Consistency of Fly Ash Quality in Making High Volume Fly Ash Concrete

Antoni[1]*, Alvin Krisnanta Widianto[1], Jerry Lakshman Wiranegara[1], Djwantoro Hardjito[1]
[1] Civil Engineering Department, Petra Christian University, Surabaya 60236, Indonesia, antoni@petra.ac.id*

Abstract: Fly ash is the by-product of coal burning process, which is widely used as a substitute for cement material. The advantages of using fly ash in concrete including the improvement of the workability and reducing bleeding and segregation. The problem that is often encountered when using fly ash is the uncertainly of the fly ash quality. The quality is influenced by the coal origin, burning techniques, mineral content, and capturing method. In this study, the consistency of fly ash from one power plant source was investigated in making a high volume fly ash (HVFA) mortar. Variations in the fly ash can be detected by applying rapid indicators that is suggested in this paper i.e. the pH value of the fly ash in aqueous solution and the percentage of fly ash particles passing sieve #325. The fly ash replacement ratio was varied from 10% to 60% of cement mass. The results showed that there are large variation in the chemical content of the fly ash shown by the variation of the pH value, while only slight variation in the physical properties of the fly ash, i.e. the particle size and shape. Superplasticizer demand for the same flow was reduced with the increase of fly ash content, and optimum fly ash replacement ratio for optimum strength could varied between fly ash from different sampling periods. The compressive strength could reach the same as control specimens for replacement ratio of 20 to 30% for some fly ash, and mortar compressive strength of 42 MPa still achievable with replacement ratio of 50%.

Keywords: Fly ash; pH value; HVFA; LOI; Setting time; Compressive Strength

1. INTRODUCTION

The utilization of fly ash as additional component for concrete mixture has gained popularity in the prior decades. The addition of the fly ash in the concrete mixture was known to have beneficial effect such as increase workability, reduction of water requirement, reduction of bleeding and segregation, reduction of alkali silica reaction and other benefits. Many papers have been published on the properties of fly ash and its effect on concrete mixture [1-5]. The use of fly ash in the concrete mixture should be encourage even more in the concrete industry, as the availability of fly ash keep increasing when there are currently several coal based power plant is being built to cope with the electrical energy demand of growing nation. Guide and handbook to determine the suitability and the use of fly ash in the concrete was also released by several researchers and organization [6-14], showing that fly ash can be use in large volume for concrete casting.

The characteristic of fly ash have been studied extensively by many authors [15-22]. Simple methods to characterize the variation of fly ash properties also has been presented by the authors [23], and it could detect the changes in the properties of the fly ash as a complementary testing to the test method that required more time and costly. Research on improving the fly ash properties also have been done to increase the utilization of the lower quality fly ash [24, 25].

Fly ash as the by-product of coal burning process was not controlled by the power plant. The plant manager only interested in obtaining the highest energy output with little care on the fly ash quality. Hence, the fly ash quality can have large deviation in the physical and chemical properties, and that could lead to problems when it was mixed in the concrete.

Variation of the fly ash including the chemical properties and calcium content, particle size and shape, reactivity and the Loss on Ignition (LOI) of the sample. The different fly ash quality would changes the fresh and hardened concrete properties [26-29].

The changes of fly ash properties on one power plant was investigated in this study. The fly ash source used was well known in the concrete industry to yield a good quality fly ash. Changes of the resulting fresh and hardened of the mortar properties the change of fly ash properties need to be understood, when replacing cement with fly ash especially at

*email address of author to whom correspondence should be addressed larger volume. The fly ash's rapid indicators was investigated to show the correlation with the resulting fresh and hardened properties in the mortar mixture.

2. EXPERIMENTAL DETAILS

A. Materials and Mortar Mixture Preparation

The research was proceeded by obtaining fly ash materials from electric power plant in Paiton, East Java. The fly ash samples were obtained in four month period with one or two weeks interval from July to October 2015. Pozzolan Portland Cement (PPC) from Semen Gresik was used in sealed bags to avoid variation effect of the cement material. Good quality sand was obtained from Lumajang quarry, East Java and conditioned to conform gradation of ASTM C778 [30]. Superplasticizer used was a polycarboxylate based Viscocrete 1003 from SIKA.

