SYNTHESIS OF FLY ASH-GGBS BLENDED GEOPOLYMER COMPOSITS

SubhashreeSamantasinghar
PhD Scholar, Department of Civil Engineering, National Institute of Technology Rourkela, Rourkela – 769008, Odisha
shree.singhar@gmail.com

Suresh Prasad Singh
Professor, Department of Civil Engineering, National Institute of Technology Rourkela, Rourkela – 769008, Odisha.
spsingh@nitrkl.ac.in

ABSTRACT: Fly ash and blast-furnace slag are well known industrial by-products and are used to manufacture blended cements and concrete. Fly ash has been used as pozzolanic material to improve the physical, mechanical as well as chemical properties of the cements and concrete whereas blast-furnace slag cements are characterized by their low heat of hydration and high sulfate and sea water resistance. On the other hand, addition of blast furnace slag to fly ash may have substantial influence on the strength development of geopolymer binder when cured under ambient temperature condition. This paper presents the compressive strength of geopolymer binders synthesized from Class F fly ash blended with ground granulated blast-furnace slag by optimizing the influential parameters. The chemical activation of fly ash-slag mixtures with different concentrations of sodium hydroxide (NaOH) for varying solution to solid ratio has been made. The test results showed that the development of compressive strength is directly concomitant to concentration of NaOH solution. Moreover, as the slag content in the mixture increases, the compressive strength increases. Hence, an inorganic polymer can be synthesized from fly ash-slag mixture by activating with appropriate amount of NaOH which can be used as cementitious material.

KEYWORDS: fly ash, GGBS, alkali concentration, solution to solid ratio, compressive strength

1 INTRODUCTION

Geopolymer binders based on industrial by-product materials such as fly ash and slag can play a vital role in the context of sustainability and environmental issues. Approximately 5% of global CO_2 emissions originate from the manufacturing of Portland cement. On the other hand cements manufactured from industrial by-products such as slag has been shown to release up to 80% less greenhouse gas emissions and there are 80–90% less greenhouse gas emissions in case of fly ash. Therefore, ground granulated blast-furnace slag (GGBS) or fly ash would significantly reduce the CO_2 emission of geopolymer binder production.

Geopolymer is an alternative binder in which an alkali activated alumino-silicate material is used as the binder instead of the traditional cement binder. Thus the traditional binder based on cement or cement and other pozzolanic materials is replaced by the alkali activated inorganic binder in geopolymer.

The major processes involve the reaction between an alumino-silicate source such as fly ash, metakaolin or blast furnace slag and an alkaline solution which leads to final hardening of the matrix by exclusion of excess water and the growth of an inorganic polymer. Previous studies indicated that the reaction of the selected pozzolanic material is the most significant factor in producing a mechanically sound binder via the geopolymerization process. The chemical reaction and the rate of strength development of geopolymer are influenced by several factors based on chemical compositions of the source materials, alkaline activators and curing condition.

2 LITERATURE REVIEW

Geopolymerization mechanism include the dissolution of aluminium and silicon in highly alkali medium, transportation of the dissolved species, and formation a three dimensional network of alumino-silicate structures (De Silva et al., 2007). Geopolymer binders usually consist of reactive solids which contains silica and alumina and an alkaline solution. When reactive solids react with alkaline solution, builds an alumino-silicate network which is amorphous to partially crystalline nature (Duxson et al., 2007a; Duxson et al., 2007b).

Puertas et al. (2000) synthesized fly ash-slag geopolymer. The ratio of fly ash to slag and the activator concentration always result to be significant factor. The influence of curing temperature in the development of the strength of the pastes is lower than the contribution due to other factors. At 28 days of reaction, the mixture of 50% fly ash and 50% slag activated with 10 M NaOH and cured at 25°C developed a compressive strength of about 50 MPa. Deb et al. (2014) blended ground granulated blast furnace slag with class-F fly ash and experimented on compressive strength and stated that strength development of the geopolymer concrete mixtures slowed down after the age of 28 days and continued to increase at slower rates until 180 days of age and the compressive strength increases with the increase of slag content in the mixtures. Rajini and Rao (2014) studied the effect of fly ash and slag on mechanical properties of geopolymer concrete and the results reveals that the compressive strength increases with slag content and curing period. Nath and Sarker (2014) experimented on effect of slag on compressive strength of fly ash geopolymer and concluded that variation of the amount of alkaline activator affects the compressive strength of the mixtures. An increase in the activator solution content from 35% to up to 45% gradually reduced the strength of geopolymer concrete and mortar.

