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Performance of Geopolymer Concrete using Varying Sizes of Steel Fibres

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Abstract

Background/Objectives: The main objective of the study is focused in producing geopolymer concrete using Ground Granulated Blast furnace Slag (GGBS) with the addition of sodium hydroxide solution. The study also comprises to gain better strength concrete by addition of different sizes of steel fibres (1%). **Methods/Statistical analysis:** In this study, total of six mixes were prepared using alkali activator solution of 8 molarity, different sizes of steel fibres (30 mm and 60 mm) and their combinations were tested to get better mechanical properties. All the specimens were oven cured and tested on 1st, 7th and 28th day. Various tests such as compressive strength, flexural strength and young's modulus of concrete were analysed in this study. **Findings:** Geopolymer concrete specimen has obtained a maximum compressive strength of 41.5 MPa and flexural strength of 7.5 MPa for M30 mix ratio. The addition of steel fibre showed a better improvement when compared to the control mix (plain GPC) and all mixes have achieved the desirable strength. Testing results have also indicated that the addition of shorter steel fibre showed better strength improvement with respect to the reference concrete than the longer steel fibre. **Applications:** It can be used in various applications such as machine foundations, industrial floorings and road pavements.

Keywords: Alkali Activator, GGBS, Geopolymer Concrete, Sodium Hydroxide, Steel Fibres

1. Introduction

The production of cement emits equal amount of carbon dioxide into the atmosphere which leads to various environmental effects. It is also observed that 7% of greenhouse gases are being emitted into the atmosphere yearly on account of production of ordinary Portland cement alone. So due to the following reasons, alternate binding material based geopolymer concrete meets the potential application with respect to the conventional cement based concrete. Among various alternatives such as fly ash, rice husk, copper slag etc. GGBS is considered as a cost effective binding material as only sodium hydroxide is alone used for the geopolymerisation reaction[6] while other material requires sodium silicate in addition. GGBS has also attained magnificent mechanical properties. GGBS along with steel fibres shows shrinkage control on account of expansion of fibres. Also steel fibre incorporation increases elastic modulus, control cracks and reduces brittleness. Many researchers have attained greater strength when using 1% of steel fibre beyond which there is a reduction in strength[3]. In this study, different sizes of steel fibres are used such as 30mm and 60mm in length at 1% in total volume with GGBS as cement replacement. Geopolymer mixtures prepared at 8 M sodium hydroxide was tested at room temperature and the incorporation of fibre percentage of 1% by mortar volume observed higher strength gain properties.

2. Literature review

The previous work done by various researchers discuss about the inclusion of steel fibres. Furthermore, this chapter shows some of the review of literature which is relevant to this project. As per Reference[1] used flyash, GGBS as binder material and Steel fibres and concluded that the result of fracture properties indicates that geopolymer concrete can substitute with the traditional Portland

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cement and also the requirement of water content ratio is less as compared to other concrete.[2] used fly ash, GGBS and Steel fibres and concluded that the compressive strength is increased by 2.25% (approximately) when steel fibres are utilized and Flexural strength of GPC with added fibres is approximately 24% more than control mix.[3] used GGBS, cement and Steel fibre and concluded that 1% of steel fibre in total volume exhibited a higher mechanical performance beyond which there was no phenomenal strength improvement.[4] used GGBS and Steel fibres which conclude that the slag based geopolymer concrete activated by 12 M NaOH showed higher compressive strength and the steel fibres have enhanced the post crack performance of the geopolymerconcrete.[6] used GGBS and Steel fibres and concluded that the addition of alkali activator containing sodium hydroxide alone provided rapid geopolymerisation.

3. Materials used

The geopolymer concrete was acquired by blending distinctive mixes of Ground Granulated Blast furnace Slags (GGBS), fine aggregates, coarse aggregates and Alkali Activator Solution (AAS).

3.1 GGBS

GGBS is a by-product from Iron smelting Industry. It is used as the source material for the production of Geo Polymer Concrete (GPC). The chemical composition of GGBS is described in Table 1.

3.2 Sodium Hydroxide (NaOH)

The most common alkali activator used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate. Leaching of Al_3 + and Si_4 + ions are generally high with sodium hydroxide solution compared to potassium hydroxide solution. Sodium hydroxide (NaOH) in the form of flakes along with water is used as alkaline activators to give a good binding solution for the geopolymeric mix. The alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) and sodium silicate as activators. Alkaline liquid is prepared by mixing water and sodium hydroxide solution with proper proportion. Sodium based solutions were selected because they were cheaper than potassium based solutions. As sodium hydroxide solution produces excessive heat, the activator solution will be prepared 4 to 5 hours prior to the concrete mixing.

