

AUTOGENOUS SHRINKAGE AND STRENGTH DEVELOPMENT OF ALKALI-ACTIVATED SLAG/FLY ASH MORTAR BLENDS

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Introduction

Alkali-activated material production is associated with lower energy consumption and lower CO₂ footprint with promising mechanical properties and excellent durability performance when compared to OPC¹. It has been extensively studied as an alternative binder to OPC^{2,3}. In recent times, hybrid alkali-activated material like alkali-activated slag/fly ash (AASF) has become more attractive, as it shows a higher compressive strength than the activation of each component individually. The dominant factor in the strength gain of this blended system is the amount of ground granulated blast furnace slag (GGBFS)⁴. The increase in GGBFS in blended systems contributes higher compressive strength⁵. Nevertheless, high GGBFS results in significant conundrums such as fast setting and volume instability, which endanger long-term properties^{6,7}. Simultaneously, the addition of fly ash affects the setting time and reduces the shrinkage deformation at early ages⁴. Therefore, the objective of this study is to determine the optimum synthesis of slag and fly ash blended system with best shrinkage performance and strength properties.

Experimental procedure

Materials and Mix proportion

The primary materials used in this study is GGBFS, blended with classified fly ash (Class F) with a mean diameter of 20µm. The basicity coefficient $K_b = \frac{(\text{CaO} + \text{MgO} + \text{Fe}_2\text{O}_3 + \text{K}_2\text{O} + \text{Na}_2\text{O})}{(\text{SiO}_2 + \text{Al}_2\text{O}_3)}$ and the hydraulic modulus $\text{HM} = \frac{(\text{CaO} + \text{MgO} + \text{Al}_2\text{O}_3)}{\text{SiO}_2}$ of the GGBFS were 1.0 and 1.65, respectively. The activators used were Sodium Hydroxide pellets (99% purity) and Sodium silicate solution (Na₂O-8.3%, SiO₂-27.5%, H₂O-64.2%) with alkali modulus (SiO₂/ Na₂O) of 3.4. In this study, mortar made with GGBFS/FA blends were activated with a combination of 50% sodium hydroxide (5M_NaOH) and 50% sodium silicate solutions. To maintain same consistency, the activator/binder (A/B) ratio was varied with a constant modulus of 1.28 as given in Table 1.

Table 1: Mix composition of the hybrid alkaline-activated slag/fly ash (AASF)						
	GGBFS/FA	100/0	75/25	50/50	25/75	0/100
Series 1	Activator/binder	0.7	0.7	0.7	0.7	0.7
Series 2	Activator/binder	0.7	0.6	0.55	0.52	0.49

Results and Discussion

Autogenous shrinkage of investigated mortars tended to decrease with the increase of fly ash replacement as shown in Figure 1. However, the reduction effect decreases with respect to age. Fly ash contains more inactive minerals and also its active constituents are mainly hollow glass pearls, which are not as active as glass phase of slag⁸. The low reactivity of the fly ash made its hydration slower than slag and thus autogenous shrinkage related to chemical shrinkage decreases. Both GGBFS/FA: 75/25, 50/50 blends show reduction in autogenous shrinkage with decrease in activator/binder ratio and whereas, high fly ash content blends (25/75, 0/100) show increases in autogenous shrinkage with decrease in activator/binder ratio (Figure 1).

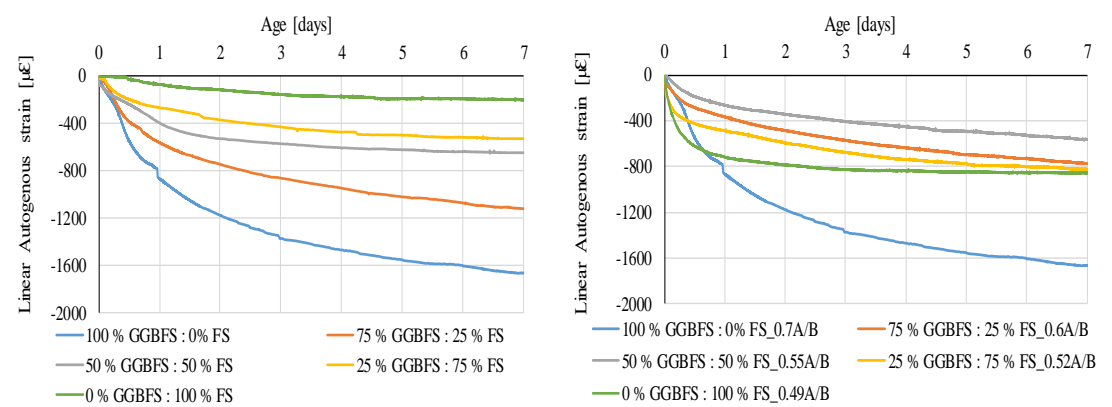


Figure 1: Autogenous shrinkage of series: 1 AASF (left) and series: 2 AASF (right) mortar specimens

One of the key factors affecting the strength of the alkali-activated slag/fly ash blend system is the amount of CaO. This arises because the presence of high amount of CaO improves the compactness of the microstructure by forming the C-S-H gel⁹. As a result, an increase in the amount of GGBFS was followed with the increase in strength properties with respect to curing age (Figure 2-5). However, the strength development of AASF with 100% slag levels off between 7 and 28 days and shows lower strength when compared to 75% GGBFS-25% FA at the age of 28 days. The reason is likely due to the development of micro-cracks caused by large autogenous shrinkage strain (Figure 1) which becomes progressively larger over time with increasing the permeable voids, porosity, water absorption and a decrease in ultrasonic pulse velocity¹⁰. Some authors also suggested, the high strength with 25% FA replacement is due to the formation of highly cross-linked structures of the reaction products caused by the presence of Al supplied by FA¹¹. On the other hand, decrease in

activator-to-binder ratio leads to increase in strength (Fig 4-5) due to reduction in total porosity.