3 EXPERIMENTAL PROGRAMME

3.1 Materials

The raw materials used for this research work are fly ash, ground granulated blast furnace slag and sodium hydroxide. The fly ash was collected from captive power plant and granulated blast furnace slag was collected from slag granulation plant of the Rourkela Steel Plant (RSP), Sundargarh, Odisha. The materials were dried in oven to remove the water present in raw material. The fly ash had grayish white colour. GGBFS was in a ball mill to increase the fineness. The materials have been sieved through 75 µm. The fineness value of the slag was 410 m^2/kg. NaOH flakes with 98% purity was used as alkaline activator and obtained from Loba chemie. The chemical compositions for the raw materials are given in Table 1.

Table 1 Chemical composition of fly ash and slag

Composition (%)	Fly ash	Slag
MgO	1.7	9.52
Al_2O_3	28.1	21.06
SiO_2	53.6	30.82
K_2O	1.97	1.04
P_2O_5	1.72	-
CaO	2.65	32.02
Fe_2O_3	1.8	1.37
Na_2O	0.5	0.088
MnO	0.3	0.14
TiO_2	0.85	1.04
SO_3	-	0.66
V_2O_5	-	-
Loss on Ignition	6.5	1.81

The XRD patterns and SEM image of fly ash and slag are shown in Fig.1 and Fig.2 respectively. The predominant constituents in fly ash are silicon dioxide, and aluminium oxide. From the XRD test result of slag it is observed that the slag is glassy material with some alumina and silica compounds. The microstructure for fly ash reveals that most of the particles are spherical structure with few irregular particles whereas slag contains rough and angular shaped particles.

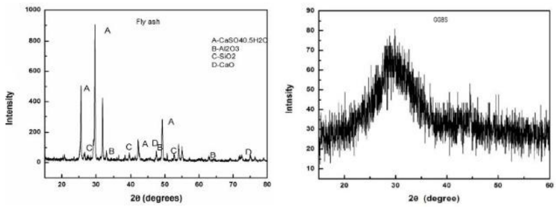

Fig. 1 XRD patterns of fly ash and GGBS

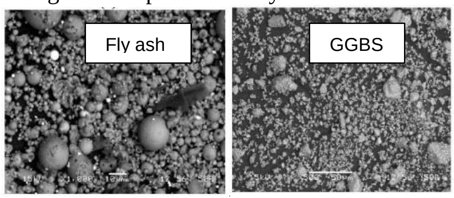

Fig. 2 SEM images of fly ash and GGBS

3.2 Specimen preparation and curing

3.2.1 *Activator solution*

The sodium hydroxide solution was prepared by dissolving the flakes in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molarity (M). For instance, NaOH solution with a concentration of 1M consisted of 1x40 = 400 grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The NaOH solution was prepared before 24 hours of sample preparation to ensure proper dissolution of the sodium hydroxide flakes. The concentrations of the sodium hydroxide solution used were 2, 4, 8, 12 and 16 M.

3.2.2 *Preparation of fresh mortar*

A total 6 fly ash-slag mixtures were prepared by varying fly ash content of the mixture from 0 to 100% at 20% intervals. The NaOH solutions of different concentrations are added to the solid fly ash-slag mixtures by varying the solution to solid ratios of 0.25, 0.3, 0.35, 0.4 and 0.45 ml/g. The solids and solutions were mixed for at least for 1 minute to achieve homogeneity.

3.2.3 *Preparation of specimen*

For each binder, cylindrical specimens with a 2:1 aspect ratio were prepared. The fresh paste of NaOH activated fly ash-slag mixture was rapidly poured into cylindrical PVC molds and vibrated for 2 minutes on vibrating table to remove the air voids. The molds were sealed from the atmosphere and after 24 hours the specimens were demolded. Immediately after demolding, the test specimens were covered with plastic film to minimize the water evaporation during curing.

