PREDICTION OF SETTING AND STRENGTH CHARACTERISTIC OF BINARY BLENDED GEOPOLYMER MATRIX

By

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ABSTRACT

The production of cement generates large amount of carbon dioxide. Normally, conventional concrete is manufactured with Portland cement, which acts as a binder. The production of cement emits CO_2 into the atmosphere, which is a greenhouse gas and causes environmental pollution. In view of this, there is a need to develop sustainable alternatives to Portland cement utilizing the industrial by-products, such as fly ash, Ground Granulated Blast furnace Slag (GGBS) which are pozzolonic in nature. It has been established that fly ash can replace the cement partially. In this context, a new material was developed known as "Geopolymer".

In this study, various parameters on the short term engineering properties of fresh and hardened properties of Geopolymer Mortar were studied. In the present investigation, cement is replaced by geopolymer source material (fly ash and GGBS) and water is replaced by alkaline activator consisting of Sodium Silicate and Sodium Hydroxide of molarity (12 M). The ratio of sodium silicate to sodium hydroxide adopted was 2.5. The test results showed that final setting time decreases as the GGBS content in the mix increases and also these is increase in compressive strength.

Keywords: Geopolymer Mortar, Normal Consistency, Setting Times, Fly Ash, GGBS.

INTRODUCTION

Concrete is one of the widely used man made construction materials. Concrete is conventionally produced by using the Ordinary Portland Cement (OPC) as the primary binder, that holds all the material of concrete together. However, the utilization of cement has environmental impacts that are caused during its production. Production of cement is not only energy intensive, but also responsible for emission of carbon dioxide (CO_2) in large quantity. The production of cement tends to release CO_2 with the burning of limestone was proximate to one ton of the production of one ton of OPC. The quantity of CO_2 produced due to cement manufacturing contributes to about 7% of the total release of CO_2 to the atmosphere.

The demand of concrete has been enormously increasing day by day due to the boom in infrastructure and housing sectors in construction industry. The increase in the demand of concrete increases the demand for cement simultaneously increasing the environmental impacts. Considering the environmental issues linked with the production of Portland cement, its use in concrete as a binder is under critical review. Due to the emission of greenhouse gases in the production of OPC, there is a need to optimize the usage of cement. One such technique is to replace the cement with pozzolanic materials and an entire retrieving is always preferable. So, it is very much essential to find an alternative material to cement in order to produce the concrete that is eco-friendly. Geopolymer concrete is one such material. Geopolymer has emerged to be promising in the field of construction and building materials.

Geopolymer has the potential to replace OPC in the construction sector. Geopolymer is used as the binder to completely replace OPC in producing geopolymer concrete. So as to produce geopolymer, fly ash and GGBS are to be mixed with an alkaline solution to produce polymeric Si-O-Al bonds. The alkaline solution is the combination of sodium hydroxide and sodium meta silicate. GPC has the ability to decrease the emission of greenhouse gases from concrete industry by about 80%.

The objective of the present study is to determine the consistency of geopolymer matrix, initial setting time, final setting time, and compressive strength of geopolymer matrix blended with two mineral admixtures, viz., Fly ash and Ground Granulated Blast Furnace Slag.

1. Literature Review

Al Bakria et al. (2011) concluded that fly ash based geopolymers required heat to increase the geopolymerization process in order to obtain higher compressive strength. The results revealed that the maximum compressive strength (67.04 MPa) was obtained at a temperature of 60 °C.

Davidovits (1991) conlcuded that the geopolymer materials can polycondense just like organic geopolymers at temperatures lower than 100 °C. This new generation of materials, whether used pure, with fillers or reinforced is already finding applications in all fields of industry.

Hardjito et al. (2008a) revealed that as the concentration of alkaline activator increases, the compressive strength of Geopolymer mortar also increases. Specimens cured at temperature of 65 °C for 1 day showed the highest 28 days compressive strength. The mass ratio of activator/fly ash of 0.4 produced the highest 28 days compressive strength for the specimen. The obtained compressive strength was in the range of 1.6 MPa - 20 MPa.

Hardjito and Tsen (2008b) concluded that as the concentration of KOH increases, the compressive strength of geopolymer mortar increases. They found that geopolymer posses superior thermal stability atleast upto 800 °C. The setting time of geopolymer was found dependent on the alkaline solution.

