ASSESSMENT OF THE USE OF RAW FLY ASH WITH HIGH LOSS ON IGNITION IN CONCRETE

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Abstract - The use of fly ash to partially replace cement in concrete is one of the effective ways of reducing the negative effect on the environment due to the use and production of cement. However, properties of concrete are strongly associated with the quality of fly ash used. This paper investigates the applicable use of raw fly ash, which is taken from Nghi Son coal power plant, Vietnam with a high loss on ignition in concrete. There are two group mixtures with different water-to-binder ratios of 0.35 and 0.45. In each group, fly ash is used to replace 10%, 20%, and 30% cement. Test results indicate that raw fly ash can be used to replace up to 20% cement with improved compressive strength. Moreover, with increasing the fly ash content, workability of fresh concrete increases while its unit weight decreases. Furthermore, all tested concrete mixtures show the good durability performance with ultrasonic pulse velocity values of greater than 4100 m/s.

Key words - Raw fly ash; loss on ignition; slump; unit weight; compressive strength; ultrasonic pulse velocity; durability.

1. Introduction

Concrete is the most popular construction material in the world. Annually, a large amount of concrete is used as well as a large quantity of cement is consumed. The production of ordinary Portland cement releases a large amount of carbon dioxide (CO_2) into the air and causes the greenhouse effect as the global warming. On the other hand, fly ash is an industrial by-product of thermal power stations and is recognized as an environmental pollutant. Recently, the utilization of fly ash as partial or full replacement of ordinary Portland cement in concrete has received much attention from researchers instead of considering it as a waste material.

The properties of concrete with fly ash strongly depend on the characteristics of fly ash used [1]. Some previous studies have indicated that fly ash could be used to replace 10÷30% cement with improved compressive strength [2-5]. Some other studies showed that fly ash could be used to replace up to 40÷60% cement in concrete with better or comparable compressive strength [6-9]. It is noted that fly ash used in these previous studies were from different sources with various qualities. Especially, the loss on ignition of fly ashused in the studies [6-9] was ranged from 0.45% to 2.1%, satisfying the requirement of less than 6% as required by ASTM C618 [10]. In other words, such fly ash was selected with good quality so that it can be used to replace up to 60% cement. It is also noted that the physical and chemical properties of fly ash used in studies [2-5] were not given. However, with the low applicable replacement level for cement, it is proposed that their quality is not as good as those used in studies [6-9].

The loss on ignition of fly ash is due to the loss amount of carbon and sulphur at high temperature. The presence of unburned (organic) carbon in fly ash affects the color of concrete (may change to black or dark gray), increases the water requirement, and reduces the efficiency of air entraining admixtures in concrete [11-13]. Most of the previous studies used fly ash as a selected material with the loss on ignition satisfying the condition stipulated by ASTM C618 [10]. So far, a study on the use of raw fly ash with ahigh loss on ignition has been still limited. Thus, the major objective of this study is to investigate the applicability of the raw fly ash with a high loss on ignition in concrete. Fly ash used in this research was taken from Nghi Son thermal power plant, Viet Nam, with the loss on ignition of 15.76%, which exceeds the ASTM C618 [10] requirement.

2. Materials and experimental program

2.1. Materials

Table 1 shows the physical and chemical properties of cement and fly ash (FA) used in this study. Ordinary Portland cement was Nghi Son type-PC40 with a specific gravity of 3.12. Raw fly ash was taken from Nghi Son coal power plant, containing a low amount of calcium. According to ASTM C618 [10], it is classified as class-F. The possibility of using the raw fly ash with a high loss on ignition value of 15.75% in concrete is examined in this study.

Natural sand with fineness modulus of 2.87, density of 2.62 T/m^3, dry rodded weight of 1.50 T/m^3, moisture content of 4.35%, and water absorption capacity of 1.08% was used as the fine aggregate. The coarse aggregate used was crushed stone with the nominal maximum size of 12.5 mm, density of 2.69 T/m^3, dry rodded weight of 1.39 T/m^3, moisture content of 0.25%, and water absorption capacity of 0.08%. In order to reduce the amount of water for good concrete quality and to increase the workability of fresh concrete, the superplasticizer (SP) of Sikament R4 with a specific gravity of 1.15 was used with a fixed dosage of 1% (by total amount of binder materials) for all concrete mixtures.