3.3 Compressive strength

The unconfined compressive strength tests of the specimens were conducted to determine the compressive strength of binder. For each mix proportion and each curing period, three identical specimens were prepared and the average of the strengths was reported as the compressive strength of the mix. Specimens are tested to determine the average compressive strength at the ages of 7 and 28 days. All specimens were prepared, cured and tested under ambient temperature.

4 RESULTS AND DISCUSSION

4.1 Effect of alkali concentration

The variation of 28 days compressive strength with varying molar concentrations of NaOH solution keeping the solution to solid ratio of 0.35 as constant are shown in Fig. 3. From the strength results obtained, it is seen that the alkali concentration played a vital role in strength achievement. As the NaOH concentration increases, the strength increases significantly up to 8 M beyond that a declination in strength is observed when the concentration increases further from 8 M to 16 M. The development in strength is mainly governed by the amount of leachable alumino-silcates. At higher concentration of NaOH excess leaching of silica hinders the geopolymerization process and hence the strength gain.

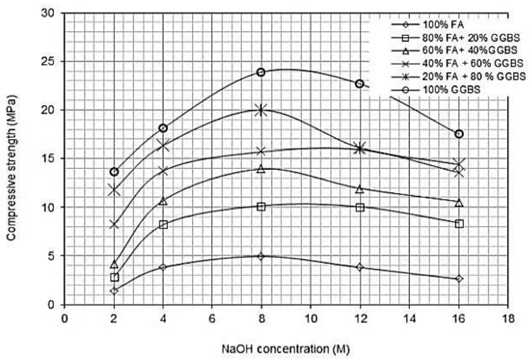

Fig. 3 Variation of 28 days compressive strength with NaOH concentration

4.2 Effect of solution to solid ratio

Fig. 4 shows variations in 28 days compressive strength with activator solution to binder solid ratio for 8 M NaOH concentration. It is observed that solution to solid ratio in the paste affects the compressive strength up to some extent. The strength gain is highest for a particular solution to solid ratio for all the mixtures. Beyond this ratio, strength gain gets hampered. This may be due to excess Na+ ions in the framework. For most of the fly ash rich mixtures, a particular solution to solid mixture of 0.3 gives higher compressive strength and the same is obtained for 0.35 in slag rich mixtures.

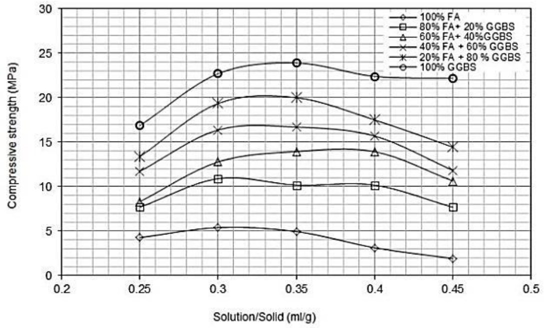

Fig. 4 Variation of 28 days compressive strength with solution/solid ratio

4.3 Effect of GGBS on the compressive strength

The compressive strength for the geopolymer binders are also significantly affected by the slag content in the mixture. Fig. 5 presenting the 28 days compressive strength for all the fly ash-slag mixture with varying slag content for 8 M NaOH. The increased slag content in the mixture resulted in increased compressive strength. This is for the reason that slag contains mostly reactive aluminosilicates. Furthermore, oxides of calcium present in GGBS plays vital role in strength gain.

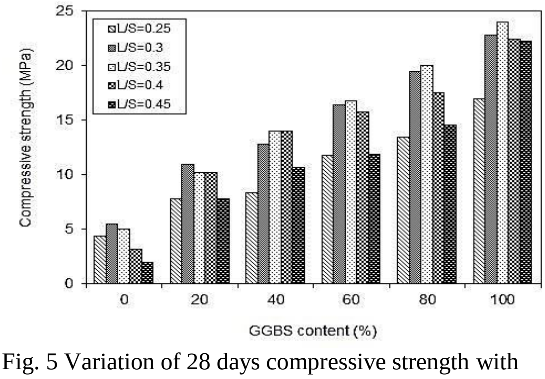

Fig. 5 Variation of 28 days compressive strength with GGBS content

4.4 Effect of curing period on the compressive strength

The development of strength at the age of 7 days and 28 days are shown in Fig. 6 where the NaOH concentration and solution to solid ratio of 8 M and 0.35 ml/g respectively are kept constant. Curing period plays an important role in the development of compressive strength. Most of the GGBS rich specimens gained 85% of 28 days strength at the age of 7 days.