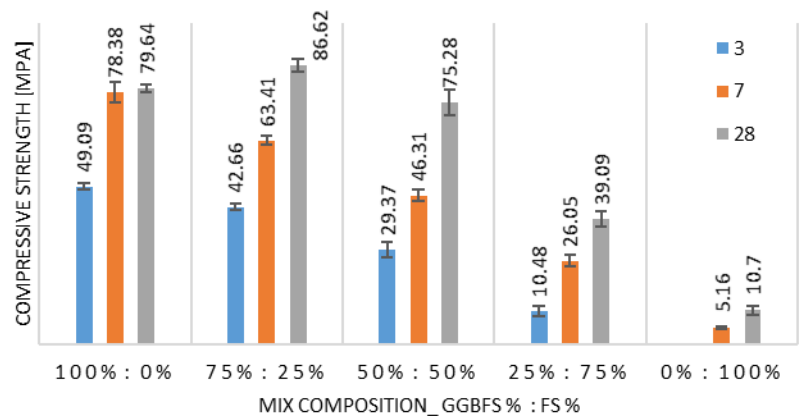


Figure 2: Compressive strength of series: 1 AASF mortar specimens

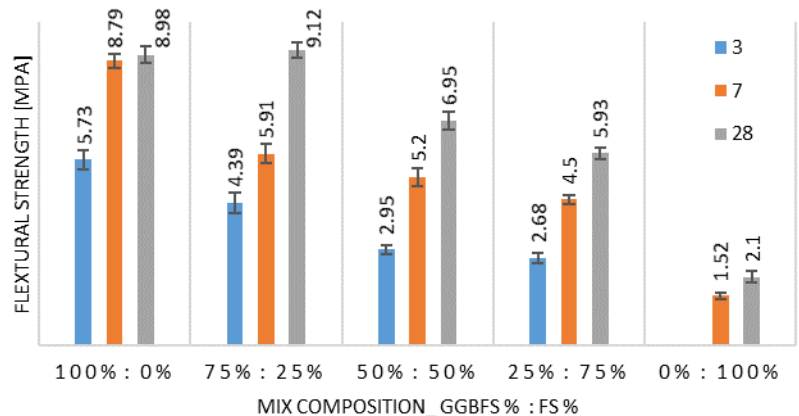


Figure 3: Flexural strength of series: 1 AASF mortar specimens

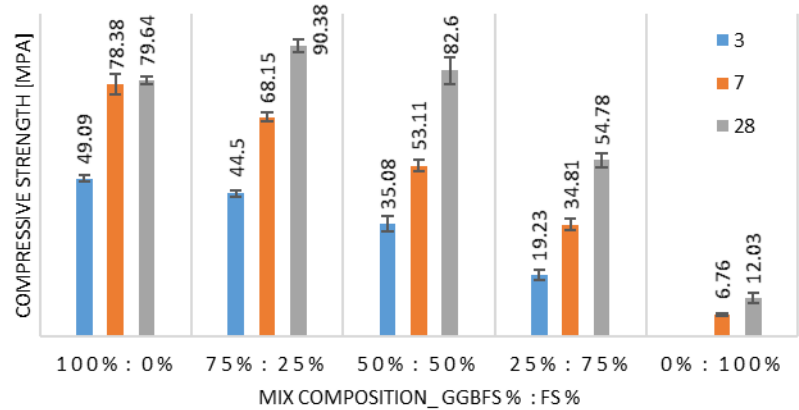


Figure 4: Compressive strength of series: 2 AASF mortar specimens

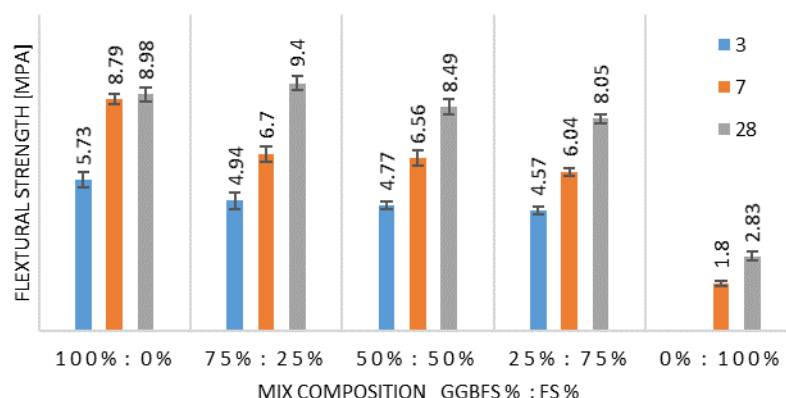


Figure 5: Flexural strength of series: 2 AASF mortar specimens

Conclusions

Autogenous shrinkage and strength of the AASF system increase with an increase in GGBFS. However, the 100% GGBFS shows lower strength than 25% FA replacement at the age of 28 due to the development of micro-cracks caused by autogenous shrinkage. Activator/binder ratio has a significant effect on strength and shrinkage deformations of AASF and increases with decrease activator/binder ratio. From results, GGBFS:FA 50:50 is suggested as an optimum synthesis.

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