Assessment of the compressive strength and strength activity index of cement incorporating fly ash

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Assessment of the compressive strength and strength activity index of cement incorporating fly ash

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Abstract. In recent years, the utilizations of industrial by-product as substitute for non-renewable material in cement and concrete production has received significant attention for sustainable development goals. In this study, fly ash blended cement was produced by replacing 5%, 10%, 15%, 20%, 25%, 30% and 35% by weight of Portland Cement with fly ash. In addition, the loss on ignition (LOI) content of fly ash, which used for the 20% replacement ratio, varies from 5 to 20% to assess the effect of unburnt carbon content in fly ash on the strength activity index of fly ash blended cement. The experimental results show that the addition of fly ash reduces the compressive strength of the mortar and strength activity index of fly ash blended cement at early ages. However, the presence of fly ash increases the strength of the mortar and the strength activity index of fly ash blended cement at longer ages when the fly ash replacement ratio is lower than 25%. The unburnt carbon in fly ash does not reduce the strength of the mortar and strength activity index of fly ash blended cement when its content does not exceed 20%.

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. According to the report of Global Cement, Vietnam produces about 90 million tons of cement annually. Cement production consumes a significant amount of materials from limited natural resources and leads to large carbon dioxide emission to the atmosphere, which causes severe environmental problems such as the global warming.

By-products from several industrial processes are used as supplementary cementitious materials (SCM) in concrete to reduce cement content but still able to display cementitious property, thus reducing the cost of using Portland cement and achieve durable and sustainable concrete. More recently, strict environmental-pollution controls and regulations have produced an abundance of industrial byproducts that can be used as supplementary cementitious materials such as fly ash and ground granulated blast furnace slag. The use of such by-products in cement and concrete not only prevents these products from being land-filled but also enhances the properties of mortar and concrete in both fresh and hardened states.

Nowadays, many concrete mixtures contain SCM that forms part of the cementitious component and filler. In Vietnam, some types of SMC can be used in concrete including fly ash, ground granulated blast furnace slag, rice hush ash and natural pozzolanas, etc. of which fly ash has the greatest potential. According to the report of the Ministry of Construction, by 2019 Vietnam has 25 coal-fired thermal power plants, generates about 13 million tons of fly ash and bottom ash annually. Most of the coal used for coal-fired thermal power plant in Vietnam is anthracite coal. Due to the nature of the anthracite coal, fly ash obtained from burning anthracite coal contains high unburnt carbon content. In

addition, fly ash from different thermal power plants has different chemical composition and physical properties [1].

The properties of concrete using fly ash strongly depend on the characteristics of fly ash used [2,3]. Many studies have indicated that fly ash could be used to replace 10÷30% cement with improved compressive strength [4-7]. Some other studies showed that fly ash could be used to replace up to 40÷60% cement in concrete with comparable long-term compressive strength [8-11]. It is noted that the LOI content of fly ash used in these studies satisfied the requirement of less than 6% as required by ASTM C618 [12]. So far, the study on the use of fly ash with a high LOI content has been still limited. On the other hand, according to ASTM C311 [13], the strength active index of fly ash was test by replacing 20% of cement with fly ash. However, in practice the fly ash content can be varied in the wide range. Thus, the major objective of this study is to investigate the strength activity index of fly ash blended cement containing fly ash with different replacement ratios (5-35% by weight of cement) and the LOI of fly ash varies from 5 to 20%.

2. Materials and experimental plan

2.1. Materials

Two types of fly ash from Pha Lai thermal power plant were used in the study. The original fly ash (FA1) was taken directly from ash pond in Pha Lai thermal power plant. The other (FA2) was taken after removing unburnt carbon by floatation method. The chemical and physical properties of FA1 and FA2 were given in Table 1. The cement used in this study is Portland Cement PC40 from Nghi Son Cement Company. The properties of cement were given in Table 2. The standard sand for use in the testing of strength activity index of cements meet the requirements of TCVN 6227:1996.

