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Characteristics of the Geopolymer using Fly Ash and Blast Furnace Slag with Alkaline Activators

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Abstract. Geopolymers were manufactured using fly ash and blast furnace slag as the raw materials with NaOH(Sodium Hydroxide) and the water glass as alkali activators. Compressive strength of geopolymers were measured and analyzed according to the replacing ratios of blast furnace slag and the concentration of activators. Under the conditions of NaOH 5.56M, water glass content 55.56 wt%, and 28 days curing after pressureless molding, the compressive strength of a geopolymer reached up to 57.79 MPa. Both the ratio of activator and replacing ration of fly ash and blast furnace slag played an important role to increase compressive strength of geopolymers.

Keywords: fly ash, blast furnace slag, sodium hydroxide, sodium silicate, compressive strength

1. Introduction

Recently, the global warming problem caused by CO_2 became one of the serious international environmental issues to be solved. In particular, the CO_2 produced in the manufacturing process of Portland cement used in most building and civil constructions are increasing every year. 0.4～1.0 tons of CO_2 were produced to make 1 ton of cement and it is as much serious as 7% of total CO_2 amount of global production were used for making cement [1]. Therefore, many researchers have focused on reducing CO_2 production and substitute materials for cement with the consideration of ecological industry in the future [2, 3]. The prospecting materials for non-sintering inorganic binders are fly ash, slag and brick powder from the industrial wastes as well as natural raw materials such as clay and incinerated kaolin. Among these prospecting materials, fly ash and blast furnace slag are the materials to enhance the properties of final products when they are used by a mixture. In particular, blast furnace slag is known to a self-hydrated material. Although fly ash cannot be self-hydrated, many researches have been conducted on the geopolymers using fly ash with alkaline activators and some of them were already commercialized [4].

Geopolymer can be synthesized by the condensation of Si^{4+} and Al^{3+} ions came from the industrial wastes or natural ores by alkaline activators. The general chemical formula is $Mn(-(SiO_2)z-Al_2O_3)n \cdot wH_2O$ where, M is alkaline or alkaline earth elements such as K, Na and Ca, Z is 1, 2 and 3, n represents the degree of condensation [2]. Geopolymer is one type of alumina-silicate cements and they produce less CO_2 and show better mechanical as well as chemical properties including heavy metal stabilization compared to Portland cement. Therefore, they are the most prospecting material for substituting conventional cement [5-9]. Geopolymers have a three dimensional network structure such as zeolite and an amorphous phase. The prospective raw materials for geopolymers are industrial wastes containing large amount of amorphous silica such as fly ash, meta-kaolin, blast furnace slag etc. and natural silicate minerals.

Therefore, the purpose of this study is recycling of fly ash and blast furnace slag as raw materials of geopolymers having no conventional cement. NaOH and water glass (sodium silicate) were used as alkaline activators. Mechanical property was measured with respect to the substituting rate of raw materials and

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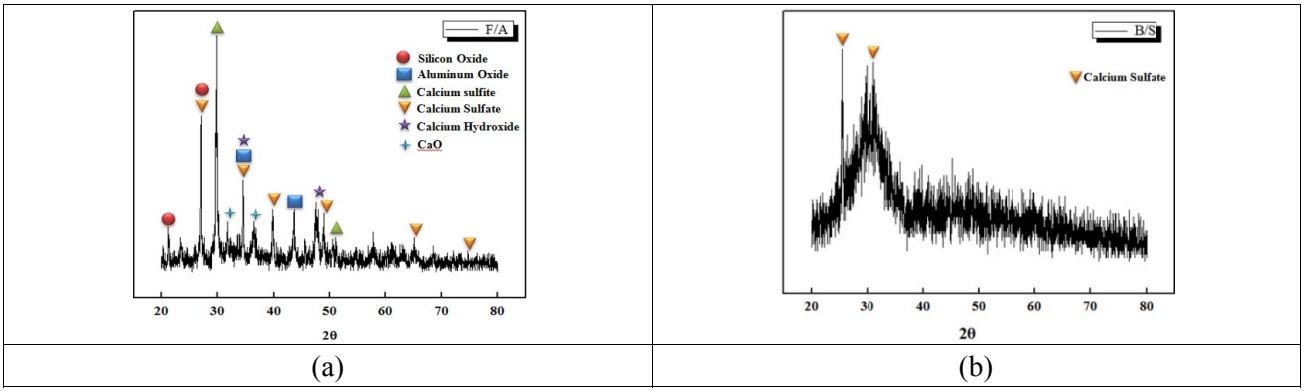
concentrations of activators. The final purpose of this study is to provide basic data for recycling industrial wastes for making geopolymers so as to reduce CO_2 by eliminating the use of conventional cement.

