Experimental Investigation on the Mechanical Properties of Hooked End Steel Fibre Reinforced Geopolymer Concrete

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Abstract

This research investigated to see how the addition of hooked end steel fibers to geopolymer concrete influenced its mechanical properties like compressive, splitting tensile, and flexural strength. The volume percent of steel fibers on grinding introduced to the geopolymer concrete varied from 0% to 3%. The geopolymer precursors comprises of fly ash and metakaolin. The results revealed that when the steel fibers were added to the geopolymer concrete at its optimum level, it significantly improved all of the mechanical properties. Cubic compressive strength, was improved when the steel fiber percentage was less than 2%. The cubic compressive strength improved by 7.34, 10.37, 13.64, 19.34%, upto 2% of hooked end steel fibers were added. The compressive strength reduced at the rate of 2.4% and 4% when the steel fiber content exceeded 2%, but still remained higher than those of geopolymer concrete without steel fibers. Incorporating steel fibers into GPSF specimens marginally improved its flexural strength and splitting tensile strength. There was a 27.97% increase in splitting tensile strength and a 129.8% increase in flexural strength when steelfiber content of 2.5% was added.

***Keywords**: Hooked end Steel Fiber, Compressive Strength, Fly ash, Metakaolin, Split tensile strength*

1. Introduction

Because of its versatility and inexpensive cost, cement concrete has been widely employed in construction around the world. Cement concrete's significance can be attributed to its superior mechanical characteristics, durability, and continuity after curing. As one of the main components of Cement concrete, ordinary Portland cement has a long production process, uses a lot of energy, and emits a lot of greenhouse gases in the process. Studies indicate that in order to produce 1 ton of cement, 1.6 tons of raw materials are needed, along with around 1,300 kW h of intrinsic energy, and about 0.8 tons of CO2 are released into the atmosphere as a by-product. More energy and CO2 are used and released in the production of cement concrete since it also requires manufactured sand, gravel, and other natural resources in addition to cement. According to the research, 7-10% of the world's total CO2 output originates during the manufacture of concrete. Consuming cement concrete is counter to the idea of sustainable development. In light of the aforementioned, it is essential to look for alternate building materials that will substitute cement concrete. Dr. Joseph

Davidovitis coined the name "Geopolymer" in 1978 to characterize a group of mineral binders having a chemical composition comparable to zeolites but with an amorphous microstructure. Instead of using calcium-silicate-hydrates (CSHs) for matrix formation and strength, as happens in traditional Portland/pozzolanic cements, Geopolymer relies on the poly condensation of silica and alumina precursors to provide its rigidity. Alumino-silicate, which is expected to be high in both silicon (Si) and aluminum, is the raw material of preference. (Al). Fly ash, silica fume, slag, rice-husk ash, red mud, etc. are numerous instances of by-product materials. Geopolymerisation results in higher solids concentration than alumino silicate gel or zeolite synthesis. Fly Ash and Granulated Blast Furnace Slag are two instances of industrial aluminosilicate waste products that can be alkali activated to produce these. A three-dimensional polymeric chain and ring structure is produced through a very rapid chemical reaction under alkaline conditions on silicon-aluminum minerals during the polymerization process. Materials most often evaluated for its structure often have a Si - Al (Si:Al) between 2 and 3.5, as this ratio greatly affects the ultimate structure of the Geopolymer. These Geopolymers typically fall into one of three categories (where sialate stands for silicon-Oxo-aluminate).

