

Strength Property of Cementless Geopolymer Concrete with Mixing Condition

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ABSTRACT: This study investigated the strength development of cementless geopolymer concrete, which used ground granulated blast furnace slag(GGBS) as a source material, based on the mix proportions for alkali activated(AA) mortar from previous research. Cementless geopolymer concrete exhibited excellent early strength development, and the strength was about 1.5 to 3 times higher than ordinary portland cement(OPC) at age 1 and 3days. As strength property with mixing condition, the compressive strength was higher as water-to-binder(W/B) ratio was lower. Although the early strength was higher as the value of alkali quality coefficient Q_A was higher, the relationship did not continue in the long-term age. The equation proposed from investigation of AA mortar was applied to cementless geopolymer concrete with a slight modification and without additional variable analysis process, and the compressive strength predicted by this modified equation at 28days corresponded well with experimental results.

Keywords: Cementless geopolymer concrete, Mixing condition, Strength property
Ground granulated blast furnace slag, Sodium silicate

1. INTRODUCTION

According to the proclamation of Kyoto Protocol in 2005, gases causing green-house effect such as carbon dioxide(CO_2) are to be reduced obligatory by collaborative efforts of advanced countries. The weather change caused by the green-house gas has become a serious threat to all nations of the world, and as Emission Trading the reduction of emission from green-house gas is connected

with economic problems as well as environmental problems.

Concrete has been used widely as main construction material for architectural and civil engineering structures for the past two centuries. However, cement which acts as the binder of the concrete, requires enormous energy consumption over $1300^\circ C$ and emissions great quantity of carbon dioxide, the mainly responsible for green-house effect. Thus, the concrete industry is aware of this problem and is trying to reduce

the quantity of cement for concrete. There have been active researches on alkali activated concrete^{1),2)}, which uses ground granulated blast furnace slag(GGBS) or fly ash(FA) as a substitute for cement.

Before investigating the concrete itself, alkali quality coefficient Q_A , was proposed as an indicator of the chemical composition of raw material and activator through a study of alkali activated(AA) mortar^{3),4)}. Then, neural network and multiple regression analysis were used to propose an evaluation model for initial flow of AAS mortar and compressive strength.

1) Alkali quality coefficient(Q_A)

$$Q_A = \left(\frac{Na_2O}{SiO_2} \cdot Al_2O_3 \cdot CaO \right) / B \quad (\text{by weight})$$

2) Initial flow

$$\frac{F_i}{F_0} = 6.5 \left[\frac{Q_A^{0.05} \times (S_A / S_{A0})^{0.3} \times (1 + S/B)^{0.5}}{(W/B)^{1.5}} \right]^{-0.85} \geq 1.0$$

3) 28-days compressive strength

$$\frac{(f_{ck})_{28}}{f_{c0}} = 148 \left[\frac{Q_A \times (S_A / S_{A0} + k_1)^{0.3}}{(W/B)} \right]^{1.23}$$

Where, S_A is blain fineness of source materials, S_{A0} is blain fineness assumed to be 4000cm²/g

$k_1 = (S/B)^{0.5}$ for $S/B \leq 2.5$ and $(S/B)^{-0.5}$ for $S/B > 2.5$.

4) The compressive strength at age t

$$f_{ck}(t) = \frac{t}{A_1 + B_1 t} (f_{ck})_{28}$$

$$A_1 = 0.39 \left[\frac{(W/B)^2 \times (1 + k_1)^{0.3}}{Q_A \times (S_A / S_{A0})^{0.1}} \right]^{0.66}$$

$$B_1 = 1.1 \left[\frac{(W/B)^2 \times (1 + k_1)^{0.3}}{Q_A \times (S_A / S_{A0})^{0.1}} \right]^{-0.09}$$

This study aims at investigating strength manifestation of cementless geopolymer concrete based on the mix proportions for cementless AA mortar from previous research. The equation proposed from investigation of AA mortar is applied to cementless geopolymer concrete with a slight modification and without additional variable analysis process, and the compressive strength predicted by this modified equation at 28days and ages are compared with experimental results.

