

# Characteristic on Compressive Strength of Blast Slag and Fly Ash Hybrid Geopolymer Mortar

G. S. Ryu, K. T. Koh, H. Y. Kim, G. H. An, D. W. Seo

**Abstract**—Geopolymer mortar is produced by alkaline activation of pozzolanic materials such as fly ground granulated blast-furnace slag (GGBFS) and fly ash (FA). Its unique reaction pathway facilitates rapid strength development in comparison with hydration of ordinary Portland cement (OPC). Geopolymer can be fabricated using various types and dosages of alkali-activator, which effectively gives a wider control over the performance of the final product. The present study investigates the effect of types of precursors and curing conditions on the fresh state and strength development characteristics of geopolymers, thereby comparatively exploring the effect of precursors from various sources of origin. The obtained result showed that the setting time and strength development of the specimens with the identical mix proportion but different precursors displayed significant variations.

**Keywords**—Alkali-activated material, blast furnace slag, fly ash, Flowability, strength development.

## I. INTRODUCTION

CONCRETE, a mixture of cement, water, aggregates and admixture, is the most widely used construction material. Of all the constituents in concrete, OPC is produced by calcination of limestone ( $\text{CaCO}_3$ ) and is a representative binder material in the concrete industry. In general, production of OPC requires melting at high temperatures (1450 °C) hence high input of energy is needed, and associates 0.7-1.0 ton of  $\text{CO}_2$  emissions per ton of cement produced [1]. This amounts to 7% of greenhouse gas globally, which necessitated immediate implementation of  $\text{CO}_2$  reduction strategy around the world [1]. Against this backdrop, the construction industry has been keen to reduce the amount of cement usage, endorsing 'zero emission' strategy whereby industrial by-product and waste are intensively recycled [2]. Various types of industrial wastes were investigated as an alternative cementitious binder material, and geopolymer produced from GGBS and FA have been a topic of numerous studies [3].

GGBS is an industrial by-product of steel manufacturing process that is ground to powder. The presence of glassy layer on the surface of a GGBS particle significantly reduces the hydraulic reactivity of GGBS, hence typical GGBS is considered latent-hydraulic and requires alkaline environment for the breakage of the glassy layer. Previous studies reported that alkaline activation product of GGBS reaches strength of 40-70 MPa at room temperature while the rapid setting and

flow loss, and high shrinkage remain a technical issue [4]. FA is generated from coal-firing power plants and is not hydraulic, while its alkaline activation product undergoes strength development in a high-temperature curing condition via polymerization [1], [5]. Since high-temperature curing causes additional energy consumption and increases the unit production cost, FA is often blended in alkali-activated slag to produce geopolymer concrete [1].

The present study investigates the basic performance properties of geopolymer produced from blend of GGBS and FA which differ in sources of origin. To this aim, the binder composition, and fresh state and strength development characteristics of the geopolymer specimens at various ages were investigated.

## II. MATERIALS USED AND MIX PROPORTION

Two types of FA and GGBS from different sources of origin were used as a binder material in this study. The chemical and physical properties of these materials are summarized in Table I.

The FA's used in this study contained 77-83% of  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ , which undergoes polymerization with aid of alkali-activator and develops strength. The GGBS's contained 43-46% of  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  where occurrence of polymerization is anticipated identically. In addition, the CaO content was as high as 43% in these materials, which can induce hydration reaction, identical to that of OPC [6].

A mixture of NaOH (98% purity) powder and sodium silicate solution (9.3%  $\text{Na}_2\text{O}$ , 27.8%  $\text{SiO}_2$ , and 62.9%  $\text{H}_2\text{O}$ ) was used as alkali-activator.

The mix proportion, as identified from preliminary tests, was as follows (Table II): GGBS:FA = 70:30, water-to-binder (W/B) ratio = 0.50, alkali modulus of the activator ( $M_s$ ,  $\text{SiO}_2/\text{Na}_2\text{O} = 1$ ), and  $\text{Na}_2\text{O}$  per binder = 4 g per 100 g of binder). The specimens were produced in dimensions of 40×40×160 mm. The specimens were sealed-cured for the initial 24 h, and thereafter were either cured in air (R.H. 65±10%) or in water (R.H. 100%) at 20±2 °C. The compressive and flexural strength tests were conducted at 3, 7, 14, and 28 days of curing.