The mixture proportion for all mortar mixture was as follows; water to binder (fly ash and cement) ratio was fix at 0.30, sand to binder ratio at 2.0, both by weight and the superplasticizer dosage was aimed to achieve diameter of the flow table test of 14±2 cm and termed as the superplasticizer (SP) demand. Fly ash replacement ratio was set at 10%, 20%, 30%, 40%, 50% and 60%, replacing the weight of the cement. Control specimen of only cement and sand was also prepared.

The mortar mixture was mixed by hand drill to obtain a uniform mixture and cast in 5×5×5 cm^3 cube specimens. Then the specimen was demolded one day after mixing and cured submerged in water until one day prior the compressive testing time.

B. Testing

The fly ash was tested by rapid testing of passing sieve #325 (44 µm) and pH value of the fly ash in aqueous solution. The pH value was determined according to ASTM D5239 [31], by measuring a solution of 20 gr fly ash in 80 gr distilled water. These rapid indicators could provide a quick assessment on the quality of the fly ash. Several fly ash samples were also tested using XRF and LOI test.

Workability of the mixture and the superplasticizer demand was determined using flow table test [32]. The addition of the SP into the mixture was conducted to achieve the target flow diameter of 14±2 cm. The SP dosage was limited at 2% of cement weight to avoid excessive retardation and bleeding. The setting time was determined by measuring the temperature rise of the paste mixture according to ASTM C1679 [33]. The compressive strength was measured at mortar age of 3, 7, 14, 28 and 56 days. Three specimens were made for each compressive test.

3. RESULTS AND DISCUSSIONS

A. Fly ash variation

Ten fly ash samples was obtained from one power plant source during the experimental period. The pH value and percentage of material passing sieve #324 was shown in Table 1. All of the fly ash sample shown to have a fine particle size exceeding the ASTM C618 requirement of 66% passing the sieve [34]. There were variation of the pH value ranging from 10.4 up to 11.8 showing that there could be large variation of the chemical composition.

Selected fly ash sample then was sent for XRF test to measure the chemical composition. The XRF results was shown in Table 2. It was found that the pH value have a good correlation with the CaO and MgO oxide content. Calcium oxide of the fly ash was in the range of medium to high fly ash, hence the fly ash can be categorized as class C fly ash. The chemical composition have broad range of percentage, and this would affect the predictability of the properties of the fresh and hardened behavior of the concrete.

The Loss on Ignition (LOI) value of the fly ash was also shown in Table 2. It was found that the fly ash from this source have a good and constant low LOI less than 1%, showing that there were excellent burning process in the power plant. Thus there were not large variation from the physical properties, but the chemical properties of fly ash from the same plant could vary between shipments.

TABLE 1. pH value and particle fineness

	FA-I	FA-II	FA-III	FA-IV	FA-V	FA-VI	FA-VII	FA-VIII	FA-IX	FA-X
pH value	10.9	11.1	10.4	11.8	10.6	10.8	10.6	11.7	11.4	11.2
Passing sieve #325 (%)	84	88	76	88	80	84	84	88	92	84

TABLE 2. XRF of selected fly ash

Compound	Chemical composition (%mass)			
	FA-II	FA-III	FA-IV	FA-V
SiO_2	43.74	43.36	32.47	42.26
Al_2O_3	22.03	29.74	14.92	24.43
Fe_2O_3	14.68	7.33	16.50	12.91
CaO	9.40	13.30	20.42	11.19
K_2O	1.55	0.42	1.32	0.80
MgO	4.33	1.80	7.95	3.69
SO_3	0.53	0.40	1.88	0.91
Mn_2O_3	0.15	0.14	0.18	0.24
TiO_2	1.28	1.00	0.71	1.01
Cr_2O_3	0.14	0.01	0.14	0.01
Na_2O	1.56	1.88	2.92	1.85
LOI	0.80	0.60	0.43	0.44

B. Fresh mortar behavior

The superplasticizer demand for target flow of 14±2 cm in flow table test and its resulting flow diameter are shown in Fig. 1 and Fig. 2, respectively. The control specimen required up to 2% of SP to achieve flow diameter of 11 cm. The increase of the fly ash replacement ratio would reduce the superplasticizer demand and increase the flow diameter. This is the norm with fly ash replacement due to the increase of the round particle in the mixture increasing the bearing ball effect.

