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Physico-Chemical Characterization of Fly Ash

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ABSTRACT

The demand of using local fly ash is growing rapidly in Indonesian cement industries. The quality of fly ash plays an important role to ensure since the quality of coal used is not uniform. Basically, good and fewer qualities of coal are mixed together in the field. Twelve representative samples of fly ash produced by five Indonesian power plants were collected from site and cement industries. All samples are class F fly ashes with good pozzolanic characteristics according to the standard. The samples were examined for their physical, mechanical and chemical properties with compression test. Mortar samples were made from each fly ash sample according to ASTM C 311. Their strength activity was examined at 7 and 28 days. The results showed that both physical and chemical properties of fly ash influenced the mechanical properties of mortars containing fly ash.

1. INTRODUCTION

In the cement industry in Indonesia, fly ash from the power plant is used as a mixture in Portland Pozzolan Cement (PPC). In general, fly ashes in Indonesia are classified as class F fly ash according to ASTM C618. However, the quality of the cement produced is highly dependent upon the quality of the fly ash used. Characterization of fly ash is needed to map and to ensure the quality of the cement produced. Currently, fly ash particles were characterized based upon fineness since the particle size distribution significantly affects the ash's reactivity (Jimenez and Palomo 2003). In contrast, the properties of fly ash is not only determined by the physical

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properties but also the source of coal, mineralogy, coal burning conditions, method of collecting fly ash, deposit duration and the sampling period.

Physical properties of fly ash are determined by the density, fineness, the surface area and particle distribution to identify the reactivity of fly ash with cement. The finer the particle size, the higher the reaction during the process of hydration in concrete to increase concrete performance. Chemical properties of fly ash are determined from its chemical composition, types of minerals and amorphous phases in fly ash. Physical and chemical properties are related to the mechanical properties of mortar or concrete containing fly ash as a cement substitute. The better the quality of fly ash, the higher the strength activity of concrete generated.

This study referred to ASTM C311 for analyzing mechanical properties of mortar at seven days and 28 days. According to the standard, the principal method for determining fly ash for use as a pozzolan in the concrete mixture is the strength activity index (SAI). In this research, sources of fly ashes were taken from five power plants in Indonesia. A total of twelve flay ash samples were analyzed to obtain the relationship between their mechanical and physico-chemical properties. Furthermore, this paper reports the findings regarding the influence of particle size and mineralogy of fly ash on the strength activity index of mortar.

2. MATERIALS

Five power plants in Indonesia where the fly ash samples collected are Suralaya, Tjiwi Kimia, PJB, IPMOMI and Jepara. Twelve fly ash samples were individually collected at different times in 2011 and 2012. The binders were made from a mixture of cement and fly ash. The cement used has a density of 3.1 g/cm^3 was the type I from PT. Semen Indonesia. Non-shrinkage fine aggregate was river sand with a specific gravity of 2.67 g/cm^3.

3. METHODS

3.1 Strength Activity Index (SAI)

Mortars were made based on the composition according to ASTM C311. Each fly ash was coded from No. 1 to 12. In the mortar samples, fly ash replaced 20% of the weight of Portland cement. Mortar mixture consisted of 400 g of Portland cement, fly ash of 100 g, 1375 g of sand and 45% of water to cement ratio. Control mixture was made of non-fly ash mortar. Cylindrical mortar specimens were prepared for meeting Strength Activity Index (SAI) with Portland cement at the age of 7 and 28 days. The size of all specimens was 5 cm in diameter and 10 cm in height. All specimens were cured in water after remolding and submitted to compressive test at specific age. SAI with Portland cement was calculated according to ASTM C311 as follows:

$$SAI = \left(\frac{A}{B}\right) \times 100 \tag{1}$$

Where:

A = average compressive strength of test mortars containing fly ash (MPa)

B = average compressive strength of control mortars (MPa)

There were three methods modified from ASTM C311 as follows:

a) Method I: non-sieved fly ash of each was used for making cube mortars. The compressive strength test was conducted at the age of seven days.
b) Method II: non-sieved fly ash of each was used for making cube mortars. The test for compressive strength was conducted at the age of 28 days.
c) Method III: sieved fly ash having particle size less than 75 mm was used for making cube mortars. The compression test was conducted at the age of seven days.

