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Influence of the Character of Fly Ash on the Fluidity of Fly Ash Cement Paste

Seung Heun Lee† **and Etsuo Sakai***

Department of Materials Science and Engineering, Kunsan National University, Gunsan 573-701, Korea
**Department of Metallurgy and Ceramic Science, Graduate School, Tokyo Institute of Technology, Tokyo 152-8552, Japan*

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ABSTRACT

The Influence of the character of fly ash on the fluidity of cement paste with a polycarboxylic acid type superplasticizer was investigated in connection with the particle size distribution, unburned carbon content, specific surface area and shape of the fly ash. The fluidity of the fly ash cement paste with an added 20 vol% fly ash increases with an increasing roundness of the fly ash and it decreases with an increasing n-value of the fly ash cement. There is a linear correlation between the roundness/n-value and the fluidity of fly ash cement paste.

Key words : Fly ash, Cement paste, Fluidity, Roundness, n-value

1. Introduction

Quantitatively understanding the influences of physical and chemical factors on the fluidity of fly ash cement paste is very important for designing the materials of new high performance concrete or mineral admixtures. Therefore, quantitatively examining the effects of unburned carbon content, particle size distribution, and particle shape of fly ash on the fluidity of fly ash cement paste will provide the basic data for designing material for high performance concrete and mineral admixtures for concrete. Many researchers have reported that adding fly ash improves the fluidity of cement paste,1) but the fluidity of cement paste with the fly ash varies because even fly ash from the same coal-fired plant have different particle characteristics.2) Few clear analyses have been done on the effect of each factor. It has been reported that the improvement of fluidity from mixing with fly ash typically comes from the ball bearing effect of fly ash that have spherical particle.3) However, the actual observation of fly ash reveals that they contain substantial amount of particles that are aggregated or irregularly shaped which results in a large difference in the content of spherical particles depending on the kind of fly ash. In addition, the particle distribution of fly ash affects the packing density of cement paste, causing the retention water restrained by the particles to vary. A large packing density indicates that a large amount of retention water is involved in the cement paste, and the fluidity increases.4) What has been used as an index for evaluating fly ash is the unburned carbon in the fly ash, which adsorbs organic admixture thereby degrading the performance of the admixture.5)

This study examined the influences of each factor, namely, particle size distribution, particle shape, unburned carbon and fineness of the fly ash on the fluidity of cement paste with fly ash.

2. Experiment

2.1. Materials

The fly ash used in the experiment was from a coal-fired power plant: class-F fly ash that was collected from a hopper attached to an electrostatic precipitator after changing the burning conditions and types of bituminous coal. The type A series is the fly ash generated when the load of the boiler was 600 MW while A' series is the fly ash when the load of the boiler was 300 MW (at night) using the same type of coal used for A series. B series is the fly ash collected when different bituminous coal was used at the same load (600 MW) as A series. The electrostatic precipitator has a few hoppers in the direction of flue gas exhaustion. Fly ash collected from the hoppers closest to the inlet was named A-1, A'-1 and B-1. Fly ash collected from the second hoppers was named A-2, A'-2 and B-2. Finally, fly ash collected from the hoppers located at the outlet was named A-3, A'-3 and B-3. Ordinary Portland cement (Blaine specific surface area, 356 m^2/kg; specific gravity, 3.15) and polycarboxylic acid superplasticizer was used to prepare paste samples for measurement of apparent viscosity.

2.2. Measurement of physical and chemical properties of fly ashes

The measurement of roundness was done as follows; the

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†Corresponding author : Seung Heun Lee
E-mail : shlee@kunsan.ac.kr
Tel : +82-63-469-4733 Fax : +82-63-469-4731

Table 1. Physical and Chemical Properties of Fly Ash

Fly ash	Blaine (m^2/kg)	Unburned carbon content (wt%)	Loss on ignition (wt%)	$SiO_2+Al_2O_3$ (wt%)
A-1	276	0.7	1.1	88.6
A-2	418	0.8	1.2	87.5
A-3	736	0.3	1.7	85.9
A'-1	358	1.5	2.1	87.4
A'-2	498	1.3	2.1	86.3
A'-3	792	0.4	1.9	86.0
B-1	264	1.0	1.0	80.1
B-2	449	1.1	1.1	78.8
B-3	729	0.5	0.5	77.7

