the current use of original fly ash has an important disadvantage that it reduces the early compressive strength of cement due to its low reactivity [8]. This significantly limits the amount of fly ash used in blended Portland cement production. Theoretically, to increase the amount of fly ash that can be added to cement, it is possible to reduce the loss of early compressive strength of cement when fly ash is added by using higher fineness of fly ash. When increasing the fineness of fly ash, the pozzolanic activity of fly ash also increases and the reaction to form C-S-H takes place faster, so it would improve the early compressive strength of cement.

The objective of this study was to evaluate the possibility of using finely ground fly ash as a mineral admixture in the production of blended Portland cement through determining the effect of original fly ash (Blaine fineness of 2600 cm^2/g) and finely ground fly ash (Blaine fineness of 5000 cm^2/g and 6500 cm^2/g) to some properties of Portland cement. The investigated cement properties include water of

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consistency, setting time, and compressive strength at ages of 1, 3, 7, 28 days.

2. Materials and experimental procedure

2.1. Materials

The clinker used in this study was produced by VICEM But Son cement company. The chemical and mineral compositions of clinker are shown in **Tables 1** and **2**.

The gypsum used was a natural gypsum whose chemical composition is shown in **Table 3**.

The fly ash used was from Ninh Binh thermal power plant which uses pulverized coal burning technology. The chemical composition of fly ash is shown in **Table 4**. Original fly ash had the Blaine fineness of 2600 cm^2/g (determined according to TCVN 4030:2003 [9]).

Table 1. Chemical composition of clinker.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
Content (%)	21.36	5.52	3.39	64.73	2.94	0.26	0.73	0.13

Table 2. Mineral composition of clinker.

Mineral	C_3S	C_2S	C_3A	C_4AF	free CaO
Content (%)	47.3	25.8	8.9	10.3	2.7

Table 3. Chemical composition of gypsum.

Composition	SO_3	$CaSO_4.2H_2O$	combined H_2O	residue
Content (%)	45.63	90.20	18.88	1.98

Table 4. Chemical composition of fly ash.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
Content (%)	52.68	21.22	6.87	1.96	1.21	0.39	10.28

2.2. Experimental procedure

The cement samples were prepared as follows:

- Step 1: Preparation of Portland cement

Clinker and gypsum were crushed separately by using a jaw crusher until all particles passed a 5 mm sieve. Clinker and gypsum were weighed at the ratio of 95% clinker and 5% gypsum, then put into a ball mill and ground until the Blaine fineness was 3400 cm^2/g (determined according to TCVN 4030:2003 [9]).

- Step 2: Preparation of finely ground fly ash

Original fly ash was ground in a laboratory ball mill to the Blaine fineness of 5000 cm^2/g and 6500 cm^2/g (determined according to TCVN 4030:2003 [9]).

- Step 3: Preparation of Portland-fly ash cement mixtures

Portland-fly ash cement mixtures were prepared by weighing and mixing (by machine) Portland cement and fly ash (original and finely ground) at the ratio of 90% Portland cement and 10% fly ash.

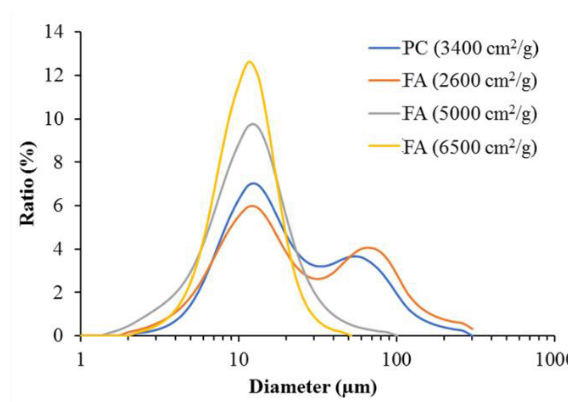
The particle size distribution of Portland cement sample and fly ash samples was determined by laser scattering method on a Horiba LA-950 machine. Water of consistency and setting time of cements were determined according to TCVN 6017:2011 [10]. The compressive strengths of cements were determined according to TCVN 6016:2011 [11].

