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OF FLY ASH QUALITY **FOR MAKING HIGH VOLUME FLY ASH** 27

CONCRETE

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Compressive strength (MPa) 80 70 60 50 40 30 2

Initial setting time (mins) 720 600 480 360 240 120 0 60% FA 30% FA 840 0% 10% 20% 30% 40% 50% 60%

Compressive strength (MPa) 70 60 50 40 30 20 10 0 30% FA 60% 8

FA 80 10 10.5 11 pH 11.5 12 70 75 80 85 90 95 Passing sieve #325 (%) 100 Article history Received XXX Received in revised foXrXmX Accepted XXX *Corresponding author antoni@petra.ac.id

Abstract Fly ash is a by-product of coal burning and is widely used as a substitute for cement material. 17

The

advantages of using fly ash in concrete include the improvement of 32

workability and reduction of bleeding and segregation. The problem often encountered

when using fly ash is the uncertainly of the fly ash quality. The quality is influenced by the 26

coal origin, burning technique, mineral content, and capturing method. In this

study, the consistency of fly ash from one power plant source was investigated for making 1

a

high- volume fly ash (HVFA) mortar. Variations in fly ash 51

can be detected by applying rapid indicators as suggested

in this paper; i.e., the pH of the fly ash in aqueous solution and the percentage of 30

fly ash particles passing sieve #325. The fly ash replacement ratio was varied from 10–60% of cement mass. The results showed a

large variation in the chemical content of the fly ash 1

as shown by variation in pH, whereas only slight variation in the

physical properties of the fly ash, i.e., particle size and shape. 3

Superplasticizer demand for the same flow was reduced

with the increase of fly ash content and the optimum fly ash 28

replacement ratio for strength varied among fly ash from different sampling periods. The compressive strength could reach that of control specimens at a replacement ratio of 20–30% for some

fly ash, and mortar compressive strength of 42 MPa was 14

still achievable at a replacement ratio of 50%.

Keywords: Fly ash; pH; HVFA; LOI; setting time; compressive strength 7

 1.0 INTRODUCTION The utilization of 24

fly ash as an additive to concrete mixtures has 19

gained popularity in past decades.

The addition of fly ash is known to 19

have beneficial effects such as increased 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 37

effects on concrete mixtures [1–5].

The use of fly ash in concrete mixtures should be 13

encouraged as the availability of fly ash keeps increasing along with the new coal-burning power plants being constructed to meet rising electrical energy demand. Guides and handbooks to determine the suitability and use

of fly ash in concrete have been published by several researchers and 38

organizations [6– 14] that show

fly ash can be used in large volume for concrete casting. The characteristics of 33

fly ash have been studied extensively by many authors [15–22]. Simple methods to characterize the

variation of fly ash properties also have been presented by the authors 3

[23] that can detect changes in fly ash properties more quickly and inexpensively than other methods. Research on improving fly ash properties also has been done to increase utilization of lower-quality fly ash [24,25]. The quality of

fly ash, a by-product of coal-burning, is 6

not a concern for the power plant, which is

only interested in obtaining the highest energy output. Given the different compositions of coal, fly ash quality can deviate significantly 1

in

both its physical and chemical properties, which could lead to problems when mixed with 9

concrete. xx:x (201x) x–x | www.jurnalteknologi.utm.my | eISSN 2180–3722 | Variations of fly ash characteristics include chemical properties, calcium content, particle size and shape, reactivity, and the

loss on ignition (LOI) of the sample. These different fly ash characteristics 13 results in differences to fresh and hardened concrete properties [26–30]. This study investigated the characteristics of fly ash samples at one power plant. The fly ash source used was well-known in the concrete industry to yield a good-quality fly ash. Changes to

fresh and hardened mortar **properties in** relation **to fly ash** 44

properties need to be understood, particularly when replacing cement with larger volumes of fly ash. Rapid indicators (pH and particle size) were investigated to determine its correlation to the fresh and hardened

properties of the mortar. **2.** 0 **EXPERIMENTAL** DETAILS **2.1 Materials and** 34

mortar mixture preparation Ten

fly ash samples were **collected** periodically **from an** electric power **plant in** 53

Paiton, East Java, from July to October 2015.

