Effect of Ground Granulated Blast Slag and Temperature Curing on the Strength of Fly Ash-based Geopolymer Concrete

Anil Kumar
Motihari College of Engineering, Motihari, India
anil.20688@gmail.com (corresponding author)

Rajkishor
Bhagalpur College of Engineering, Bhagalpur, India
rk.bce22@gmail.com

Niraj Kumar
Motihari College of Engineering, Motihari, India
nirajdsi10@gmail.com

Anil Kumar Chhotu
Motihari College of Engineering, Motihari, India
akcjucivil@gmail.com

Bhushan Kumar
Government Engineering College, Vaishali, India
bhushanmit08@gmail.com

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ABSTRACT

Concrete is used most extensively after water to meet construction requirements. Since the population is increasing day by day, the demand for concrete will always increase, hence, the demand for cement will also increase. The production of cement requires a lot of energy and emits greenhouse gases into the environment. Therefore, an alternative material for cement concrete is required. Geopolymer concrete (GPC) is an alternative to cement made of aluminosilicate materials such as fly ash, Ground Granulated Blast Slag (GGBS), silica fume, metakaolin, etc. If these materials are activated with an alkaline activator, then a bond that is responsible for the strength develops. GPC made with fly ash needs temperature curing to develop its strength, which limits its use on a large scale. In this study, a mix ratio of GPC equivalent to conventional M20 concrete was obtained at ambient curing conditions. The effect of temperature curing was also studied. GPC was prepared in three different mixes. In each mix, the binder content was changed by varying the fly ash and GGBS content. Two sets of cube, beam, and cylindrical samples were prepared from each mixture. One set was cured at ambient temperatures and the other at increased temperatures. The temperature-cured specimens provided higher strength than the ambient-cured. If a strength equivalent to conventional M20 concrete is required for ambient curing, then the mix should be 70% fly ash and 30% GGBS, and the ratio of binder, fine aggregate, and coarse aggregate should be 1:1.5:3.

Keywords-ambient curing; compressive strength; GGBS; geopolymer concrete; fly ash; temperature curing

I. INTRODUCTION

The demand for a substitute for cement is increasing due to the environmental pollution associated with its production. Cement production is responsible for 5-9% of global CO_2 emissions [1-5]. Cement production requires raw materials, such as limestone, which is a non-renewable resource. With the increasing development of infrastructure, concrete has become the second most consumed material after water [6]. At the same time, the world faces environmental issues due to the disposal of industrial waste such as fly ash, Ground Granulated Blast Slag (GGBS), silica fume, rice husk ash, etc. Disposed industrial waste causes land degradation. Therefore, it is important to find an application for this industrial waste in the construction sector, as such an application will promote sustainable development. One of the alternate materials for cement concrete is geopolymer concrete (GPC), which uses industrial waste such as fly ash, GGBS, and silica fume as binding materials (aluminosilicate materials). GPC has good engineering properties [7-11]. GPC is prepared with fine aggregates, coarse aggregates, aluminosilicate materials, and alkaline activators. The best combination of alkaline activators is the combination of sodium hydroxide and sodium silicate solution [12]. The concentration of alkaline activators also affects the properties of GPC [13], along with curing time, curing temperature, and admixture content [14-17]. In the case of conventional concrete, the C-S-H gel is responsible for the formation of a bond. However, in the case of GPCs, polymerization is responsible for the formation of the bond. GPC has good performance even at elevated temperatures [18-20]. Since temperature-curing improves the strength of GPC [21-27] and GPC has less strength at ambient curing, this may be a drawback to its use on a large scale. Therefore, if GPC is to be used on a large scale, it is necessary to prepare it to have good strength even at ambient curing. If GGBS is used along with fly ash as a binding material, then the strength of GPC may be good even at ambient curing.

In this study, a mixture of GPC was obtained that had a strength similar to conventional M20 grade concrete even in ambient curing, using fly ash and GGBS as binding materials. Three different mixes were prepared using varying percentages of fly ash and GGBS. Cubical (150×150×150 mm), beam (100×100×500 mm), and cylindrical (150×300 mm) samples were prepared using the different mixtures. Half of the samples from each mix were provided ambient-curing and the other half were provided temperature-curing for comparison. After 28 days, compressive strength, flexural strength, and split tensile strength were evaluated for the samples prepared from each mix. The results showed that the mix with 70% fly ash and 30% GGBS had a strength similar to the conventional M20 grade concrete. As expected, the temperature-cured samples had higher strength compared to ambient-cured samples.

