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EVALUATION OF SHRINKAGE AND DURABILITY OF GEOPOLYMER CONCRETE USING F-CLASS COAL ASHES

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This paper evaluates the strength, shrinkage and durability characteristics of concrete using 100% fly ash and bottom ash as binder. It is seen that the compressive strength of activated fly ash and bottom ash concrete reaches respectively 25 MPa and 30 MPa, and that the change in strength is insignificant as per the content of bottom ash powder. Moreover, the total amount of shrinkage of the activated bottom ash concrete appears to be larger than that of the activated fly ash concrete. In addition, the drying shrinkage and durable performance of the activated ash geopolymer concrete is verified to be superior to that of ordinary cement concrete.

Keywords: Geopolymer concrete, Fly ash, Bottom ash, Strength, Shrinkage, Durability.

1 INTRODUCTION

The construction industry has undertaken diversified research for reducing its consumption of cement in the fabrication of concrete in an effort to solve the environmental impact caused by the manufacture of cement. As part of these efforts, the industrial by-products of fly ash and blast furnace slag have received the most interest as substitutes for cement, in order to fabricate the so-called activated geopolymer concrete currently under review (Cheriaf *et al*. 1999, Jo *et al*. 2006, Zhao *et al*. 2007, Kang *et al.* 2011).

Most of the studies dedicated to geopolymer concrete using coal ash focus on fly ash. A comparison of the studies on the use of fly ash and bottom ash as binder shows that the results related to bottom ash reach merely 50% of those on concrete using fly ash as binder, even if the bottom ash is a by-product as rich in Si and Al as fly ash (Chindaprasirt *et al*. 2009). However, Ryu *et al.* (2013) reported that, contrary to the results of Slavik *et al.* (2008), remarkable mechanical compressive strength of about 60 MPa can be achieved according to the fineness of bottom ash milled physically, presenting a chemical composition similar to F-class fly ash.

This study will evaluate the strength and durability characteristics of alkali-activated concretes that are using fly ash and dry-type bottom ash that has gone through physical milling using a ball mill.

2 EXPERIMENTS

2.1 Materials

The fly ash and bottom ash used in this study are produced at the Hadong thermoelectric power plant in Korea. The bottom ash is milled using a vibrating mill. Table 1 arranges the physical and chemical properties of fly ash and bottom ash with respect to the fineness. The average grain size D_{50} of fly ash runs around 12.6 μm, and that of bottom ash is approximately 51.7 μm. Therefore, the average grain size D_{50} of bottom ash has been modified to 8.5 μm by physical milling to achieve a fineness slightly superior to fly ash, increasing its reactivity.

In this study, the alkali activator used as reagent for the activation of the coal ash is mixed one day before the tests. NaOH 9M, with purity higher than 98%, and sodium silicate (Na_2O = 10%, SiO_2 = 30%, solid content of 38.5%, density of 1.39 g/cm^3) are used, and maintained in a chemically-stable state.

The coarse aggregate is crushed stone presenting a specific gravity of 2.63 and maximum dimensions of 19 mm. Land sand with specific gravity of 2.63 is used as the fine aggregate.

Table 1. Physical and chemical properties of fly ash.

Ash type	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	K_2O (%)	Na_2O (%)	L.O.I	Density (g/cm^3)	Fineness (cm^2/g)	D_{50} (μm)
Raw FA	53.0	25.2	9.21	2.96	1.3	0.63	1.22	0.67	3.18	2.24	3,489	12.26
Raw BA	56.2	23.4	9.69	4.17	1.55	0.62	1.19	0.43	0.6	2.39	1,598	51.70
Milling BA	56.6	155	9.97	4.16	1.56	0.64	1.19	0.43	0.5	2.53	4,841	8.47

FA: fly ash, BA: bottom ash

2.2 Mix Composition, Curing and Testing Method

Table 2 arranges the mix composition adopted in this study. The mix composition corresponds to that of ordinary ready-mixed concrete with design strength of 30 MPa. Concrete is manufactured using a twin-shaft mixer with a capacity of 100 liters through dry mixing at 40 rpm for 2 minutes, followed by 3 minutes of mixing at 40 rpm after introducing water and alkali activator composed of NaOH and sodium silicate.

Table 2. Mix composition of concrete (unit: kg).