2. Experiments

Fly ash (F/A) produced in a domestic coal firing power plant and blast furnace slag (B/S) were used as raw materials for geopolymers and the chemical compositions of both are shown in Table 1. The Si/Al mole ration of B/S is much larger than that of F/A. In particular, ignition loss (6.65%) of F/A was relatively higher than average value of F/A in Korea. The contents of CaO in F/A and B/S were similar; however, most of the phases in FA were crystalized. Calcium sulfite, calcium sulfate, calcium hydroxide, silicon oxide, aluminum oxide etc were found by XRD analysis ash shown in Fig 1(a). On the other hand, most phases of B/S were amorphous as shown in Fig. 1(b). Because this phase difference of these two raw materials exist, it was expected that the condensation characteristics would be far different each other during the process of geopolymer.

Table 1. Chemical compositions of fly ash(F/A) and blast furnace slag(B/S)

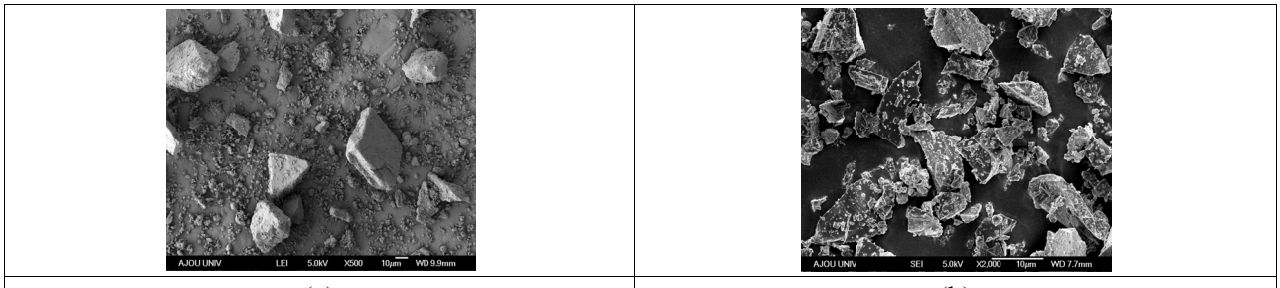
	Chemical Compositions (wt%)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Ig.Loss
F/A	21.94	8.46	6.05	45.4	6.06	0	6.65
B/S	37.33	12.49	0.26	43.3	5.31	0	0



(a) (b)

Fig. 1: XRD patterns of raw materials. (a) fly ash(F/A) and (b) blast furnace slag(B/S).

The microstructures of both raw materials were observed by SEM as shown in Fig. 2. The particle size of F/A and B/S was 10~50 ㎛ and less than 20 ㎛, respectively. A glassy phase was easily observed on the surfaces of each particle, which is good accordance with the result of XRD analysis as shown in Fig. 1. It is very important factor to select proper activator for the effective extraction of Al^{3+}, Si^{4+} ions from the amorphous glassy phase as mentioned just before [10].



(a) (b)

Fig. 2: Microstructure of the fly ash(F/A) and blast furnace slag(B/S) observed by SEM. (a) F/A and (b) B/S.

NaOH (Deajung, Sodium Hydroxide) and water glass (Daejung, sodium silicate) No. 3 were used as alkaline activators. Geopolymer specimens were molded with 50 x 50 x 50mm^3 cubic steel mold to measure the compressive strength. The compressive strength at 1, 7 and 28 days were measured after 24 hours curing out of mold.

