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MORPHOLOGICAL AND PROPERTIES OF PORTLAND-COMPOSITE CEMENTS WITH CLASS C FLY ASH

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Abstract

Portland-composite cements (PCC) were prepared with partial substitution of 5 to 25% of class C fly ash, obtained from East Java steam power plant. Properties of the composite cements was evaluated, through the setting time (initial and final) and compressive strength (3, 7, and 28 days) compared with control PCC. Setting time is retarded in Portland-composite cements with higher fly ash content. The retardation is highest in PCC with substitution of 25% fly ash. Lower compressive strength was obtained after 3 and 7 days of curing for PCC with 5-25% fly ash substitution in comparison with control cement, since pozzolanic reaction still did not show its effect. After 28 days, compressive strength was higher than that for control cement because pozzolanic reaction show its effect, highlighted by compressive strength increase of PCC substituted by 5% and 10% fly ash, 16.48 MPa and 16.52 MPa, respectively. This attributed to the differences in the pozzolanic activity of the applied fly ash. The results of observations using SEM showed that PCC with 10% fly ash substitution had more Tobermorite content than the control cement. This indicates that the compressive stress increases with increase in percentage of fly ash.

Keywords: Portland-Composite Cements, Class-C Fly Ash, Retardation, Compressive Strength, Tobermorite

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1. Introduction

Infrastructure development in Indonesia is increasing to support the industrial construction and the progress of the country. This means that the requirement for building materials, such as cement and admixture has increased. Portland-composite cement (PCC) is a type of hydraulic cement that hardens due to its combination with water and hydration reaction. This type of cement is made from a combination of hydraulic lime and clay and plays a very important role in the construction industry. The compound mainly consists of silica, alumina, calcium oxide and iron oxide. When cement is mixed with water it will form a mixture called paste.

Cement has negative effect on global warming and generates carbon footprint[1-3]. Hence, partial substitution material is needed. Fly ash, one of the wastes generated from coal-fired power plants is very abundant. It can be used as a mixture of cement paste to reduce industrial waste in power plants since fly ash has similar oxide contents to Portland cement[4,5]. These materials now can be widely applicable in Indonesia since Government regulation (PP No. 22 Tahun 2021) states that fly ash and bottom ash (FABA) is no longer categorized as dangerous toxic material (B3). The coal ash yield of power plants is about 550 tons per day.

Fly ash is very dangerous if disposed openly. It can cause pollution since fly ash contains several heavy metal elements such as arsenic, vanadium, antimony, boron and chromium[6,7]. To prevent the by-product material from contaminating the environment is to use the material as a partial replacement for cement in construction material such as concrete[8]. Another way is to utilize fly ash as zero cement material called Geopolymer[9].

Currently, in East Java, fly ash is a by-product of steam power plant that uses coal as fuel for power generation in the form of light, round, and fine grains. Fly ash is categorized as pozzolanic material, means a silica and alumina rich material which chemically reacts with calcium hydroxide at ordinary temperatures to form cementitious compounds[10]. This means fly ash can be a good mineral admixture material cement substitution to increase the compressive strength[11].

The main objective of this study was to investigate the substitution of PCC with class C fly ash to the setting time, compressive strength, and morphological of mortar by using Scanning Electron Microscope (SEM), thus enhancing some properties of mortar while serving as a method of utilizing the

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fly ash.

2. Experimental and Procedures

2.1 Materials

Portland Cement Composite (PCC) was used for binding material conformed to SNI 7064-2014. Fly ash was obtained from East Java steam power plant. Tap water for mixing was obtained from Sukamahi, Deltamas, Indonesia.

2.2 Experiment

Six mortar mixes were prepared according to Table 1. In all mixes, PCC was used and substituted by 5-25% fly ash. The water/cement (w/c) ratio was kept at 0.5.

Table 1. Mix design in this study

No	Code	PCC (%)	Fly ash (%)
1	FA-0	100	0
2	FA-5	95	5
3	FA-10	90	10
4	FA-15	85	15
5	FA-20	80	20
6	FA-25	75	25

note:
FA = fly ash content in mixture

The manufacture of aforementioned mixture was conducted in Laboratory of Metallurgical and Heat Treatment, Institut Teknologi Sains Bandung. Setting time test was conducted using vicat apparatus according to ASTM C191 “Standard Test Methods for time of Setting of Hydraulic Cement by Vicat Needle”[12]. The mixture of PCC, fly ash, and water was casted into 50x50x50 mm^3 cubical mold used to test the compressive strength of mortars. This test used an Iber Test Machine with a capacity of 100 tons at the Center for Infrastructure and Built Environment (CIBE), Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung. Compressive strength was measured at 3, 7, and 28 days according to ASTM C109 “Compressive Strength of Hydraulic Cement Mortars using 2-in. or [50-mm] Cube Specimens” [13]. Debris from compression testing was collected for characterization using Scanning Electron Microscope (SEM). This was conducted with purpose to study the morphological of PCC specimens substituted with fly ash. To show the oxide composition of PCC and fly ash, X-Ray Fluorescence (XRF) was conducted using EDAX instrument. Both characterizations were conducted at Center of Advanced Sciences (CAS), Institut Teknologi Bandung.

