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Modeling of the Compressive Strength Development for Alkali Activated Slag(AAS) Concrete

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ABSTRACT

Recently, the cement industries brought very severe environment problems such as resource depletion and global warming with massive carbon dioxide emission during its production. The use of industrial by-products such as the ground granulated blast furnace slag(GGBFS) and fly ash as a mineral admixture has increased in order to resolve the environmental issues. Many attempts have been made to develop alkali activated slag(AAS) concrete using only ground granulated blast furnace slag with no cement. AAS concrete exhibits high strength development at room temperature; however, it is known to have a difficulty of securing work time due to the rapid fluidity loss and quick setting. In this study, the compressive strength and fluidity characteristics of high strength AAS concrete were investigated and modeling of compressive strength development were carried out to obtain fundamental data for the application of AAS concrete structural members.

1. INTRODUCTION

There are various influencing factors on a compressive strength of AAS concrete such as the type of alkali activator, W/B, and the amount of alkali activator.(Brough 2002) The previous studies investigated the characteristics of compressive strength and fluidity of AAS mortar or concrete taking into consideration of the factors.(Collins 1999, Oh 2013)

In this study, compressive test was carried out in order to examine the factors affecting the compressive strength of AAS concrete, such as the water-binder ratio (W/B = 0.35, 0.45), the unit water content (165, 185 kg/m^3), the amount of alkali activator (Na_2O), and the curing temperature (20, 60℃). Finally, the strength prediction model was proposed to estimate the compressive strength of AAS concrete at various age.

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2. EXPERIMENTAL WORK

2.1 Materials

Ground granulated blast furnace slag was used as a binder and its chemical composition and basic properties are shown in Table 1. In general, dissolved alkali or alkali salt is used as alkali activator for AAS concrete.(Wang 1994)

In this study, sodium hydroxide (density: 2.13 g/cm^2, purity: 98%) and sodium silicate solution (Na_2O = 9.29 %, SiO_2 = 28.8 %) were used as alkali activators, and polycarboxylate (PC) type of superplasticizer was used to secure the initial fluidity of AAS concrete.

2.2 Mix proportion

The amount of alkali activator, W/B, and unit water content were set as the AAS concrete mix variables, as shown in Table 2. Sodium silicate solution and sodium hydroxide were blended providing the modulus(mass ratio of SiO_2 to Na_2O, Ms) in solution, equal to 1.0 and 4, 6% Na_2O in mixture with slag.

2.3 Test methods

2.3.1 Slump & Air content

Slumps of AAS concrete were measured every 30 minutes after mixing. Air content of AAS concrete was measured using digital air content meter.

2.3.2 Compressive strength

Cylinders (Ø100x200mm) were prepared for compressive strength test of AAS concrete and the compressive strength was measured at the age of 1, 3, 7 and 28 days.

Table 1 Chemical composition of GGBFS

Material	SiO_2	Fe_2O	Al_2O_3	CaO	MgO	SO_3	K_2O	TiO_2	MnO	Density (g/cm^2)	fineness (cm^2/g)
GGBFS	33.7	0.11	13.8	44.04	5.20	1.23	0.48	0.74	0.24	2.90	4,253

Table 2 Mix proportion of AAS concrete

Mix	W/B	Unit weight (kg/m^3)				Activator		SP/Slag (%)
		Water	Slag	S	G	Na_2O/Slag (%)	Ms	
1	0.45	165	367	776	967	6 %	1.0	1.0 %
2	0.45	185	411	735	916	6 %		1.0 %
3	0.35	165	471	734	915	4 %		1.5 %
4	0.35	165	471	734	915	6 %		1.5 %
5	0.35	185	529	687	857	4 %		1.5 %
6	0.35	185	529	687	857	6 %		PC 1.5 %

3. Results & Discussions

3.1 Properties of fresh concrete

Securing the workability of AAS concrete is known to be difficult because of high viscosity and early rapid alkaline reaction. In this study, 150±25 mm of target slump and 4.5±1.5 % of air content were satisfied by adding PC-type of superplasicizer. It is found from the slump test by elapsed time that the slump has rapidly decreased after 30 minutes and the slump of AAs concrete with Na_2O = 6 % could not be measured after 60 minutes.

