EFFECT OF FLY ASH CONTENT ON THE COMPRESSIVE STRENGTHDEVELOPMENT OF CONCRETE

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Abstract: *The production and use of ordinary Portland cement in concrete havea significant effect on the surrounding environment by generating a large quantity of carbon dioxide and depletingthe natural resource. The objective of this research is to partially replace ordinary Portland cement in concrete mixture with fly ash, which isa by-productfrom thermal power plant. The effect of fly ash content on compressive strength development of concrete is investigated. Three mixtures were designed with 10%, 20%, and 30% fly ash replacement for cement compared with a control mixture. Test results indicate that the workability of fresh concrete increases and the unit weight of concrete reduces with increasing fly ash content. The compressive strength of concrete with 10% fly ash is the highest, while that ofconcrete with 30% fly ash is the worst. Concrete with 20% fly ash has lower compressive strength than control concrete before 28 days; after 56 days it gets higher.*

Keywords:*Ordinary Portland cement, fly ash, workability, concrete mass, compressive strength.*

Tóm tắt:*Quá trình sản xuất và sử dụng xi măng ảnh hưởng lớn đến môi trường xung quanh bởi hàm lượng khí thải CO_2 và làm cạn kiệt nguồn tài nguyên thiên nhiên. Mục đích của nghiên cứu này là thay thế một phần xi măng bởi tro bay, một dạng phế thải của nhà máy nhiệt điện. Sự ảnh hưởng của hàm lượng tro bay lên sự phát triển cường độ chịu nén của bê tông được nghiên cứu trong bài báo này. Ba hỗn hợp bê tông thiết kế với 10%, 20% và 30% xi măng được thay thế bởi tro bay so sánh với hỗn hợp bê tông không sử dụng tro bay. Kết quả thí nghiệm cho thấy rằng, độ linh động của bê tông tươi tăng và khối lượng thể tích của bê tông giảm khi tăng hàm lượng tro bay. Hỗn hợp bê tông sử dụng 10% tro bay có cường độ nén cao nhất, trong khi hỗn hợp bê tông chứa 30% tro bay có cường độ nén thấp nhất. Cường độ nén của hỗn hợp bê tông sử dụng 20% tro bay thấp hơn so với cường độ nén của hỗn hợp bê tông không tro bay ở thời điểm trước 28 ngày tuổi, và cao hơn sau 56 ngày tuổi.*

Từ khóa: *Xi măng, tro bay, độ linh động của bê tông, khối lượng bê tông, cường độ chịu nén*.

1. Introduction

Portland cement concrete is a popular construction material in the world. Unfortunately, the production of and use ofordinary Portland cement releases a large amount of carbon dioxide (CO_2), which is a major contributor to the greenhouse effect and the global warming of the planet. Generally, the production of each ton of cement releases approximately 0.7 ton of CO_2 to the environment [1], accounting for around 8% of global CO_2 emissions [2]. Furthermore, cement production process causes a depletion of thenatural resource. Therefore, with concerning the global sustainable development, it is necessary to use supplementary cementitious materials (SCM) as a partial or full replacement of ordinary Portland cement in concrete. The most available SCM world-wide is fly ash, a by-product from thermal power plant.

The effect of fly ash on hardened properties of concrete, especially on compressive strength has received much attention from researchers; however, results are largely different. Naik and Ramme (1990) indicated that fly ash could be used to replace up to 40% cement with improved compressive strength [3]. Siddique (2003) showed that the use of fly ashas replacement of 40-60% cement in concrete decreased its 28-day compressive strength; however, its 91-day and 360-day compressive strengths were acontinuous and significant improvement [4]. Oner et al. (2003) [5], Mohamed (2011) [6], and Marthong and Agrawal (2012) [7] found out that the optimum amount of fly ash to replace a part of cement were 40%, 30%, and 20% in their studies, respectively. However, Kayali and

Ahmed (2013) reported that replacing a part of cement with fly ash resulted in a reduction in compressive strength of concrete [8]. Recent years, Wankhede and Fulari (2014) have shown that concrete with 10% and 20% replacement of cement with fly ash showed better compressive strength at 28 days than that of normal concrete without fly ash; but in the case of 30% replacement, thecompressive strength of concrete decreased [9]. On the contrary, Bansal et al. (2015) [10] have reported that 10% replacement of cement with fly ash led to a reduction in compressive strengthof concrete; while 20% and 30% replacement resulted in an increase in compressive strength. All previous studies mentioned above have different results because fly ash used in each research possessed different physical and chemical properties. It is interesting to note that the properties of fly ash concrete are strongly dependent on the characteristic of fly ash used [11].