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

Items		Cement	FA
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

2.2. Mixture proportions

Table 2 shows the mixture proportions for the preparation of concrete samples used in this investigation.

There are eight mixtures that are divided into two groups (M35 and M45) with different water-to-binder ratios of 0.35 and 0.45. Nomenclature of the mixtures is described as follows: M35 and M45 denote the water-to-binder ratio of 0.35 and 0.45, respectively; the number after them (0, 10, 20 and 30) are the percentages of fly ash replacing cement. In each group, the control mixture was designed without fly ash, while three others used fly ash to replace cement by 10, 20, and 30% by weight. The purpose of these design mixtures is to find out the optimal level of fly ash replacement for cement in concrete. All of the mixtures were designed in accordance with ACI 211.91 [14]. It is noted that the amount of water was controlled lower than 180 kg/m^3 in order to ensure the good quality of concrete.

Table 2. *Concrete mixture proportions*

Mixture	Concrete ingredient proportions (kg/m^3)					
	Cement	FA	Sand	Stone	Water	SP
M35-0	514.1	0.0	985.2	751.1	175.5	5.1
M35-10	459.7	50.6	978.1	745.7	174.3	5.1
M35-20	405.1	101.5	970.9	740.3	173.0	5.0
M35-30	352.3	150.7	964.0	735.0	171.8	5.0
M45-0	400.4	0.0	1082.1	751.8	175.7	4.0
M45-10	358.3	39.8	1076.0	747.5	174.7	4.0
M45-20	316.7	79.2	1069.9	743.3	173.7	4.0
M45-30	275.6	118.1	1063.9	739.1	172.7	3.9

2.3. Specimens preparation and test programs

The experimental works were conducted in the construction material laboratory of Hong Duc University. After mixing, fresh concrete properties including slump and unit weight were measured. Concrete specimens were prepared in a cylinder with 10 cm in diameter and 20 cm in height. After one day of casting, they were demolded and immersed in water at a room temperature until the testing age as shown in Figure 1. Compressive strength and ultrasonic pulse velocity (UPV) were measured at 3, 7, 14, 28, 56, and 91 days. Figure 2 shows pictures of the compressive strength test and ultrasonic pulse velocity test. The values reported herein are the average value of three specimens. Slump, compressive strength, and ultrasonic pulse velocity tests were performed in accordance withASTM C143 [15], ASTM C39 [16], and ASTM C597 [17], respectively.

Figure 1. *Concrete specimens were cured in water*

(a) (b)

Figure 2. *a) Compressive strength test; b) Ultrasonic pulse velocity test*

3. Results and discussion

3.1. Fresh concrete properties

The slump and unit weight of all concrete mixtures are given in Table 3. The slump values of M45 mixtures are greater than those of corresponding M35 mixtures. It means that higher water-to-binder ratio results in a higher slump. It is clear that the workability of fresh concrete is closely associated with the amount of water. Thus, the amount of water increases as the increase of water-to-binder ratio, leading to increasing concrete workability.

As shown in Table 3, for the same water-to-binder ratio, the slump of fresh concrete increases with increasing the replacement level of cement by fly ash. In general, the fly ash particles are spherical while cement particles are irregular polygonal [18]. The spherical shape of fly ash contributes to reducing the friction of the aggregate-paste interface, thus increases the workability of fresh 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 in the paste volume leads to the increase of plasticity and cohesion, then increases the workability of fresh concrete. Therefore, with increasing fly ash content, the slump of concrete increases. This finding is similar to the result from Naik and Ramme [6].

On the other hand, for the same water-to-binder ratio, the unit weight of fresh concrete decreases with increasing fly ash content. This is also due to the low specific gravity of fly ash as compared with that of ordinary Portland cement. With the same amount, the volume of fly ash is more than that of cement, therefore the unit weight of fresh concrete decreases with increasing fly ash content in the concrete mixture. Moreover, when water-to-binder ratio increases, the unit weight of concrete decreases. Similarly, due to the highest specific gravity of cement as compared with other ingredients in concrete, the amount of cement increases with the water-to-binder ratio, leading to an increase in mass of concrete with the higher water-to-binder ratio.

