Experimental Investigation of High Strength Geopolymer Concrete

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Abstract: ***This paper presents the determination of the mechanical properties (compressive, split tensile and flexural tests) of the specimens (cubes, cylinders, and beams). The specimens are of M60 grade high strength geopolymer concrete which includes GGBS, Fly Ash and Metakaolin as triple mix binding material with a different concentration of NaOH. The specimens are prepared for 3 different molalities of NaOH concentration which is 14M, 16M and 18M. The tests are conducted after 7, 14 and 28 days of direct sunlight curing period.***

Keywords: GFM (GGBS, Flay Ash and Metakaolin), geopolymer, Molality, NaHO, Compressive, Flexural and split tensile test

1. Introduction

The High Strength Geopolymer Concrete is the type of high-performance concrete which gives better strength with nominal quantities of the ingredients. The HSGC is one which gives the compressive strength of concrete at a range of 50MPa and above (up to 120MPa). The main difference with the nominal concrete is the strength. The main requirement of HSC is to provide a higher strength by consuming less quantity of material. When compared to the nominal concrete the ingredients used are more i.e., GGBS and metakaolin are added to the normal fly ash based GPC to give higher strength. For this dissertation paper M60 grade as HSGC concrete. The binding materials used are a triple combination of GGBS, Fly Ash and Metakali (GFM) for this high strength Geopolymer concrete and the alkaline activators are sodium hydroxide and sodium silicate with a different molality of NaOH concentration. The molarities of NaOH are 14M, 16M, and 18M.

2. Objective

The main objective of this project is to determine the mechanical properties and workability of a High Strength Geopolymer Concrete, for the different molality of NaOH in GFM based GPC.

3. Materials and Methodology

Table 3.1: Physical and Chemical Properties of Binding Material

Properties	Fly Ash	GGBS	Metakaolin
Physical			
Specific gravity	2.4	2.9	2.3
Fineness of Modulas	2.80%	3%	2.84%
Colour	Dark Grey	Off-White	White
Chemical compositions (%)			
Silicon dioxide (SiO_2)	62.63	33.77	51.5
Aluminium oxide (Al_2O_3)	23.35	13.24	40.2
Iron oxide (Fe_2O_3)	3..93	0.67	1.23
Calcium oxide(CaO)	2.04	33.77	2
Magnesium oxide (MgO)	0.46	10.13	0.12
Sulfur Trioxide (SO_3)	1.34	0.23	0.28
Sodium oxide (Na_2O)	0.032	-	0.08
Potassium oxide (K_2O)	0.030	-	0.53
Titanium dioxide (TiO_2)	-	-	2.27
Loss on ignition	0.39	0.19	2.01

- Fly ash- The fine powder that is produced from the combustion of pulverized coal in the thermal power plants. The fly ash class F conforming to IS 3812-1981 was used in the research with a specific gravity of 2.4.
- GGBS- The granulated conforming to IS: 12089 – 1987 was used in the research with a specific gravity of 2.9.
- Metakaolin - The Metakaolin IS: 12089 – 1987 was used in the research with a specific gravity of 2.84.
- Coarse Aggregate- Crushed stone aggregate with 20mm from a local source having the specific gravity of 2.64 conforming to IS: 383-1970 was used.
- Fine Aggregate- Locally available M- sand passing through 4.75 mm IS sieve conforming to grading zone-II of IS: 383-1970 was used with a specific gravity of 2.60.
- Water- Potable water is used for mixing and curing concrete.
- The superplasticizer used is Glenium 8233. Master Glenium SKY 8233 is an admixture of a new generation based on modified polycarboxylic ether.

4. Mix Design

The HSGC is defined as higher Geopolymer concrete whose characteristic strength ranges from 50 and above. Hence for my work, I'm considering M60 grade geopolymer concrete. The mix design for M60 grade geopolymer concrete is carried out using the trail mixes. For which alkaline liquid to source material ratio is 0.40. The fine aggregate of Zone I, and a coarse aggregate of 20mm size and below.

- Admixture = 11.22(3% of cementitious material)
- The proportion for the mix is 1:1.75:3

Table 4.1: Mix Design of GFM Based M60 GPC

No.	Quantities (kg/m^3)	Mix (Kg/m^3)	Mix (Kg/m^3)	Mix (Kg/m^3)
1	Fly Ash (60%)	228.4	228.4	228.4
2	GGBS (20%)	72.8	72.8	72.8
3	Metakoalin (20%)	72.8	72.8	72.8
4	Fine Aggregate (M-sand)	655.2	655.2	655.2
5	Coarse Aggregate (20mm)	1123.2	1123.2	1123.2
6	Sodium Silicate (Na2SiO3)	82 (14M)	108 (16M)	164 (18M)
7	Sodium Hydroxide (NaOH)	46.86	46.86	46.86
8	Extra water	117.14	117.14	117.14

5. RESULTS AND DISCUSSIONS

5.1 Workability of geopolymer concrete

In order to study the effect of molarity of NaOH in geopolymer concrete, on the fresh property, GPC mixes were tested for the slump. The workability test for GPC in the fresh state is carried out as per IS: 1199 – 1959. The slump for different molarities of NaOH in GPC is given in table 5.1.