The primary aim of this research is to investigate the effect of raw fly ash content, which is taken from Nghi Son coal power plant as a local material, on compressive strength development of concrete. Its effect on fresh concrete properties is also investigated.

2. Experimental program

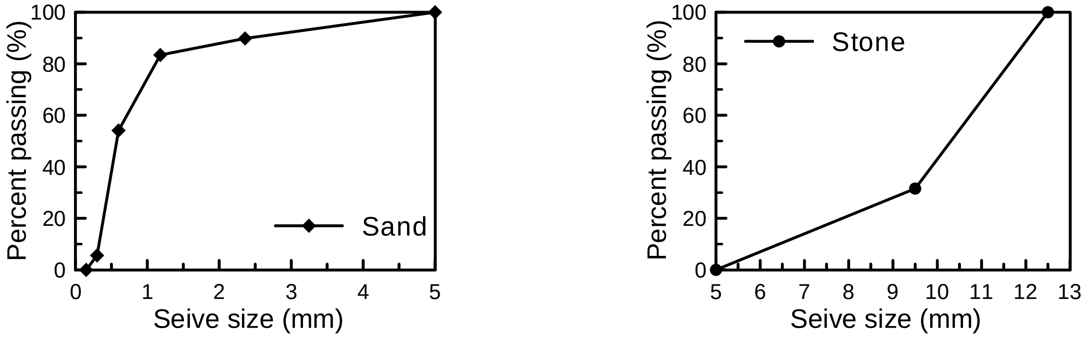
2.1. Material properties

Ordinary Portland cement used in this research was Nghi Son Type-PC40 with a compressive strength value of 45 MPa. Fly ash was taken from Nghi Son coal power plant. The chemical and physical characteristic of cement and fly ash are given in Table 1. According to ASTM C618 (2005) [12] and TCVN 10302 (2014) [13], fly ash used in this research is classified as class-F. It is noted that the loss on ignition of fly ash is 15.75% over the requirement of 6% and 12% that stipulated by ASTM C618 (2005) [12] and TCVN 10302 (2014) [13], respectively. That is because fly ash used herein is raw material, which is not selected as compared with fly ash used in previous studies [3-5], where the loss on ignition is lower than 2%. This means the quality of fly ash used in this study is worse than that used in previous studies [3-5].

The fine aggregate used was natural sand with particle size from 0.15 mm to 5 mm, fineness modulus of 2.67, density of 2.62 T/m^3, dry rodded weight of 1.43 T/m^3, moisture content of 5.65%, and water absorption capacity of 1.4%. The coarse aggregate used was stone with the nominal maximum size of 12.5 mm, density of 2.69 T/m^3, dry rodded weight of 1.41 T/m^3, moisture content of 0.05%, and water absorption capacity of 0.68%. Figure 1 shows the gradation curves for sand and crushed stone. Compared with ASTM C33 [14], only the gradation curve of sand is conformed to the requirement for fine aggregate. That curve of crushed stone has violated the requirement for the coarse aggregate. However, they are existed as local construction materials and does not affect so much to the objective of this research because they are used the same for all mixtures. The superplasticizer (SP) of Sikament R7 with a specific gravity of 1.15 is used to reduce water dosage and ensure the desired workability.