3. Results and Discussions

3.1. Effect of Mixing Ratio

Table 2 shows mixing ratio of raw materials after fixing the ratio of water glass, NaOH, and water. Fig. 3 shows the effect of the mixing ratio of fly ash(F/A) and blast furnace slag(B/S) on compressive strength with alkali activation mortar under the room temperature curing condition. In general, the more aged specimen, the stronger the compressive strength is. Measuring compressive strength of compound of Raw-Ⅰ (FA:BS=100:0), the lowest strength was 0.79 MPa after 1day and 2.81 MPa after 28days and it seemed that there was no polymerization because the contents of $Al_2O_3$and SiO_2 was not reached to 30wt%. With compound of Raw-Ⅲ (FA:BS=0:100), the highest compressive strength of 22.67 MPa was after 1day, and the strength was increased up to 44.41 MPa after 28days. With compound of Raw-Ⅱ (FA:BS=50:50), compressive strength after 1 day was 12.33 MPa, which is relatively lower than Raw-III; however, it reached 23.61 MPa after 28days. As shown in Fig. 3, the strength of specimens made of fly ash and blast furnace slag was higher than those of made only fly ash. Therefore, it is concluded that fly ash itself cannot be used as a raw material for making geopolymers having enough compressive strength for the practical application of construction materials.

Table 2. Mixing ratio of F/A and B/S

Sample	F/A, B/S : NaOH, Water	F/A : B/S	NaOH (M)
Raw-Ⅰ	100 : 40	100 : 0	2.78
Raw-Ⅱ		50 : 50	
Raw-Ⅲ		0 : 100	

Table 3. Mixing ratio of NaOH with fixed ratios of F/A B/S, and water

Sample	F/A, B/S : NaOH, Water	F/A : B/S	NaOH (M)
NaOH-Ⅰ	100 : 40	50 : 50	2.78
NaOH-Ⅱ			5.56
NaOH-Ⅲ			8.34
NaOH-Ⅳ			11.12

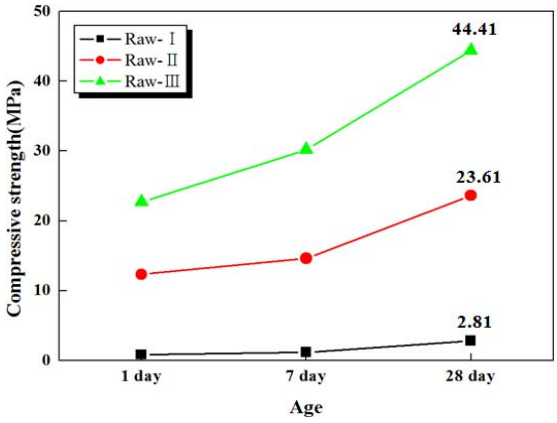


Fig. 3: Effect of the mixing ratio of fly ash(F/A) and blast furnace slag(B/S) on compressive strength. Raw-Ⅰ, Raw-Ⅱ and Raw-Ⅲ indicate FA100, FA50Slag50 and Slag100, respectively.

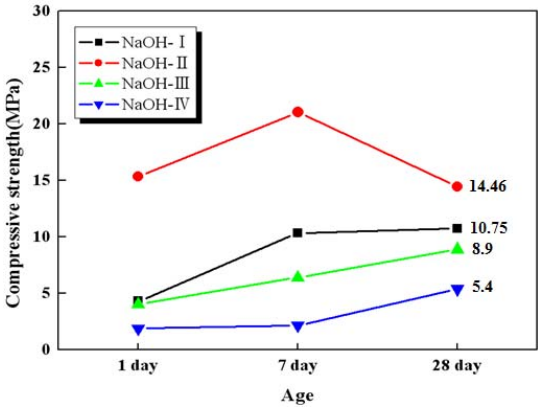


Fig. 4: Effect of the mixing ratio of NaOH on compressive strength. NaOH- Ⅰ, -Ⅱ, -Ⅲ and -Ⅳ indicate NaOH 2.78M, 5.56M, 8.34M and 11.12M, respectively. The ratios of F/A:B/S, water glass, and water were fixed to 50:50, 33.33 wt%, 66.67 wt%, respectively.