Table 1. Chemical composition of GGBS

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	Mn_2O_3	SO_3
GGBS	33.45	13.46	0.31	41.7	5.99	0.16	0.29	0.84	0.40	2.74

3.3 Aggregates

The river sand available in local which is passing through 4.75 mm sieve is used as fine aggregate and crushed stones of size 20 mm is used as coarse aggregate.

3.4 Steel Fibres

Use of hook ended steel fibres of 60mm and 30mm length were used. The fibre is often described by a convenient parameter called aspect ratio. The aspect ratio is the ratio of its length to its diameter. Steel fibres will reduce steel reinforcement requirements, improve ductility, structural strength, reduce crack widths and control the crack widths tightly thus improve durability, improve impact and abrasion resistance The fibre composite pronounced post cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied shock or impact loading. These fibres are short, discrete lengths having an aspect ratio in the range of 20–100, with any cross section that are sufficiently small to be randomly dispersed in an unhardened concrete mixture using usual mixing procedures.

4. Methodology

4.1 Compressive Strength Test

As per [10], the compressive strength test was carried out on hardened concrete cube specimens. The compressive strength is determined for various mixes by testing the specimens in adigital compression machine of 2000 kN capacity operated at a loading rate of 2.5kN/s. Cube specimens of size 100x100x100 mm used to assess the compressive strength various geopolymer concrete. Figure 1 which is shown below clearly indicates the cube specimen subjected to compression testing containing steel fibre incorporation.

Figure 1. Geopolymer concrete specimen subjected to compression testing containing steel fibres.

4.2 Flexural Strength Test

The flexural strength value was obtained using a concrete prism of size 100 x 100 x 500 mm for various geopolymer concrete with and without addition of steel fibres. The specimens after the accelerated curing in the hot air oven for 6 hours is kept in room temperature for 24 hours and tested in a load controlled machine at a loading rate of 2kN/s and subjected to third point loading arrangement and is showed in Figure 2.

4.3 Modulus of Elasticity

In this project, cylinders of size 150 mm in diameter and 300 mm height were tested under uniaxial compression machine. The deformations were measured by means of dial gauge. The deflected value divided by the gauge length gives the strain and load applied by area of cross section will give the stress. A series of readings are taken and the stress-strain relationship is plotted which gives the modulus of elasticity. The test on concrete cylinder specimens were carried out as per[10]. Figure 3 shows the modulus of elasticity testing arrangement.

5. Results and Discussions

5.1 Proportion of Geo polymer Mix

GGBS, coarse and fine aggregate and steel fibres are mixed thoroughly in a dry state and then alkaline solution is added to make the mix wet until it gains homogeneous state. A sodium hydroxide based alkali activator at concentration level of 8 M was used for accelerating the geo polymer reaction. The specimens were cured in hot air oven. In the case of hot air oven curing, the specimens

Figure 2. Flexural strength testing machine - third point loading arrangement.

Figure 3. Young's modulus testing

were transferred to the oven immediately after casting the specimens and kept it at 100°C for 6 hours. Mix proportion and quantity of fibre content in each mix is explained below in Table 2.

5.2 Compressive Strength

The average compressive strength of various geo polymer based concrete mixture with and without incorporation of

Steel fibres at 1st, 7th and 28th day are provided in Table 3 and shown in Figure 4. From the test results obtained, it can be noted that the GGBS based geo polymer mixture can be used as an alternative material to cement concrete. The addition of steel fibres generated an increase in the compressive strength when compared to plain concrete. Mix 5 which consisted of 60% of 30 mm and 40% of 60mm steel fibres produces a maximum compressive strength of about 41.2 MPa and also it have attained the 95% of strength in day 1. From the experiments and

Table 2. Geopolymer mix proportions

Mix ID	GGBS (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Water (lit/m³)	Superplasticizer (lit/m³)	Steel fibres (kg/m³)		NaOH (8M) (kg/m³)
						30mm	60mm	
GPS 1	400	845.9	1107.7	140	8	0	0	320
GPS 2	400	845.9	1107.7	140	8	78.50	0	320
GPS 3	400	845.9	1107.7	140	8	0	78.50	320
GPS 4	400	845.9	1107.7	140	8	39.25	39.25	320
GPS 5	400	845.9	1107.7	140	8	47.10	31.40	320
GPS 6	400	845.9	1107.7	140	8	31.40	47.10	320