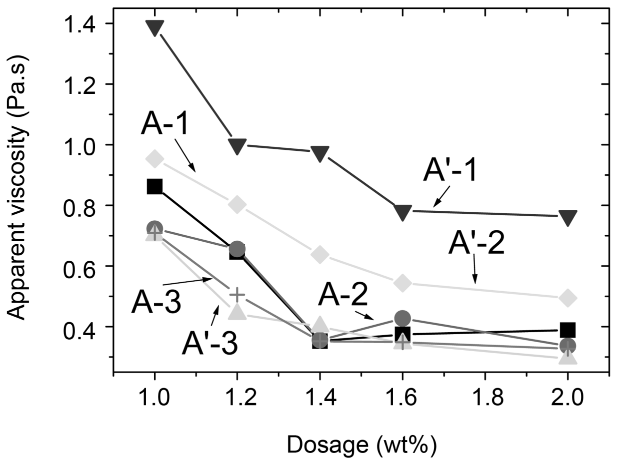

Fig. 1. The effect of the polycarboxylic acid superplasticizer on the apparent viscosity of fly ash cement paste.

distributed fly ash was observed with SEM (JEOL 5410, Japan), and then the LEICA Qwin32, an imaging processing program processed the SEM photographs to obtain the roundness of a particle according to equation (1).

$$\text{Roundness} = \text{Area}/\text{Perimeter}^2 \times 1.064 \qquad (1)$$

Where, perimeter is the projected perimeter of a particle, and 1.064 is the adjustment coefficient for perimeter. This value is a coefficient to decrease the edge effect resulting from the binary image. The particle size distribution for fly ash was measured with the laser diffraction method (Microtrak-9320HRA, USA). The measured particle size distribution was evaluated using an n-value of Rosin-Rammler function, which is represented in equation (2),

$$R(Dp) = 100\ \exp[-(Dp/De)^n] \qquad (2)$$

where R(Dp) is the cumulative percentage over size (%), Dp is the corresponding particle diameter (μm) and the parameter Dp is the constant related particle size. The exponent n is the constant indicating the width of distribution, where the smaller the n, the wider the width of distribution. Unburned carbon content (Horiuti Co., Chromatic C, Japan), loss on ignition and the Blaine value were measured as well. Table 1 represents the physical and chemical properties of fly ash.

2.3. Measurement of apparent viscosity

Fly ash was mixed with ordinary Portland cement in 20 vol% and the amount of polycarboxylic acid superplasticizer was 1.0~2.0 wt%. The sample was mixed with water at water/solid volume ratio of 0.9 for 3 min. The apparent viscosity of the pastes with fly ash was measured at 200 Pa after shear stress was changed up and down between 0 and 200 Pa at 20 °C using a rotary viscometer (Cordix, Germany). The inverse of the apparent viscosity was used as the fluidity value.

3. Results and Discussion

3.1. The effects from each factor of fly ash

Fig. 1 presents the variation of the apparent viscosity according to the content of the superplasticizer. Increasing the content of the superplasticizer tends to decrease the apparent viscosity up to a certain point at which adding a superplasticizer did not cause the apparent viscosity to decrease any more. A'-1 and A'-2 fly ash containing a large quantity of unburned carbon had greater apparent viscosity than other fly ash. For these fly ash, the content at which the apparent viscosity reached a saturation value was 1.6 wt%, while that of fly ashes containing less than 1.0 wt.% of unburned carbon content was 1.4 wt%. The relationship between the fluidity and the unburned carbon when 1.6 wt% of superplasticizer was added is shown in Fig. 2. Overall, no correlation was observed except that the B series with broad particle size distribution had large fluidity. For A-1 and A'-1, both of which were collected from the first hopper, n-values, roundness, and Blaine values were similar to each other, but the unburned carbon contents were different by as much as 0.8 wt%. However, the fluidity was similar. For A-1 and A-2, the unburned carbon contents were similar while A-2 had a larger fluidity of approximately 0.4 $Pa^{-1} \cdot s^{-1}$, which might be due to the large n-value and roundness of A-2.