Type	Binder			W	NaOH 9M	Sodium silicate	Sand	Coarse aggregate
	Cement	FA	BA					
OPC	350		–	168	–	–	785.0	974.0
FA350	–	350		–	100	100	747.0	927.1
BA350	–		350	–	100	100	747.0	927.1
BA400	–		400	–	114	114	694.8	862.3

In order to prevent the evaporation of moisture following the temperature rise induced by the change in curing temperature after placing, the specimens are sealed in vinyl prior to high temperature curing at 60°C for 24 hours. Finally, stripping is performed.

Ordinary Portland Cement (OPC) concrete is also fabricated by curing at ambient temperature for further comparison with the fly ash and bottom ash-activated concretes.

A Universal Testing Machine (UTM) with capacity of 3,000 kN is used to conduct the compressive strength test. A shrinkage test is carried out on FA350 and BA350 in a constant temperature and humidity chamber at 23° ±3°C, and humidity of 50% ±5% after completion of high-temperature curing to evaluate the effect of shrinkage. In addition, a freeze-thaw resistance test is also conducted through freezing in water and thawing in air from –18°C to +4.5°C, to examine the durability of the fly ash and bottom ash-activated concretes.

3 TEST RESULTS AND DISCUSSION

3.1 Workability and Compressive Strength

Specimens FA350, BA350, BA400 and OPC exhibited satisfactory workability with respective slump of 240 mm, 260 mm, 238 mm, and 210 mm. The corresponding air content ranged between 2 to 3%. The reason for the larger slump of the specimens FA350, BA350, and BA400 using coal ash compared to OPC can be found in the smaller density of fly ash and bottom ash, which results in a volume ratio higher by 1.1 than cement and, in turn, in higher specific surface area.

Figure 1. Slump test.

Table 3 arranges the compressive strength test results. The compressive strength at 3 days and 28 days of the fly ash-activated concrete FA350 runs respectively around 25 MPa and 31 MPa. For the bottom ash activated concrete, these values are 26.3 MPa and 24.4 MPa, which correspond to approximately 86% of the compressive strength of FA350. Furthermore, the compressive strength at 3 days and 28 days of the bottom ash-activated concrete BA400 using 400 kg of powder runs respectively around 25.3 MPa and 27.2 MPa. This indicates that the quantity of binder has no significant effect on the compressive strength.

The maximum compressive strength of OPC concrete at 3 days remains at a level corresponding to about 60% of that at 28 days, whereas the coal ash-based concretes exhibit compressive strengths at 3 days comparable to those at 28 days. This shows that the coal ash-activated concrete develops high strength at early age, owing to the acceleration of polymerization induced by high temperature curing.

Table 3. Compressive strength test results (unit: MPa).

	OPC		FA350		BA350		BA400	
Age	**Test**	**Avg.**	**Test**	**Avg.**	**Test**	**Avg.**	**Test**	**Avg.**
	16.7		25.1		26.2		27.6	
3 days	14.7	15.9	25.4	25.1	26.6	26.3	20.7	25.3
	16.3		26.9		26.2		27.7	
	26.1		30.7		26.3		28.0	
28 days	24.9	25.1	30.0	30.7	23.7	24.4	26.6	27.2
	24.2		28.8		23.4		26.9	

3.2 Shrinkage Characteristics

Figure 2 plots the total amount of shrinkage according to the age of the fly ash, bottom ash and OPC concretes considered in this study. Figure 3 presents the amount of drying shrinkage for these concretes.

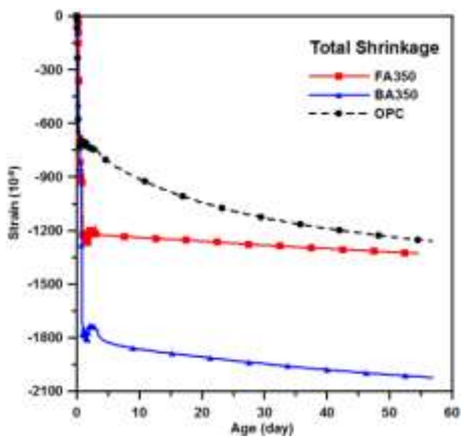

Figure 2. Total shrinkage.

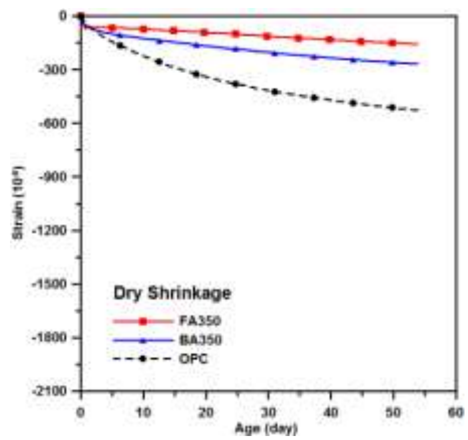

Figure 3. Drying shrinkage.