2. Literature Review

The combination of a geopolymer binder, coarse aggregates, and fine aggregates creates geopolymer concrete, a novel, innovative, and sustainable engineering material. Due to the lack of cement and the low amount of water used in the geopolymerization process, geopolymer concrete is considered a green building material [12]. In addition, geopolymer concrete may be made from solid wastes such fly ash and blast furnace slag [13,14], which conserves materials and decreases the amount of area required for the disposal of debris [15]. In addition, the mechanical performance of geopolymer concrete is either the same as or even superior to that of conventional cement concrete [16-18]. Because of these benefits, geopolymer concrete has recently replaced traditional cement concrete in the construction sector [10,19]. In contrast to traditional cement concrete, geopolymer concrete is more brittle and has a lower elastic modulus [20,21]. Adding fibers to geopolymer concrete can improve its mechanical properties. Steel fibers, polyvinyl alcohol fibers, polypropylene fibers, nylon fibers, carbon fibers, glass fibers, and natural fibers are all examples of common fiber types [22-27]. Scientists have found that steelfibers to have among the most desirable due to their high elastic modulus and fracture strain [28, 29]. Numerous studies on steel fiber-reinforced geopolymer concrete have been published so far. Gomes et al. [30] utilized a three-point bending test to determine crack mouth opening displacement, energy retention rate, and other fracture variables. Steel fibers used with geopolymer concrete were found to significantly slow crack growth and protect against brittle fractures in concrete composites. The effects of axial and flexural loads on a geopolymer concrete containing various types of steel fibers were investigated by Farhan et al.

3. Experimental Investigation

3.1 Fly Ash

The fine particles that are blown out of the boiler with the flue gases constitute fly ash, one of the byproducts by burning coal generating power. Before the flue gases reach the chimneys of coal-fired power plants, fly ash is often collected by electrostatic precipitators or other particle filtration equipment. All fly ash contains significant amounts of silicon dioxide (SiO_2), both amorphous and crystalline, aluminum oxide ($Al2O_3$), and calcium oxide (CaO), the main mineral compounds in coal-bearing rock strata. However, these components vary widely depending on the source and production of the coal being burned.

Table 1: Percentage of Component Present in Fly Ash

Component	Bituminous	Subbituminous	Lignite
SiO_2 (%)	20-65	45-60	20-45
Al_2O_3 (%)	5-30	20-25	20-30
Fe_2O_3 (%)	10-40	5-10	4-20
CaO (%)	1-12	5-30	15-40
LOI (%)	0-15	0-3	0-5

3.2 Metakaolin

Pozzolan metakaolin is among the most efficient pozzolanic ingredients for construction projects. China clay, often known as the mineral kaolin, is produced when it is heated to temperatures between 600 and 800 degree Celsius. Its quality is managed during production, making it a more consistent product than by-product industrial pozzolans. When several enormous structures were being built all over the world in the 1960s, metakaolin was successfully added to the concrete in order to avert deterioration caused by the alkali-silica reaction.

Table 2: Chemical Composition of Metakaolin

Component	Results
SiO_2 (%)	54
Al_2O_3 (%)	41
Fe_2O_3 (%)	1.2
CaO+MgO (%)	0.6
K2O+Na2O (%)	0.4

3.3 Alkaline Activator

In this experiment, an alkaline activator comprised of sodium silicates (Na_2SO_3) and sodium hydroxide was utilized. (NaOH). Na_2SO_3, NaOH, and regular tap water were used in its preparation. 99% pure NaOH solid flakes were utilized.

3.4 Hooked End Steel Fibres

More than 25 years have passed since the introduction of hooked end steel fiber. In terms of the longevity and widespread use of steel fiber reinforced concrete, this form has undoubtedly been the most prominent. This is because, within the last decade, the hooked end shape has become standard across the board among fibre manufacturers. While undulated fibers perform better in preventing shrinkage, high aspect ratio (HE) fibers nevertheless offer excellent workability. The practicality of aspect ratios up to 80 is adequate. Unlike undulated or flat-end fibers, Hooked end fibers can be utilized with any concrete mix, and a high concrete density is not required. This particular form of the fiber is excellent in transferring loads over cracks. Thus, after the first fracture appears, there is an immediate drop in load-bearing ability, followed by a stabilization and, in some situations, a resumption of expansion prevails

Table 3: Physical Properties of Hooked End Steel Fibers

S. No	Description	Results
1	Length (mm)	2.6
2	Specific Gravity (kg/cu.m)	7.85
3	Thickness	0.37
4	Standard Length	40
5	Aspect Ratio	38
6	Split Tensile Strength (MPa)	900
7	Elastic Moduli (GPa)	250