Table 3. Test results on compressive strength

Mix Id	Compressive Strength. (MPa)		
	1st day	7th day	28th day
GPS 1	20.4	24.5	30.4
GPS 2	22.3	27.2	34.8
GPS 3	25.4	26.9	31.3
GPS 4	27.1	31.5	36.1
GPS 5	37.5	40.3	41.2
GPS 6	31.0	32.3	36.6

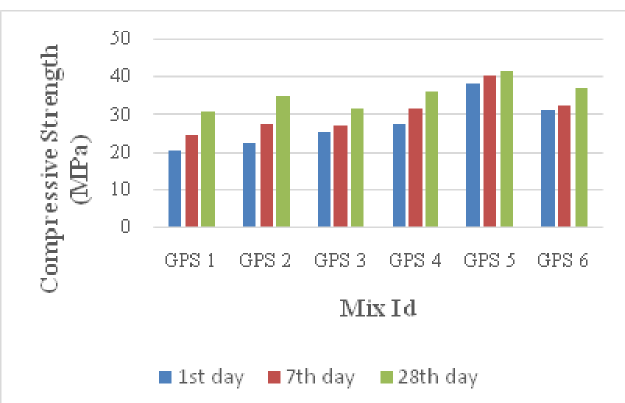

Figure 4. Compressive strength property of the geopolymer concrete reinforced with steel fibre.

testing, it is observed that the shorter length steel fibre showed magnificent strength on comparing longer steel fibre. The main advantage of using geopolymerbased material possesses the maximum polymerisation reaction within the shorter curing period. The results also confirm that the 28th day strength was almost similar to 1st and 7th day which indicates very early achievement of strength. From the experimental work it is persuaded that 1% of 30mm steel filaments demonstrates better quality changes than 1% of 60mm steel fibre and there is a sudden diminishing in GPS 6 (0.6% of 60mm and 0.4% of 30mm steel fibres) when we build the rate of longer steel fibre. So the shorter steel fibre finds a noteworthy part in the mechanical properties of geopolymer concrete. The rate of quality increment from 1st day to 28th day in GPS 5 (0.6% of 30mm and 0.4% of 60mm steel fibres) is less than 8% but it has achieved more than the target strength on 1st day so it gives us the advantage of early usage of concrete at site. The outcomes have demonstrated that there is a positive increment in the compressive strength quality because of the toughness of steel fibres. The percentage of strength increase with respect to the reference concrete (GPS 1) is showed in Figure 5.

5.3 Flexural Strength

The flexural strength of various geopolymer based concrete mixture with and without incorporation of steel fibres at 1st, 7th and 28th day is provided in Table 4 and shown in Figure 6.

Flexural properties of geopolymer concrete showed significant improvements with the steel fibre addition.

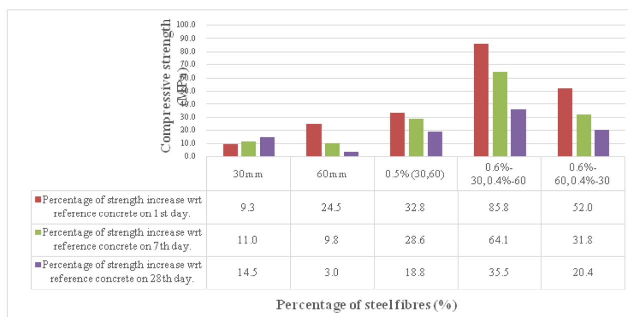

Figure 5. Percentage of strength increase–compressive strength

Table 4. Test results on flexural strength.

Mix Id	Flexural Strength (MPa)		
	1st day	7th day	28th day
GPS 1	2.50	3.00	3.75
GPS 2	4.75	4.75	5.00
GPS 3	4.25	4.50	4.50
GPS 4	5.00	5.00	5.25
GPS 5	7.00	7.00	7.50
GPS 6	6.25	6.25	6.75

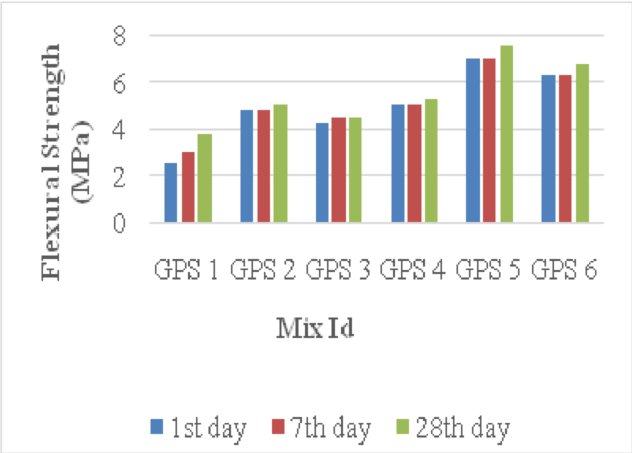

Figure 6. Flexural strength property of the geopolymer concrete reinforced with steel fibre.

