Mechanical Properties of Hybrid Fiber Reinforced Geopolymer Concrete

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Abstract – *Engineering properties such as compressive strength, splitting tensile strength, modulus of rupture of normal concrete (NC), Geopolymer concrete (GPC) and hybrid fiber reinforced geopolymer concrete have been obtained from standard tests and compared. A total of 98 specimens were tested for determining the mechanical properties. The grade of geopolymer concrete used was M30. The total volume of fibers was fixed as 0.5% of total volume of geopolymer concrete. Seven geopolymer concrete mixes were selected for study. Which include control mix without fiber (NC), geopolymer mix without fibers(GPC), steel fiber reinforced geopolymer concrete (SFRGPC) with 0.5% steel fibers, and four hybrid fiber reinforced (HFRGPC) concrete of steel and glass fibers with total volume fraction as 0.5%. In general, the addition of fibers improved the mechanical properties. However the increase was found to be nominal in case of compressive strength (33.15%), significant in the case of splitting tensile strength (80.82%), modulus of rupture (28.03%) at 0.35% steel fibers and 0.15% glass fibers.*

***Key Words*: Geopolymer concrete, Hybrid fiber reinforced geopolymer concrete, steel fibers, Glass fibers, Mechanical properties**

1. INTRODUCTION

Concrete is the most commonly used construction material. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete. The manufacturing of the Portland cement releases enormous amount of green house gas emission to atmosphere, which is an energy intensive process. India is the second-largest cement producing country in the world after China. The country's cement production was 300 million tonnes during the year 2010 and the figure is expected to double, to reach almost 550 million tonnes by 2020, as per the estimates by the Cement Manufacturers Association (CMA). On the other hand, global warming has become a major concern due to the climatic changes. The global warming is the increase of earth's average surface temperature due to the effect of greenhouse gases. Among the greenhouse gases, CO_2 contributes about 65% of global warming. Therefore, efforts are being taken to develop the other forms of cementious materials for producing concrete. One such material, Geopolymer concrete is produced with activated fly ash as a binder there by eliminating Portland cement. Davidovits (1982) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders.

Concrete exhibits brittle behavior due to its low tensile strength. The addition of fibers, either short or continuous, changes its brittle behaviour to ductile with significant improvement in tensile strength, tensile strain, toughness and energy absorption capacities. The binder in the Fiber Reinforced Cement Composites (FRCCs) is mainly Portland cement. Efforts have been made to replace the cement based binder in the current FRCC with "geopolymeric" binder resulting in Fiber Reinforced Geopolymer Composites (FRGCs), which is greener than the former one.

Hybrid Fiber Reinforced Geopolymer Concrete (HFRGPC) is a combination of different types of fibers, which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. In HFRGPC, two or more different types of fibers are rationally combined to produce a composite that derives benefits from each of the individual fibers and exhibits a synergistic response. The hybrid combination of metallic and non-metallic fibers can offer potential advantages in improving the properties of concrete. The use of different types of fiber in a suitable combination may potentially improve the mechanical properties of concrete and result in synergic performance. Recently studies have been carrying out in the area of hybrid fibers but hybridization with steel and glass fibers are limited. Hence this area is focused in this study.

1.1 Objectives

- To develop the proper mix proportion of M30 grade geopolymer concrete.
- To study the effect of steel fibers on the mechanical properties of geopolymer concrete.
- To study the effect of hybrid fibers on the mechanical properties of geopolymer concrete and find its optimum.

2. METHODOLOGY

- Materials required for the experiments were procured and their properties were found as per IS codes.

- Mix design of M30 grade geopolymer concrete was done.
- Specimens for determining mechanical properties with control, geopolymer concrte and hybrid (steel and glass) fiber reinforced geopolymer concrete mix were prepared.
- Optimum combination of fibers contents were obtained from compressive strength , split tensile strength and flexural strength of geopolymer concrete

3. EXPERIMENTAL PROGRAMME

The experimentation involves the comparative study of effect of steel fibers and hybrid (steel and glass fibers) on compressive, split tensile, and flexural strength of M30 grade concrete at 28 days of ambient curing. Seven mixes were selected for the study. Which include control mix without fibers (NC), geopolymer concrete without fibers (GPC), steel fiber reinforced concrete (SFRGPC) with 0.5% steel fibers and four hybrid fiber reinforced (HFRGPC) geopolymer concrete of steel and glass fibers with total volume fraction as 0.5%. Designation of mixes is shown in Table-1

Table -1: Mix Designation

Sl No	Designation	Steel Fiber (%)	Glass Fiber (%)
1	NC	0	0
2	GPC	0	0
3	SFRGPC	100	0
4	HFRGPC1	90	10
5	HFRGPC2	80	20
6	HFRGPC3	60	30
7	HFRGPC4	70	40

3.1 Materials and Mix proportion

Flyash: Class F flyash of specific gravity 2.25 was used for the experiments.