Jeyasehar et al. (2013) revealed their objective is to improve the quality of geopolymer mortar through special treatments and study the property, particularly the acid resistance. The durability tests, such as water absorption test and acid resistance test (HCl and H_2SO_4) were also conducted. The main focus of the investigation is on optimum utility of the available fly ash and minimizing the water absorption and attaining high compressive strength.

Khan (2004) revealed that Fly ash Brick (FAB) is a building material, specifically masonry units, containing class C fly ash and water, compressed at 28 MPa and cured for 24 hrs in a 66 °C steam bath, then toughened with an air entrainment agent, the bricks last for more than 100 freeze-thaw cycles.

Radhakrishna et al.'s (2008) test results revealed that the increase in fluid to binder ratio showed increase in compressive strength up to certain extent thereafter it showed decrease in compressive strength and geo-polymer paste did not set at room temperature, which indicates that curing temperature plays an important role in the geo-polymerization. The geopolymer mortar setting time is much faster when it is cured at elevated temperature (Oven curing), whereas in case of sunlight curing, setting time is comparatively better with respect to ambient curing.

Sabna et al. (2014) aimed at developing fibrous geopolymer in order to study its strength properties under heat and ambient curing. Based on the results obtained, the heat cured fiber reinforced geopolymer composite with 0.5% fibre was found to be have superior strength.

Sahana (2013) reported on the study of the processing of geopolymer using fly ash, GGBS and alkaline activator with geopolymerization process. The geopolymer pastes were prepared using different binder combinations mixed with the alkaline solution. The setting time of geopolymer paste increases with the increase of GGBS content and then decreases. However, the compressive strength of the paste increases with the increase in GGBS content. The compressive strength of the paste was found to be as high as 57.6 MPa at the age of 28 days, which was cured in ambient conditions. The microstructure of the paste showed formation of new amorphous alumina- silicate and calcium silicate hydrates.

Temuujin et al. (2009) studied the effect of the mechanical activation of fly ash on the properties of the geopolymers cured at ambient temperature. They concluded that mechanical activation of the fly ash results in the particle size and morphology changes with concomitant increase in reactivity with alkaline liquid.

Thampi et al. (2014) presented the mechanical properties with emphasis on compressive strength and tensile strength of geopolymer mortar at ambient and heat curing for construction of a geopolymer water tank.

2. Materials Used

Materials used in this work are fly ash procured from Vijayawada Thermal Power Station (VTPS) in Vijayawada, Class F with a specific gravity of 2.65 Ground Granulated Blast Furnace Slag (GGBS) was obtained from Vizag Steel Plant with a specific gravity of 2.86. The chemical compositions of fly ash and Ground Granulated Blast Furnace Slag are tabulated in Table 1.

River sand is used as Fine aggregate. They were tested as per IS:2386 standards. Saturated surface dry specific gravity of sand is 2.67 which confirms to zone III as per BIS: 383-198.

2.1 Alkaline Solution

The solution of Sodium Hydroxide and Sodium Silicate (Water Glass) is used as an alkaline solution in the present study. Sodium hydroxide of 98% purity is in flakes and pellets form and was shown in Figure 1. These pellets/flakes are dissolved in distilled water to obtain sodium hydroxide solution of required molarity and was shown in Figure 2. The sodium silicate solution in liquid form was shown in Figure 3. The ratio of mass of Silicon Dioxide to Sodium Oxide of the Na_2SiO_3 solution is 2.5 (Silicon Dioxide = 34.16%, Sodium Oxide = 13.72%, and Water = 47.2%). NaOH solution of required molarity and Na_2SiO_3 in liquid form are mixed and stored at room temperature of $24\pm2\,^{\circ}C$ for 24 h prior to casting.

