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INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EXPERIMENTAL INVESTIGATION ON EFFECT OF INCLUSION OF HOOKED STEEL FIBER ON GGBS BASED GEOPOLYMER CONCRETE

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DOI: 10.5281/zenodo.1228802

ABSTRACT

This paper presents the result of an experimental investigation on the mechanical properties of geopolymer composites containing Ground Granulated Blast Furnace Slag (GGBS), alkaline liquids and steel fibers. This study analyses the impact of steel fiber on mechanical properties such as compressive strength, split tensile strength, and flexural strength of hardened Geopolymer Concrete (GPC). The mixture was prepared with alkaline to GGBS ratio as 0.4. Steel fibers were added to the GPC in volume fractions of 0.25%, 0.5%, 0.75%, and 1% volume of concrete. Specimens were subjected to 8 hours of oven curing at 72^{0}C. Based on the test results the optimum percentage of steel were formulated.

KEYWORDS: Geopolymer concrete, steel fibers, Compressive strength, split tensile strength, flexural strength

I. INTRODUCTION

Demand for concrete as a construction material is on the increase and so is the production of cement. The production of one tone of cement emits one tone of carbon dioxide to the atmosphere. So an alternative to ordinary Portland cement is to be made. The alternative has developed and known as Geopolymer concrete developed by Davidovits, proposed that binders could be produced by a polymeric reaction of alkaline liquid with silica and aluminium in source material. It used industrial waste such as fly ash and ground granulated blast furnace slag to produce concrete. Usually plain concrete is weak in tension ,addition of different fibers could act as crack arrester in concrete.Inclusion of fibres increases tensile and toughness properties of concrete. Many studied proved that addition of different types of fibres improves the strength parameters of geopolymer concrete. Arya et.al studied mechanical properties of geopolymer concrete reinforced with steel fibers. This study involved in finding compressive and split tensile strength of geopolymer concrete by varying fly ash to chemical ratio 0.3.0.35,0.4 percentage and steel fibre as 0,0.5 and 1%.increase in the percentage of steel fiber increased the compressive as well as the tensile strength of geopolymer concrete. Increase in strength occurred at curing temperature ranging between 30^{0}C,90^{0}C. The optimum percentage obtained in this study was 1% with 26.8Mpa compressive strength and 3.5Mpa split tensile strength. Ramkumar et.al. developed a geopolymer concrete reinforced with crimped mild steel and crimped stainless steel. Three mixes were studied with 50%GGBS and 50% fly ash as control mix , added stainless steel and added mild steel. The strength properties were compared with ordinary Portland cement mix. Results shown an increased strength properties than normal concrete. Addition of crimped mild steel shows gradual increase in compressive strength, split tensile strength and flexural strength. Crimped mild steel shows better result on mechanical properties than crimped stainless steel. Compressive strength increased by 2.25% when steel fibers were added to normal geopolymer. Literatures indicated that several studies have investigated the effect of steel fibers to geopolymer concrete with different percentage of replacement of source. The present investigation is aimed to evaluate the mechanical properties of steel fiber on GGBS based geopolymer concrete.

II. MATERIALS AND METHODS

2 Materials used

Ground Granulated Blast furnace Slag (GGBS)

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder .For this study GGBS was collected from Astrra Chemicals, Chennai.Table 2.1 gives the properties of GGBS provided from the company.

Table 2.1 properties of GGBS

Sl.No	Charecteristics	Value
1	Fineness(m^2/Kg)	390
2	Specific gravity	2.85
3	Particle size (cumulative %)	97.10
4	Loss in ignition	0.26
5	Moisture content	0.10
6	Chemical moduli	
	Cao +MgO+SiO2	76.0
	(CaO+MgO)/SiO2	1.30
	CaO/SiO2	1.07

(Source : Astrra chemicals)

Fine Aggregate (M-Sand)

Fine aggregate is a reliable material used for concreting, plastering and masonry work. The main problem of fine aggregate is acute shortage, high price and enormous usage of sand in the construction. The manufactured sand (M-sand) is a better substitute to river sand because it has no silt or organic impurities and is mostly well graded. M-sand with proper gradation shall be used in this study for casting the concrete. As per IS 383:1970 (reaffirmed 2016) the size of fine aggregate should be in the range 4.75mm to 75µ and shall have a maximum water absorption of 2.3%

Coarse Aggregate

The coarse aggregates generally occupy 35 to 75% of the concrete volume and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. Coarse aggregates consist of one or a combination of gravels or crushed stone with particles predominantly larger than 5 mm (0.2 in.) and generally between 9.5 mm and 37.5 mm (3 ⁄8 in. and 11 ⁄2 in.). Crushed stone is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. The aggregates are usually washed and graded at the pit or plant. Some variation in the type, quality, cleanliness, grading, moisture content, and other properties is expected. The various properties of aggregates include shape and texture, gradation of size, moisture content, specific gravity, reactivity, soundness, and bulk density as these plays an important role in strength, workability and durability of concrete. IS383:1970 gives specification for coarse aggregate and the size should be ranging from 20 mm to 4.75 mm.