II. MATERIALS

A. Fly Ash

The combustion of pulverized coal in power plants produces a thin, powdery waste known as fly ash. Fly ash is made up of mineral granules that are expelled from the boiler by the hot gases. Electrostatic precipitators and cloth filter baghouses are used to capture and recycle these particles. Using fly ash instead of Portland cement, can reduce the environmental impact of building materials such as concrete and greenhouse gas emissions. Fly ash can be used to make bricks, blocks, and even road bases. For this study, fly ash was obtained from the Kanti thermal power plant, in Muzaffarpur, Bihar, India.

B. Ground Granulated Blast Slag (GGBS)

GGBS is a waste product of the blast furnace process, which involves melting iron ore, coke, and limestone into molten iron. Glassy GGBSs are created when the molten slag is rapidly quenched with water. Most GGBS is made up of calcium-based silicates and alumino-silicates. Lime, alumina, and some other elements are present at trace levels. Physically distinct from Portland cement, it shares many of its chemical characteristics. The use of GGBS leads to improved durability and strength properties.

C. Aggregates and Plasticizer

Fine aggregates from naturally available sand satisfying the criteria of zone II were used. Coarse aggregates having a nominal size of 20 mm (60%) and 10 mm (40%) were used. Since GPC has low workability compared to conventional concrete [24], a plasticizer was used to improve workability.

D. Alkaline Activator

A mixture of sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) solution was used as an alkaline activator. For the preparation of the alkaline activator, NaOH was mixed uniformly with water so that 480 g (12 M molarity) NaOH produced 1 l solution, as shown in Figure 1. The weight of sodium NaOH was taken and 2.5 times Na_2SiO_3 solution was added.

Fig. 1. Preparation of NaOH solution.

III. METHODS

A. Mixing

The ratio of binder, fine aggregates, and coarse aggregates was 1:1.5:3. Fly ash and GGBS were used as binders with varying percentages so that the total binder was the same in all mixes (Figure 2). The alkaline activator to binder ratio was 0.55. Table I shows the details of the mix. A sample ID was assigned for each mix. FA90G10 indicates that fly ash and GGBS were 90% and 10% of the total binder content, respectively. The plasticizer was 1% of the binder content in each mix. Figure 3 shows one of the prepared mix.

B. Casting and Curing

The GPC mix was transferred to cube, beam, and cylinder molds, as shown in Figure 4. From each mixture, 6 cube, 6 beam, and 6 cylinder samples were prepared. Manual and table vibrations were given to the samples to ensure proper compaction. The samples were left to cure for 24 hr. After 24 hr the samples were de-molded and half of each type was temperature-cured for 4 hr at 150 °C (Figure 5). Half of the other samples were left for ambient curing (Figure 6).

Fig. 2. Preparation of dry mix.

Fig. 3. GPC mix.

Fig. 4. Casted GPC specimens.

Fig. 5. Temperature curing of GPC specimens.

Fig. 6. Ambient curing of GPC specimens.

TABLE I. MIX DETAILS OF GPC SPECIMENS

Sample ID	**NaOH (kg/m^3)**	**Na_2SiO_3 (kg/m^3)**	**Binder (kg/m^3)**		**Fine aggregates (kg/m^3)**	**Coarse aggregates (kg/m^3)**	
			FA	**GGBS**		**20 mm**	**10 mm**
FA90G10	85	212	485	54	808	970	646
FA80G20	85	212	431	108	808	970	646
FA70G30	85	212	377	162	808	970	646

C. Testing of GPC Specimens

After 28 days, the samples were subjected to tests to evaluate their compression, flexural, and split tensile strength. The compressive strength test was performed foloowing IS 516:1959. Ambient-cured and temperature-cured cubes were placed in a digital testing machine so that normal stress would develop on the cube. The load was applied at 140 kg/cm^2/min. As the cube sample failed, the failure stress of the samples was taken. The IS 516:2002 guidelines were followed to evaluate the flexural strength. The beams were placed and two-point loading was applied such that the rate of total load application was 180 kg/min. As the samples failed, the failure stresses were taken from the digital flexural testing machine. The IS 5816:1999 was followed to evaluate the split tensile strength of the samples. The cylindrical samples were placed horizontally so that the load would pass through their center. The rate of load application was kept at 2.4 N/mm^2/min. As the sample failed, failure load was taken and split tensile strength was evaluated as:

$$\sigma = \frac{2P}{\pi DL} \tag{1}$$

where σ is the split tensile strength (Mpa), P is the failure load (N), D is the diameter of the cylinder (mm), and L is the length of cylinder (mm). Figure 7 shows the test setups.