Pozzolan Portland Cement (PPC) from **Semen Gresik was** 54

obtained in sealed bags to avoid variation of the cement material. Good quality

sand was obtained from Lumajang quarry, East Java, **and conditioned to conform to** a **gradation of ASTM C778** 1

[31]. Polycarboxylate-based Viscocrete 1003 from SIKA was used as the superplasticizer (SP). The mixture proportion for all mortar mixtures was as follows: the water to binder (fly ash and cement) ratio was fixed at 0.30; sand to binder ratio was 2.0 (both by mass); and the superplasticizer dosage was aimed to achieve a diameter of 14±2 cm (by flow table test) and designated as the “superplasticizer demand.” The fly ash to cement replacement ratios were set at 10%, 20%, 30%, 40%, 50%, and 60%. A control specimen of only cement and sand was also prepared. The mortar mixture was mixed using a hand drill to obtain a uniform mixture and cast as 5 cm × 5 cm × 5 cm specimens.

The specimens were demolded one day **after** mixing **and cured** under **water** 50

until one day prior to compressive testing. 2.2 Testing The fly ash was passed through sieve size #325 (44 μm) and the

pH of the particulate **fly ash** was measured **in** aqueous **solution** 7

(20 g

fly ash in 80 ml distilled **water)** 9

according to ASTM D5239 [32]. The pH provided rapid determination of the fly ash quality. Several

fly ash samples were also **tested using XRF and** 9

LOI tests. Workability

of the fly ash and cement mixture **and the** 49

superplasticizer demand were determined using a flow table test [33]. The addition of the SP into the mixture was conducted

to achieve a target **flow diameter of** 14±2 **cm. The** 15

SP dosage was limited to 2% of cement mass to avoid excessive retardation and bleeding. The

setting time was determined by measuring **the** temperature rise **of the** paste mixture **according to** 4

ASTM C1679 [34]. The compressive strength

was measured at mortar **age of 3, 7, 14, 28, and** 56 **days.** 23

Three specimens were made **for each compressive test. 3.** 0 **RESULTS AND DISCUSSION 3.1** 10

Fly ash variation Ten **fly ash** samples were **obtained from** one **power plant** 46

source during the experimental period. The pH and percentage of material passing sieve #324

are shown in Table 1. All **fly ash samples were** shown **to** 31

have a fine particle size exceeding the ASTM C618 requirement of 66% passing the sieve [35]. The pH values ranged from 10.4 to 11.8, indicating a potentially large variation in chemical composition. Selected fly ash samples were sent for XRF analysis to measure their chemical compositions. The XRF results are shown in Table 2. It was found that the pH had good correlation with the CaO and MgO content. The CaO content

was in the range of medium **to** high; hence, **the fly ash** 40

can be categorized as class C fly ash. The chemical composition had a broad range of percentages, which affects the predictability of

the properties of the **fresh and hardened concrete.** Table 1 pH **and** 42

Particle Size

FA- FA- FA- FA- FA- FA- FA- FA- FA- FA-I II III IV **V** 21

VI VII VIII IX X

pH 10.9 11.1 10.4 11.8 10.6 10.8 10.6 11.7 11.4 11.2 Passing sieve #325 1

(%) 84 88 76 88 80 84 84 88 92 84

Table 2 XRF of **Selected Fly Ash Compound Chemical Composition (% mass)** 1

FA-II FA-III FA-IV FA-V 47

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

The loss on ignition (LOI) values of the **fly ash** are also shown **in** 2

Table 2. It was found that the fly ash from this source had a good and constant low LOI (< 1%), indicating an excellent burning process in the power plant. Thus, there was no large variation in physical properties, whereas

the chemical properties of fly ash from the same 1

plant varied between collections. 3.2 Fresh mortar behavior The superplasticizer demand for a target flow of 14±2 600 cm by flow table test and the resulting flow diameters are shown in Figures 1 and 2, respectively. The control 480 specimen required up to 2% of SP

to achieve a flow 360 **diameter of** 11 **cm. The** 15 increase of the fly ash 240 replacement ratio reduced SP demand and increased 120 the flow diameter. This is the norm with fly ash Initial setting time (mins) 0 replacement due to the increase of round particles in the mixture, which increases the bearing ball effect. 0% 10% 20% 30% 40% 50% 60% 2.5% Figure 3 Initial setting time of the paste SP demand (%) 2.0% 1.5% 3.3 Strength development 1.0% The compressive strength values of the mortar 0.5% specimens for all mixtures are shown in Figures 4–13. The control specimens had compressive strength of 0.0% 45.8 MPa at 3 days and developed up to 67.4 MPa at 56 days. As expected, higher fly ash replacement 0% 10% 20% 30% 40% 50% 60% ratios reduced the compressive strength compared with the control specimen. The highest compressive Figure 1 Superplasticizer demand for targeted flow strength of 73.27 MPa at 56 days was attained from FA- VIII at 30% replacement ratio, which was greater than Flow diameter (cm) 18 100 the control specimen. The lowest compressive strength at 37.07 MPa at 56 days was recorded for FA-VI. At the 16 75 10% fly ash replacement ratio, there was a slight drop 14 50 of compressive strength as the workability of the mixture was lower compared with higher replacement 12 25 ratios as shown in Figures 9 and 10. 10 0 Passing sieve #325 80 70 60 0% 10% 20% 30% 40% 50% 60% sieve Compressive strength (MPa) 50 Figure 2 Flow of the fly ash mortar and percentage passing 40 sieve #325 30 20 FA-I 56 days 10 28 days 14 days The SP demand for FA-IV and FA-V at 30% and 40% 7 days 3 days 0 replacement ratio was slightly higher than other fly ash; 0% 10% 20% 30% 40% 50% 60% however, there was no detrimental effect on the flow Fly ash replacement (%) properties. The SP demand needs to be determined Figure 4 Strength development of FA-I for the concrete mixture when obtaining a new batch of fly ash as it could affect the concrete's workability. Compressive strength (MPa) 80 The increase of the