Table 1. *Physical and chemical analysis of cement and fly ash*

Items		Cement	Fly ash
Physical properties	Specific gravity	3.12	2.16
Chemical compositions (%)	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
	Loss on ignition	1.98	15.76



(a) (b)

Figure 1. *Gradation curve for (a) sand and (b) stone*

2.2 Mixture proportions

Table 2. *Concrete mixture proportions*

Mixture ID.	Fly ash (%)	w/b	Concrete proportion ingredients (kg/m^3)					
			Cement	Fly ash	Sand	Stone	Water	SP
A	0	0.4	459.3	0.0	867.5	909.4	179.6	4.6
B	10		410.7	45.6	861.9	903.5	178.5	4.6
C	20		362.7	90.7	856.3	897.6	177.3	4.5
D	30		315.3	135.1	850.8	891.9	176.2	4.5

Four concrete mixtures were designed in according with ACI 211.1 [15] with a constant water-to-binder (w/b) ratio of 0.4. The proportion of concrete ingredients is shown in Table 2. Mixture A is a control mixture without fly ash. While 10%, 20%, and 30% amount of cement were replaced by fly ash in mixtures B, C, and D, respectively. The purpose of these designed mixtures is to investigate the effect of fly ash content on properties of concrete, including concrete unit weight, workability, and compressive strength.

2.3 Specimens preparation and test programs

The concrete ingredients were mixed in a laboratory mixer. The binder materials (cement and fly ash) were first mixed with a part of water for a couple of minutes. A portion of SP was then added gradually to the mixture and mixedfor another 3 minutes to achieve a homogeneous paste. Then, the sand was added to the paste and the mixer was allowed to run additional 1 minute then addingthe stone, followed by the rest of the mixing water and SP. The mixer was run for a further 3 minutes in order to obtain a uniform mixture.

(a) (b)

Figure 2. *Concrete specimens(a) after demolding; and (b) curing in water*

It is noted that this study just only focused on investigating the possibility of using raw fly ash in the production of concrete samples without reinforcement and on evaluating the effect of raw fly ash content on the compressive strength development of the concrete. Thus, the effect of raw fly ash with high loss on ignition on reinforcement corrosion will be considered in further research, as well as the application of this type of concrete in any specific area (structural or non-structural elements) will not be discussed in this study.

Cylindrical concrete specimens with 10 cm in diameter and 20 cm in length were prepared in the laboratory. After one day of casting, they were demolded (as shown in Figure 2a) and immersed in saturated lime-water (as shown in Figure 2b) at a room temperature until the testing age.

Fresh concrete properties including slump and unit weight were determined. The compressive strength of hardened concrete was measured using a controlled compression machine with a loading capacity of 3,000 kN at 3, 7, 14, 28, 56, and 91 days. The reported value of compressive strength is the average value of three concrete specimens. The measurement of slump and compressive strength of concrete specimens were performed in accordance with ASTM C143 [16] and ASTM C39 [17], respectively.It is noted that the compressive strength values presented herein were converted to equivalent values of cylindrical specimen with 15 cm in diameter and 30 cm in length based on TCVN 3118 (1993) [18].

3. Results and Discussion

3.1 Fresh concrete properties

Workability and unit weight of fresh concreteare given in Table 3. The unit weight decreased with increasing fly ash content in theconcrete mixture. Since replaced 30% cement by fly ash, concrete unit weight reduced to approximate 3%. This is due to the low specific gravity of fly ash in comparison with that of ordinary Portland cement (Table 1). Thus, with the same amount, the volume of fly ash is more than that of cement. This leads to a reduction in mass of fly ash concrete specimen as increasing fly ash replacement level.

On the other hand, workability of fresh concrete increased with increasing of fly ash content. Mixture A (without fly ash) and Mixture B (10% fly ash) had the same slump value of 20 mm. Further replacing cement with fly ash resulted in increasing workability of fresh concrete. When fly ash content increased to 20% (Mixture C), the slump slightly increased to 35 mm. The slump of fresh concrete significantly increased to 70 mm since 30% cement was replaced by fly ash (mixture D). This is mainly due to the spherical shape of fly ash particles and its dispersive ability. Generally, cement particles have irregular polygonal shape, while fly ash particles have spherical shape with various sizes [19]. The spherical shape leads to reduce the friction at the aggregate-paste interface, thus increases the workability of concrete. Moreover, the paste volume of fly ash is greater than that of cement because the specific gravity of fly ash is lower than that of cement (Table 1). The increase of the paste volume leads to the increase of plasticity and cohesion, then increase the workability of concrete. This finding is in good agreement with previous studies [3,7,20].