3.2 Compressive strength

Table 4 shows the compressive strength test results of AAS concretes. The compressive strength of AAS concrete with 6% of Na_2O reached 50 MPa at 7 days regardless of W/B.

The compressive strength at 7 days of AAS concrete with the unit water content (W) of 185 kg/m^3, is somewhat larger than that of AAS concrete with W = 165 kg/m^3. On the other hand, there is little difference in compressive strength at 28 days. It means that unit water content greatly influences on the early age compressive strength of high-strength AAS concrete.

At 60℃ of curing temperature, compressive strength in early age significantly increased. However, the development rate of compressive strength gradually decreased after 7 days.

Table 3 Slump & Air content of AAS concrete

Mix	Slump (mm)			Air content (%)
	Initial	30 min	60 min	
1	190	40	-	3.7
2	220	70	-	4.2
3	180	90	30	3.5
4	190	60	-	3.8
5	170	40	40	3.2
6	230	-	-	3.7

Table 4 Compressive strength of AAS concrete

Mix	Curing	Compressive strength (MPa)			
		1 day	3 days	7 days	28 days
1	20℃	21.9	34.7	49.2	61.2
	60℃	34.4	44.8	47.4	52.5
2	20℃	28.2	44.1	56.5	61.8
3	20℃	14.4	25.1	28.8	38.3
4	20℃	42.4	60.0	65.5	74.3
	60℃	56.8	59.7	62.3	69.6
5	20℃	19.2	37.3	40.7	44.9
6	20℃	43.2	58.1	67.0	72.9

3.3 Modeling of compressive strength development

Eurocode 2 (2004) suggests basic Eq. (1) for estimating the compressive strength development of concrete at age *t.* In this study, the compressive strength of AAS concrete at various age may be estimated by

$$f_{cm}(t) = \exp\left\{ s\left[1 - \left(\frac{28}{t} \right)^{1/2} \right] \right\} f_{cm} \tag{1}$$

where , $f_{cm}(t)$ is the mean concrete compressive strength at an age of t days

f_{cm} is the mean compressive strength at 28 days

t is the age of the concrete in days

s is a coefficient which represents the strength development rate.