S. No.	Composition	Fly Ash	GGBS
1.	Silicon Dioxide (SiO_2)	66.80	39.18
2.	Aluminum Oxide (Al_2O_3)	24.50	10.18
3.	Iron Oxide (Fe_2O_3)	4	2.02
4.	Calcium Oxide (CaO)	1.50	32.82
5.	Magnesium Oxide (MgO)	0.45	8.52
6.	Sodium Oxide (Na_2O)	0.40	1.14
7.	Potassium Oxide (K_2O)	0.22	0.30

Table 1. Chemical Composition of Fly Ash and GGBS

2.2 Mortar Preparation

Geopolymer Mortar can be prepared by using the conventional techniques used in the manufacture of Portland Pozzolana Cement (PPC). Fly ash and GGBS were mixed together in different proportions in dry condition in a mixer. The binder first ensures homogeneity by uniform

Figure 1. Sodium Hydroxide (NaOH) in Pellets Form

Figure 2. Sodium Hydroxide Solution

Figure 3. Sodium Silicate Solution

color. A series of dry components are mixed together in a mixer for 1 to 2 minutes to ensure compatibility of the mixture. Later, the alkaline solution which consists of mixture of Sodium Hydroxide and Sodium Silicate of required molarity is added to the binder and is mixed for 10 minutes. The mixing process is to be done at a room temperature of $\pm$25 °C. The ratio of binder to fine aggregate is 1:1 and alkaline liquid to binder ratio adopted was 0.4. Table vibrator is used for compaction of the mortar. Cast Iron moulds of dimensions 100 x 100 x 100 mm are used for casting cube mortar specimens. The specimens are demolded after 24 h of casting and cured in outdoor curing, specimens are left out in outdoor environment (temperature-35$\pm$2 °C) up to testing.

3. Determination of Normal Consistency and Setting Times

As per BIS: 4031 (Part IV-1988), normal consistency of cement is determined by using the Vicat's apparatus. Similar procedure is adopted for testing geopolymer material.

As per BIS:4031 (Part V-1988), initial and final setting time of cement is determined by using the Vicat's apparatus. Similar procedure is adopted for testing the geopolymer material.

Final setting time of geopolymer paste was determined with the help of Vicat's apparatus taking 500 g of binder combinations (fly ash and GGBS) and 0.85 times of alkaline activator to produce geopolymer paste of normal consistency (0.85 P). Three cubes of each geopolymer mortar set with dimensions 100 × 100 × 100 mm are cast and tested in compression to determine 28-day compressive strength.

4. Discussions

4.1 Normal Consistency

From Table 2 and Figure 4 it can be observed that GPC paste with 100% fly ash need less alkaline solution than GPC paste with 100% GGBS. This is due to the dense and strong microstructure of the interfacial aggregate/binder transition zone are probably responsible. In case of intermediate mixes, increase in GGBS content resulted in increased normal consistency value.

The reason for this behavior can be attributed to the fact that fly ash particles are spherical and exhibit less internal friction, allowing free movement of Vicat's plunger for lower alkaline activator content.

S. No.	Mix (Fly Ash+GGBS)	Percentage of Alkaline Activator Required to Produce Geopolymer Paste (p)
1.	F_{100}	27
2.	$F_{90}+G_{10}$	29
3.	$F_{80}+G_{20}$	30
4.	$F_{70}+G_{30}$	31
5.	$F_{60}+G_{40}$	33
6.	$F_{50}+F_{50}$	33
7.	$F_{40}+G_{60}$	35
8.	$F_{30}+G_{70}$	35
9.	$F_{20}+G_{80}$	37
10	$F_{10}+G_{90}$	37
11.	G_{100}	39

Table 2. Normal Consistency of Geopolymer Paste of NaOH Molarity 12

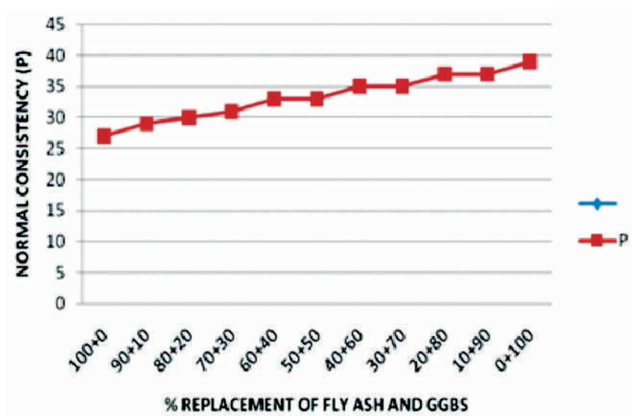

Figure 4. Showing Variation in Normal Consistency with % Increase in % Replacement of GGBS

4.2 Final Setting

The procedure adopted to find the GPC final setting time is as same as for the Ordinary concrete. The variation of final setting time of geopolymer with the variation in concentration of sodium hydroxide in alkaline activator for different mixes of fly ash and GGBS is presented in Table 3 and Figure 5. The final setting time of different mixes considered in this investigation varied from 235 to 50 min.