3. Results and Discussion

3.1 XRF analysis

XRF was conducted not only to determine the oxide composition of PCC and fly ash, but also to categorize the class of the latter. Characterization results were presented in Table 2.

Table 2. Oxide composition of PCC and fly ash using XRF method

No	Oxide	PCC (%)	Fly ash (%)
1	Na_2O	0.21	10.44
2	MgO	1.84	1.79
3	Al_2O_3	4.74	10.91
4	SiO_2	20.60	44.04
5	K_2O	0.38	1.38
6	CaO	64.82	18.72
7	Fe_2O_3	3.28	12.84

According to ASTM C618 “Composition requirement for fly ash classes”[14], fly ash used in this study can be categorized as class-C, since the calculated SiO_2+Al_2O_3+Fe_2O_3 percentage are 67.79%, which meets the minimum 50% requirement.

3.2 Setting Time

The results of the setting time test in accordance to ASTM C191 can be seen in Table 3 and Fig. 1. Based on the results of the test experiment, substitution of PCC with fly ash delay both the initial and final setting time of specimens. Fly ash as pozzolanic materials tends to give the retardation effect to cement paste mixtures, shown by the required penetration time is longer than the duration of the PCC control mixture. Fly ash causes the cement to be susceptible to acid which can delay the hydration rate[15-17]. Several research also has studied the effect of chemical admixture to setting time[18,19].

Table 3. Initial and final set of PCC specimens with class C fly ash substitution

No	Code	Initial set (min)	Final set (min)
1	FA-0	135	255
2	FA-5	180	300
3	FA-10	195	405
4	FA-15	195	405
5	FA-20	285	465
6	FA-25	315	480

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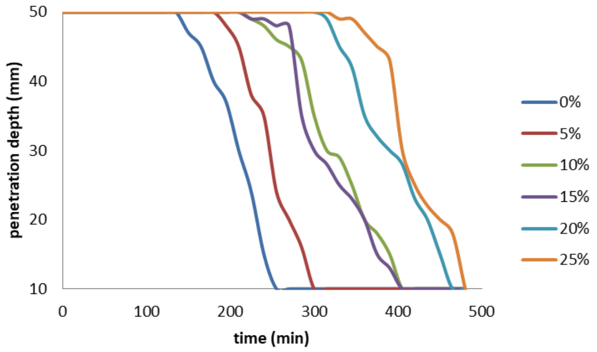

Fig. 1. Setting time of mortar with addition of new and used engine oil

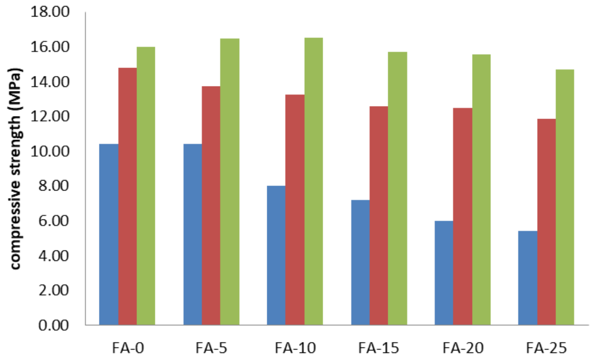

Fig. 2. Compressive strength of PCC specimens with class-C fly ash as substitution material

The retardation effect is due to lack of CaO content in fly ash (18.72%) compared to PCC (64.82%), which contributes to the hydration of cement. This effect is useful since Indonesia is a tropical climate country that has average temperature of 25-28°C, with some cities day temperature can be as high as 38°C. The hot temperature can be a problem for construction in mid-day since the water will evaporates quicker which leads to incomplete hydration and as the results, the compressive strength will be different from originally planned by mix design calculation.

3.3 Compressive Strength

The resulting compressive strength of specimens at 3, 7, and 28 days with fly ash as substitution material were represented at Table 4 and Figure 2. Fly ash content as substitution material in PCC specimens has decreasing effect at 3 and 7 days. This property means that cement can be substituted with a high proportion of fly ash only when the early compressive strength is not required [20].