IV. RESULTS AND DISCUSSION

Table II shows the test results of the GPC specimens tested after 28 days. Figures 8-10 show a similar trend in compressive strength, flexural strength, and split tensile strength mixes. As the percentage of GGBS increased, the strength of cube, beam, and cylinder specimens increased. Considering the curing conditions, the specimens subjected to temperature curing showed higher strength than those subjected to ambient curing. For ambient cured specimens, the specimen having 70% fly ash and 30% GGBS exhibited a compressive strength similar to the conventional M20 concrete prepared with Ordinary Portlant Concrete (OPC).

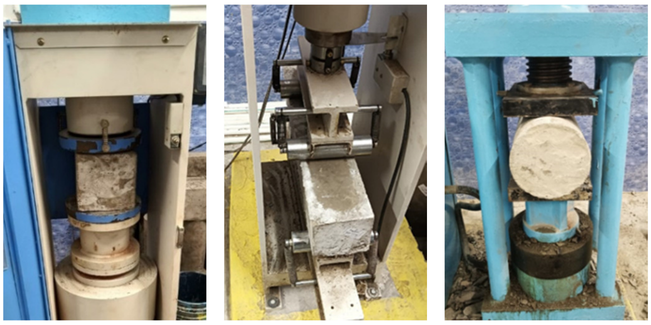
(a) (b) (c)

Fig. 7. Testing the GPC specimens: (a) Compressive strength test, (b) flexural strength test, (c) split tensile strength test.

TABLE II. STRENGTH OF GPC SPECIMENS AFTER 28 DAYS

Sample ID	Compressive strength (Mpa)		Flexural strength (Mpa)		Split tensile strength (Mpa)	
	TC	AC	TC	AC	TC	AC
FA90G10	22.04	17.78	5.85	5.34	2.36	2.10
FA80G20	33.18	20.37	6.36	6.03	3.30	2.26
FA70G30	35.77	24.74	6.97	6.11	3.44	2.69

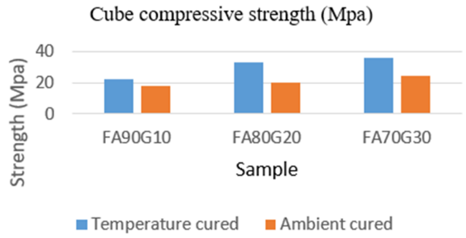

Fig. 8. Comparison of compressive strength of temperature-cured and ambient-cured GPC.

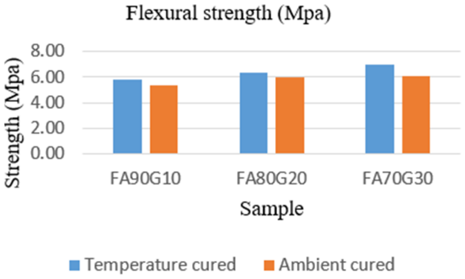

Fig. 9. Comparison of flexural strength of temperature-cured and ambient-cured GPC.

Compressive strength equivalent to conventional M20 concrete can be obtained at ambient temperature if using 70% fly ash and 30% GGBS and keeping the ratio of binder, fine aggregate, and coarse aggregate at 1:1.5:3, respectively. Split tensile strength was found similar to conventional concrete. However, the flexural tensile strength was found to be better (50% higher) than conventional concrete. If temperature curing is not required for GPC, then it can be used on a large scale in the construction industry which will minimize this industrial waste disposal problem and, as a result, reduce environmental pollution. The high strength of GPC prepared under ambient conditions will promote its use and reduce the use of conventional concrete, which will ultimately minimize the use of cement and the emission of greenhouse gases from the cement industry.

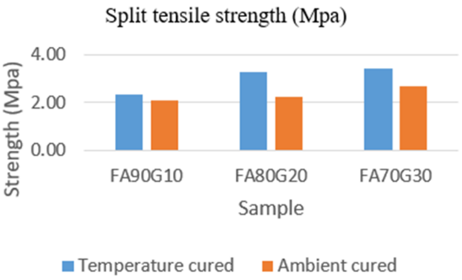

Fig. 10. Comparison of split tensile strength of temperature-cured and ambient-cured GPC.

V. CONCLUSION

Based on the experimental work presented, the following conclusions can be drawn:

- Ambient-cured GPC can give a good result if using 70% fly ash and 30% GGBS as a binder. A compressive strength comparable to the M20 grade of conventional concrete can be obtained by keeping the same ratio of nominal mix (1:1.5:3) as conventional concrete.
- If a higher strength of GPC is required at low GGBS content, then temperature-curing should be provided.
- The strength of GPC increases with increasing GGBS content as the binding material.
- The flexural strength of GPC is better (around 50% higher) than conventional concrete with similar compressive strength.
- Its split tensile strength is similar to that of conventional concrete.
- If GPC provides better results even at ambient curing, it will solve the fly ash disposal problem and reduce environmental pollution and greenhouse gas emissions caused by the cement industry.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding this study.

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