## III. RESULTS AND DISCUSSIONS

The flow and setting time of the geopolymer specimens produced from precursors with varying sources of origin are summarized in Table III. The flow of AAM-G and AAM-K with varying sources of origin was 113 and 99 mm, respectively. The initial setting time of these two specimens was 2h 30 min, 1 h 15 min, and the final setting time was 4h 30 min and 2h 20 min, respectively, showing two folds difference

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according to the source of origin. This can be associated with the  $Al_2O_3$  contents which differed in the two GGBS's. For instance, the  $Al_2O_3$  contents were 9.8% and 14.2%,

respectively, hence the lower setting time of GGBS-K can be attributed to its 45% higher content of  $Al_2O_3$ .

TABLE I  
PHYSICAL AND CHEMICAL PROPERTIES OF BINDER MATERIALS

Materials	SiO <sub>2</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	CaO (%)	MgO (%)	SO <sub>3</sub> (%)	L.O.I (%)	Specific surface area (cm <sup>2</sup> /g)	Density (g/cm <sup>3</sup> )
GGBS-G	33.3	9.8	1.07	43.6	5.95	3.34	0.62	4,430	2.90
BS-K	32.2	14.2	0.42	45.1	2.95	3.36	2.61	4,280	2.90
FA-G	54.3	22.6	12.8	4.35	1.3	1.49	2.4	4,040	2.18
FA-K	63.8	18.8	7.08	2.89	0.895	0.691	2.4	3,900	2.18

TABLE II  
MIXTURE PROPORTIONS OF GEOPOLYMER SPECIMENS

Type	Ms (%)	W/B (%)	Water (g)	Na <sub>2</sub> O (g)	GGBS	FA	Unit weight (kg/m <sup>3</sup> )			
							Sodium Silicate	NaOH	Water	Sand
AAM-G	1.0	0.5	305.1	24.4	427.2	183.1	86.2	21.1	250.9	1098.4
AAM-K										

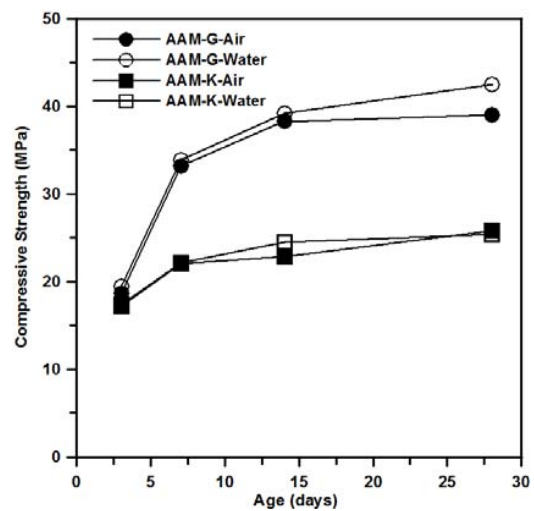
TABLE III  
FLOWABILITY AND SETTING TIME OF GEOPOLYMER SPECIMENS

Type	Flow (mm)		Setting Time (h:min)	
	Initial	After shaking for 25 times	Initial	Final
AAM-G	113	226	2:40	4:30
AAM-K	99	171	1:15	2:20

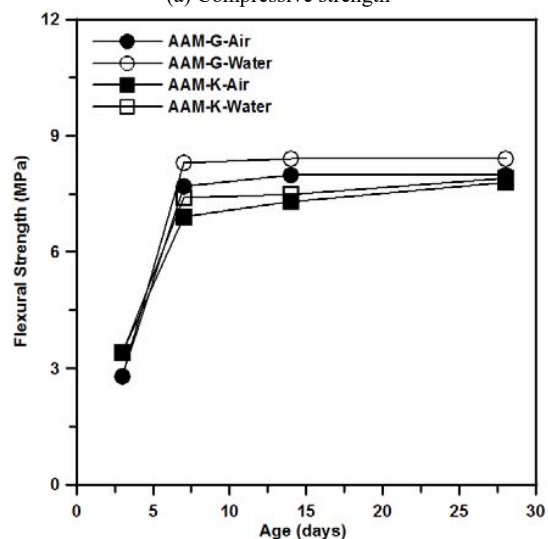
The compressive and flexural strength of the geopolymer specimens produced from precursors with varying sources of origin are illustrated in Fig. 1. The compressive strength of the specimens cured in air at 28 days was 38.3 and 25.8 MPa, while those cured in water reached 42.5 and 25.4 MPa, respectively, corresponding to 51-67% difference according to the curing condition. Meanwhile, the flexural strength results shown in Fig. 1 (b) showed no significant variation according to the source of origin. The X-ray diffraction (XRD) patterns of the raw GGBS and FA are shown in Fig. 2. Peaks corresponding to the presence of mullite, quartz and an amorphous hump due to the presence of the glassy phase are observed in the XRD patterns of the FA's, while the intensity of these peaks were similar regardless of the source of origin. On the other hand, a significant variation is observed in the XRD patterns of the GGBS's. The XRD pattern of GGBS-K showed the peaks assigned to anhydrite, calcite, brucite and glassy phase, while GGBS-G was found to be mostly amorphous displaying a broad hump of glassy phase in the XRD pattern. It can be inferred that the physicochemical properties of binder materials significantly differ according to the sources of origin; despite the use of the identical activator throughout the mixtures, the degree of hydration and polymerization notably differed, leading to different values of mechanical strength.