The average of Strength Activity Index (SAI Average) of three methods were then determined.

3.2 Physical and Chemical Characterization

Testing to determine the specific gravity, particle size distribution and specific surface area of each fly ash were conducted for physical characterization. XRD and wet method were used for mineralogy and chemical characterization. Global amorphous of fly ash was analyzed based on the mineral components (mullite, quartz, hematite, magnetite, etc.).

4. RESULTS AND DISCUSSIONS

4.1 Results of Strength Activity Index (SAI)

SAI of each method was analyzed for each mortar. The average of SAI and rank of specimens were listed in Table 1. The average of SAI range between 0.87 and 1.18. It is well known that incorporating fly ash in mortar dissuade a considerable increase in compressive strength up to 28 days due to slow pozzolanic activity (Remond *at al*. 2002). In general, sieved fly ash used in the Method III increases the compressive strength of mortar. Denser pore structures to generate mortar strength at the early age are contributed by finer particles (Zeng *et al*. 2012). Fig. 1 represents the results of SAI and the rank of specimens according to the average of SAI.

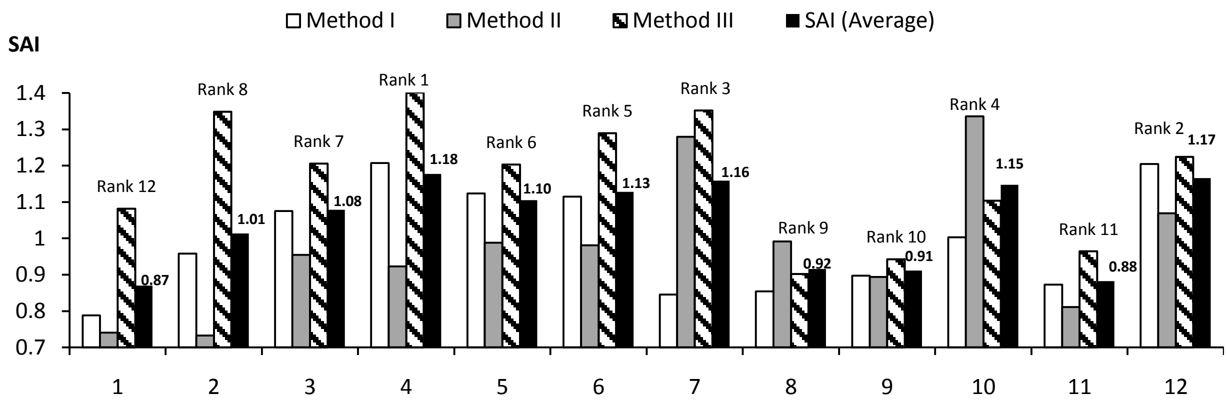


Fig. 1 Strength Activity Index of Specimens

Table 1 SAI of specimens

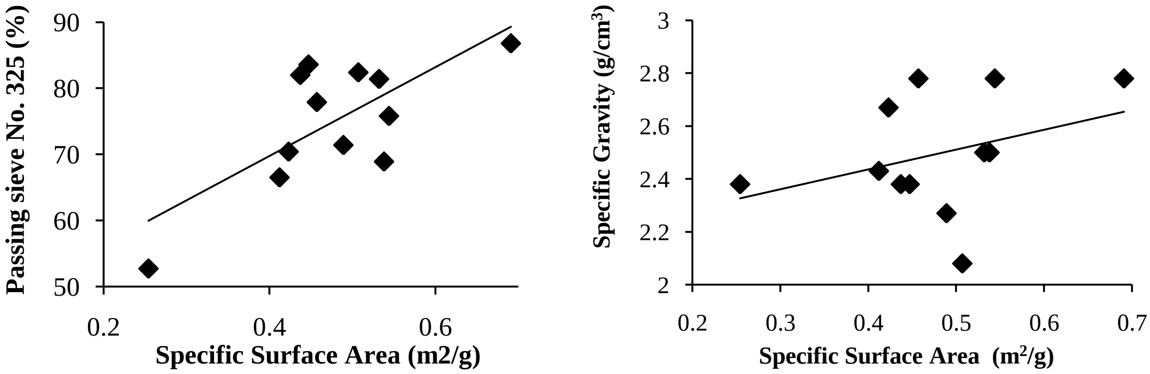
Specimen Code	Method I		Method II		Method III		SAI (Average)	SAI Rank
	fc' (1)	SAI	fc' (2)	SAI	fc' (3)	SAI		
1	21.6	0.79	26.6	0.74	29.64	0.97	0.87	12
2	26.3	0.96	26.3	0.73	36.94	1.15	1.01	8
3	29.5	1.08	34.3	0.95	33.04	1.16	1.08	7
4	33.1	1.21	33.1	0.92	38.39	1.29	1.18	1
5	30.8	1.12	35.5	0.99	32.95	1.18	1.10	6
6	30.6	1.11	35.2	0.98	35.33	1.22	1.13	5
7	23.2	0.85	45.9	1.28	37.03	1.26	1.16	3
8	23.4	0.85	35.6	0.99	24.71	0.95	0.92	9
9	24.6	0.90	32.1	0.89	25.82	0.96	0.91	10
10	27.5	1.00	48.0	1.34	30.23	1.18	1.15	4
11	23.9	0.87	29.1	0.81	26.41	0.94	0.88	11
12	33.0	1.20	38.4	1.07	33.55	1.23	1.17	2