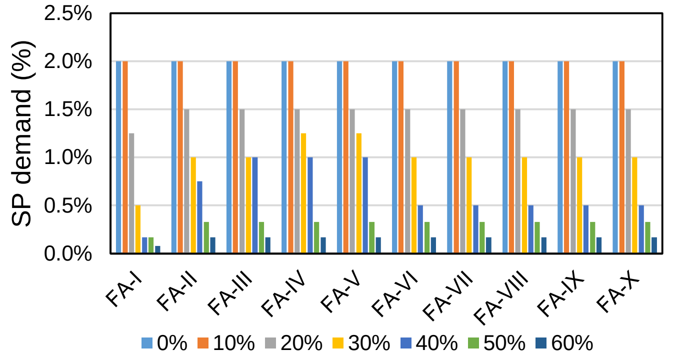

Fig. 1. Superplasticizer demand for targeted flow

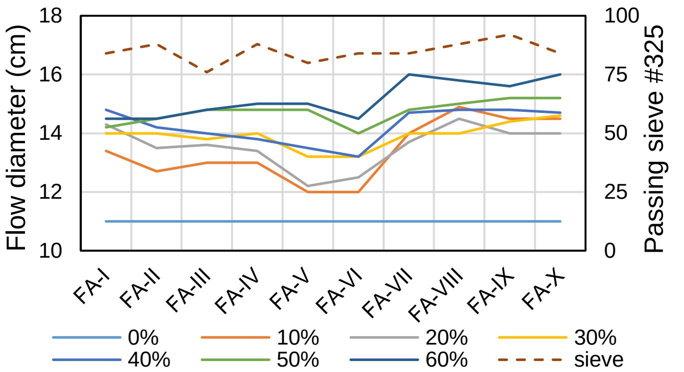

Fig. 2. Flow of the fly ash mortar and percentage passing sieve #325

The SP demand for FA-IV and FA-V at 30% and 40% replacement ratio was slightly higher than other fly ash, but there was not any detrimental effect on the flow properties. The SP demand need to be determined for the concrete mixture when obtaining new batch of fly ash as it could affect the concrete's workability.

The increase of the fly ash replacement ratio increases the setting time of the mixture. The initial setting time of the mixture with different fly ash and replacement ratio is shown in Fig. 3. The initial setting time was increased with the increase of fly ash content at different rate depending on the fly ash used. The increase of setting time could be beneficial when casting in-situ, as it would have longer handling time. But the opposite effect would occurs when large volume of fly ash used in precast industry as the increase of setting time would prolong the demolding cycle. Higher replacement ratio increase the setting time at higher rate as shown by FA-IX and FA-IV.

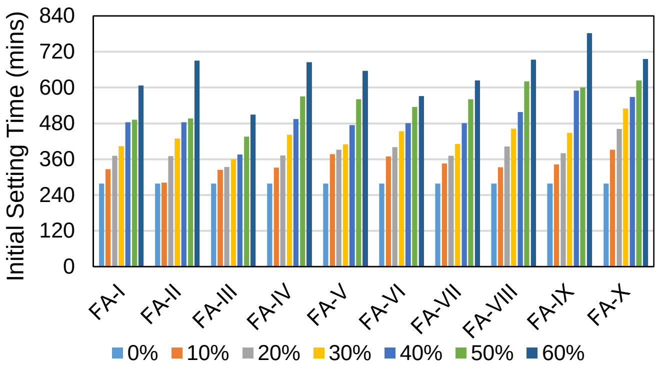

Fig. 3. Initial setting time of the paste

C. Strength Development

The compressive strength of the mortar specimens for all mixture are shown in Fig. 4 to Fig. 13. The control specimens had compressive strength of 45.8 MPa at 3 days and developed up to 67.4 MPa at 56 days. As expected, higher fly ash replacement ratio would have some reduction of compressive strength compared with the control specimen. The highest compressive strength of 73.27 MPa at 56 days was attained from FA-VIII at 30% replacement ratio, this result was higher than the control specimen. The lowest compressive strength at 37.07 MPa at 56 days could still be attained from FA-VI. At the 10% fly ash replacement ratio, there were slight drop of compressive strength as the workability of the mixture was lower compared to other higher replacement ratio, as shown in Fig. 9 and Fig. 10. The limit of superplasticizer at 2% also limit the mixture's workability. Thus it is suggested that the fly ash replacement ratio should be higher that 10% to benefit the effect of a more workable mix.