3.5 Mix Proportion and Preparation of Specimens

M sand, Coarse Aggregate, Flyash, Metakaolin, Alkaline activator, Water were proportioned in terms of 7 replacement levels considering hooked end steel fibers by volume fraction ranging from control mix 0%, 0.5%, 1%11.5%,2%, 2.5%,3%. Alkaline activators say sodium hydroxide, sodium silicate were kept constant at 50 and 280 kg/cu.m stabilizing its molarity at the rate of 1.2. Water binder ratio was fixed at 0.35 and the mass ratio of flyash to metakaolin was 2:3. After combining the steel fibers, binder, and aggregates, they were agitated for 3 minutes. After that, 3 minutes were spent stirring in the alkali solution. NaOH solution was prepared 12 hours ahead of time due to the release of heat during the dissolving of NaOH flakes in water. Prepared Geopolymer concrete mix concrete was placed into moulds after thorough mixing. The specimens were demoulded and transferred to a conventional curing environment after 24 hours of curing at room temperature. After 28 days, the cured pieces were removed and taken to a atmospheric dried area to cure for another three days. Finally, the geopolymer concretes reinforced with steel fibers were evaluated for their mechanical properties.

Table 4: Mix Proportion for GPC Blended with Hooked End Steel Fibre by (Vf)

S.No	Specimen ID	M Sand	CA	Steel Fiber (Vf)	FlyAsh	Meta kaolin	Admi xture	Alkaline Activator		
								NaOH	Na2SO3	Water
		(kg/cu.m)								
1	CM	570	1060	0	192	270	2.1	50	280	60
2	GPSF1	560	1035	0.5	192	270	2.1	50	280	60
3	GPSF2	540	1010	1	192	270	2.3	50	280	60
4	GPSF3	530	990	1.5	192	270	2.55	50	280	60
5	GPSF4	520	970	2	192	270	2.8	50	280	60
6	GPSF5	505	950	2.5	192	270	3	50	280	60
7	GPSF6	495	940	3	192	270	3.2	50	280	60

4. Compressive Strength

The GPSF samples whose dimensions are 150mm x 150mm x 150mm, after completing their curing time frame are subjected to compressive strength test. The samples dry density was recorded and loaded in a 2-ton compressive strength testing machine. Care should be ensured that the sample adheres direct contact with the machine's impactor by positioning the sample in the centre of the axis of the test setup. Following which a gradual load is applied and the sample tend to fracture eventually where the maximum load carried by the sample will be recorded as P from the red dial gauge as displayed in the test setup eventually the compressive strength is carried out as per the relevant codal provision. Table 5 indicates the variation in the compressive strength of GPSF specimens.

Table 5: Variation in the compressive strength of GPSFfor different Vf

S.No	Specimen ID	Steel Fiber (Vf)	Compressive Strength (MPa)
1	CM	0	42.66
2	GPSF1	0.5	45.99
3	GPSF2	1	47.6
4	GPSF3	1.5	49.4
5	GPSF4	2	52.89
6	GPSF5	2.5	51.61
7	GPSF6	3	50.76

5. Split Tensile Strength

The GPSF samples whose dimensions are 150mm *300mm, after completing their curing time frame are subjected to split tensile test. The samples dry density was recorded and loaded in a 2-ton compressive strength testing machine. Care should be ensured that the sample adheres direct contact with the machine's impactor by positioning the sample in the centre of the axis of the test setup. Following which a gradual load is applied and the sample tend to split into halves eventually where the maximum load carried by the sample will be recorded as P from the red dial gauge as displayed in the test setup eventually the split strength is carried out as per the relevant codal provision. Table 6 indicates the variation in the compressive strength of GPSF specimens.

Table 6: Variation in the split tensile strength of GPSF for different Vf

S.No	Specimen ID	Steel Fiber (Vf)	Split Tensile Strength (MPa)
1	CM	0	2.6
2	GPSF1	0.5	2.73
3	GPSF2	1	2.88
4	GPSF3	1.5	2.96
5	GPSF4	2	3.17
6	GPSF5	2.5	3.59
7	GPSF6	3	3.61

6. Flexural Strength

The GPSF prism samples whose dimensions are 100mm *100mm*500mm, after completing their curing time frame are subjected to flexural test. Two steel rollers with a diameter of 38 mm should be mounted on the bed of the testing machine such that the distance between them is 60 cm for 150 mm specimens and 40 cm for 100 mm specimens. Two identical rollers positioned at the third places of the supporting span, with a distance of 20 or 13.3 cm center to center, will distribute the weight. All rollers must be positioned in such a way that the load is applied axially and without subjecting the specimen to any torsional stresses or constraints, and the load must be distributed evenly across the two loading rollers. Table 7 indicates the variation in the compressive strength of GPSF specimens.