4.2 The Effect of Physical Properties on SAI

Table 2 Physical properties of fly ash

Code of fly ash	No.325 sieve	Specific gravity	Specific Surface Area
	% weight	g/cm^3	m^2/g
1	52.7	2.38	0.254
2	68.9	2.5	0.538
3	86.8	2.78	0.691
4	70.4	2.67	0.423
5	77.9	2.78	0.457
6	75.8	2.78	0.544
7	81.4	2.5	0.532
8	82.4	2.08	0.507
9	82	2.38	0.437
10	66.5	2.43	0.412
11	83.6	2.38	0.447
12	71.4	2.27	0.489

Table 2 shows the result of physical characterization. Specific gravity of all specimens varies from 2.0 to 2.78 g/cm^3. With regard to the fineness determination of fly ash, two approaches were used: (1) Amount of particles smaller than than 45 μm and (2) specific surface are determination. The first one was analyzed with the amount of the fly ash sample passed when wet-sieved on a no 325 sieve (45 μm). Sample No.1 is the coarsest as compared to others. The relation two approaches are given in Fig. 2a and Fig. 2b. It is verified that smaller particles of the ashes contribute higher surface area. Moreover, specific gravity increased as the particle size decreased.



(a) Relation of surface area and particle size less than 45μm

(b) Relation of surface area and specific gravity

Fig. 2 Physical properties of fly ash

The physical characterization consisted fundamentally particle size distribution was conducted with laser diffraction method. The range of granulometrical analysis was between 3 μm and 100 μm although coarser particles may exist. The distribution of particle size plays the important role in the reactivity of fly ash. Fig. 3 and Fig. 4 show the granulometry distribution. Except sampel no. 1, the majority of particle sizes (75%) were distributed smaller than 45 μm with 20% of the particles at less than 5 μm. In general, diameter at 90% distribution is less than 100 μm. According to these results, sample no. 1 presents the greatest particles while smallest particles for the most part were contained in sample no. 3.