Sodium Hydroxide

Sodium hydroxide is generally available in pellets or flakes forms. The dissolution of sodium hydroxide with water is highly exothermic and produces heat. The cost of the Sodium Hydroxide is mainly varied according to the purity of the substance and the requirement of concrete. IS 252:1991 provides the specification for caustic soda, purity and technical uses. In this investigation the Sodium Hydroxide pellets of purity 94 - 96% were used. Fig 3.2 shows sodium hydroxide pellets. Table 2.2 shows its properties.

Table2.2 Properties of sodium hydroxide

Description	Quantity
Colour	colourless
Specific gravity	2.13
pH	14
Assay	96%
Carbonate (Na_2CO_3)	2%
Chloride (Cl)	0.01%
Sulphate (SO_2)	0.05%
Lead (Pb)	0.01%

Iron (Fe)	0.01%
Potassium (K)	0.1%
Zinc	0.02%

(Source:Nice chemicals Pvt.Ltd)

Sodium Silicate

Sodium silicate called water glass or liquid glass is commercially available in liquid form. Sodium silicate solution take a major role in geopolymerisation process under high alkaline condition when reactive aluminosilicates are rapidly dissolved and free $[SiO_4]^-$ and $[AlO_4]^-$ tetrahedral units are released in solution and are alternatively linked to polymeric precursor by sharing oxygen atom. Thus forming Si –o–Al –O bonds. Table 2.3 gives chemical properties and the physical properties of the Sodium Silicates. Table 3.3shows its properties.

Table2.3 Properties of sodium silicate

Property	Description
Appearance	Liquid(gel)
Boiling point	102^0 C for 40% acqeous solution
Molecular weight	184.04 Dalton
Specific gravity	1.6
Na_2O	15.9%
H_2O	52.7%
SiO_2	31.4%

(Source:Nice chemicals Pvt.Ltd)

Steel fiber

Fibers are generally utilized in concrete to manage the plastic shrink cracking and drying shrink cracking. They also lessen the permeability of concrete and therefore reduce the flow of water. Some types of fibers create greater impact, abrasion and shatter resistance in the concrete .Many types of steel fibers are used for concrete reinforcement. Round fibers are the most common type and their diameter ranges from 0.25 to 0.75 mm. Rectangular steel fibers are usually 0.25 mm thick, although 0.3 to 0.5 mm wires have been used in India. Deformed fibers in the form of a bundle are also used. The main advantage of deformed fibers is their ability to distribute uniformly within the matrix. Fig 3.4 shows steel fibers and Table 2.4 shows its characteristics.

Fig 3.4 Steel fiber

(Source:By author)

Table 2.4 Properties of steel fiber

Type of steel fiber	Hooked end steel fiber
Length	25mm
Diameter	0.5mm
Aspect ratio	50
Tensile strength	500 MPa
Density	7900 kg/m^3
Young’s modulus	2×10^5 N/m^2

(Source:Go Green Products, Chennai

2.1Design of Geopolymer concrete

Based on previous studies carried out in geopolymer concrete the GGBS based geopolymer concrete was designed. Sodium hydroxide of 8Molarity is used. Steel fibers are added at 0.25%, 0.5%, 0.75% and 1% by volume of concrete. Results were noted and compared with normal geopolymer concrete (GPC) with out steel fiber. The optimum percentage of steel was obtained.

2.2 Testing Method

Compressive Strength Test

The compressive strength involves testing and calculating how well a given specimen can survive compressive stresses. Calculating compressive strength involves testing to find failure point. The concrete is poured in the mould of size 150×150×150 mm and tampered properly to avoid pores. It is then placed in an oven for heat curing at 72^{0}C for 8hours. The mould is then removed and the geopolymer cubes are kept in ambient condition. The compressive strength test is conducted as per IS 516-1959 (reaffirmed 1999) after 7 days and 28 days. Specimen was placed centrally in the compression testing machine and uniform load of 140 kg/cm^2 was applied continuously. The load at which specimen fails is noted and mean compressive strength of 3 specimen was calculated.

Split Tensile Strength Test

The tensile strength is one of the basic and important properties of the concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The cracking is a form of tension failure. The test consists of applying a compressive load along diametrical ends of a concrete cylinder placed with its axis horizontal between the compressive platens. The load was increased continuously until the specimen fails and the readings were recorded. Average values of 3 specimen is noted as the tensile strength .The split tensile strength test was conducted as per IS 5816-1999 (reaffirmed 2004).