Table 7: Variation in the flexural strength of GPSF for different Vf

S.No	Specimen ID	Steel Fiber (Vf)	Flexural Strength (MPa)
1	CM	0	3.1
2	GPSF1	0.5	4.24
3	GPSF2	1	4.53
4	GPSF3	1.5	5.39
5	GPSF4	2	6.13
6	GPSF5	2.5	7.13
7	GPSF6	3	7.16

7. Elastic Moduli

The elastic moduli has been arrived based on the obtained results of the compressive strength for different Vf at 28 days which is determined for Ec=5000x [sq.rt (fck)] GPa as per IS 456:2000. Table 8 indicates the variation in the elastic moduli of GPSF specimens.

Table 8: Variation in the Elastic Moduli of GPSF for different Vf

S.No	Specimen ID	Steel Fiber (Vf)	Elastic Modulus (GPa)
1	CM	0	32.65
2	GPSF1	0.5	33.9
3	GPSF2	1	34.49
4	GPSF3	1.5	35.14
5	GPSF4	2	36.36
6	GPSF5	2.5	35.92
7	GPSF6	3	35.62

8. Results and Discussions

From Table.5, it was observed that, the compressive strength for conventional geopolymer concrete without the addition of steel fibres attained 42.66 MPa at 28 days whereas the compressive strength marginally increased holding values say 45.99 MPa, 47.6 MPa, 49.4 MPa, 52.89 MPa when the hooked end steel fibres were added at 0.5%,1%,1.5% and 2% by volume fraction. However the compressive strength drastically detained to 51.61 MPa, 50.76 MPa when the steel fibres were added at 2.5% and 3% by volume fraction respectively. Thus comparing with conventional geopolymer concrete without steel fibers, there was a marginal increase in strength gain at 7.24%, 10.37%, 13.64% and 19.34%. When the fibres were added at 2.5% and 3%, the compressive strength marginally decreased at 2.42% and 4% when compared with GPSF.

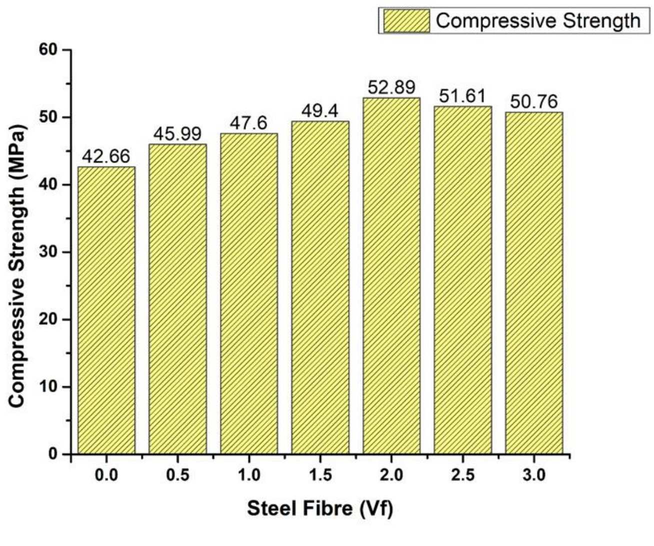

Figure.1: Graph showing Variation in the compressive strength of GPSF

From Table.6 it was observed that, the split tensile strength for conventional geopolymer concrete without the addition of steel fibres attained 2.6 MPa at 28 days whereas the split tensile strength marginally increased holding values say 2.73 MPa, 2.88 MPa, 2.96 MPa, 3.17 MPa when the hooked end steel fibres were added at 0.5%, 1%, 1.5% and 2% by volume fraction. However the split tensile strength steadily increased to 3.59 MPa, 3.61 MPa when the steel fibres were added at 2.5% and 3% by volume fraction respectively when compared with GPSF4. Thus comparing with conventional geopolymer concrete without steel fibers, there was a marginal increase in strength gain at 3.7%, 9.72%, 12.16% and 17.98%. When the fibres were added at 2.5% and 3%, the split tensile strength rapidly increased at 27% and 27.97% when compared with GPSF.