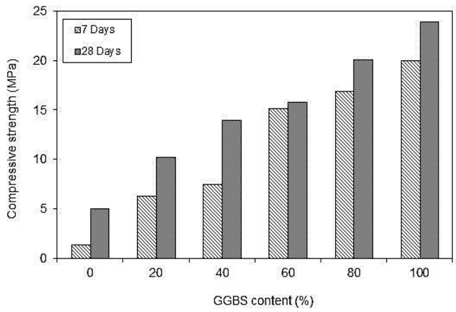

Fig. 6 Development of compressive strength with curing period

5 CONCLUSIONS

The following conclusions can be drawn from this experimental study:

1. The compressive strength increases up to 8M NaOH concentration after which showed a declination in strength gain.
2. For most of the fly ash rich mixtures, maximum compressive strength is achieved at lower solution to solid ratio compared to slag rich mixtures.
3. The compressive strength of geopolymer mortar increases as the GGBS content is increased.
4. The strength gain increases as the curing period increases from 7 days to 28 days.
5. The use of locally available waste materials such as GGBS and FA could be used for development of sustainable binding material.

References

Chi, M., and Huang, R. (2013) ‘Binding mechanism and properties of alkali-activated fly ash/slag mortars’, *Construction and Building Materials*, 40, pp291-298.

Deb, P. S., Nath, P., and Sarker, P. K. (2014) ‘The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature’, *Materials & Design*, 62, pp32-39.

De Silva, P., Sagoe-Crenstil, K. and Sirivivatnanon, V., (2007) ‘Kinetics of geopolymerization: role of Al_2O_3 and SiO_2’, *Cement and Concrete Research*, 37(4), pp512-518.

Duxson, P., Fernández-Jiménez, A., Provis, J.L., Lukey, G.C., Palomo, A. and Van Deventer, J.S.J., 2007. Geopolymer technology: the current state of the art. Journal of Materials Science, 42(9), pp.2917-2933.

Duxson, P.S.W.M., Mallicoat, S.W., Lukey, G.C., Kriven, W.M. and Van Deventer, J.S.J. (2007) ‘The effect of alkali and Si/Al ratio on the development of mechanical properties of metakaolin-based geopolymers’, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 292(1), pp8-20.

Li, Z., and Liu, S. (2007) ‘Influence of slag as additive on compressive strength of fly ash-based geopolymer’, *Journal of Materials in civil engineering*, 19(6), pp470-474.

Marjanovic, N., Komljenovic, M., Bascarevic, Z., Nikolic, V., and Petrovic, R. (2015) ‘Physical–mechanical and microstructural properties of alkali-activated fly ash–blast furnace slag blends’, *Ceramics International*, 41(1), pp1421-1435.

Nath, P., and Sarker, P. K. (2014) ‘Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition’, *Construction and Building Materials*, 66, pp163-171.

Partha, S. D., Pradip, N., and Prabir, K. S. (2013) ‘Strength and permeation properties of slag blended fly ash based geopolymer concrete’, *Advanced Materials Research, Trans Tech Publications*, 651, pp168-173..

Puertas, F., Martıinez-Ramıirez, S., Alonso, S., and Vazquez, T. (2000) ‘Alkali-activated fly ash/slag cements: strength behaviour and hydration products’, *Cement and Concrete Research*, 30(10), pp1625-1632.

Rajini B., Narasimha Rao A.V. (2014) ‘Mechanical Properties of Geopolymer Concrete with Fly Ash and GGBS as Source Materials’, ***I**nternational Journal of Innovative Research in Science, Engineering and Technology*, 3(9).

Wardhono, A., Law, D. W., and Molyneaux, T. C. (2012) ‘Strength of alkali activated slag and fly ash-based geopolymer mortar’, *Proceedings of Microstructural-related Durability of Cementitious Composites, Microdurability*.

Wardhono, A., Law, D. W., and Strano, A. (2015) ‘The strength of alkali-activated slag/fly ash mortar blends at ambient temperature, *Procedia Engineering*, 125, pp650-656.