There are two effects of the Blaine value of fly ash on the fluidity of cement paste with fly ash. One concerns the particle size and the number of contact points of the particle. The larger the Blaine value is, the larger the coordination number of the particle becomes, which increases the collision resistance and lowering the fluidity. The other effect is the opposite idea, adding fine fly ash can obtain dense packing density that cannot be obtained in particle size distribution of cement, and thereby increase the fluidity of cement paste by adding fly ash. In this experiment, however, the Blain vale and the fluidity exhibited no overall correlation.

Variation of the particle size distribution of the cement system will change the packing density, and result in a change in the fluidity of the cement paste. High packing density indicates a small amount of retention water con-

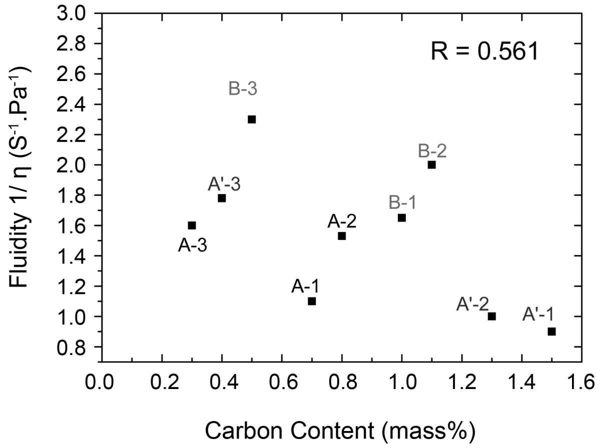

Fig. 2. The effect of the unburned carbon in fly ash on the fluidity of fly ash cement paste.

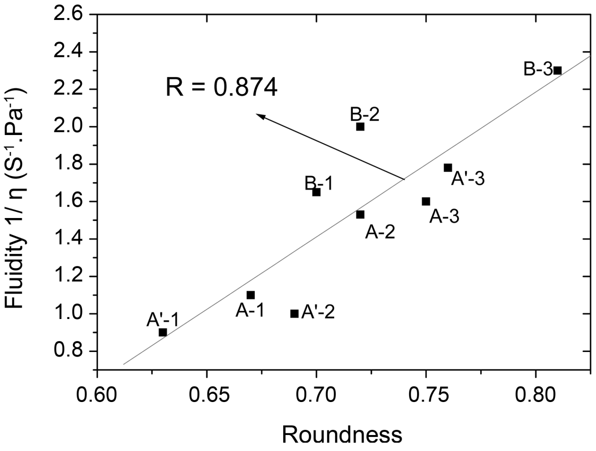

Fig. 4. Relationship between the roundness of fly ash and the fluidity of fly ash cement paste.

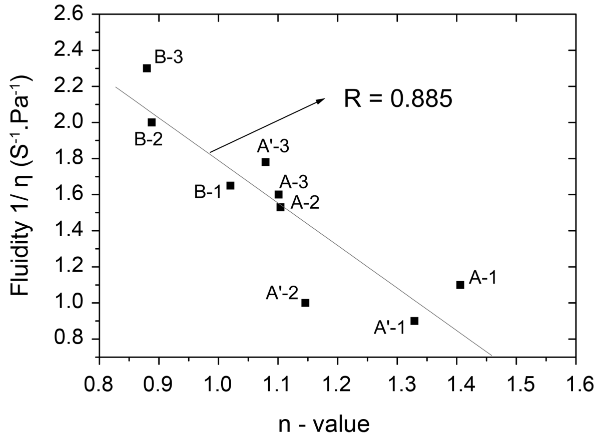

Fig. 3. Relationship between the n-value of fly ash cement and the fluidity of fly ash cement paste.