Flexural Strength Test

Flexural strength, also known as transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test. The flexural strength test was carried out as per IS 516:1959.Prism concrete specimen of size 100mm×100mm×500mm as width, height and length were used. The universal testing machine is used for the flexural strength testing at the age of 28 days. The loading was done without shock and increasing continuously. Fig 3.8 shows Flexural strength test on fiber reinforced GPC

The load increased until the specimen failed and the maximum load was recorded as 'F' and the flexural strength is given by:

$$f_b = \frac{FL}{bd^2}$$

Where F is the load (force) at the fracture point, L is the length of the support (outer) span, b is width, d is thickness

III. RESULTS AND DISCUSSION

3.1Compressive strength of steel fiber reinforced GPC

The compressive strength was tested using compression testing machine. The 7 day and 28 day compressive strength of M65 equivalent GPC and steel fiber reinforced GPC is given in table 3.1. The GPC had a compressive strength of 53.55 MPa and 63 MPa at 7day and 28day respectively. For 0.25% addition of Steel fiber to GPC, the 7day and 28day compressive strength obtained as 58.65 MPa and 69 MPa respectively. The 7day compressive strength was increased to 60.35 MPa, 62.05 MPa and 57.80 MPa, corresponding to the fiber content of .5%, .75%, and 1% respectively.

Addition of Steel fiber beyond 0.75% in GPC indicated a decrease in compressive strength. The increase in strength of GPC after the addition of steel fiber up to .75% may be due to the crack arresting effect of fibers and higher percentage of Steel fiber may not be effective in preventing crack propagation because it resulted in balling effect of fibers during mixing. Fig 3.1 shows the compressive strength results.

Table 3.1 Compressive strength results

Mix designation	7day compressive strength (MPa)	28day compressive strength (MPa)
GPC	53.55	63
GPC+.25%	58.65	69
GPC+.5%	60.35	71
GPC+.75%	62.05	73
GPC+1%	57.80	68

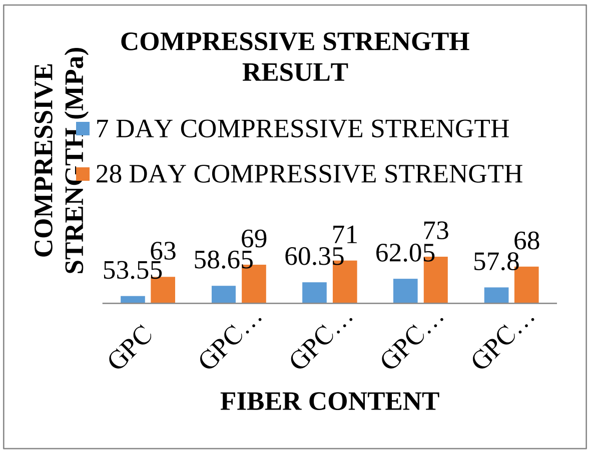

Fig 3.1 Compressive strength results

3.2 Split tensile strength of steel fiber reinforced GPC

The 7 day and 28 day split tensile strength of GPC and Steel fiber reinforced GPC is given in Table 3.2. The split tensile strength of GGBS based geopolymer concrete at 7 day and 28 day was 4.10 MPa and 5.72 MPa respectively. For 0.25% addition of Steel fiber to GPC, the 7 day and 28 day split tensile strength obtained were 4.25 MPa and 6.25 MPa respectively. The 7day split tensile strength was increased to 4.34 MPa, 4.41MPa and 4.05 MPa corresponding to the fiber content of 0.5%, 0.75%, and 1% respectively.
A maximum of 7.6% increase in split tensile strength was noticed corresponding to the addition of 0.75%steel fiber in GPC in 7 days and 18.8% increase in 28 days. The increase in split tensile strength may be due to the bridging action of the fibers across the cracks. Fig 3.2 shows the split tensile strength results.