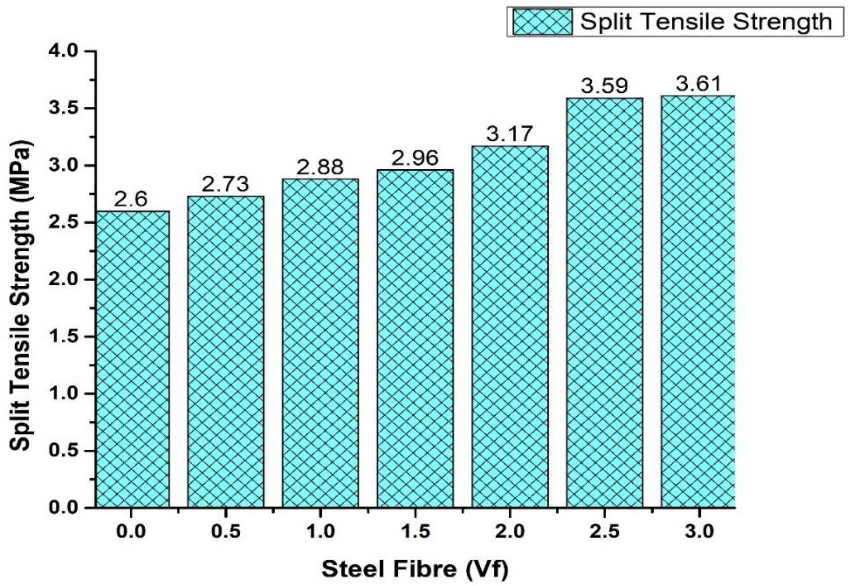

Figure.2: Graph showing Variation in the split tensile strength of GPSF

From Table.7, it was noted that, the flexural strength for conventional geopolymer concrete without the addition of steel fibres attained 3.1 MPa at 28 days whereas the flexural strength marginally increased holding values say 4.24 MPa, 4.53 MPa, 5.39 MPa, 6.13 MPa when the hooked end steel fibres were added at 0.5%,1%,1.5% and 2% by volume fraction. However the split tensile strength steadily increased to 7.13 MPa, 7.16 MPa when the steel fibres were added at 2.5% and 3% by volume fraction respectively when compared with GPSF4. Thus comparing with conventional geopolymer concrete without steel fibers, there was a marginal increase in strength gain at 26.88%, 31.56%, 42.48%and 49.42%. When the fibres were added at 2.5% and 3%, the flexural strength rapidly increased at 56.52% and 56.70% when compared with GPSF.