Table 3. *Fresh concrete properties*

MixtureID.	Fly ash (%)	Slump (mm)	Unit weight (T/m^3)
A	0	20	2.55
B	10	20	2.52
C	20	35	2.51
D	30	70	2.48

3.2 Compressive strength development of concrete

The compressive strength development of concrete versus age is presented in Figure 3. As a result, concrete with 10% fly ash (Mixture B) showed the highest compressive strength, while concrete with 30% fly ash (Mixture D) showed the lowest compressive strength. Additionally, concrete with 20% fly ash (Mixture C) had lower compressive strength than control concrete (Mixture A) before 28-day ages, after 56-day ages it got higher.At 3 day ages, Mixtures A and B (with low fly ash content) had higher compressive strength than Mixtures C and D (with high fly ash content). The low compressive strength at the early age and the increased strength at the later age of fly ash concrete are associated with the continuous pozzolanic reaction of fly ash in concrete, which only starts significantly after one or more weeks [21].

The use of fly ash with optimum dosage increased the compressive strength was proved in previous studies [5,22,23]. The main products of cement hydration are calcium silicate hydrate (C-S-H) gel and calcium hydroxide ($Ca(OH)_2$) (see equation (1)). While C-S-H is the main carrier of strength in hardened concrete, $Ca(OH)_2$ has anegative effect on quality of the hardened concrete because of its solubility in water to form cavities and its low strength. When fly ash is added, $Ca(OH)_2$ is transformed into thesecondary C-S-Hgel as a result of pozzolanic reaction (see equation (2)). However, if fly ash dosage is added over the optimum value, all of it does not enter into the reaction, it acts as fine aggregate in the mixture rather than a cementitious additive. In other word, the fly ash is not used in efficiency.

Cement hydration: $Cement\ (C_3S,\ C_2S) + H_2O \rightarrow C-S-H + Ca(OH)_2$ (1)

Pozzolanic reaction: $Ca(OH)_2 + SiO_2 \rightarrow C-S-H$ (2)

As can be seen from Figure 4, the quantity of fly ash used in this study can be replaced upto 20% cement. This amount is lower than that in previous published studies (from 40% to 60%) [3-5]. That is because fly ash used in this study is araw material with low quality as compared with fly ash used in previous studies [3-5]. It means that the optimum fly ash content used in concrete as cement replacement is dependent on its quality.

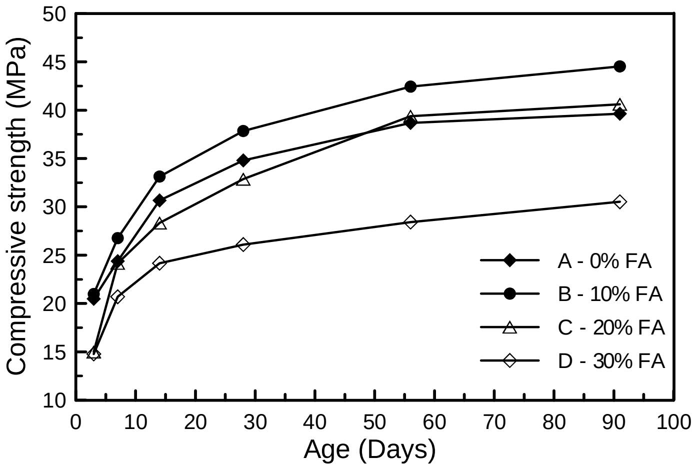


Figure 3. *Compressive strength development of hardened concrete*

4. Conclusions

This paper investigates the effect of using raw fly ash taken from Nghi Son coal power plant on the properties of concrete. Based on the above experimental results, the following conclusions may be drawn:

1) Increasing fly ash content as an ordinary Portland cement replacement in the concrete mixture resulted in improving the workability of fresh concrete and decreasing its unit weight. Since 30% weight of cement was replaced by fly ash, the unit weight reduced to around 3% and workability of concrete increased from 20 mm to 70 mm.
2) Concrete with 10% fly ash achieved the highest compressive strength, while concrete with30% fly ash has the lowest compressive strength among all tested concrete.
3) At the early age, concrete with 20% fly ash exhibited lower compressive strength than control concrete. However, itgot higher at the later age of concrete. This phenomenon is mainly associated with the continuous pozzolanic reaction of fly ash in concrete.
4) Fly ash from this source can be used to replacefor ordinary Portland cement in concrete mixture upto 20% with improved compressive strength.

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