Table 3.2 Split tensile strength results

Mix designation	7day split tensile strength (MPa)	28day split tensile strength (MPa)
GPC	4.10	5.72
GPC+.25%	4.25	6.25
GPC+.5%	4.34	6.53
GPC+.75%	4.41	6.80
GPC+1%	4.05	5.26

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

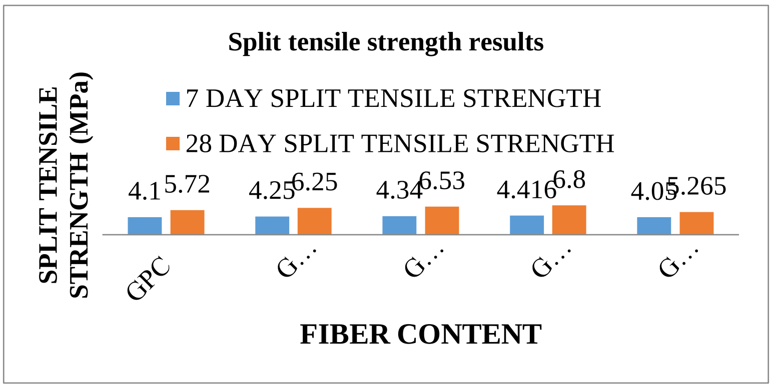

Fig 3.2 Split tensile strength results

3.3 Flexural strength of steel fiber reinforced GPC

The specimens of GPC and steel fiber reinforced GPC were ambient cured for 28 days and tested using universal testing machine by two point loading to obtain flexural strength. The 28day flexural strength of GPC and Steel fiber reinforced GPC are given in Table 3.3. The GPC showed a flexural strength of 6.91 MPa at 28 day. For a steel fiber content of 0.25% flexural strength obtained was 7.02 MPa. The flexural strength obtained were increased to 7.3 MPa, 7.6 MPa, and 7.4 MPa corresponding to the fiber content of 0.5%, 0.75%, and 1% respectively.

A maximum of 9.9% increase in flexural strength was noticed corresponding to the addition of 0.75% steel fiber in GPC. Flexural strength gets reduced as the fiber content is increased beyond0.75%. Fig 3.3 shows flexural strength results

Table 3.3 Flexural strength results

Mix designation	28day flexural strength(MPa)
GPC	6.91
GPC+.25%	7.02
GPC+.5%	7.3
GPC+.75%	7.6
GPC+1%	7.4

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

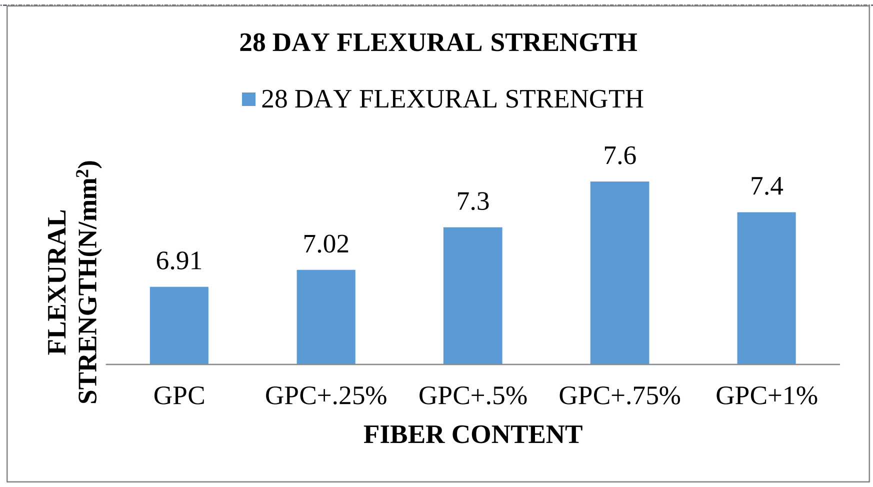

Fig 3.3Flexural strength results

IV. CONCLUSION

In this study, an experimental investigation on the strength parameters of steel fiber reinforced GPC was conducted. For obtaining a relation between geopolymer concrete and steel fiber reinforced geopolymer concrete specimens were casted. All further values of mechanical properties obtained from the current investigation are compared with the. The results of mechanical characteristics are evaluated to arrive at the optimum percentage of steel fiber. The following conclusions were drawn from this investigation.

- Geopolymer concrete is an excellent alternative to OPC concrete
- The oven cured GPC attained its maximum strength within 7days.
- The GPC control specimen showed 63 MPa, 4.10 MPa and 6.91 MPa compressive strength, split tensile strength and flexural strength respectively.
- Inclusion of steel fiber in GPC showed considerable increase in strength parameters with respect to GPC without fiber. A maximum of 15.8 %, 7.6% and 10% increase in compressive strength, split tensile strength and flexural strength respectively were noticed corresponding to the addition of 0.75% steel fiber in GPC.
- The optimum percentage of steel fiber is found to be 0.75%.

V. ACKNOWLEDGEMENTS

The authors of the present paper work would like to acknowledge Toc H Institute of Science and Technology

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CITE AN ARTICLE

Ajay, A. N., & George, E. H. (n.d.). EXPERIMENTAL INVESTIGATION ON EFFECT OF INCLUSION OF HOOKED STEEL FIBER ON GGBS BASED GEOPOLYMER CONCRETE. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *7*(4), 716-723.