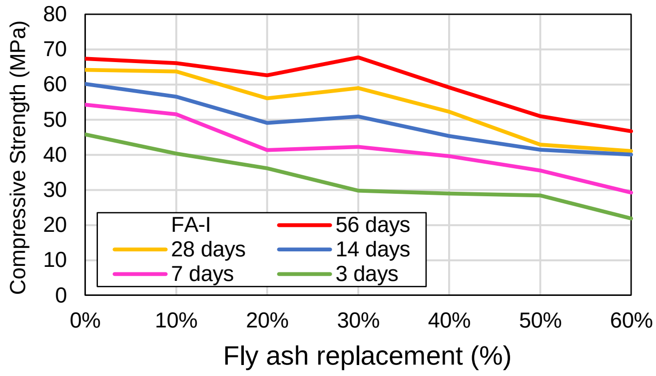

Fig. 4. Strength development of FA-I

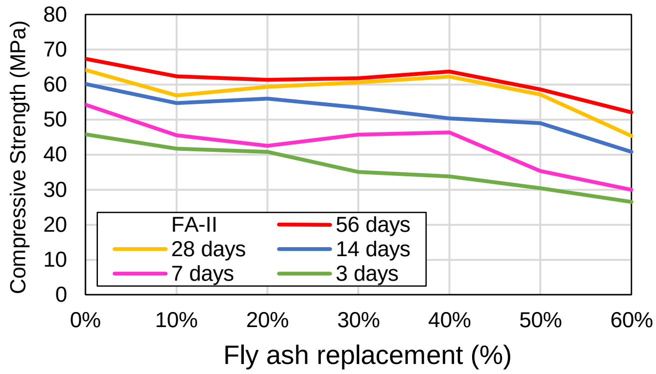

Fig. 5. Strength development of FA-II

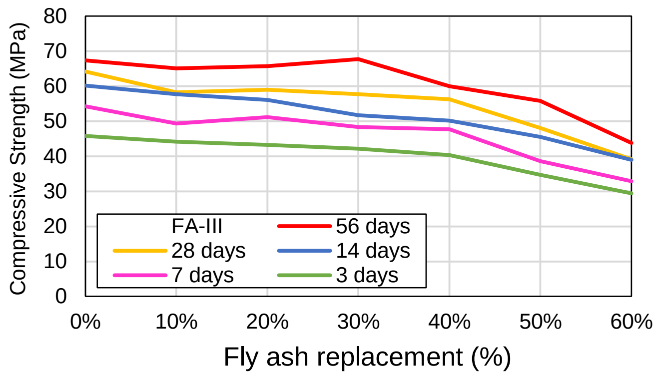

Fig. 6. Strength development of FA-III

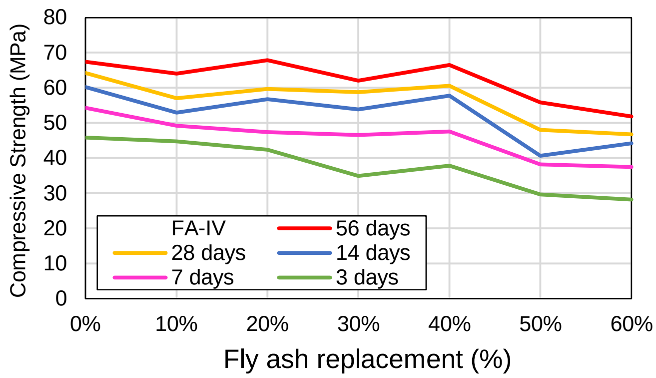

Fig. 7. Strength development of FA-IV

The increase of the compressive strength with age was shown to be not uniform for all of the fly ash sample. The increase of the compressive strength with the fly ash replacement normally occurs at later age of mortar from 28 days to 56 days was found on some fly ash sample but not all. FA-I, FA-III, FA-IV, FA-V and FA-IX have strength increment at later age, showing the pozzolanic reaction occurring at later age. However, FA-II, FA-VI, FA-VII, FA-VIII and FA-X did not show significant increase of strength at later age, and could be a sign of low pozzolanic reaction rate.