4.3 Compressive Strength

From Table 4 and Figure 6 it can be concluded that as the percentage of GGBS increases the compressive strength also increases. The reason behind this is due to higher calcium content present in the Ground Granulated Blast Furnace Slag i.e., GGBS.

Conclusions

- Higher amounts of fly ash content decreases the final setting times of geopolymer mortar.
- Compressive strength is higher as the percentage replacement of GGBS increases.
- The strength of Geopolymer paste increases with the increase of GGBS.
- GPC Paste with 100% fly ash needs less alkaline solution than GPC paste with 100% GGBS. This is due to fly ash particles are spherical, while GGBS are flaky and rough texture.
- Overall effect of Fly Ash, GGBS on standard consistency, initial and final setting times is to retard the setting time. The influence of increasing the levels of GGBS is to provide greater retardation in the setting time, due to less content of C_3A.

S. No.	Mix (Fly Ash+GGBS)	Final Setting Time (Minutes)
1.	F_{100}	235
2.	$F_{90}+G_{10}$	150
3.	$F_{80}+G_{20}$	135
4.	$F_{70}+G_{30}$	125
5.	$F_{60}+G_{40}$	110
6.	$F_{50}+F_{50}$	100
7.	$F_{40}+G_{60}$	85
8.	$F_{30}+G_{70}$	70
9.	$F_{20}+G_{80}$	65
10	$F_{10}+G_{90}$	50
11.	G_{100}	50

Table 3. Final Setting Time of Geopolymer Paste of NaOH Molarity 12

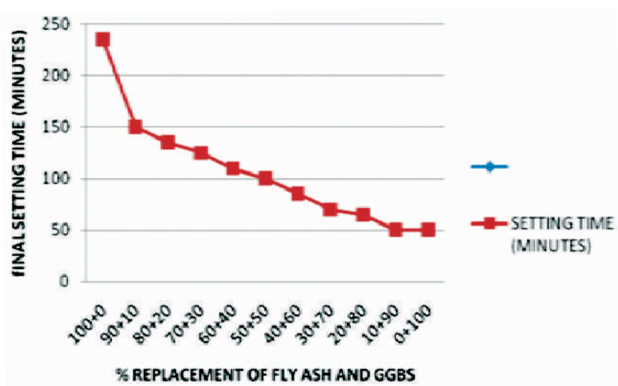

Figure 5. Variation of Final Setting Times with % Increase in % Replacement of GGBS

S.No	Mix (Fly Ash+GGBS)	Compressive Strength (Mpa)
1.	F_{100}	41
2.	$F_{90}+G_{10}$	43
3.	$F_{80}+G_{20}$	44
4.	$F_{70}+G_{30}$	46
5.	$F_{60}+G_{40}$	50
6.	$F_{50}+F_{50}$	53
7.	$F_{40}+G_{60}$	57
8.	$F_{30}+G_{70}$	63
9.	$F_{20}+G_{80}$	66
10	$F_{10}+G_{90}$	75
11.	G_{100}	76

Table 4. Compressive Strength of Geopolymer Mortar Cubes of NaOH Molarity 12 in Ambient Curing after 28 Days

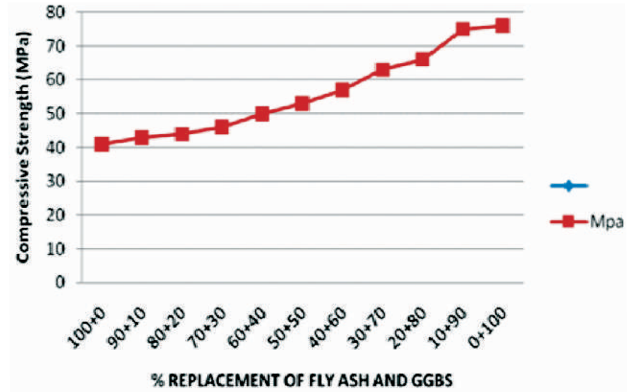

Figure 6. Variation in Compressive Strengths with Increase in % Replacement of GGBS

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