fly ash replacement ratio 70 **increased the** setting time **of the** mixture. **The**	43

initial setting times

of the mixture with different fly ash	7

and 60 replacement ratios are shown in Figure 3. The initial 50 setting time was increased

with the increase of **fly ash** 40 **content at different** rate depending on **the**	36

different fly 30 ash samples. The increase of setting time could be 20 FA-II 56 days beneficial when casting in situ as it would have a 10

28 days 14 days 7 days 3 days	12

longer handling time. However, the opposite effect 0 occurs when large

volumes of fly ash are used in the	6

0% 10% 20% 30% 40% 50% 60% precast industry as the increased setting time would Fly ash replacement (%) prolong the demolding cycle. A higher replacement Figure 5 Strength development of FA-II ratio increases the setting time at higher rate as shown by FA-IX and FA-IV.

Compressive strength (MPa) 70 60 50 40 30 20 10 0	5

FA-III 56

days 28 days 14 days 7 days 3 days	12

80 Compressive strength (MPa) 70 60 50 40 30 20 10 0	20

FA-IV 56 days 28 days 14

days 7 days 3 days 80 **0% 10% 20% 30% 40% 50%**	4

Fly ash replacement (%) Figure 6 Strength development of FA-III 60%

Compressive strength (MPa) 70 60 50 40 30 20 10 0	5

FA-V 56 days 28 days 14

days 7 days 3 days 80 **0% 10% 20% 30% 40%** 50% Fly ash **replacement**	16

(%) Figure 7 Strength development of

FA-IV 60%

Compressive strength (MPa) 70 60 50 40 30 20 10 0 5

FA-VI 56 days 28 days 14

days 7 days 3 days 80 0% 10% 20% 30% 40% 50% 4

Fly ash replacement (%) Figure 8 Strength development of FA-V 60% 0% 10% 20% 30% 40% 50% 60% Fly ash replacement (%) Figure 9 Strength development of FA-VI

Compressive strength (MPa) 60 50 40 30 20 2

FA-VII 56 days 10 28 days 14 days 0 7 days 3

days Compressive strength (MPa) 70 60 50 40 30 20 25

FA-VIII 56 days 10 28 days 14

days 7 days 3 days 0 0% 10% 20% 30% 40% 50% 60% 4

Fly ash replacement (%) Figure 10 Strength development of FA-VII

80 Compressive strength (MPa) 70 60 50 40 30 20 2

FA-IX 56 days 10 28 days 14 days 0 7 days 3

days 0% 10% 20% 30% 40% 50% 60% Fly ash 11

replacement (%) Figure 11 Strength development of FA-VIII

80 Compressive strength (MPa) 70 60 50 40 30 20 2

FA-X 56 days 10 28 days 14 days 0 7 days 3

days 0% 10% 20% 30% 40% 50% 60% Fly ash 11

replacement (%) Figure 12 Strength development of FA-IX 80 0% 10% 20% 30% 40% 50% 60% Fly ash replacement (%) Figure 13 Strength development of FA-X The SP limit of 2% also limited the mixture's workability. Thus, it is suggested that the fly ash replacement ratio should be higher than 10% to benefit the effect of a more workable mix. The increase of compressive strength with age was shown to be not uniform for the entire

fly ash samples. An increase in compressive strength with the fly ash 29

replacement—normally at a later age

of mortar from 28 days to 56 days— 7

was found for some fly ash samples, but not all.