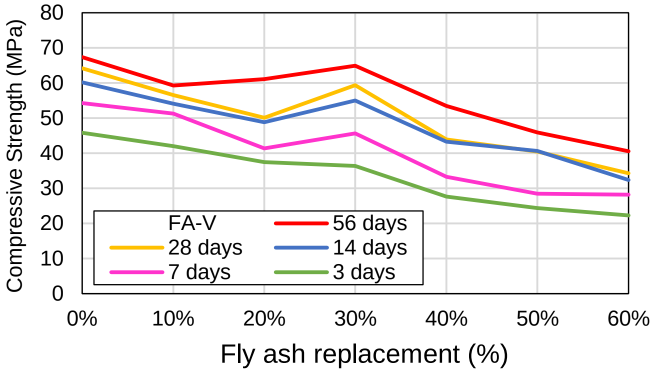

Fig. 8. Strength development of FA-V

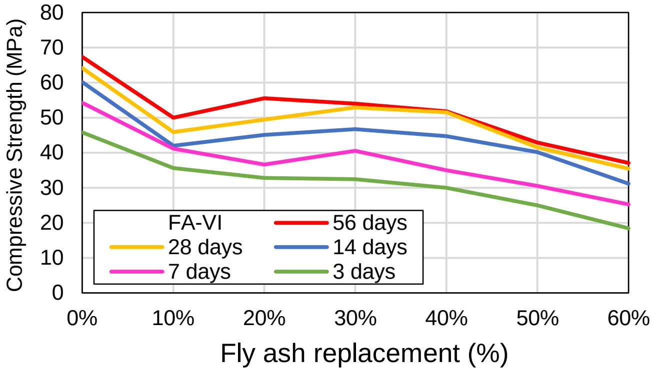

Fig. 9. Strength development of FA-VI

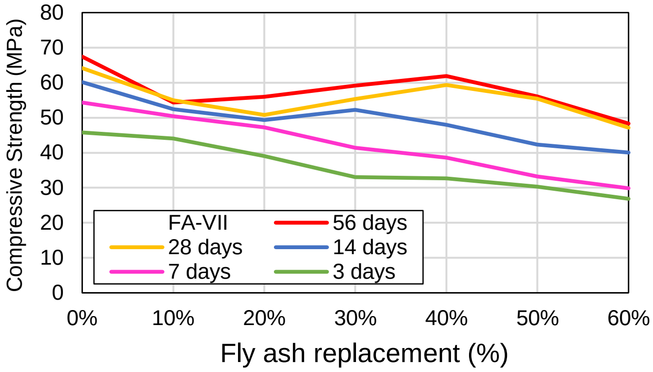

Fig. 10. Strength development of FA-VII

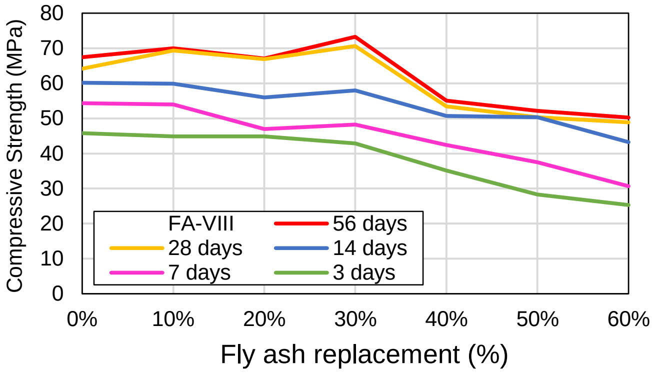

Fig. 11. Strength development of FA-VIII

The different behavior of the strength development could be due to the availability of the calcium hydroxide in the gel solution. The cement used in this result was a pozzolanic cement, meaning that the extra calcium hydroxide could be consumed by the cement material itself. Fly ash that contain higher calcium oxide hence could contribute the later age strength development.