Table 5.1 Effect of Molarity on Workability of GPC Mixes

S.No.	Molarity	Slump
1	14	11
2	16	9
3	18	5

It was observed that all the fresh GFM based GPC mixes were extremely cohesive and viscous in nature. The workability of geopolymer concrete decreased as molarity of sodium hydroxide was increased, this is because of the high alkalinity of the mix, As the molarity of NaOH increased the alkalinity of mix increase, due to high alkalinity rate of reaction increase i.e. rate of Geopolymerization increase. As the rate of reaction increase setting times of geopolymer mix decrease so it's set very fast. The 3 binder mix GFM based geopolymer concrete is very less workable after 10-15 minutes. The amount of extra water added was kept constant for all the GPC mixes, therefore workability went on decreasing, as increasing in molarity of NaOH. Fig 4.1 shows the variation of workability of GPC mixes with a variation of molarity.

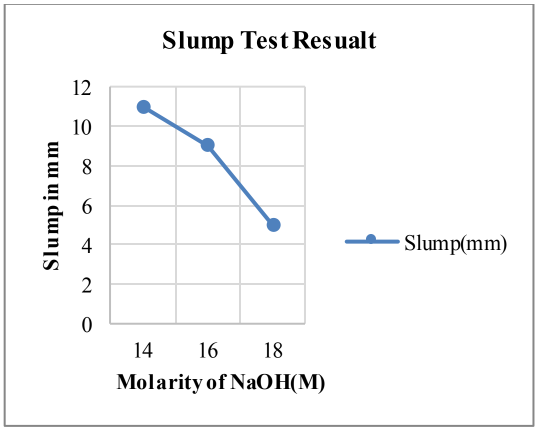

Figure 5.1: Slump Test Result of GFM Based GPC

5.2 Hardened Geopolymer Concrete Properties

5.2.1 Compressive Strength

To study the effect of variation of molarity of sodium hydroxide on compressive strength of geopolymer concrete, standard cube specimens of dimension 150×150×150 mm were prepared and tested in accordance with IS specifications. The molarity of NaOH used in GFM based geopolymer was 14M, 16M, and 18M. All the specimens were cured in direct sunlight then tested for compressive strength.

Table 5.2 Average Split Tensile Strength of GPC Mixes at Different Ages and Molality

Age of Specimens (Day)	Average Compressive Strength of High Strength GPC Mixes in N/mm^2		
	Mix A (14M)	Mix B (16M)	Mix C (18M)
7	60.5	63.23	65.96
14	64.22	68.11	70.08
28	68.21	72.79	76.45

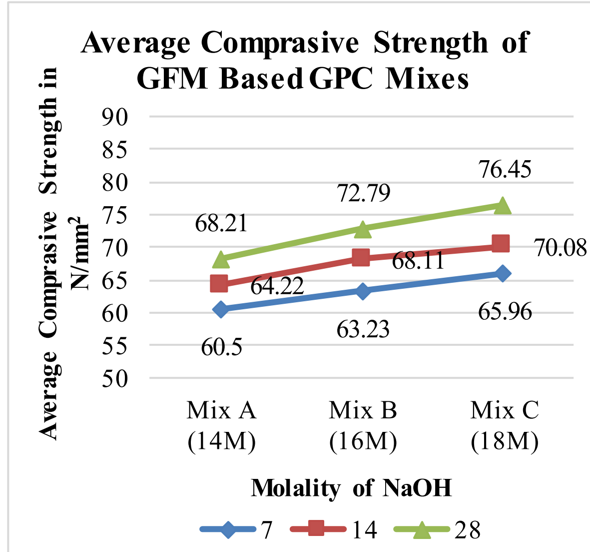

Figure 5.2 Variation of Compressive Strength of High Strength GPC Mixes With Molarity of NaOH

Geopolymer concrete gained maximum strength in initial age, about 80% of 28 days strength can be achieved in 7 days. In case of GPC mix containing 14M molarity NaOH solution, 14 days strength increased by 6.15%, and 28 days strength increased by 6.60% when compared to 7 days test results. Similarly, for GPC mix containing 16M molarity NaOH solution, 14 days strength increased by 7.72%, and 28 days strength increased by 6.9%, compared to 7 days strength. For 18M molarity NaOH solution, 14 days strength increased by 6.25%, and 28 days strength increased by 9.08%compared to 7 days strength.