2. CONCRETE MIX

2.1 Materials

GGBS is an industrial by-product obtained from process of producing iron in the furnace, and this experiment used three kinds of fine powder of domestically produced GGBS. Additionally, because GGBS has the property of latent hydraulic activity, added sodium silicate to activate for strength development. The chemical composition and physical properties of materials used in this experiment are shown in table 1.

Table 1 : The chemical composition and physical properties of materials

Materials	MgO	Al ₂ O ₃	SiO ₂	SO ₃	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃	Na ₂ O	LiO	*specific gravity	Blain fineness
GGBS	4.38	34.7	13.80	950.48	44.60	740.24	0.11	-	-	2.93	4204		
Sodium Silicate	-	-	45.7	-	-	-	-	-	-	50.3	4.0	-	-

* Loss on ignition.

2.2 Mix proportions

The quantity of sodium oxide(Na₂O), which directly affects the composition of sodium silicate, water-to-binder ratio(W/B), and fine aggregate ratio(S/A) were selected as the concrete variables through preliminary tests of mortar and concrete. Then, alkali quality coefficient Q_A , is predicted as shown in table 2 by the chemical composition of the materials.

Table 2 : Mixing details

Name	Source Materials (SM)	A/B	W/B (W/C) (%)	Na ₂ O /SM	S/A (%)	Alkali quality coefficient Q _A
C1	OPC	4	50	-	45	-
C2			55	-	45	-
G1	GGBS	4	40	0.12	40	0.020535
G2			40	0.12	45	0.020535
G3			50	0.12	40	0.020535
G4			50	0.12	45	0.020535
G5			55	0.12	40	0.020535
G6			55	0.12	45	0.020535
G7			50	0.18	40	0.025620
G8			50	0.18	45	0.025620
G9			55	0.18	40	0.025620
G10			55	0.18	45	0.025620
G11			60	0.22	40	0.025620
G12			60	0.22	45	0.025620
G13			55	0.22	40	0.027862
G14			55	0.22	45	0.027862
G15			60	0.22	40	0.027862
G16			60	0.22	45	0.027862

2.3 Test specimens casting and compressive strength test

Concrete is mixed forcefully in a mixer of 60ℓ capacity as shown in figure 1, and three cylindrical test specimens of $\varnothing 10 \text{ cm} \times 20 \text{ cm}$ size dimension are produced by each age in accordance with KS F 2403 and are cured at a room temperature of $21 \pm 3 \text{ }^\circ\text{C}$.

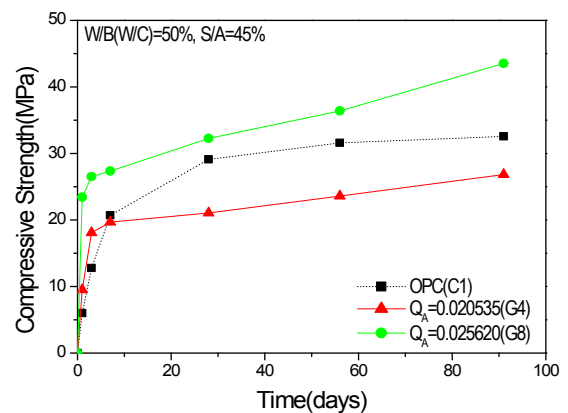
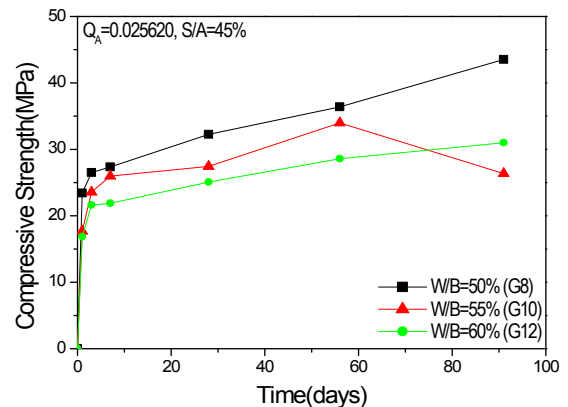
**Figure 1** : Mixing and casting

According to the concrete compressive strength test specification of KS F 2405, the compressive strength of the concrete specimens at age 1, 3, 7, 28, 56 and 91days were tested. The compressive strength used the strength calibration coefficient of 0.97⁵⁾ in consideration of the size of the specimen mold and used the average of three test datas.