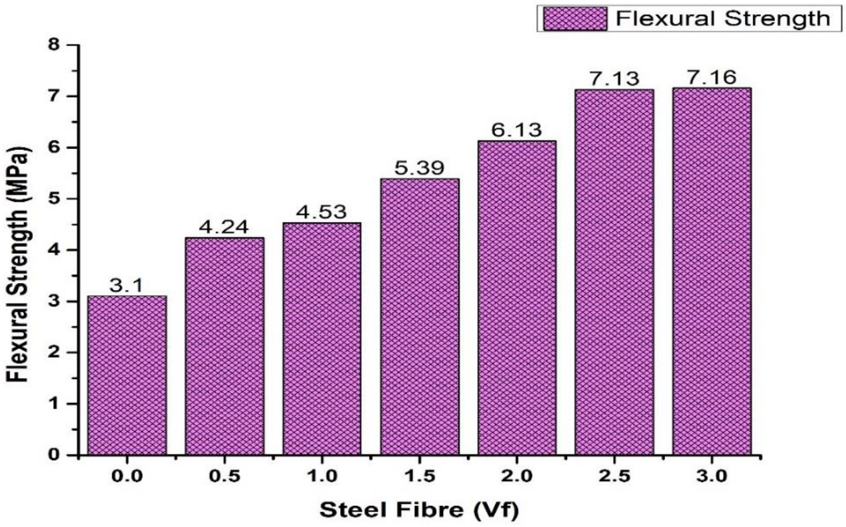

Figure.3: Graph showing Variation in the flexural strength of GPSF

From Table.8, it was noted that, the elastic moduli for conventional geopolymer concrete without the addition of steel fibres attained 32.65 GPa at 28 days whereas the elastic moduli marginally increased holding values say 33.9 GPa, 34.49 GPa, 35.14 GPa, 36.36 GPa when the hooked end steel fibres were added at 0.5%,1%,1.5% and 2% by volume fraction. However the elastic moduli enhances to hold at 35.92 GPa, 35.62 GPa when the steel fibres were added at 2.5% and 3% by volume fraction respectively when compared with GPSF4.

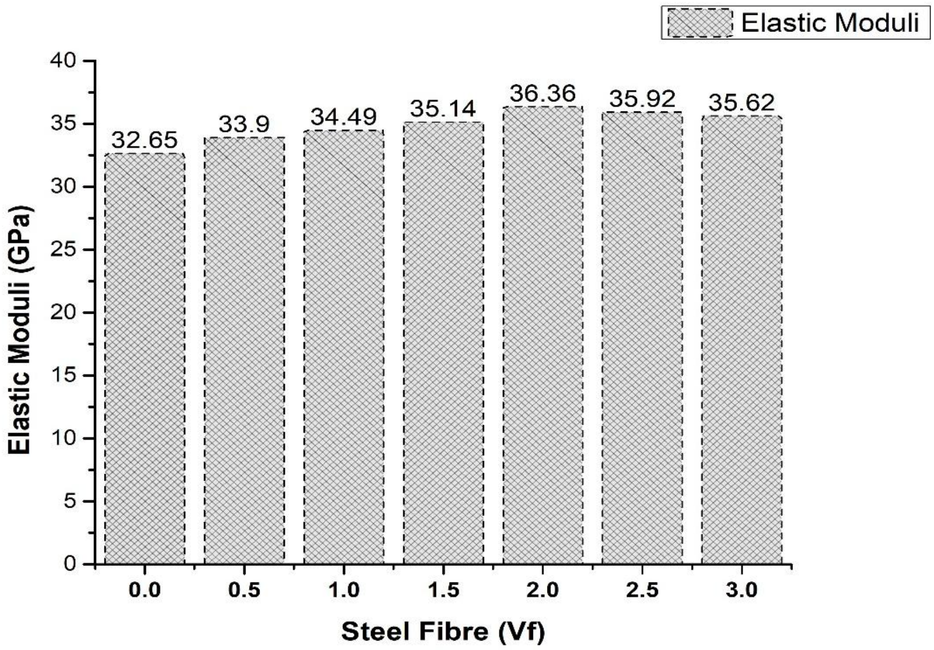

Figure.4: Graph showing Variation in the Elastic Moduli of GPSF

9. Conclusion

- When comparing with conventional geopolymer concrete without steel fibers, there was a marginal increase in strength gain at 7.24%, 10.37%, 13.64% and 19.34%. When the fibres were added at 2.5% and 3%, the compressive strength marginally decreased at 2.42% and 4% when compared with GPSF4

- With regard to split tensile property of GPSF, on comparing with conventional geopolymer concrete without steel fibers, there was a marginal increase in strength gain at 3.7%, 9.72%, 12.16% and 17.98%. When the fibres were added at 2.5% and 3%, the split tensile strength rapidly increased at 27% and 27.97% when compared with GPSF

- With regard to flexural property of GPSF, comparing with conventional geopolymer concrete without steel fibers, there was a marginal increase in strength gain at 26.88%, 31.56%, 42.48% and 49.42%. When the fibres were added at 2.5% and 3%, the flexural strength rapidly increased at 56.52% and 56.70% when compared with GPSF
- Adopting hooked end steel fibres in geopolymer concrete enhances its split tensile and flexural capability as the steel fibres will remain intact in the hardened form and will expand so as to sustain load when the sample attains and also the steel fibre will help to control the crack behaviour after attaining initial stage of failure and changing the property of failure from brittle to ductile
- GPSF essentially helps to curb carbon dioxide emissions when compared to OPC concrete which favours reduction towards environmental and ecological impact

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