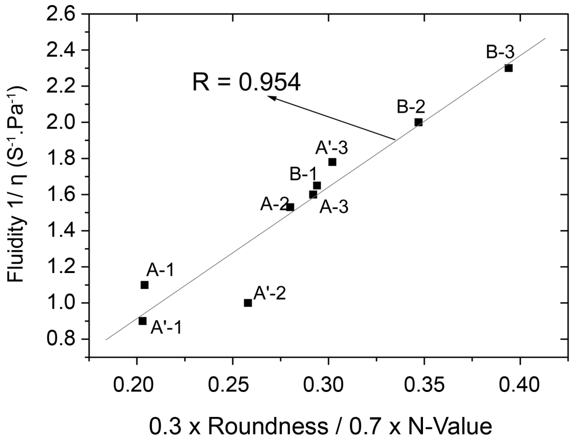

Fig. 5. Effect of the roundness/n-value of fly ash on the fluidity of fly ash cement paste.

strained in the aggregated particles, which in turn indicates a large amount of free water involved with the fluidity. In other words, the larger the packing density of fly ash particles is, the larger the fluidity becomes. The packing density of the powder is affected by particle size distribution, particle shape and the interaction between the particles. For particle size distribution, the broader the particle size distribution is, the higher the packing density becomes. The n-value of the Rosin-Rammler function is used as the index representing the breadth of the particle size distribution. The relationship between the n-value and the fluidity of fly ash cement paste is represented in Fig. 3. The fluidity of the paste increased with a smaller n-value, which is broader particle size distribution, although there might be deviation in some degree due to other factors such as the particle shape.

Adding inorganic powder with spherical particles improves the fluidity of the cement paste, which may result from the effect of improved packing density and the ball bearing effect. The relationship between the roundness of fly ash and the fluidity of fly ash cement paste is represented in Fig. 4. A larger roundness of fly ash was accompanied by larger fluidity of fly ash cement paste, but the B series with broad particle size distribution had a larger value than expected.

3.2. Evaluation of the fluidity of fly ash cement paste

In order to determine the contributions of the factors of fly ash to the fluidity of fly ash cement paste, a multiple regression analysis was performed. The Blaine value and the unburned carbon value were excluded from the analysis because a high correlation between independent variables could derive an incorrect formula of the multiple regression analysis. Since the Blaine value is involved in packing density by changing the particle size distribution of cement by mixing with cement and fly ashes, it was included in the n-value. The fly ash used for this experiment had an unburned carbon content of less than 1.6 wt%, and the superplasticizer added was also saturated. The effects from the shape and size of the unburned carbon particles were not considered as independent variables because they were already reflected in both the roundness and the n-value. The following equation was obtained as a result. The contributions of the n-value of fly ash cement and the roundness of fly ash were about 70% and about 30% respectively.

$$Y = 3.33X_1 - 1.84X_2 + 4.15 \ (R=0.912), \tag{3}$$

where Y is the fluidity of the fly ash cement paste with fly ash, X_1 is the roundness of the fly ash and X_2 is the n-value of the fly ash cement. Accordingly, (0.3 X roundness)/(0.7 X n-value) can be used as an index to evaluate the fluidity of fly ash cement paste when there is enough superplasticizer added and a small amount of unburned carbon content is present. The relationship between this value and the fluidity of the fly ash cement paste is represented in Fig. 5. A higher (roundness/n-value) is accompanied by an increased fluidity of fly ash cement paste, and shows a higher correlation than the individual case.

4. Conclusions

Examining the effects of the characters of fly ash on the fluidity of fly ash cement paste when the added superplasticizer is saturated using the fly ash collected directly from an electrostatic precipitator led to the following conclusions.

When the added superplasticizer was saturated, and the unburned carbon content of the fly ash was small, both the particle distribution of the fly ash cement and the roundness of the fly ash were greatest among the factors of fly ash that influence the fluidity of fly ash cement paste. The contributions of fly ash factors to the fluidity of fly ash cement paste obtained from the multiple regression analysis were about 70% for particle size distribution of the fly ash cement and about 30% for roundness of the fly ash. When there is enough superplasticizer added and small amount of unburned carbon content is present, the (0.3 X roundness)/(0.7 X n value) can be used as an index to evaluate the fluidity of fly ash cement paste with superplasticizer.

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