3. EXPERIMENTAL RESULT AND ANALYSIS

3.1 Compressive strength

As shown in figure 2, cementless geopolymer concrete exhibited the early strength development compared to OPC concrete. Especially, the early strength of cementless geopolymer concrete at age 1 and 3 days were about 1.5 to 3 times higher than OPC concrete, and after age 7days the strengths differed by Q_A. Figure 3 shows that the compressive strength of cementless geopolymer concrete was higher as the W/B ratio was lower, and its compressive strength for the case of 50% W/B was about 1.25 times and about 1.4 times higher than that for the case of W/B ratio of 60% at 7days and 91 days, respectively.

**Figure 2** : Compressive strength as source materials**Figure 3** : Compressive strength as W/B ratio

3.2 Verification of proposed equation

The equation proposed from AA mortar was applied to cementless geopolymer concrete with a slight modification and without additional variable analysis process, and the compressive strength predicted by this modified equation at 28days and ages. These predicted values are then verified by experiment. The sand-to-binder(S/B) ratio in the mortar equation is replaced with aggregate-to-binder(A/B) ratio, and the value for the coefficient, k_2 , is added in consideration of the fine aggregate ratio(S/A). Because the compressive strength by ages of the concrete requires additional variable analysis process, the mortar equation is used as it is. Table 4 compares the predictions of compressive strength with experimental results at 28days and ages.

$$(f_{ck})_{28} = 1480 \left[\frac{Q_A \times (S_A / S_{A0} + k_1)^{0.3}}{(W/B)} \right]^{1.23} \times k_2$$

Where, $k_1 = (A/B)^{0.5}$ for $A/B \leq 2.5$ and $(A/B)^{-0.5}$ for $A/B > 2.5$, $k_2 = (S/A)^{0.6}$

Table 3 : Test result and Analysis

Name	Q_A	$(f_{28})_{Pre}$ $(f_{28})_{Exp}$		$(f)_{Exp}/(f)_{Pre}$							
		(MPa)	(MPa)	$(f)_1$	$(f)_3$	$(f)_7$	$(f)_{28}$	$(f)_{56}$	$(f)_{91}$		
G1	0.020535	26.04	31.04	2.15	1.42	1.24	1.19	1.19	1.18		
G2	0.020535	27.95	27.26	1.73	1.17	1.07	0.98	0.96	1.03		
G3	0.020535	19.79	21.01	2.30	1.51	1.13	1.06	1.06	1.16		
G4	0.020535	21.24	21.05	1.32	1.31	1.05	0.99	0.97	1.08		
G5	0.020535	17.60	15.67	1.82	1.22	0.95	0.89	0.97	0.98		
G6	0.020535	18.89	19.12	2.54	1.53	1.23	1.01	1.01	1.04		
G7	0.025620	25.98	30.00	2.22	1.35	1.30	1.15	1.38	1.31		
G8	0.025620	27.88	32.26	2.25	1.39	1.09	1.16	1.15	1.36		
G9	0.025620	23.11	25.73	2.51	1.52	1.22	1.11	1.03	1.20		
G10	0.025620	24.80	27.44	2.07	1.45	1.19	1.11	1.20	0.91		
G11	0.025620	20.76	18.27	2.21	1.39	1.16	0.88	0.82	1.25		
G12	0.025620	22.28	25.08	2.38	1.55	1.14	1.13	1.11	1.18		
G13	0.027862	25.62	24.10	1.80	1.12	1.07	0.94	1.05	1.25		
G14	0.027862	27.49	24.31	2.13	1.11	0.93	0.88	0.87	1.14		
G15	0.027862	23.02	28.20	2.46	1.53	1.21	1.23	1.07	1.16		
G16	0.027862	24.70	25.90	2.26	1.41	1.08	1.05	0.99	1.06		