Table 1. Chemical composition and physical properties of fly ash

Sample	Chemical composition, %									Specific gravity	Residual by 45μm sieve, %
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	SO_3	LOI	others		
FA1	46.82	19.6	4.79	0.84	0.3	2.71	0.1	22.93	1.91	2.21	29
FA2	57.26	22.90	6.75	1.69	0.20	3.09	0.15	4.86	3.10	2.47	25.3

Table 2. Properties of Portland Cement

Specific gravity	Normal consistency	Setting time, min.		Compressive strength, Mpa	
		Initial	Final	3 days	28 days
3.12	29.5	90	215	32.6	46.4

2.2. Experimental plan

In this study, the strength activity index of cement incorporating fly ash was investigated in two cases:

2.2.1. Change the fly ash content

According to ASTM C311 [13], the strength active index of fly ash was test by replacing 20% of cement with fly ash. However, in practice the fly ash content can be varied in the wide range. Therefore, in this case the fly ash content varies from 0 to 35% by weight. Fly ash with low LOI content (FA2) was used for these tests, the mix proportions of mortar were shown in Table 3.

Table 3. Mix proportions of mortar

No.	*Fly ash, %*	*Cement, g*	*Fly ash, g*	*Sand, g*	*Water, g*	*Flow, mm*
1	0	450.0	0.0	1350	225.0	17.0
2	5	427.5	22.5	1350	223.9	16.9
3	10	405.0	45.0	1350	222.8	17.1
4	15	382.5	67.5	1350	221.6	17.1
5	20	360.0	90.0	1350	220.5	16.9
6	25	337.5	112.5	1350	219.4	17.0
7	30	315.0	135.0	1350	218.3	17.1
8	35	292.5	157.5	1350	216.0	17.1

2.2.2. Change the LOI content of fly ash

According to ASTM C618, the LOI of fly ash should be less than 6%. However, the LOI of fly ash in Vietnam is often higher than 6% [1]. The previous study has indicated that high LOI fly ash (LOI content can be up to 15%) can be used for concrete with the enhanced compressive strength [14]. In this study, the effect of LOI content of fly ash on compressive strength of mortar and strength activity index of fly ash blended cement. Therefore, with the fly ash replacement ratio of 20%, the LOI contents of fly ash were 5%, 8%, 11%, 13%, 17% and 20%.

In order to get the fly ash with the LOI content as above, FA1 and FA2 are mixed together in a certain ratio.

3. Results and discussion

3.1. Effect of fly ash content on strength activity index of blended cement

Compressive strength of mortar and strength activity index of fly ash blended cement at the ages of 7 days, 28 days and 91 days were shown in Table 4, Figure 1 and Figure 2.

The experimental results show that at the early ages (7 days), the addition of fly ash reduces the compressive strength of the mortar, the higher the fly ash content, the stronger reduction the compressive strength of mortar. When fly ash content was used up to 20%, the strength activity index of fly ash blended cement is still higher than 75% (in accordance with requirements of ASTM C618). However, when using up to 35% of fly ash, the strength activity index is only 52.6% (Figure 2).

Table 4. Compressive strength of mortar and strength activity index of fly ash blended cement

No.	fly ash content, %	Compressive strength					
		7 days		28 days		91 days	
		MPa	%	MPa	%	MPa	%
1	0	36.93	100.0	46.36	100.0	49.16	100.0
2	5	34.02	92.1	46.79	100.9	57.31	116.6
3	10	33.00	89.4	47.17	101.7	57.58	117.1
4	15	28.47	77.1	46.48	100.3	55.63	113.2
5	20	27.72	75.1	40.10	86.5	52.89	107.6
6	25	23.69	64.1	34.44	74.3	50.21	102.1
7	30	23.53	63.7	33.41	72.1	47.91	97.5
8	35	19.42	52.6	29.32	63.2	43.50	88.5