3. Results and discussion

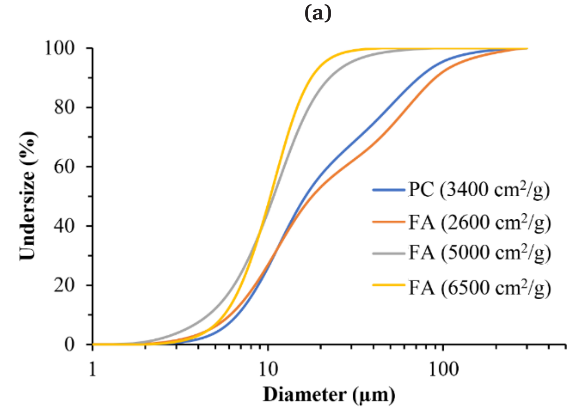
3.1. Particle size distribution

The results of particle size analysis of Portland cement sample and fly ash samples are shown in **Figure 1** and **Table 5**.

The results in **Table 5** show that the D_{av}, D50 and D90 values of original fly ash were bigger than those of Portland cement. While these parameters of the two ground fly ash samples were smaller than those of Portland cement. This shows that when compared with Portland cement, the original fly ash was coarser while the two finely ground fly ash samples were finer. The higher the Blaine fineness of fly ash, the smaller the D_{av}, D50 and D90 values, the fine-particle ratio increases and the coarse-particle ratio decreases.



(a)



(b)

Figure 1. Particle size distribution of Portland cement sample (PC) and fly ash samples (FA).

Table 5. Particle size distribution of Portland cement sample (PC) and fly ash samples (FA).

Sample	Blaine (cm^2/g)	D_{av}* (μm)	D50** (μm)	D90*** (μm)
PC	3400	30.7	16.5	72.9
TB	2600	37.7	18.0	90.6
TB	5000	14.0	11.0	22.8
TB	6500	11.2	10.5	17.8

* Average diameter

** Size which 50% particles have sizes smaller or equal to

*** Size which 90% particles have sizes smaller or equal to

Results in **Figure 1a** show that both curves of both Portland cement sample and original fly ash sample had two distinct peaks, a larger peak in the fine-particle region and a lower peak in the coarse-particle region. The positions of these two peaks of Portland cement sample were 10.9 μm and 61.5 μm, respectively. The positions of these two peaks of the original fly ash sample were 10.9 μm and 67.5 μm, respectively. Each curve of finely ground fly ash samples had only 1 peak in the fine-particle region. The peak positions of two fly ash samples with Blaine fineness of 5000 cm^2/g and 6500 cm^2/g were approximately equal, 10.9 μm and 10.8 μm, respectively.

3.2. Water of consistency

The results of water of consistency of cement samples are shown in **Figure 2**. The results in **Figure 2** show that, the values of water of consistency of Portland cement sample and the cement sample using primary fly ash were similar (28%), while the values of water of consistency of the two cement samples using finely ground fly ashes were higher (29%). Therefore, increasing the fineness of fly ash increased the water of consistency of cement with an increase of 1% when increasing the fly ash fineness from 2600 cm^2/g to 6500 cm^2/g. This increase could be due to that the increase in fly ash fineness increased the fineness and specific surface area of the Portland- fly ash cement mixture. Therefore, more water would be required to lubricate the surface of the particles for the cement paste to reach the standard consistency [12].

3.3. Setting time

The experimental results of initial and final setting time of the cement samples are shown in **Figure 3**.

The results in **Figure 3** show that the initial and final setting time of cement samples containing fly ash were higher than those of the sample without fly ash. This would be due to the dilution effect of fly ash, which reduced the Portland cement content. For samples using fly ash, when increasing the fineness of fly ash, the initial and final setting time increased slightly. When the fineness of fly ash increased from 2600 cm^2/g to 6500 cm^2/g, the initial setting time increased from 105 min to 110 min while the final setting time increased from 185 min to 195 min. When the fly ash content remained unchanged, the main reason for the increase in setting time would be that the higher water of consistency of samples using finely ground fly ash prolonged the induction period in the hydration of cement [13]. **Figure 3** also shows that the initial and final setting time of the samples using fly ash met TCVN 6260:2009 standard (initial setting time not less than 45 min and the final setting time not greater than 420 min [14]).