Table 4. Compressive strength of mortar with addition of new and used engine oil

No	Code	Fly ash (%)	Compressive strength, σ_c (MPa)		
			3 days	7 days	28 days
1	FA-0	0	10.40	14.80	16.00
2	FA-5	5	10.40	13.72	16.48
3	FA-10	10	8.00	13.26	16.52
4	FA-15	15	7.20	12.60	15.72
5	FA-20	20	6.00	12.50	15.56
6	FA-25	25	5.40	11.88	14.68

The decrease in compressive strength is due to pozzolanic reaction still not occur at both of age. At 28 days of age, 5% and 10% of fly ash substitution to PCC can increase the compressive strength of specimens. This is due to pozzolanic reaction shown its effect. Class-C fly ash has smaller particle size compared to PCC, which means the fly ash filled the micropores left by PCC particles, resulting in denser material and explains the increase in compressive strength. Subsequent addition of fly ash above 10% decrease the compressive strength of specimens, because the lack of CaO in fly ash means the hydration will be disrupted and the compressive strength will be lower than specimens with fly ash content ≤10%.

3.4 SEM Images

Fig. 3 and 4 represents the SEM Images of FA-0 and FA-10 at 28 days of age, respectively. The characterization was conducted to explain the difference in compressive strength.

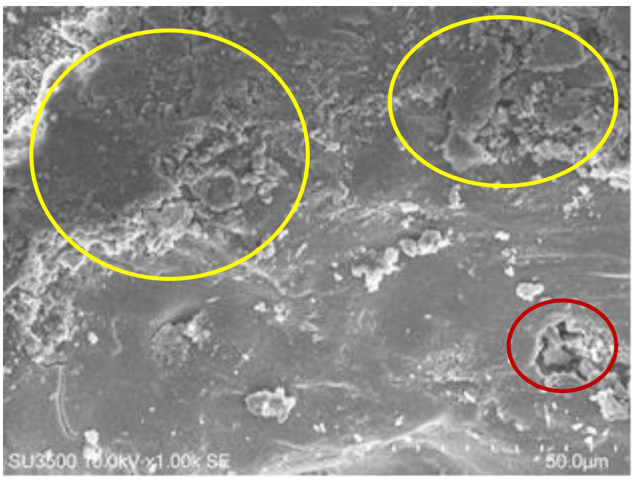

Fig. 3. SEM images of FA-0 (magnification 1000x). Yellow circle marks the tobermorite/calcium silicate hydrate (C-S-H) formation

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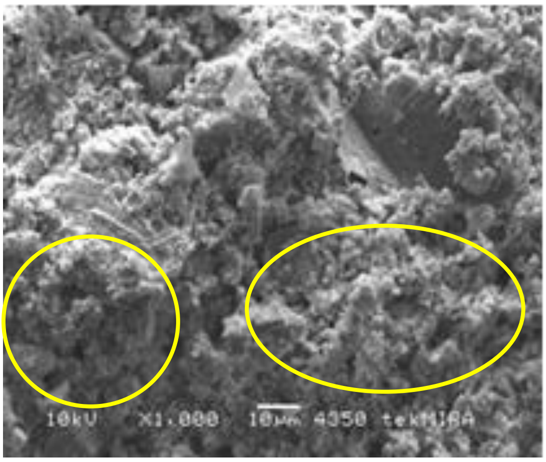

Fig. 4. SEM Images of FA-10 (Magnification 1000X). Yellow circle marks the tobermorite formation

Fig. 3 shown the SEM image from PCC without fly ash substitution (FA-0). It shows there are micropores that has ±10μm diameter, marked by dark red circle. This defect explains why it has lower compressive strength than PCC samples with 10% fly ash substitution (FA-10). Fly ash were used to cover these micropores, which make the specimens more compact and denser, allows it to withstand larger force compared to specimens without fly ash. The increase of compressive strength value of FA-10 is due to increase in tobermorite formation shown in Fig. 4 as a cluster of agglomeration. Tobermorite ($Ca_5Si_6O_{16}(OH)_2{\cdot}4H_2O$) is a compound resulted from the reaction of CaO and SiO_2 in cement with water (H_2O), or commonly referred as hydration. This compound has major role in compressive strength of cement-based material [21]. Several research also add supplementary material to increase the C-S-H formation[22,23].

4. Conclusions

From this study, it can be concluded that class-C fly ash tends to prolong the setting time on PCC specimens, which can be useful as retarder chemical admixture when used at tropical climate country such as Indonesia. There was a difference at compressive strength development of PCC specimens with class-C fly ash as substitution material at 3, 7, and 28 days of age in terms of compressive strength development. Compressive strength of specimens at 3 dan 7 days was decreased when 5-25% fly ash used as substitution of PCC. Fly ash content up to 10% in specimens at 28 days has the increasing effect of compressive strength due to pozzolanic reaction shown its effect. SEM characterization shows that fly ash content in PCC specimens increase the tobermorite compound compared to PCC without fly ash substitution.

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