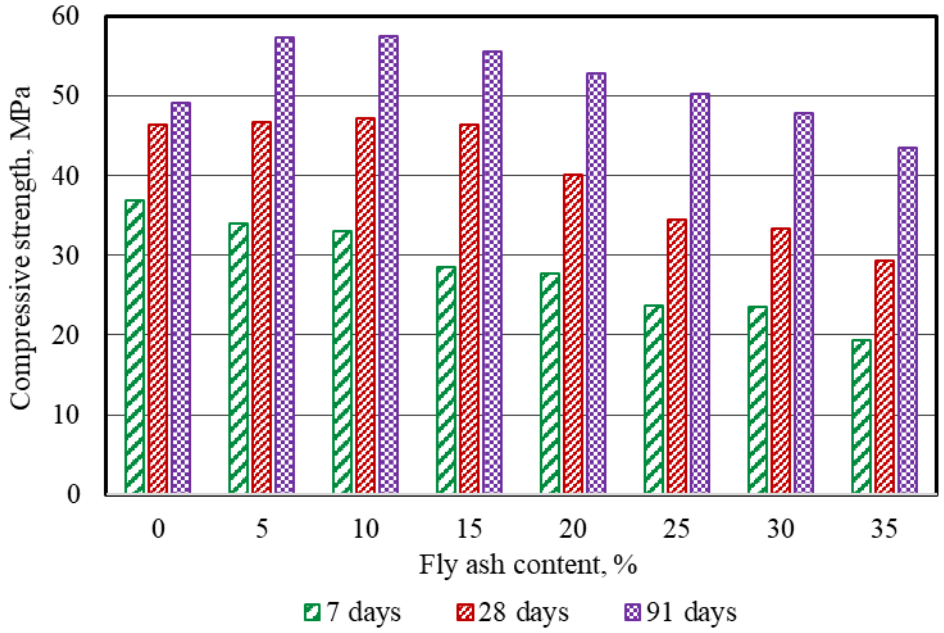

Figure 1. Compressive strength of mortar at 7 days, 28 days and 91 days

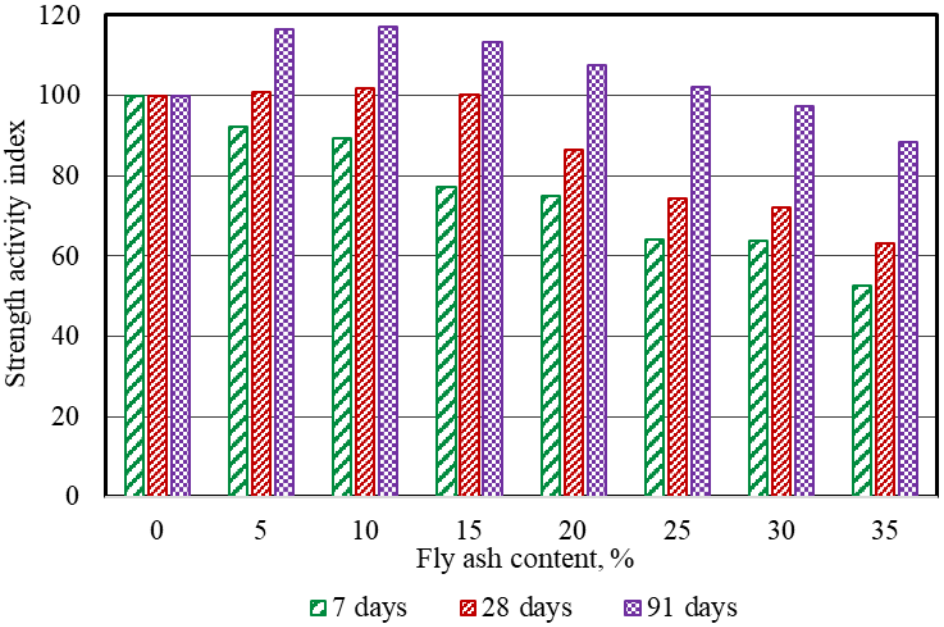

Figure 2. Strength activity index of fly ash blended cement at 7 days, 28 days and 91 days

At the age of 28 days, when using up to 15% fly ash, the compressive strength of mortars is almost the same as controlled mixture (0% fly ash). When using 20% fly ash, the strength activity index of fly ash blended cement is 86.5%, higher than the requirement of ASTM C618 (75%). However, when fly ash content is higher than 25%, the strength activity index of fly ash blended cement is lower than 75%, not satisfy the requirements of ASTM C618. At the fly ash replacement ratio of 20%, 25%, 30% and 35%; the compressive strength of the mortar decreased by 13.5%, 25.7%, 27.9% and 36.8%, respectively. The strength reduction at 28 days is much smaller than that at 7 days (24.9%, 35.9%, 36.3% and 47.4%).