#### IV. CONCLUSIONS

The present study investigated the fresh state and strength development characteristics of geopolymer produced from GGBS and FA with varying sources of origin at 70:30 mass ratio. The findings of this study can be summarized as below:



(a) Compressive strength

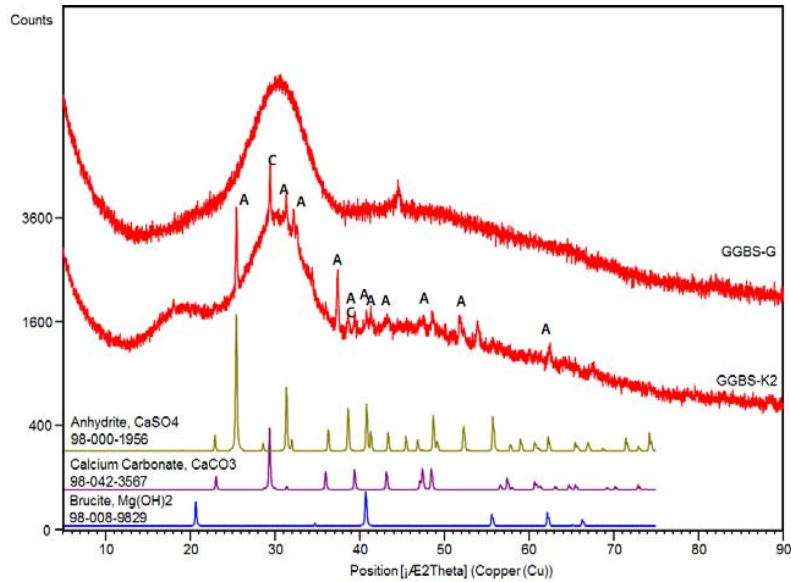


(b) Flexural strength

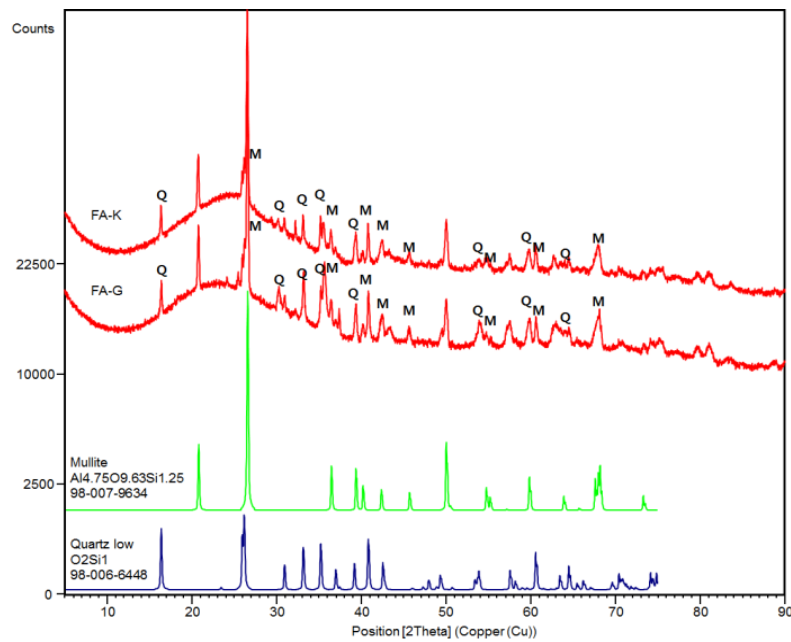
Fig. 1 Compressive and flexural strength of geopolymer specimens

1. Despite the fact that the strength of geopolymer was excellent at an early age attributed to the alkaline activation of inorganic precursors, the strength development as a function of time was found to be significantly affected by the curing condition.
2. The physicochemical properties of the precursors significantly differed according to the source of origin,

hence the strength attained by the specimens with the identical mix proportion was different. A cautious choice of binder materials is therefore required, since the physicochemical properties which differ according to the binder materials would lead to variations in the degree of hydration and polymerization.



(a) GGBS



(b) FA

Fig. 2 XRD patterns of GGBS and FA

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