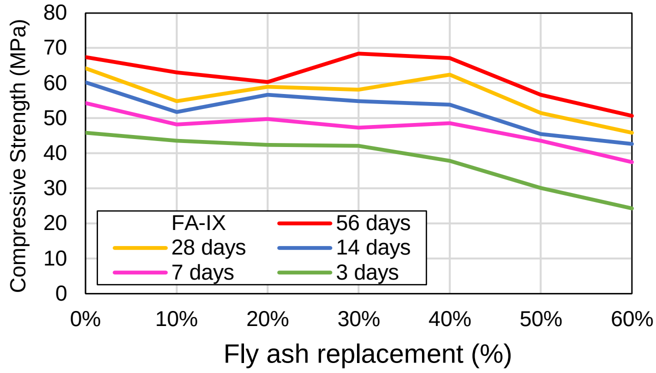

Fig. 12. Strength development of FA-IX

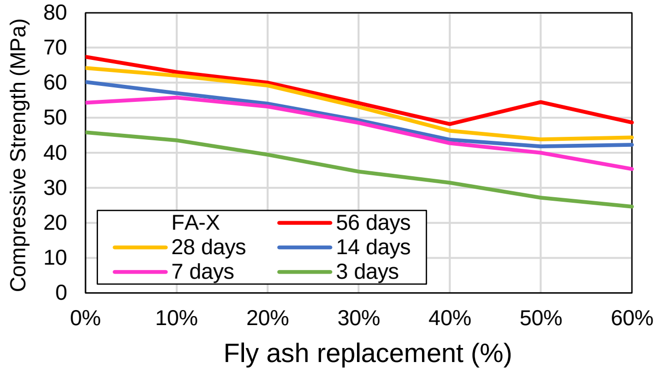

Fig. 13. Strength development of FA-X

D. Fly Ash Variations on the Resulting Properties

The compressive strength of the mortar specimens at 56 days is shown in Fig. 14. It was shown that all mortar mixes could have strength higher than 30 MPa, however the maximum strength was not the same for comparable replacement ratio. The different fly ash sampling time have significant effect on the strength development and the peak compressive strength as other variable was being kept constant.

FA-VI and FA-V generally have lower strength compared to other fly ash. The effect was correlated with the slump flow (Fig. 2), as these two fly ash sample have lower workability. FA-VIII have the highest compressive strength compared with other fly ash, and the strength development seem to be occurring before 28 days (Fig. 11).

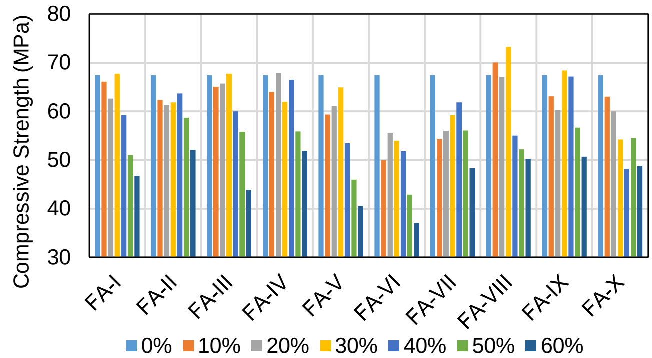

Fig. 14. Overall compressive strength at 56 days

The correlation of initial setting time with pH value of the fly ash is shown in Fig. 15. Higher pH value have retarding effect on the mortar mixture. This could be due to interaction of alkali content with the cement paste. Further study need to be done to clarify the actual mechanism as higher fly ash replacement ratio and pH value showing longer initial setting time.

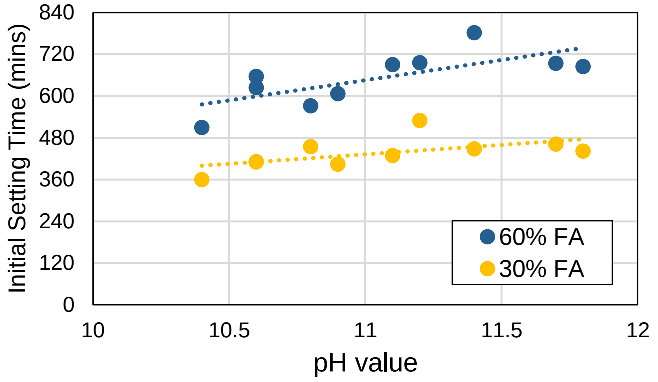

Fig. 15. Relationship of initial setting time and the pH value

The correlation of the mortar's compressive strength at 56 days for fly ash replacement ratio of 30% and 60% with the pH value and percentage of particle finer than 44 µm are shown in Fig. 16 and Fig. 17, respectively. Higher compressive strength was obtained when using fly ash with higher pH, as there could be additional hydration reaction with the availability of the calcium oxide in the mixture. The increase of strength was more pronounce at higher replacement ratio. Finer fly ash particle also could have better reaction in the mixture. The result of the compressive strength of 60% replacement ratio have a positive correlation with the finer particle size.