At the later ages (91 days), the compressive strength of mortar samples using fly ash with replacement ratio up to 25% is much higher than that of the control samples (0% fly ash). Especially, when using 10% of fly ash, the compressive strength of mortar is 17.1% higher than that of the control sample. When using 30% and 35% fly ash, the strength activity indexes of fly ash blended cement are 97.5% and 88.5%, respectively; equivalent to the strength reduction are only 2.5% and 11.5%. The reduction in 91 days compressive strength is much smaller as compared to 7 days and 28 days compressive strength. These results show that strength of fly ash mortar increases with age. Further, it is also observed that at the age of 91 days the rate of compressive strength gain mortar is increased and being maximum in the range of 5-20% fly ash replacement ratio (Figure 1). The rate of compressive strength gain is up to 22.5 - 48.4% over that of 28 days for mortar samples using 5-35% fly ash while the compressive strength gain of control samples is only 6.1%.

The low compressive strength value at the early ages and the increased strength at the later age of the fly ash mortar are associated with the slow and continuous pozzolanic reaction of fly ash in concrete, which only starts significantly after several weeks [15]. The major products of cement hydration 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. 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 a filler in the mixture rather than a cementitious additive.

3.2. Effect of LOI content of fly ash on strength activity index of blended cement

Compressive strength of mortar and strength activity index of fly ash blended cement containing 20% fly ash with different LOI content were shown in Table 5 and Figure 3. The experimental results show that unburnt carbon in fly ash does not affect so much on the strength of mortar and strength activity index of fly ash blended cement. When LOI content increases, the compressive strength of mortar even increases. This phenomenon occurred at the age of 7 days, 28 days and 91 days. The positive effect of unburnt carbon on mortar and concrete properties has also been confirmed by the previous study [14].

The LOI content of fly ash does not show clear effect on the strength development of mortar using 20% fly ash. At the early ages (7 days), when using fly ash with high LOI content (5-20%) the compressive strength of mortar reduced slightly. However, at 28 days, when using fly ash with high LOI content the compressive strength of mortar increased slightly, the increase in compressive strength of mortar was higher at the age of 91 days.

Table 5. Compressive strength of mortar containing 20% fly ash with different LOI content

No.	LOI, %	Compressive strength					
		7 days		28 days		91 days	
		Mpa	%	Mpa	%	Mpa	%
0	-	36.93	100.0	46.36	100.0	49.16	100.0
1	5	26.86	72.7	40.04	86.4	52.46	106.7
2	8	26.17	70.9	41.04	88.5	52.96	107.7
3	11	26.51	71.8	42.13	90.9	52.29	106.4
4	14	27.02	73.2	42.26	91.2	52.96	107.7
5	17	27.43	74.3	43.11	93.0	53.82	109.5
6	20	27.18	73.6	42.10	90.8	52.45	106.7