5.2.1 Split tensile strength

From figure 5.3 it can be shown that split tensile strength for 7 days increased with the increase of molarity, for an increase in molarity from 14M to 16M tensile strength increased 4.62%, and 16M to 18M strength increased 1.59%. Strength increased for molarity of 16M but after 16M strength increased with less increment. Similarly, for 28 days, compressive strength increased with the increase of molarity of sodium hydroxide, for increase in molarity from 14M to 16M strength increase 3.8%, and 16M to18M strength increase 2.78%.

Table 5.3 Average Split Tensile Strength of GPC Mixes at Different Ages and Molality

Age of Specimens in Day	Average Split Tensile Strength of GPC Mixes (N/mm^2)		
	Mix A (14M)	Mix B (16M)	Mix C (18M)
7	5.41	5.66	5.75
14	5.76	6.07	6.21
28	6.58	6.83	7.02

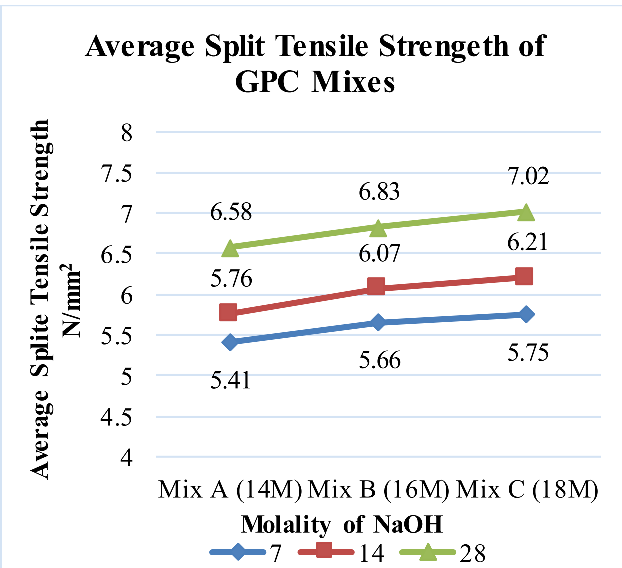

Figure 5.3 Variation of Split Tensile Strength with Molarity of NaOH

5.2.3 Flexural Strength

Table 5.4 shows flexural strength also increases with the age of concrete for all mixes and molarity of sodium hydroxide just like compressive strength and split tensile strength. In figure 4.6 shows GFM based high strength GPC mix containing 14M molarity NaOH solution, 14 days strength increased by 15.38%, 28 days strength increased by 30.77%, as compared to 7 days results. Similarly, for GPC with 16M NaOH solution, 14 days strength increased by 13.33%, 28 days strength increased by 33% increased by 68.84% as compared to 7 days strength. For GFM based high strength GPC with 18M NaOH solution, 14 days strength increased by 9.6%, and 28 days strength increased by 32.87%.

Table 5.4 Average Flexural Strength of GPC Mixes

Age of Specimens in Day	Average Flexural Strength of GPC Mixes (N/mm^2)		
	Mix A (14M)	Mix B (16M)	Mix C (18M)
7	6.9	7.12	7.21
14	7.9	8.09	8.14
28	8.8	8.9	9.03

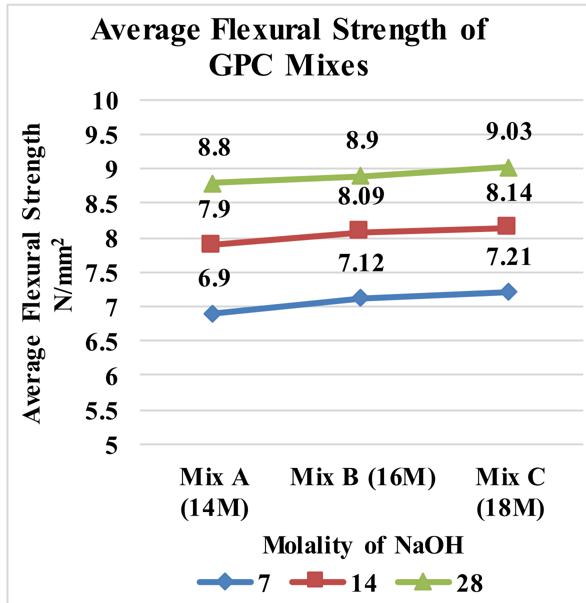

Figure 5.4 Variation of Flexural Strength with Molarity of NaOH

5. Conclusion

- Increased Molality of NaHO increased the strength of GFM based GPC.
- 16M of NaHO attained significant Split tensile, Compressive and flexural strength.
- The highest strength attends in 18M of NaOH is used.
- The workability of GFM based GPC depends on the concentration of NaOH.
- Increase the concentration of NaOH decrease the workability of GFM based GPC.

6. Recommendation

- To improve the workability add extra water in the mixing process.
- To study the optimal combination of GGBS, Fly Ash and Metakaolin
- Further study on the curing technique and implementation on the site.

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