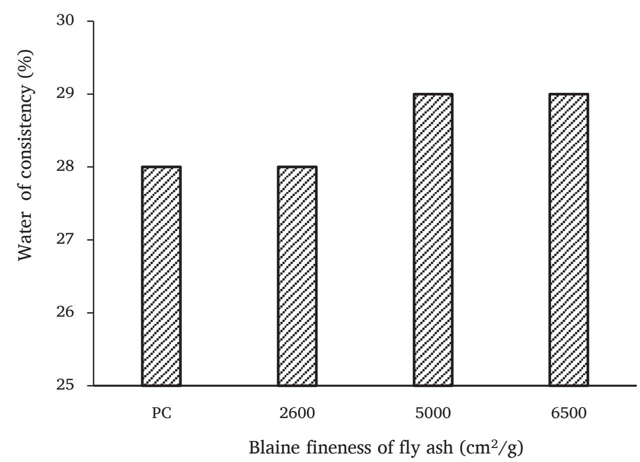


Figure 2. Water of consistency of Portland cement sample and Portland- fly ash cement samples.

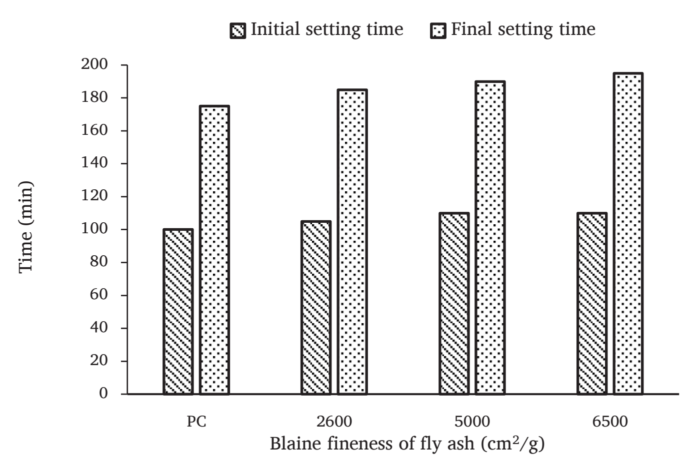


Figure 3. Setting time of Portland cement sample and Portland-fly ash cement samples.

3.4. Compressive strength

The results of the compressive strength of the cement samples are shown in **Figure 4**.

The results in **Figure 4** show that the compressive strengths of cement samples using ground fly ash were higher than those of cement sample using original fly ash at both early and late age. As the fineness of fly ash increased, the compressive strengths of the cement samples using fly ash increased. At the age of 3 days, the strengths of cements using fly ash with Blaine fineness of 2600 cm^2/g, 5000 cm^2/g and 6500 cm^2/g were 30.1 MPa, 32.9 MPa, and 33.6 MPa, respectively. At the age of 28 days, the strengths of cements using fly ash with Blaine fineness of 2600 cm^2/g, 5000 cm^2/g and 6500 cm^2/g were 48.2 MPa, 49.7 MPa, and 52.8 MPa, respectively. This increase in strength would be due to that when the increase in fineness of fly ash increased the surface area of fly ash particles for participating in pozzolanic reaction with $Ca(OH)_2$ to produce high strength C-S-H hydrate. In addition, finely ground fly ash particles could also fill the voids within cement matrix to increase the density of cement matrix, therefore, this would increase the compressive strength of cement.