FA-I, FA-III, FA-IV, FA-V, and FA- 35

IX have strength increments at a later age, showing the pozzolanic reaction occurs at this stage. However, FA- II, FA-VI, FA-VII, FA-VIII, and FA-X did not show significant increase of strength at a later age, which could signal a low pozzolanic reaction rate. The different behavior of strength development could be

due to the availability of calcium hydroxide in the gel solution. 39

The cement used in this case was pozzolanic, meaning that extra calcium hydroxide could be consumed by the cement material itself. Therefore,

fly ash with higher CaO content could contribute to 3

later-age strength development. 3.4 Fly ash variations and resulting properties Peak hydration temperatures of the specimens were measured during the initial setting time evaluation. The correlation of peak temperatures and 3-day compressive strength

with different fly ash replacement ratio are shown in Figure 14

14. The peak temperatures vary with the fly ash used at the same replacement ratio, where higher peak temperature may indicate higher fly ash reactivity. Higher early age compressive strengths are obtained by paste specimens with higher peak

temperatures. Compressive strength (MPa) 50 45 40 35 30 25 20 15 2

10% 20% 10 30% 40% 5 50% 60% 0 20 30 40 50 60 Peak temperature (C) Figure 14 Relationship of peak temperature and 3 days

compressive strength The compressive strength values for the mortar specimens 10

at 56 days are shown in Figure 15. This shows that all mortar mixes could have strengths higher than 30 MPa; however, the maximum strength was not the same for comparable replacement ratios. The different fly ash sampling times

had a significant effect on strength development and the peak compressive strength 52

when other variables were held constant. FA-VI and FA-V generally have lower strength compared with the other fly ash samples. The effect was correlated with the slump flow (Figure 2) as these two fly ash samples both had lower workability. FA-VIII had the highest compressive strength compared with other fly ash samples and strength development seemed to occur before 28 days (Figure 11).

Compressive strength (MPa) 60 50 40 30 0% 10% 20% 30% 40% 50% 5

60% Figure 15 Overall

compressive strength at 56 days The correlations of 6

initial setting time with pH

of the fly ash are shown in Figure 6

16. A higher pH had a retarding effect on the mortar mixture. This could be due to interaction of alkali content with the cement paste. Further study is needed to clarify the actual mechanism as higher fly ash replacement ratio and pH showed a longer initial setting time. The correlation of mortar compressive strengths at 56 days for fly ash replacement ratios of 30% and 60% and pH are graphed in Figure 17. The correlation of mortar compressive strengths at these ratios and particle size are graphed in Figure 18. Higher compressive strength was obtained when using fly ash with higher pH, which drives additional hydration of the available CaO. The increase of strength was more pronounced at higher replacement ratios. Finer fly ash particles also resulted in a better reaction in the mixture. The compressive strength at 60% replacement ratio had a positive correlation with finer particle size. Initial setting time (mins) 840 720 600 480 360 240 60% FA 120 30% FA 0 10 10.5 11 11.5 12 pH Figure 16 Relationship of initial setting time and pH

Compressive strength (MPa) 80 70 60 50 40 30 20 30% FA 10 22

60% FA 0 10 10.5 11 11.5 12 pH Figure 17 Relationship

of compressive strength at 56 days and 18

pH

Compressive strength (MPa) 70 60 50 40 30 20 10 0 30% FA 60% 8

FA 80 70 75 Passing sieve #325 (%) 80 85 90 95 100 Figure 18 Relationship

of compressive strength at 56 days and the 18

percentage of passing sieve #325 From the experimental data, it can be shown that the rapid indicator method can determine critical predictive properties in fly ash. However, variations in fly ash quality are not limited to particle size and pH only, as other factors, such as LOI and particle shape also vary depending on the coal-burning conditions. In particular, special care is needed when using fly ash after a power plant maintenance cycle, as the fly ash could have high LOI when the burning process is restarted. 4.0 CONCLUSIONS The consistency of fly ash quality was investigated in this research and the following conclusions can be identified: (a) There are changes of fly ash quality between shipments, especially in the chemical properties. It depends on the properties of coal that cannot be kept constant. Variation in fly ash quality affects

the fresh and hardened properties of mortar or concrete. (b) Higher workability and 45

longer setting time was found at higher fly ash replacement ratios. However, due to content variation, the optimum ratio needs to be determined for each shipment. (c) The optimum range of fly ash replacement ratio was found around 20–40%. Some fly ash samples could

have higher compressive strength than the control specimens at replacement ratio 48

of 30% and 40%, and mortar compressive strength of 42 MPa was still achievable with replacement ratio of 50%. (d) The rapid indicator method implemented in this study (i.e., using pH

and passing sieve #325) can be used to assess the quality of fly ash and to estimate the 1

resulting properties

when high volumes of fly ash is mixed in concrete. 6

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