3.2. Effect of NaOH

Table 3 shows mixing ratio of NaOH with the fixing ratios of F/A, B/S and Water. The ratios of F/A:B/S, water glass, and water were fixed to 50:50, 33.33 wt%, and 66.67 wt%, respectively. The mole concentrations of NaOH were changed to 2.78 M, 5.56 M, 8.34 M, and 11.12 M. Fig. 4 shows the effect of NaOH alkaline activator content on the compressive strength. The 28days compressive strength of NaOH-II of which mole concentration of NaOH is 5.56 M was 22 MPa which is highest of all. When mole concentration of NaOH increased, compressive strength increased for a certain degree; however, when the mole concentration increased more, the compressive strength decreased. It seemed that the increased mole concentration of NaOH actually hindered the curing reaction with excessive alkali ions. For NaOH-II, compressive strength of 28days was lower than that of 7days. It seemed that moisture evaporation caused by small cracks inside of the specimens resulted in lower compressive strength.

3.3. Effect of water glass and water

Mixing ratio of water glass is a very important factor for making geopolymers. In general, NaOH, KOH, and Na_2CO_3 are mainly used as alkaline activators. In addition, water glass (sodium silicate) was used to improve the physical properties of geopolymers. Therefore, the effect of additive contents of water glass on the geopolymer was investigated. Fig. 5 shows the compressive strength according to the contents of water glass. As shown in Table 4, B/S and NaOH were fixed to 100 and 5.56 M, respectively and water glass content was changed from 0 wt%, 11.11 wt%, 33.33 wt%, and up to 55.56 wt%. WG-Ⅳ that contains the highest water glass content showed the highest compressive strength of 45.59 MPa after 1day and 57.79 MPa after 28days, respectively. WG-II having lowest water glass content showed the lowest compressive strength of 18.51 MPa after 1day and 43.64 MPa after 28days, respectively. It was found that compressive strength was increased as water glass content was increased. With the increasing water glass content, overall increasing rate of compressive strength was decreased as increasing period of curing. As shown in Fig. 5, the more contents of water glass, the higher the compressive strength after 1 day is. WG-III with water glass content of 33.33wt% showed 45.59 MPa of compressive strength, which is higher than those of Portland cement mortars which showed compressive strength of 32 – 37 MPa after 28days. It is concluded that WG-III composition of geopolymer showed good enough compressive strength to replace the normal Portland cement for the purpose of structural application.

4. Conclusions

The effect of additive contents of alkaline activators and mixture ratio of materials on compressive strength by mixing fly ash and blast furnace slag as powder material with water glass and NaOH as basic activators were investigated and conclusions are as follows:

1) When the mixture of fly ash and blast furnace slag powder used for making geopolymers, the compressive strength increased with increasing both contents of B/S and curing period. Geopolymer made of fly ash only did not show enough compressive strength to replace Portland cement.

2) For compressive strength in accordance with NaOH mole concentration, the highest strength was 14.46 MPa after 28days when fly ash and blast furnace slag were mixed 50:50 with 5.56 M NaOH.

3) For compressive strength in accordance with glass-water content, WG-IV, of which blast furnace slag was 100; NaOH was 5.56 M; and glass water was 55.56 wt%, showed highest value with 57.79 MPa of 28days and the initial compressive strength was increased when water glass content was increased.

Table 4. Mixing ratio of water glass and water

Sample	F/A, B/S : NaOH, Water	F/A : B/S	NaOH (M)	Water glass (wt%)	Water (wt%)
WG-Ⅰ	100 : 40	0 : 100	5.56	0	100
WG-Ⅱ				11.11	88.89
WG-Ⅲ				33.33	66.67
WG-Ⅳ				55.56	44.44

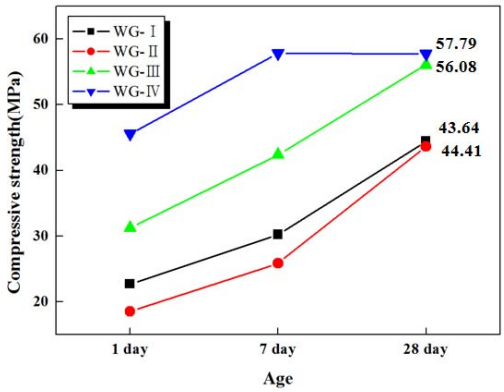


Fig. 5: Effect of the mixing ratio of water and water glass on compressive strength. The ratio of B/S and NaOH were fixed to 100 and 5.56M, respectively.

5. Acknowledgement

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