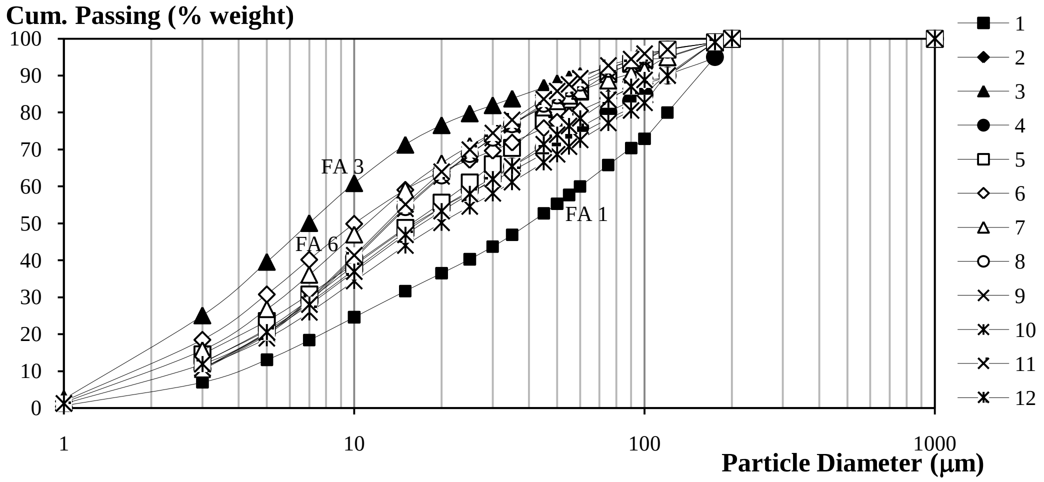


Fig. 3 Cummulative of particle distribution

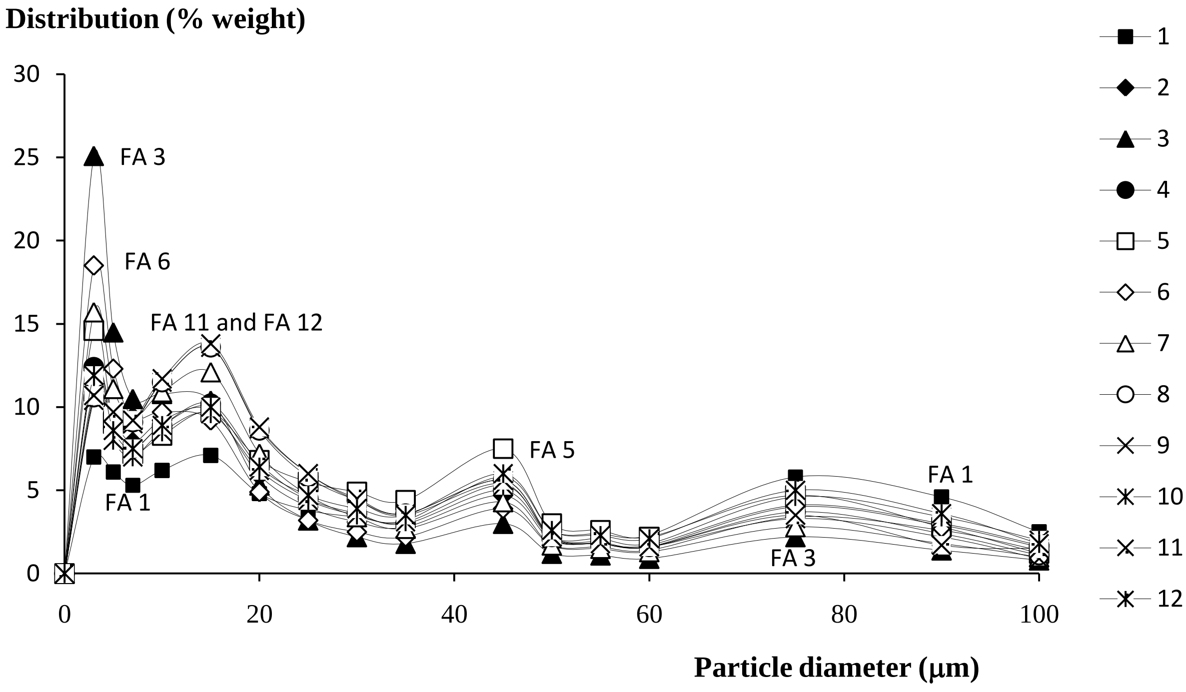


Fig. 4 Granulometry distribution of fly ash

In Fig. 5 the relation of physical properties of fly ash and SAI of mortar is presented. In Fig. 5a and Fig. 5c, it is illustrated that the specific gravity and the total weight of particles having a diameter up to 45 μm has less influence to SAI. However, smaller particle size leads the increase of SAI (see Fig. 5b). The fine particles in fly ash approximately smaller than 5 μm play an important role in the hydration process at the early age of mortar because of their large active surface area (see Fig. 5d).