Table 3. *Fresh concrete properties*

Mixture	FA content (%)	Slump (mm)	Unit weight (T/m^3)
M35-0	0	0	2.58
M35-10	10	5	2.55
M35-20	20	10	2.51
M35-30	30	30	2.49
M45-0	0	30	2.53
M45-10	10	45	2.51
M45-20	20	55	2.48
M45-30	30	70	2.46

3.2. Compressive strength development

Compressive strength is an important property used to evaluate the concrete quality. The compressive strength development of concrete with different water-to-binder ratios of 0.35 and 0.45 is presented in Figures 3 and 4, respectively. The concrete mixtures with lower water-to-binder ratio have higher compressive strength values than those of corresponding mixtures with the higher water-to-binder ratio. A low water-to-binder ratio is associated with a high content of cement paste, hence a high value of compressive strength is.

For the water-to-binder ratio of 0.35, the mixture with 10% fly ash (M35-10) shows the highest compressive strength after 14 days. The mixtures with 20% and 30% fly ash content exhibit lower compressive strength than control mixture without fly ash (M35-0). Similarly, for the water-to-binder ratio of 0.45, the mixtures with 10% (M45-10) and 20% (M45-20) fly ash show higher compressive strength than the control mixture (M45-0), while mixture with 30% fly ash (M45-30) shows the lowest compressive strength value. The replacement level of cement by fly ash in this study is lower than that reported from previous studies [6-9] because the fly ash used herein is a raw material with low quality as compared with that of previous studies [6-9]. This also means that even with a high loss on ignition (15.76%), raw fly ash can be used to replace up to 20% cement in concrete with improved compressive strength. Although the compressive strength of concrete mixtures with 30% fly ash is lower than those of control mixture, the ultimate compressive strength of the M35-30 and M45-30 mixtures are 35.1 MPa and 24.8 MPa, respectively. It means that depending on the strength requirement, the replacement level of cement by fly ash is determined accordingly.