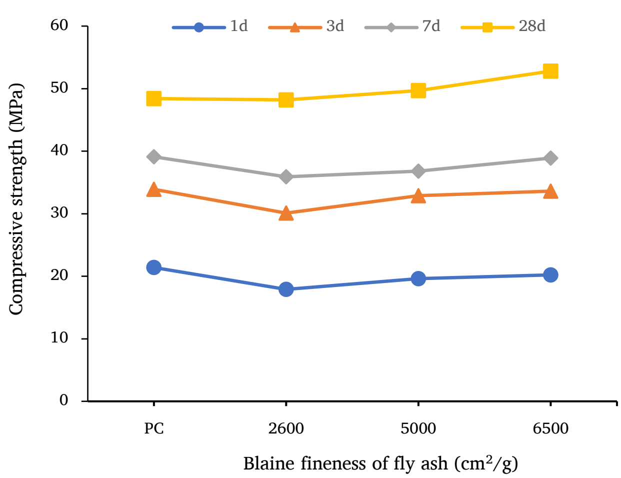


Figure 4. Compressive strength of Portland cement sample and Portland-fly ash cement samples.

Figure 5 presents the relative compressive strengths of Portland-fly ash cement samples in comparison with the strength of Portland cement sample. The results show that the cement sample using finely ground fly ash with the Blaine fineness of 5000 cm^2/g had an increase about 8% in strength at ages of 1 and 3 days in comparison with the cement sample using original fly ash with the Blaine fineness of 2600 cm^2/g, at the ages of 7 and 28 days the increase was approximately 3%. This means the average increase was about 5.5%. Meanwhile, the cement sample using finely ground fly ash with the Blaine fineness of 6500 cm^2/g had an increase of about 8% in all ages in comparison with the cement sample using original fly ash with the Blaine fineness of 2600 cm^2/g. These results indicate that the fine grinding fly ash improves significantly the strength of cement samples using fly ash at both early and late ages.

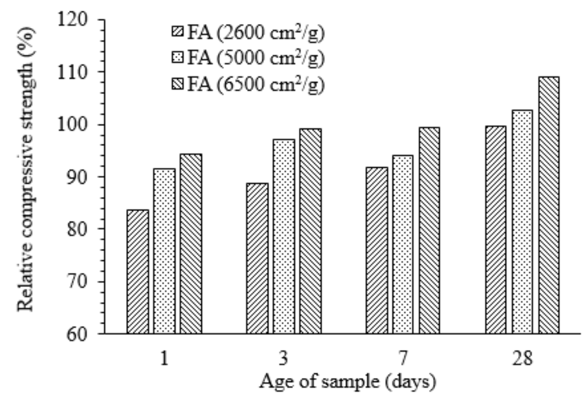


Figure 5. Relative compressive strengths of Portland-fly ash cement samples in comparison with Portland cement sample.

4. Conclusions

From the experimental results of Portland cement and cement containing 10% fly ash (original one with the Blaine fineness of 2600 cm^2/g and finely ground ones with the Blaine fineness of 5000 cm^2/g and 6500 cm^2/g), we can draw the following conclusions:

- Increasing the fineness of fly ash increased the water of consistency of cement. When fly ash fineness increased from 2600 cm^2/g to 5000 cm^2/g and 6500 cm^2/g, the water of consistency of cement increased 1% from 28% to 29%.
- Increasing the fineness of fly ash prolonged slightly the setting time of cement. When the fineness of fly ash increased from 2600 cm^2/g to 5000 cm^2/g and 6500 cm^2/g, the initial setting time increased from 105 min to 110 min while the final setting time increased from 185 min to 195 min. The setting time of all samples met the requirements of TCVN 6260:2009 for blended Portland cement.
- Increasing the fineness of fly ash increased the compressive strength of cement at both early and late ages. When the fineness of fly ash increased from 2600 cm^2/g to 5000 cm^2/g, the average increase in strength at ages (1, 3, 7, 28 days) was 5.5%. When fly ash fineness increased from 2600 cm^2/g to 6500 cm^2/g, the average increase in strength at all ages was 8%.

The experimental results indicate that finely ground fly ash can be used as a mineral admixture in the production of blended Portland cement to improve the early compressive strength of cement using fly ash, thereby allowing the use of higher fly ash content in production blended Portland cement.

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