Figure 4 shows the relationship between the compressive strength predicted from the proposed equation and the experimental

compressive strength at 28days. Figure 5 shows the relationship between the predicted compressive strengths and the experimental result by ages and Q_A . The prediction of compressive strength corresponded well with the experimental result at 28days. The experimental compressive strength by ages was generally greater than prediction, and there was more corresponding at long-term age than early age.

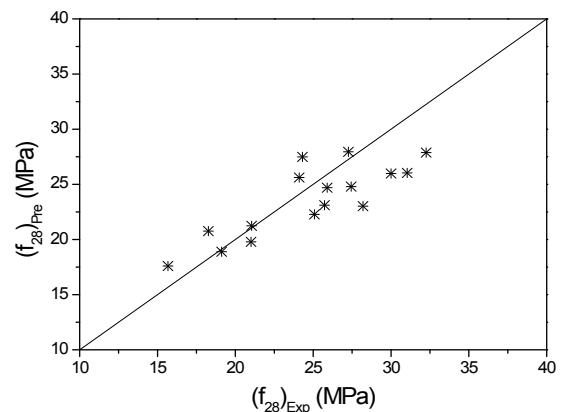


Figure 4 : Comparison of predictions and experiment results (28days compressive strength)

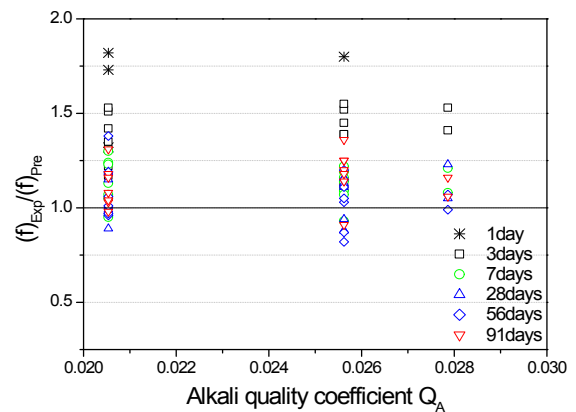


Figure 5 : Comparisons of compressive strength by ages and Q_A

4. CONCLUSION

The results of investigating strength property of cementless geopolymer concrete

based on the mix condition of AA mortar are summarized in the following.

1) The cementless geopolymers concrete shows a high strength development compared to that of OPC concrete at early age (<7days). Especially, the early strength at age 1 and 3 days was about 1.5 to 3 times greater than OPC concrete. Then, they differed by Q_A after 7days. Additionally, as W/B ratio was lower, compressive strength was higher, and the compressive strength for the case of 50% W/B ratio was about 1.25 times and about 1.4 times higher than that for the case of W/B of 60% at 7days and 91days, respectively. Additionally, as Q_A was higher, the early strength was higher. However, this relationship was not clearly observed at long-term age, and an appropriate quantity of alkali activator should be determined.

2) The equation proposed from AAS mortar was applied to cementless geopolymers concrete with a slight modification and without additional variable analysis process, and the compressive strength predicted by this modified equation at 28days and ages were compared and verified through experiment. The predicted 28days compressive strength corresponded well with experimental compressive strength of the cementless geopolymers concrete.

3) The result of comparing prediction and experimental result of compressive strength by Q_A and ages, the experimental values were generally higher than predicted values, and there was more corresponding at long-term age than early age. It is construed that this difference comes from the fact that, although the computational equation for compressive strength predicts the strength by ages on the basis of the compressive strength at 28days, strength of cementless geopolymers concrete develops at age 1 and 3days. Thus, it is necessary to consider early strength development of cementless

geopolymers concrete when compressive strength is to be predicted by ages.

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