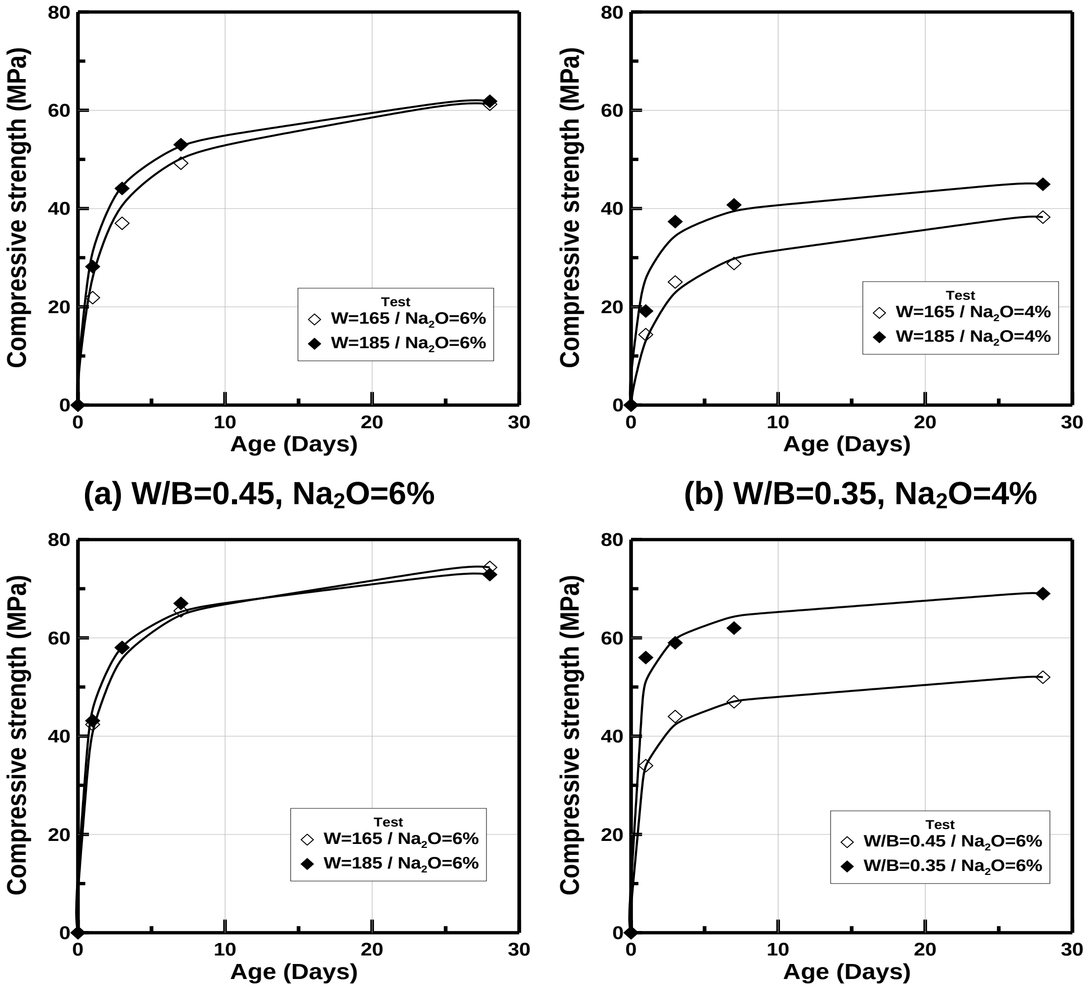
Table 5 shows *s* values for six types of AAS concrete, which were obtained by curve-fitting. When the amount of Na_2O increased from 4% to 6%, *s* decreased by 45% at W = 165 kg/cm^3 and by 16% at W = 185 kg/cm^3. For mix 1 and mix 4, *s* decreased by 30% at 20 ℃ of curing temp. and decreased by 50% at 60 ℃ of curing temp.

Eurocode 2 specifies the coefficient of *s* as 0.20, 0.25 and 0.38 depending on the type of cement, but in the case of AAS concrete, the coefficient *s* is generally lower than 0.20 except of mix 3(Na_2O=4%) because the rapid strength development occurs at early age due to the active alkaline reaction.

Fig. 1 shows the comparison between the predicted and experimental compressive strength results. The predictions using Eq. (1) showed good agreements with the experimental results. However, it is noted that the type of alkali activator which significantly affects on AAS concrete properties should be considered for the accurate prediction of concrete strength development for AAS concrete.(Kim 2012)

Table 5 Values of *s* for AAS concretes

Mix	W/B	W (kg/cm^3)	Na_2O (%)	s	
				20℃	60℃
1	0.45	165	6 %	0.20	0.10
2	0.45	185	6 %	0.16	-
3	0.35	165	4 %	0.25	-
4	0.35	165	6 %	0.14	0.07
5	0.35	185	4 %	0.13	-
6	0.35	185	6 %	0.11	-



(a) W/B=0.45, Na_2O=6% **(b) W/B=0.35, Na_2O=4%**

(c) W/B=0.35, Na_2O=6% **(d) Curing temp. at 60℃**

Fig. 4 Comparison of prediction value and test value

4. CONCLUSIONS

1) AAS concrete showed a rapid fluidity loss by elapsed time due to active alkaline reaction. The compressive strength development of AAS concrete were significantly dependent on the amount of Na_2O and curing temperature.

2) Compressive strength of AAS concrete at various ages could be estimated using an equation suggested in Eurocode 2. However, model equations of should be improved through the more experimental work taking into consideration of the factors such as alkali activator.

5. ACKNOWLEDGEMENT

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