Ground Granulated Blast Furnace Slag: Obtained from Astrra Chemicals, Channai of specific gravity 2.88 was used for the study. 10% of flyash was replaced with GGBS in the study.

Fine aggregate: River sand is used as fine aggregate. River sand passing through 4.75mm IS sieve conforming to grading zone III IS 383: 1970 was used. Specific gravity and fineness modulus of sand were 2.54 and 3.02 respectively.

Coarse aggregate: Coarse aggregate of maximum size 20 mm from local source was used.

Alkaline liquid: A combination of sodium hydroxide and sodium silicate solutions was used as the alkaline liquid to activate fly ash. A sodium hydroxide solution was prepared by dissolving sodium hydroxide flakes in water. It was obtained from Chemind Chemicals, Calicut.

Steel Fiber: Crimped steel fibers having diameter 0.6 mm and length 50 mm were used for the present study.

A R Glass Fiber: A R fibers of length 13mm and aspect ratio 875 was used for the study.

Superplasticizer: Naphthalene based superplasticizer Conplast SP-430, supplied by Fosroc Chemical (India) Pvt. Ltd. was used as superplasticizer.

Fig-1 Crimped steel fiber **Fig-2** AR Glass fiber

Reinforcing bars: Main reinforcement consists of 8mm ϕ HYSD steel bars of Fe 500 grade. 6mm ϕ steel bars were used as stirrups.

In order to arrive the mix proportion for the present study, the optimum values of different parameters were adopted from previous literature. Anuradha *et al* (2012) suggested a design procedure for geopolymer concrete by using Indian standard. The addition of fibers reduced the workability of concrete and the dosages of super plasticizer were adjusted to maintain the workability. The mix proportion details are given in Table-2.

Table-2 Mix Proportion

Materials	Quantity (kg/m^3)
Fly ash	404.34
Fine aggregates	562.35
Coarse aggregates	1035.64
NaOH	53.14
Na_2SiO_3	132.86
Super plasticizer	4.04

3.2 Casting of specimen

For the preparation of test specimens, Fly ash, GGBS, River sand, coarse aggregate, alkaline activators and admixture were used. Firstly mixing of dry materials was done in a drum type mixer. Super plasticizer was mixed with water and was then added to the dry materials. The required quantities of steel and polyester fibers were taken according to the volume fraction and these fibers were added during mixing. Workability of fresh concrete was checked using a standard slump cone. The freshly mixed concrete was poured layer by layer, into standard cubes of size 150mm for compressive strength test, 150 × 300 mm cylinders for splitting tensile test and into 100 × 100 × 500 mm prisms for finding modulus of rupture. Total number of layers was three. Each layer was compacted by giving 35 strokes per layer with standard tamping bar. The top surface was levelled using a smooth trowel after compaction. For each mix cubes, cylinders and prism were cast. Each specimen was tested after 28 days of ambient curing.

3.3 Test methods

The compressive strength tests were carried on concrete cubes as per IS 516:1959 (reaffirmed 2013). The cubes were loaded in the compression testing machine of 1000kN capacity until failure. The splitting tensile tests, were carried on cylinders in accordance with IS 5816: 1999 (reaffirmed 2013) and was split along its length in the Universal testing machine of 600kN capacity. For finding the modulus of rupture, two point loading tests were conducted on prisms as per IS 516:1959 (reaffirmed 2013).

4. RESULTS AND DISCUSSION

4.1 Fresh geopolymer concrete properties

Here slump test were carried out for finding the workability of geopolymer concrete for each mix. Slump values obtained for different mixes are shown in Table-3. The workability of geopolymer concrete was decreased while adding fibers and hence Conplast SP430 was used as a super plasticizer for maintaining workability.