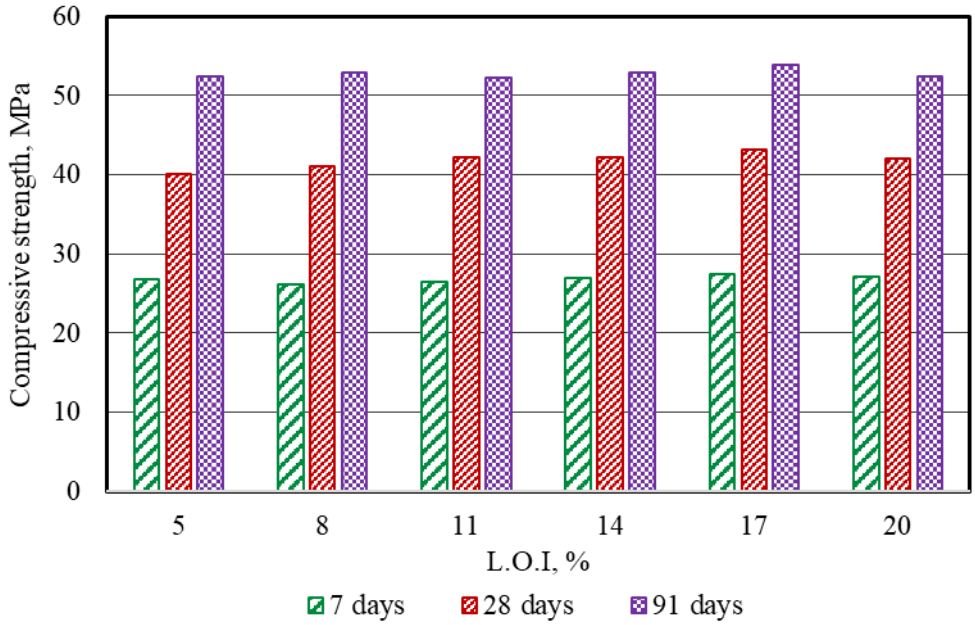

Figure 3. Compressive strength of mortar containing 20% fly ash with different LOI content

4. Conclusions

From the results and discussion presented in this paper, the following conclusions can be drawn;

1) The addition of fly ash reduces the compressive strength of the mortar and strength activity index of fly ash blended cement at early ages;
2) When fly ash replacement ratio is higher than 20%, the strength activity index of fly ash blended cement is lower than 75% at the ages of 7 days and 28 days;
3) At the later ages (91 days), when fly ash replacement ratio is up to 35%, the strength activity index of Fly ash blended cement is almost higher than 90%;
4) At the age of 91 days the rate of compressive strength gain being maximum in the range of 5-20% fly ash replacement ratio;
5) The LOI content of fly ash does not affect so much on the strength of mortar and strength activity index of fly ash blended cement, even when the unburnt carbon in fly ash is up to 20%.

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References

[1] Nguyen Trong Lam 2019 Assessing the usability of Fly ash in Vietnam for Building Materials *Final report of Project No. 67-2019/KHXD*
[2] Bilodeau A and Malhotra M 2000 High-volume fly ash system: Concrete solution for sustainable development *ACI Materials Journal* **97 (1)** pp 41-47
[3] Wesche K 1990 Fly Ash in Concrete: Properties and performance *Taylor & Francis*
[4] Wankhede PR and Fulari VA 2014 Effect of fly ash on properties of concrete *International Journal of Emerging Technology and Advanced Engineering* **4(7)** pp 284-89
[5] Marthong C and Agrawal TP 2012 Effect of fly ash additive on concrete properties *International Journal of Engineering Research and Applications* **2 (4)** pp 1986-91

[6] Bansal R, Singh V, and Pareek RK 2015 Effect on compressive strength with partial replacement of fly ash *International Journal on Emerging Technologies* **6 (1)** pp 1-6
[7] Mohamed HA 2011 Effect of fly ash and silica fume on compressive strength of self compacting concrete under different curing conditions *Ain Shams Engineering Journal* **2** pp 79-86
[8] Nail TR and Ramme BW 1990 Effect of high-lime fly ash content on water demand, time of set, and compressive strength of concrete *ACI Materials Journal* **87 (6)** pp 619-26
[9] Oner A, Akyuz S, and Yildiz R 2005 An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash in concrete *Cement and Concrete Research* **35** pp 1165-71
[10] Siddique R 2003 Performance characteristics of high-volume class F fly ash concrete *Cement and Concrete Research* **34** pp 487-93
[11] Li G and Zhao X 2003 Properties of concrete incorporating fly ash and ground granulated blast-furnace slag *Cement and Concrete Composites* **25** pp 293-99
[12] ASTM C618 2005 Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete
[13] ASTM C311 2013 Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete
[14] Coppola L, Troli LR, Zaffaroni P, Belz G and Collepardi M 1998 Influence of Unburnt Carbon in the Performance of Concrete Mixtures, *ACI Special Publication* SP **178** pp 257-72
[15] Fraay ALA, Bijen JM, and de Haan YM 1989 The reaction of fly ash in concrete a critical examination *Cement and Concrete Research* **19 (2)** pp 235-46