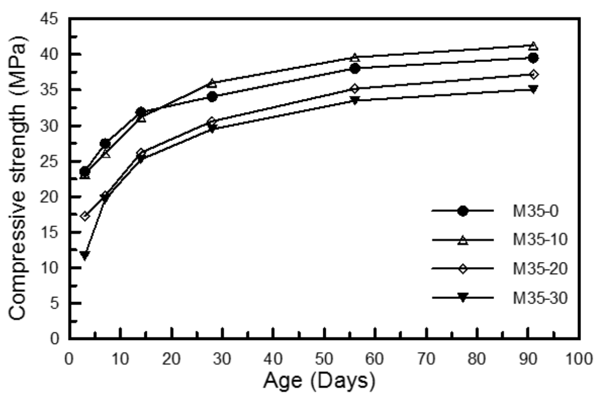

Figure 3. *Compressive strength development of M35 mixtures*

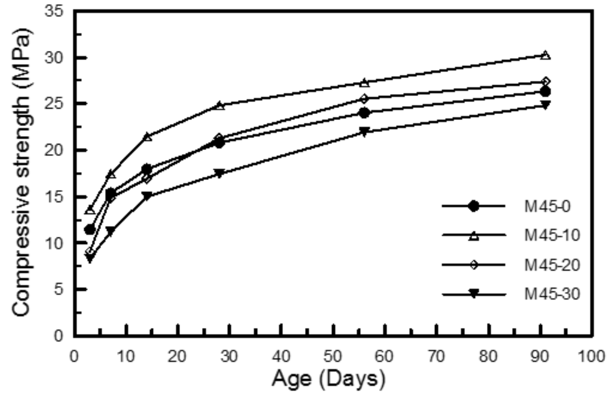

Figure 4. *Compressive strength development of M45 mixtures*

As can be seen from Figures 3 and 4, before 28-day ages, the fly ash-free concrete mixture shows a relatively high compressive strength value as compared with that of fly ash concrete mixtures. Additionally, after 56 days, the fly ash-free concrete shows a lower strength development rate than the other mixtures containing fly ash. The low compressive strength value at the early age and the increased strength at the later age of the fly ash concrete are associated with the slow and continuous pozzolanic reaction of fly ash in concrete, which only starts significantly after one or more weeks [19]. The major products of cement hydration (see equation (1)) are calcium silicate hydrate (C-S-H) gel and calcium hydroxide ($Ca(OH)_2$). While C-S-H is the main carrier of strength in hardened concrete, $Ca(OH)_2$ has a negative effect on quality of hardened concrete because of its solubility in water to form cavities and its low strength. However, when fly ash is added to the mixture as a cement substitution, $Ca(OH)_2$ is transformed into the secondary C-S-H gel as a result of the pozzolanic reaction (see equation (2)). However, if the fly ash content is added over the optimum value, such fly ash amount does not fully involve in the chemical reaction process. In this case, it mainly acts as fine aggregate in the mixture rather than a cementitious additive. In other words, the fly ash is not used efficiently.

Cement hydration:

$$(C_3S,\ C_2S) + H_2O \rightarrow C - S - H + Ca\left(OH\right)_2 \tag{1}$$

Pozzolanic reaction:

$$Ca\left(OH\right)_2 + SiO_2 \rightarrow C - S - H \tag{2}$$

3.3. Ultrasonic pulse velocity (UPV)

To assess the uniformity and relative quality of concrete as the presence of voids and cracks, the ultrasonic pulse velocity (UPV) test is conducted in accordance with ASTM C597 [17]. Generally, a high UPV value indicates good quality concrete. As suggested by Malhotra [20], concrete has good durability when it obtains UPV value of higher than 3660 m/s. Figures 5 and 6 show the UPV of concrete with different water-to-binder ratios of 0.35 and 0.45, respectively. As a result, all concrete mixtures show the good quality with the UPV values of higher than 4100 m/s. In addition, before 91 days, the UPV values of the fly ash-free concrete mixtures (M35-0 and M45-0) are higher than those of mixtures containing fly ash. However, at 91 days, the UPV value of the M35-10 mixture is close to that of M35-0 mixture. Moreover, the increasing rate of the UPV values of the fly ash concrete is higher than that of the fly ash-free concrete regardless of the water-to-binder ratios of 0.35 or 0.45. This phenomenon may be explained by the fact that the control mixture contains a greater quantity of cement than fly ash mixtures. Thus, due to the higher specific gravity of cement in comparison with that of fly ash, the control mixture shows a higher density and a faster cement hydration than the fly ash mixtures at the early age. This leads to a higher UPV value of control concrete as compared with that of the fly ash concrete. However, after 56 days, with a great contribution of pozzolanic reaction due to the presence of fly ash in concrete, the inner structure of fly ash concrete is improved, indicated by an increase of UPV values, and such concrete mixtures exhibit good quality and durability.

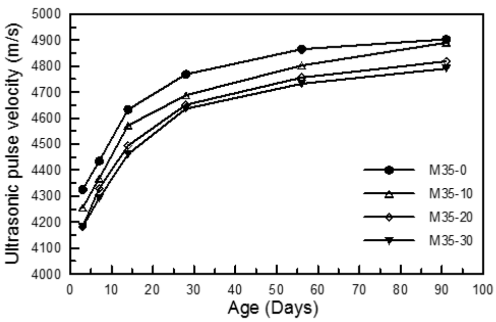

Figure 5. *Ultrasonic pulse velocity values of M35 mixtures*

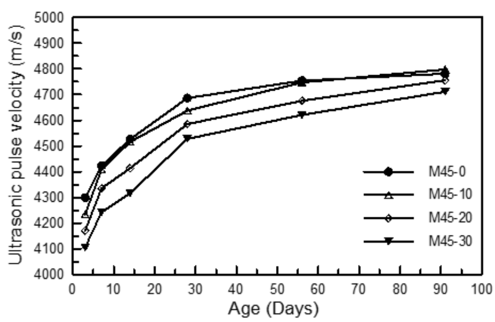

Figure 6. *Ultrasonic pulse velocity values of M45 mixtures*

4. Conclusions

This paper investigates the applicable use of raw fly ash with a high loss on ignition in concrete. Based on the above experimental results, the main conclusions are summarized as follows.