In Figure 2, the total amount of shrinkage of BA350, FA350 and OPC is respectively 2,023, 1,328 and 1,259, with the largest amount of shrinkage developed by the bottom ash-activated concrete, while the fly ash-activated concrete and OPC concrete exhibit a similar amount of shrinkage.

In Figure 3, the amount of drying shrinkage of BA350, FA350, and OPC is respectively 269, 158, and 527, with the largest value for OPC concrete. Specimen OPC underwent continuously drying shrinkage even after 28 days to reach approximately 500 μm. Besides, FA350 and BA350 presented shrinkage reaching respectively about 40% and 20% of that of OPC. Accordingly, the coal ash-activated concretes are seen to develop remarkable performance in terms of the drying shrinkage compared to ordinary cement concrete. Additional studies shall be implemented to control the autogenous shrinkage occurring at early high-temperature curing.

3.3 Resistance to freeze-thaw

Figure 4 shows the freeze-thaw test results. It can be seen that the coal ash-based concretes develop higher resistance to freeze-thaw than the OPC concrete. The corresponding freeze-thaw resistance index expressed in term of the relative dynamic modulus of elasticity appears to be 94%, 84%, and 79% for FA350, BA350 and OPC respectively.

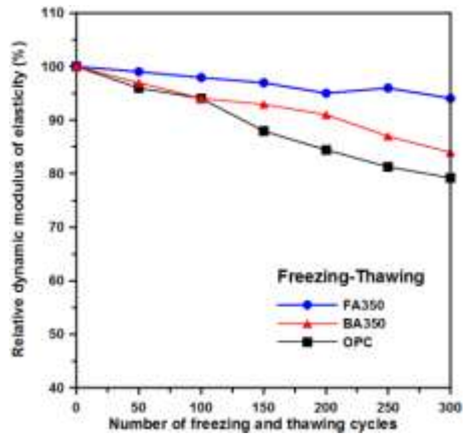

Figure 4. Resistance to freezing and thawing.

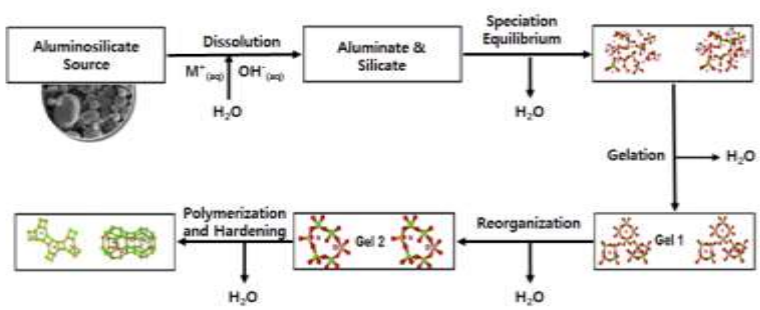

Figure 5. Reaction mechanism of fly and bottom ash-based geopolymers.

In general, the void fraction of OPC concrete decreases with higher strength characteristics, and reports indicate that the metakaolin-based geopolymer shows a similar trend. In addition, the coal ash-activated concrete exhibits concurrent increase of the void fraction with its strength. This phenomenon can be explained by polymerization, which is the hardening mechanism of the geopolymer due to coal ash rich in Al and Si (Figure 5). The better resistance to freeze-thaw of the coal ash-activated concrete compared to OPC concrete can be attributed to this polymerization, which make the micro-pores generated inside concrete absorb the expansion pressure of the water content.

4 CONCLUSION

This study carried out a series of tests on the compressive strength, drying shrinkage and resistance to freeze-thaw of activated concretes using fly ash and bottom ash as binder. The following conclusions can be drawn with regard to the durable characteristics of these concretes:

(1) The coal ash-activated concrete is featured by its early strength development, which within 3 days reaches more than 80% of its value at 28 days, due to the sudden occurrence of polymerization through high-temperature curing. The compressive strengths of the fly ash and bottom ash concretes are seen to be similar.

(2) Compared to ordinary Portland cement (OPC) concrete, the coal ash-activated concrete is verified to exhibit remarkable performance in term of drying shrinkage.

(3) The higher resistance to freeze-thaw of the coal ash-activated concrete compared to OPC concrete can be attributed to the generation of micro-pores during the polymerization, which absorb the expansion pressure of moisture provoked by freezing.

Acknowledgments

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