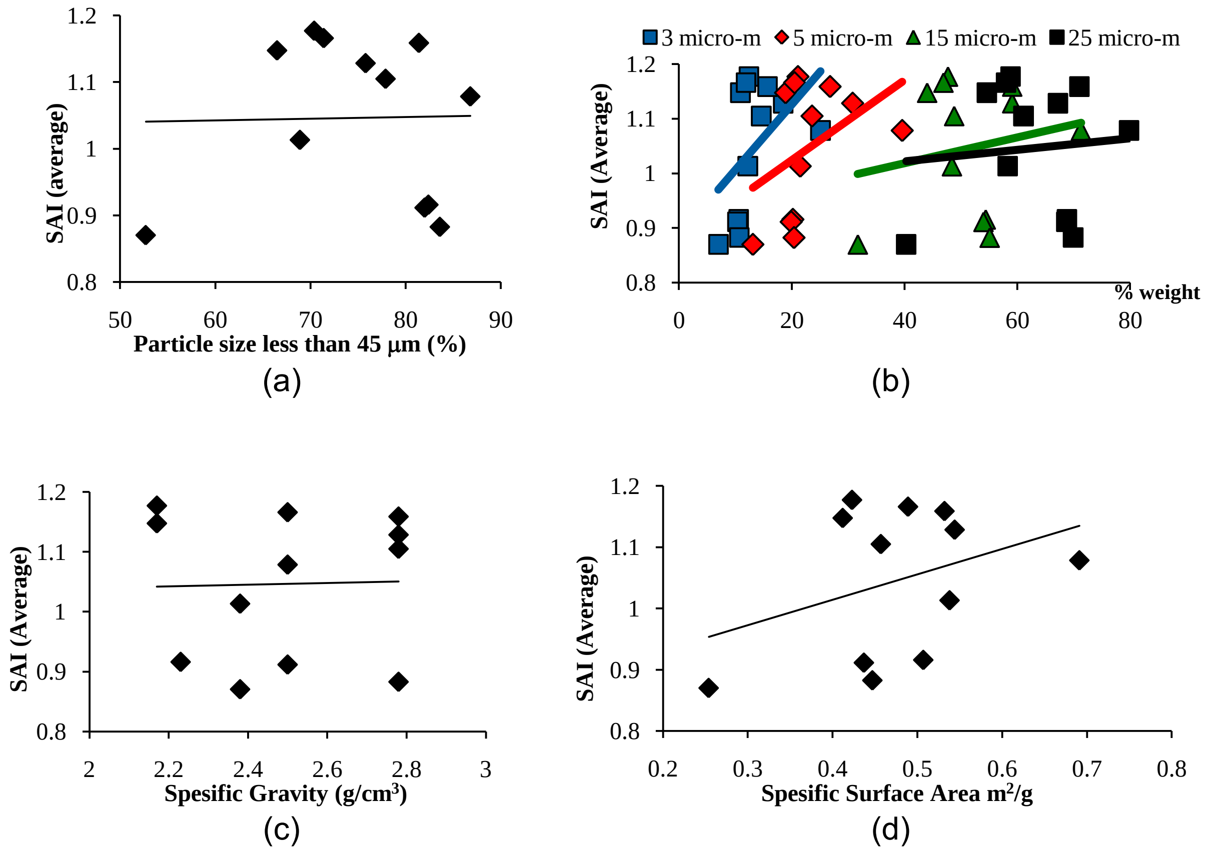


Fig. 5 The relation of physical properties and SAI

4.2 The Effect of Chemical Composition

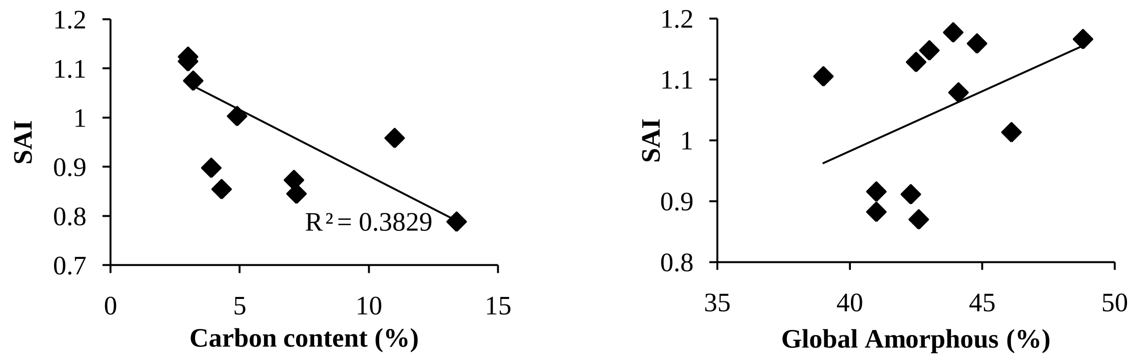
Chemical composition and global amorphous of fly ash samples were listed in Table 3. All samples are classified as class F fly ash according to ASTM C618. Moreno *et al.* (2005) investigated that chemical composition is enabled for fly ash characterization based on the content of the oxides. The quality of fly ash is related to the amorphous of the mineral composition.