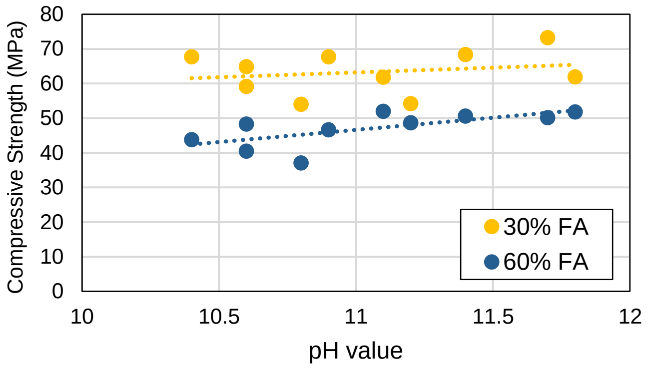

Fig. 16. Relationship of compressive strength at 56 days and the pH value

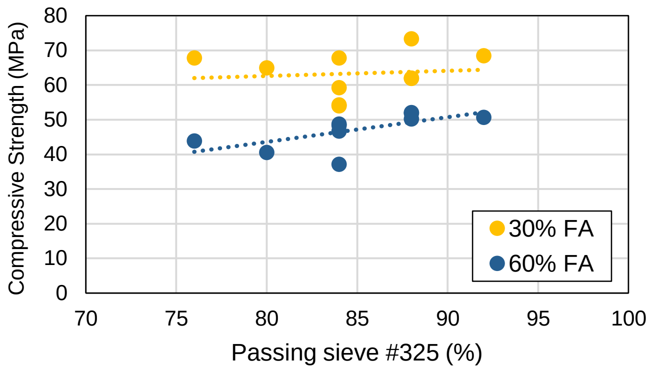

Fig. 17. Relationship of compressive strength at 56 days and the percentage of passing sieve #325

From the experiment data, it can be shown that the rapid indicator could detect the variation of the fly ash and the resulting properties. However, the changing of the fly ash quality was not limited to the particle size and the pH value only, as other factors such as LOI and particle shape that are influenced by the seamless coal burning condition. Special care should also need to be carefully considered when using fly ash after the power plant maintenance cycle, as the fly ash could have high LOI content, when the plant was starting up the burning process.

4. CONCLUSIONS

The consistency of the fly ash quality was investigated in this research and the following conclusions can be identified:

1. There are changes of fly ash quality between shipment especially in the chemical properties, as it was determined by the chemical properties of the coal source that cannot be kept constant, and the variation of the fly ash quality would affect the fresh and hardened properties of the concrete when using fly ash as cement replacement.
2. Higher workability and longer setting time was found when fly ash was used to replace cement material at higher ratio. However due to the variation of fly ash, the resulting properties need to be checked with each shipment.
3. The optimum range of fly ash replacement ratio was found around 20 to 40% from this research and some fly ash sample could have higher compressive strength than the control specimens at replacement ratio of 30% and 40%, and mortar compressive strength of 42 MPa still achievable with replacement ratio of 50%.
4. Rapid indicator suggested in this study i.e pH value and passing sieve #325 can be used to assess the quality of the fly ash, and to estimate the resulting properties when high volume of fly ash is mixed in concrete.

ACKNOWLEDGMENTS:

The authors gratefully acknowledge The Ministry of Research, Technology and Higher Education, Indonesia, who provided the research grant under the Fundamental Research scheme.

REFERENCES

[1] M. Ahmaruzzaman, A review on the utilization of fly ash, Progress in Energy and Combustion Science, 36 (2010) 327-363.
[2] R.S. Blissett, N.A. Rowson, A review of the multi-component utilisation of coal fly ash, Fuel, 97 (2012) 1-23.
[3] S.V. Deo, A Review of High Volume Low Lime Fly Ash Concrete, International Conference on Biological, Civil and Environmental Engineering (BCEE-2014)Dubai (UAE), 2014.
[4] Z.T. Yao, X.S. Ji, P.K. Sarker, J.H. Tang, L.Q. Ge, M.S. Xia, Y.Q. Xi, A comprehensive review on the applications of coal fly ash, Earth-Science Reviews, 141 (2015) 105-121.
[5] D.-z. Cao, E. Selic, J.-D. Herbell, Utilization of fly ash from coal-fired power plants in China, Journal of Zhejiang University SCIENCE A, 9 (2008) 681-687.
[6] A.D.A.o. Australia, Guide to the use of fly ash in concrete in Australia, Fly ash reference data sheet no. 1, Ash Development Association of Australia, 2009.
[7] A.D.A.o. Australia, Australian experience with fly ash in concrete: Applications and opportunities, Fly ash Technical Note