Steel fibre incorporation in the concrete shows better performance than the reference concrete. The highest performance was noted for the geopolymer mixture consisting of higher steel fibre content of shorter length and the maximum flexural strength was noted in the case of GPS 5(0.6% of 30mm and 0.4% of 60mm steel fibres) mixture with the maximum flexural strength of 7.5 MPa. Though all the mixes which have been included with steel fibres showed positive results, the flexural strength was found to be affected and reduction in strength when the mix contains longer steel fibres. Analysing all the mechanical properties tested, it is noted that the geopolymer concrete mixtures containing GGBS were found to be a possible and useful material in replacing the plain cement concrete in construction practice. The percentage of strength increase with respect to the reference concrete (GPS 1) is shown in Figure 7.

5.4 Modulus of Elasticity

A compresso meter attached cylindrical specimen of size 150 mm in diameter and 300 mm height subjected to compression to determine the deflection values for every 5kN of compressive load was obtained. The stress-strain graph was plotted for load and deflection values. The slope of the line drawn to 40 percent of stress at the ultimate load was taken as the modulus of elasticity. The modulus of elasticity obtained on 28thday is tabulated in Table 5 and shown in Figure 8.GPS 5 (0.6% of 30 mm and 0.4% of 60 mm) has obtained better results on comparing with other mixes. It has obtained the maximum value of 18.28 GPa.

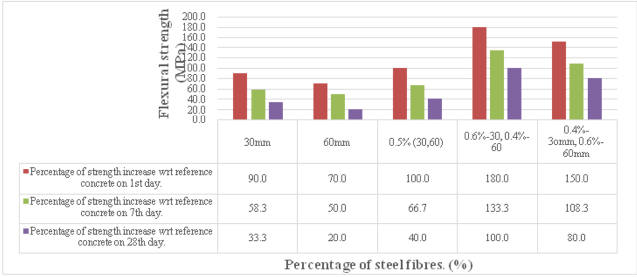

Figure 7. Percentage of strength increase-flexural strength

Table 5. Test results on modulus of elasticity.

Mix Id	Ultimate stress (MPa)	Modulus of Elasticity (GPa)
GPS 1	30.10	8.70
GPS 2	43.57	16.34
GPS 3	33.90	10.11
GPS 4	34.51	15.20
GPS 5	44.70	18.28
GPS 6	35.25	14.70

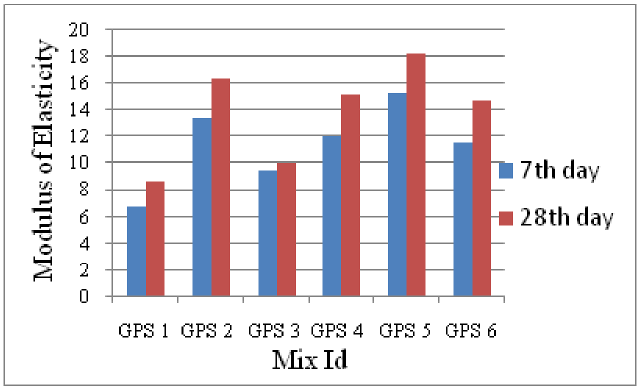

Figure 8. Young's modulus property of the geopolymer concrete reinforced with Steel fibre.

6. Conclusion

From the experimental work, GGBS can be used as an effective replacement of cement and it can be replaced with 100% in concrete. There is no need of exposing geopolymer concrete to longer curing period. The compressive strength is increased by 85.8 % with the addition of steel fibres. Flexural strength is increased by 75% when compared with the control mix (plain GPC). The maximum compressive strength and flexural strength value obtained were 41.2 MPa and 7.5 MPa respectively. Among all the mixes tested, GPS 5 which contained 0.6% of 30 mm and 0.4% of 60 mm steel fibre showed better results in which the modulus of elasticity is also higher for that mix. The geopolymer concrete achieved early strength on 1stday after that there was no phenomenal strength improvement. The geopolymer concrete with steel fibres incorporation achieved 90% of strength on 1st day. Addition of shorter steel fibres (30 mm) showed higher strength gain with respect to the longer steel fibre (60 mm). Requirement of water content ratio in GPC (0.35) is less when compared with cement concrete. GGBS based geopolymer concrete requires only sodium hydroxide as an alkali activator for the polymerisation process, so it is cost effective when compared to other geopolymer concrete like fly ash, metakao line, rice husk based.

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