In general, low carbon fly ashes are required and limited up to 6% or allowable up to 12% for certain circumstances. In this research, carbon content was determined in size fraction less than 75 µm (mesh no 200). Foner et al. (1998) reported that fly ash having particle size at 75-100 µm contains 4% of carbon. Smaller size fractions have lesser carbon content. Lesser carbon content in fly ash increases SAI of mortar.

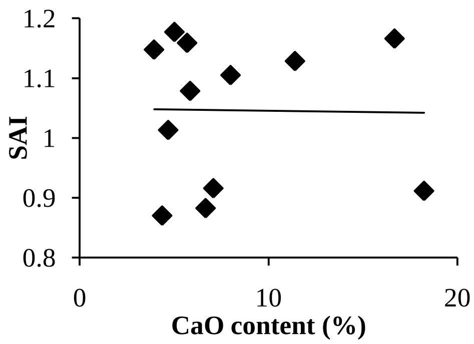
Table 3 Chemical composition of fly ashes

Code of fly ash	SiO_2	Al_2O_3	Fe_2O_3	SO_3	$SiO_2 + Al_2O_3 + Fe_2O_3$	CaO	Carbon	Global amorphous
1	48	28.28	12.3	0.59	88.58	4.37	9.4	42.6
2	50.18	26.16	11.9	0.53	88.24	4.69	11	46.1
3	48.36	16.75	22.15	0.57	87.26	5.85	3.2	44.1
4	51.62	24.68	11.4	0.48	87.7	5.02	5.1	43.9
5	43.52	26.5	14.88	0.25	84.9	7.99	3	39
6	38.58	20.06	9.45	1.28	68.09	11.4	3	42.5
7	49.68	22.18	15	0.5	91.19	5.69	7.2	44.8
8	47.74	22	16.8	0.61	88.94	7.08	4.3	41
9	38.56	16.82	17.3	0.9	74.34	18.23	3.9	42.3
10	52.62	27.1	11.4	0.01	91.12	3.94	4.9	43
11	48.14	33.6	8.8	0.41	90.54	6.67	7.1	41
12	37.22	24.9	11.6	0.39	73.72	16.67	3	48.8

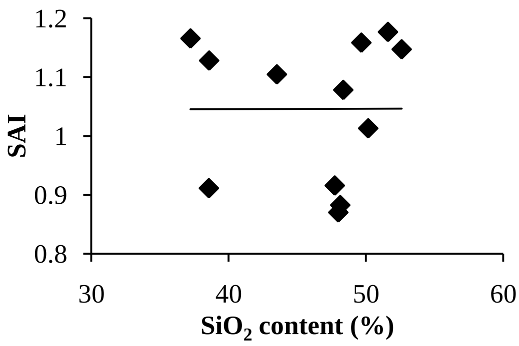
It is shown in Fig. 6a and Fig. 6b that carbon content in fly ash and global amorphous of mineral in fly ash influence the strength of mortar. SAI is rather independent on calcium and silica content (see Fig. 6c and Fig. 6d). The minimum of 70% by fly ash weight containing the total amount of SiO_2, Al_2O_3 and Fe_2O_3 is the requirement of class F fly ash as a pozzolan. However, the representation of fly ash reactivity is more influenced by the amorphous mineral than the oxides content. Silica content refers to crystalline and amorphous phase. Silica presents in amorphous form may increase the mechanical properties of mortar (Walker and Pavia 2011).



(a) (b)



(c)



(d)

Fig. 6 The relation of chemical properties and SAI

3. CONCLUSIONS

The physico-chemical and mineralogical characteristics of twelve fly ashes sample have been studied. The strength activity index (SAI) of mortars containing 20% fly ash as cement substitution has been determined. The results evidenced that SAI is influenced by the surface area, carbon content and the amorphous of mineral content in fly ash. SAI is independent of the oxides content in fly ash.

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