no. 8, Ash Development Association of Australia, 2009.
[8] D.P. Bentz, C.F. Ferraris, K.A. Snyder, Best Practices Guide for High-Volume Fly Ash Concretes, NIST Technical Note 1812, 2013.
[9] K.H. Obla, Specifying fly ash for use in concrete, Concrete InFocus, 2008, pp. 60-66.
[10] C. Rao, R.D. Stehly, A. Ardani, Handbook for Proportioning Fly Ash as Cementitious Material in Airfield Pavement Concrete Mixtures, in: I.P.R. Foundation (Ed.)IL, USA, 2011, pp. 74.
[11] A.M. Rashad, A brief on high-volume Class F fly ash as cement replacement – A guide for Civil Engineer, International Journal of Sustainable Built Environment, 4 (2015) 278-306.
[12] M. Thomas, Optimizing the use of fly ash in concrete, Portland Cement Association Skokie, IL, USA, Place Published, 2007.
[13] K. Wesche, Fly ash in concrete: properties and performance, CRC Press, Place Published, 2004.
[14] F. Rivera, P. Martínez, J. Castro, M. López, Massive volume fly-ash concrete: A more sustainable material with fly ash replacing cement and aggregates, Cement and Concrete Composites, 63 (2015) 104-112.
[15] F. Blanco, M.P. Garcia, J. Ayala, Variation in fly ash properties with milling and acid leaching, Fuel, 84 (2005) 89-96.
[16] A. Fernández-Jiménez, A. Palomo, Characterisation of fly ashes. Potential reactivity as alkaline cements, Fuel, 82 (2003) 2259-2265.
[17] T. Hemalatha, M. Mapa, N. George, S. Sasmal, Physico-chemical and mechanical characterization of high volume fly ash incorporated and engineered cement system towards developing greener cement, Journal of Cleaner Production, 125 (2016) 268-281.
[18] M. Jones, A. McCarthy, A. Booth, Characteristics of the ultrafine component of fly ash, Fuel, 85 (2006) 2250-2259.
[19] M. Romagnoli, P. Sassatelli, M. Lassinantti Gualtieri, G. Tari, Rheological characterization of fly ash-based suspensions, Construction and Building Materials, 65 (2014) 526-534.
[20] R. Siddique, Performance characteristics of high-volume Class F fly ash concrete, Cement and Concrete Research, 34 (2004) 487-493.
[21] S.W.M. Supit, F.U.A. Shaikh, P.K. Sarker, Effect of ultrafine fly ash on mechanical properties of high volume fly ash mortar, Construction and Building Materials, 51 (2014) 278-286.
[22] X.-Y. Wang, Effect of fly ash on properties evolution of cement based materials, Construction and Building Materials, 69 (2014) 32-40.
[23] Antoni, R. Gunawan, D. Hardjito, Rapid indicators in detecting variation of fly ash for making HVFA concrete, Applied Mechanics and Materials, 815 (2015) 153-157.
[24] Antoni, S. V, H. D, Simple mechanical beneficiation method of coarse fly ash with high LOI for making HVFA mortar, Civil Engineering Dimension, 17 (2015).
[25] F. Blanco, M.P. Garcia, J. Ayala, G. Mayoral, M.A. Garcia, The effect of mechanically and chemically activated fly ashes on mortar properties, Fuel, 85 (2006) 2018-2026.
[26] F.U.A. Shaikh, S.W.M. Supit, Compressive strength and durability properties of high volume fly ash (HVFA) concretes containing ultrafine fly ash (UFFA), Construction and Building Materials, 82 (2015) 192-205.
[27] Ş. Yazici, H.Ş. Arel, Effects of fly ash fineness on the mechanical properties of concrete, Sadhana, 37 (2012) 389-403.
[28] A. Nawaz, P. Julnipitawong, P. Krammart, S. Tangtermsirikul, Effect and limitation of free lime content in cement-fly ash mixtures, Construction and Building Materials, 102 (2016) 515-530.
[29] E. Tkaczewska, Effect of the superplasticizer type on the properties of the fly ash
blended cement, Construction and Building Materials, 70 (2014) 388-393.
[30] ASTM, C778, Standard specification for standard sand, ASTM International, 2005.
[31] ASTM, D5239, Standard Practice for Characterizing Fly Ash for Use in Soil Stabilization. American Society for Testing and Materials,, ASTM International, West Conshohocken, PA, USA, 2003.
[32] ASTM, C 230, Standard Specification for Flow Table for Use in Tests of Hydraulic Cement, ASTM International, West Conshohocken, PA, 2008.
[33] ASTM, C1679, Standard Practice for Measuring Hydration Kinetics of Hydraulic Cementitious Mixtures Using Isothermal Calorimetry, ASTM International, West Conshohocken, PA,, 2014.
[34] ASTM, C618, Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete, ASTM International, 2003.

Received: .. month year. Accepted: … month year