SYNTHESIS OF FLY ASH-GGBS BLENDED GEOPOLYMER COMPOSITS

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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 (FA) blended with ground granulated blast-furnace slag (GGBS) 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 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. Marjanovic, Komljenovic, Bascarevic, Nikolic and Petrovic (2015) tested the compressive strength of blast furnace slag-fly ash blended mortars. The strength is highly depended on the blend composition, activator concentration and water/binder ratio. Wardhono, Law and Strano (2015) investigated the strength of alkali activated slag/fly ash (AASF) mortar blends. AASF specimen test results suggest that the hydration reaction of slag and the polymerization reaction of fly ash could occur separately or simultaneously. The simultaneous reaction is the most likely with the GGBS reaction activating the fly ash, enabling it to react at room temperature.

3 EXPERIMENTAL PROGRAMME
3.1 Materials

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
Loss on Ignition	6.5	1.81

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. The slag was ground in a ball mill to increase the fineness to enhance the reactivity of the material. 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, Mumbai. The chemical compositions for the raw materials are given in Table 1.

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.

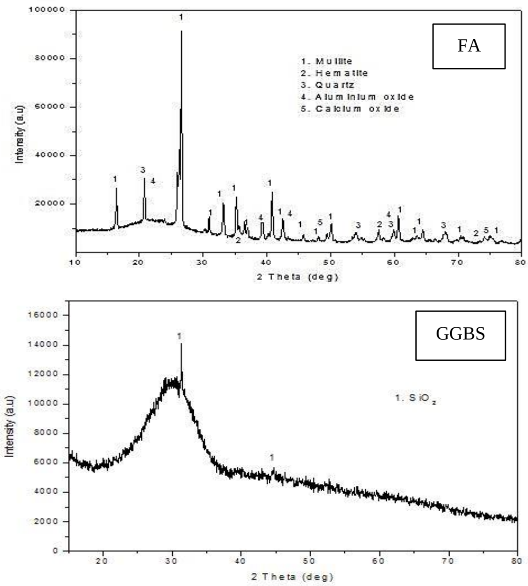

Fig. 1 XRD patterns of fly ash and GGBS

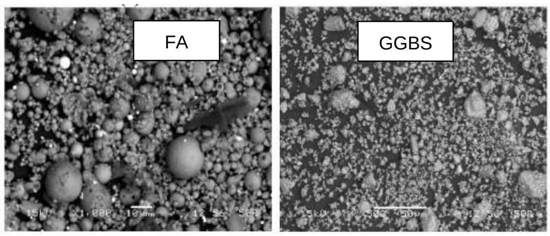

Fig. 2 SEM images of fly ash and GGBS

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 Unconfined compressive strength

The unconfined compressive strength (UCS) 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 unconfined compressive strength with varying molar concentrations of NaOH solution keeping the solution to solid ratio of 0.35 ml/g 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. The development in strength is mainly governed by the amount of leachable alumino-silcates which is high for 8 M NaOH concentration. But, at a higher concentration (when the NaOH concentration increases from 8 M to 16 M) of NaOH excess leaching of silica obstructs further leaching and geopolymerization process. Hence a reduced strength is obtained.

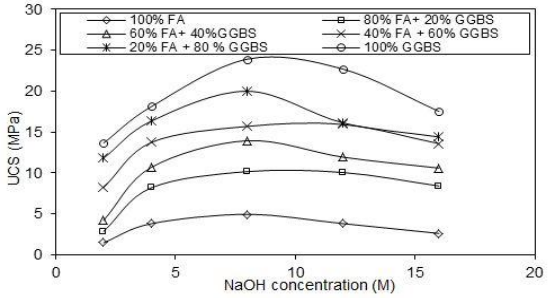

Fig. 3 Variation of 28 days UCS value with NaOH concentration

4.2 Effect of solution to solid ratio

Fig. 4 shows variations in 28 days unconfined 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 is maximum for a particular solution to solid ratio for all the mixtures. Beyond this ratio, strength improvement gets hampered. This may be due to excess Na^+ ions (at higher solution to solid ratio) in the matrix which disturbs the geopolymer structure. As the polymer structure comprises of SiO_4 and AlO_4 tetrahedral anions, and the positive charges of the Na^+ ions compensates the negative charge of Al^{3+}, an excess of Na^+ ions hinders the framework. For most of the fly ash rich mixtures, a particular solution to solid mixture of 0.3 gives higher strength and the same is obtained for 0.35 in slag rich mixtures.

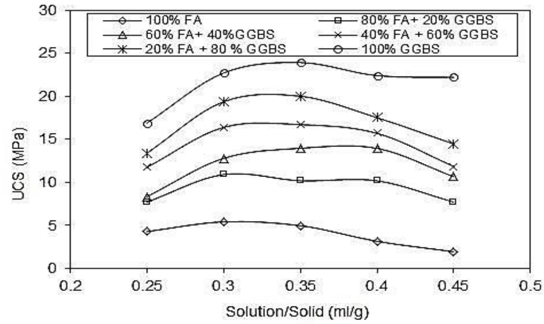

Fig. 4 Variation of 28 days UCS value with solution/solid ratio

4.3 Effect of GGBS

The compressive strength for the geopolymer binders are also significantly affected by the slag content in the fly ash-slag mixture. Fig. 5 presents the 28 days unconfined 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 strength. This is for the reason that the high reactive contents of alumino-silicates in slag are primarily responsible for increased strength. Furthermore, oxides of calcium present in slag plays vital role in strength improvement.

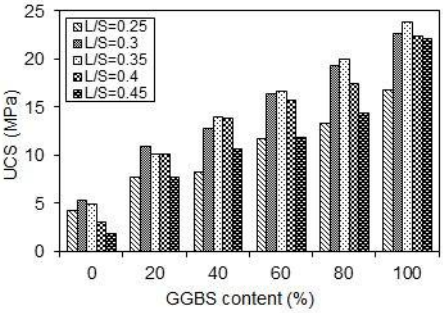

Fig. 5 Variation of 28 days UCS value with GGBS content

4.4 Effect of curing period

The development of unconfined compressive 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 is a parameter which influences the strength development performance. Most of the slag rich specimens gained 85% of 28 days strength at the age of 7 days.

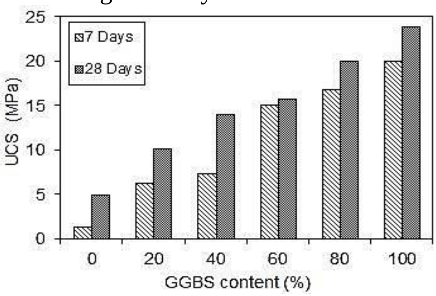

Fig. 6 Development of UCS value with curing period

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.
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 improves with increased curing period 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.

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