Table-3 Slump value of different mixes

Mix designation	Slump Value(mm)	Degree of workability
NC	60	Medium
GPC	58	Medium
SFRGPC	53	Medium
HFRGPC1	57	Medium
HFRGPC2	59	Medium
HFRGPC3	62	Medium
HFRGPC4	61	Medium

From Table-3 it is clear that the addition of fibers decreases the workability. Among all the seven mixes the slump value for 0.5% SFRGPC is obtained as the minimum. On hybridizing by replacing the steel fibers with glass fiber there will be an increase in workability were observed. However for HFRGPC4 (0.3% Steel + 0.2% glass) a little decrease in slump value was observed. This may be due to the balling effect of fibers at higher volume fractions.

4.2 Compressive strength

Table-4 gives the average values of test results of compressive strength. From Table-4 it can be noted that all the fiber reinforced geopolymer shows improvement in the compressive strength. HFRGPC (0.35% steel + 0.15% glass) shows the maximum increase and is about 33.15 % of NC.

Table- 4 Compressive strength of geopolymer concrete

Mix designation	Compressive strength (N/mm^2)			Percentage increase
	3 days	7 days	28 days	
NC	12.52	24.33	33.33	-
GPC	14.44	30.67	37.98	13.95
SFRGPC	17.77	33.88	39.15	17.46
HFRGPC1	19.78	34.02	40.45	21.36
HFRGPC2	21.02	36.14	42.23	26.70
HFRGPC3	23.33	37.34	44.38	33.15
HFRGPC4	21.77	36.00	43.34	30.03

4.3 Split tensile strength

Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The test results are given in Table-5.

Table-5 Split tensile strength

Mix designation	Split tensile strength (N/mm^2)		Percentage increase
	7 Days	28 Days	
NC	1.89	2.19	-
GPC	3.11	3.33	52.05
SFRGPC	3.40	3.76	71.68
HFRGPC1	3.32	3.59	63.92
HFRGPC2	3.53	3.83	74.88
HFRGPC3	3.67	3.96	80.82
HFRGPC4	3.57	3.87	76.71

It is clear from Table-5 that addition of fibers has a significant effect on split tensile strength. HFRGPC3 gives the maximum value of split tensile strength and which is more than that of SFRGPC.

4.4. Modulus of Rupture

Flexural strength is also known as modulus of rupture is a material property, defined as the stress in a material just before it yields in flexure test. The transverse bending test is most frequently employed, in which a specimen is having either a circular or a rectangular cross-section is bend until fracture using a two point load test technique. The test results are given in Table- 6. From Table-6 it can be noted that steel and glass fibers has a significant role in improving the flexural strength of geopolymer concrete. All the hybrid fiber combination shows improvement in flexural strength than that of mono fiber reinforced geopolymer concrete (SFRGPC). However, a reduction in strength at 0.2% of glass fiber content (HFRGPC4) has been found. This may be due to the balling effect of fiber at higher fiber contents.

Table-6 Modulus of rupture

Mix designation	Flexural strength (N/mm^2)	Percentage increase
NC	6.67	-
GPC	7.61	14.09
SFRGPC	7.84	17.54
HFRGPC1	8.03	20.38
HFRGPC2	8.27	23.98
HFRGPC3	8.54	28.03
HFRGPC4	8.38	25.63

5. CONCLUSIONS

Based on the investigation of the mechanical properties of mono and hybrid fiber reinforced concrete, following conclusions were arrived at.

- The addition of fibers decreases the workability. Among all the six mixes the slump value for 0.5% SFRGPC is obtained as the minimum.
- The compressive strength of NC is obtained as 33.33 N/mm^2. Maximum compressive strength is obtained for HFRGPC3 with 0.35% steel and 0.15% glass fiber with 33.15% increase than NC.
- The split tensile strength of NC is obtained as 2.19 N/mm^2. There is a strength gain of 52.05% were obtained for GPC. There is a marginal variation in split tensile strength for all HFRGPC with respect to that of GPC. The maximum split tensile strength was obtained for HFRGPC3 which is 80.82 % more than that of NC.
- The modulus of rupture of NC is obtained as 6.67 N/mm^2. Addition of fibers plays a significant role in improving the flexural strength of geopolymer concrete. For SFRGPC with 0.5% steel fibers the modulus of rupture increased about 17.54%. For all HFRGPC mixes the modulus of rupture increased with respect to SFRGPC. Maximum value is obtained for HFRGPC 3 (0.35% steel and 0.15% glass) and there is 28.03% increase than NC.

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