1) The slump of concrete increases and the unit weight of fresh concrete decreases with the increased level of fly ash replacement for cement.

2) Raw fly ash can be used to replace up to 20% of cement in concrete with the enhanced compressive strength. Further increasing fly ash content results in a reduction in compressive strength. Thus, the level of fly ash replacement can be increased or decreased depending on the requirement for compressive strength of concrete.

3) Fly ash concrete shows a low compressive strength at an early age and a great strength improvement at the later age. This is mainly due to the pozzolanic reaction of fly ash in concrete.

4) All concrete mixtures with raw fly ash in this study exhibit good durability with the ultrasonic pulse velocity of higher than 4100 m/s.

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REFERENCES

[1] A. Bilodeau, and M. Malhotra, "High-volume fly ash system: Concrete solution for sustainable development", *ACI Material Journal*, 2000, Vol. 97, No. 1, pp. 41-47.

[2] P. R. Wankhede, and V. A. Fulari, "Effect of fly ash on properties of concrete", *International Journal of Emerging Technology and Advanced Engineering*, 2014, Vol. 4, No. 7, pp. 284-289.

[3] C. Marthong, and T. P. Agrawal, "Effect of fly ash additive on concrete pro perties", *International Journal of Engineering Research and Applications*, 2012, Vol. 2, No. 4, pp. 1986-1991.

[4] R. Bansal, V. Singh, and R. K. Pareek, "Effect on compressive strength with partial replacement of fly ash", *International Journal onEmmerging Technologies*, 2015, Vol. 6, No. 1, pp. 1-6.

[5] H. A. Mohamed, "Effect of fly ash and silica fume on compressive strength of self-compacting concrete under different curing conditions", *Ain Shams Engineering Journal*, 2011, Vol. 2, pp. 79-86.

[6] T. R. Nail and B. W. Ramme, "Effect of high-lime fly ash content on water demand, time of set, and compressive strength of concrete", *ACI Materials Journal*, 1990, Vol. 87, No. 6, pp. 619-626.

[7] Oner, S. Akyuz, and R. Yildiz, "An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash in concrete", *Cement and Concrete Research*, 2004, Vol. 35, pp. 1165-1171.

[8] R. Siddique, "Performance characteristics of high-volume class F fly ash concrete", *Cement and Concrete Research*, 2003, Vol. 34, pp. 487-493.

[9] G. Li, and X. Zhao, "Properties of concrete incorporating fly ash and ground granulated blast-furnace slag", *Cement and Concrete Composites*, 2003, Vol. 25, pp. 293-299.

[10] ASTM C618, *Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete*, 2005.

[11] M. Mohebbi, F. Rajabipour, B.E. Scheetz, "Reliability of loss on ignition test for determining the unburned carbon content in fly ash", *World of Coal Ash Conference in Nasvhille*, 2015.

[12] K. Wesch, *Fly ash in concrete: Properties and performance. Report of Technical Committee 67-FAB use of fly ash in buildings*, E&FN Spon, London, 1991.

[13] J. Paya, J. Monzo, M.V. Borrachero, E. Perris, and F. Amahjour, "Thermo gravimetric methods for determining carbon content in fly ashes," *Cement and Concrete Research*, 1998, Vol. 28, pp. 675-688.

[14] ACI 211.1, *Standard practice for selecting proportions for normal, heavyweight, and mass concrete*, 1991.

[15] ASTM C143, *Standard test method for slump of hydraulic-cement concrete*, 2015.

[16] ASTM C39, *Standard test method for compressive strength of cylindrical concrete specimens*, 2012.

[17] ASTM C597, *Standard test method for pulse veloscity through concrete*, 2009.

[18] V. G. Papadakis, "Effect of fly ash on Portland cement systems – Part I. Low-calcium fly ash", *Cement and Concrete Research*, 1999, Vol. 29, No. 11, pp. 1727-1736.

[19] A. L. A. Fraay, J. M. Bijen, and Y. M. de Haan, "The reaction of fly ash in concrete a critical examination", *Cement and Concrete Research*, 1989, Vol. 19, No. 2, pp. 235-246.

[20] V.M Malhotra, *Testing hardened concrete: Nondestructure methods*, American Concrete Institute Monograph Series, 1976.

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