Investigation on the effect of steel fibers in geopolymer concrete

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Abstract: This research work throws lime light in mitigating the brittleness of GGBS based geopolymer concrete through the addition of high modulus fibers. This work invests the effects of incorporation of steel fibers in geopolymer concrete over workability, compressive, split tensile, flexural, ductility factor and energy absorption capacity. The steel fibers were added in proportions such as 0.25, 0.5, 0.75, 1 and 1.25 percent of the volume of concrete. The results report that addition of steel fibers have positive impacts over mechanical properties, ductility and energy absorption capacity. This paves way for extending the scope of geopolymer concrete in various facets to replace the cement concrete effectively.

1. INTRODUCTION

Ordinary Portland Cement (OPC) is most consumed commodity in the world after water. Cement production in industry leads high emission of CO$_2$ which in turn accounts for global warming. Mining of cement also leads to environmental degradation. Hence the utilization of cement has to be reduced for the sustainable development. On the other hand there has been a huge problems for the disposal of industrial by-products like flyash and Ground Granulated Blast Furnace Slag (GGBS) that are expelled out of thermal and steel plants. Geopolymer concrete fabricated using various industrial by-products exhibited similar or better mechanical, physical and durability properties as compared to OPC concrete. In recent years, geopolymer has attracted considerable attention among these binders because of its early compressive strength, low permeability, good chemical resistance and excellent fire resistance behavior [1-3]. Geopolymer concrete exhibits better engineering properties than cement concrete at elevated temperatures [4-5]. GPC is brittle when compared to OPC counterpart due to the highly cross-linked framework. The failure of Geopolymer is of more brittle nature and its energy absorption characteristics have to be improved for sustaining the impact load.

Another contemporary development made in the arena of concrete is the Fiber Reinforced Concrete (FRC). Augmentation of fibers were found to increase the mechanical properties and the integrity of the matrix. In general fibers that are to be added to the concrete are divided in to two types such as high modulus fibers and low modulus fibers. Each type of fibers inhibit different types of properties over the concrete[6-14]. High elastic modulus steel fibres enhance the flexural toughness and ductility of cement concrete. The contribution of steel fibres can be observed mainly after matrix cracking in concrete, in that they help in bridging the propagating cracks [15]. Hence an approach can be made by incorporating steel fibers in GPC to mitigate the brittleness and increase the impact energy.

In this work an effort has been made to investigate the properties of steel fiber reinforced geopolymer concrete. Steel fibers have been added in various proportions such as 0.25, 0.5, 0.75, 1 and 1.25 percent of the volume of concrete and compared with the GPC without steel fibers. In this work,
mechanical properties such as compressive, split tensile and flexural strength, ductility factor and impact strength are determined.

2. MATERIALS

In this work GGBS is used as the alumino silicate source material. GGBS slag was obtained from the JSW cements. Specific gravity of GGBS was found to be 2.94. Manufactured sand was used as the fine aggregate. Specific gravity of M-sand was found to be 2.63. Locally available coarse aggregates of size 10mm are utilized as the coarse aggregate. Specific gravity of coarse aggregate was determined to be 2.8. A concoction of Sodium silicate solution and sodium hydroxide solution was used as the alkaline activator solution. The molarity of the solution was fixed as 13M. These fibers are available in packs of around 30 strands, which were fibrillated with water-dissolvable paste to guarantee prompt scattering in concrete during mixing. All the materials are mixed in a pan mixer for about 4-5 minutes. The quantities of the material are determined from the previous work carried out by the researcher. The mix proportion adapted in this work are tabulated in Table 1

Table 1. Mix details

| Materials       | Mass (kg/m3) |
|-----------------|--------------|
| GGBS            | 610          |
| M-Sand          | 517.88       |
| Coarse aggregate| 851.36       |
| Sodium silicate | 265.79       |
| Sodium hydroxide| 106.31       |
| Water           | 18.3         |

3.EXPERIMENTAL STUDY

3.1 Compressive Strength:
Compressive strength test was carried out as per IS : 516 -1959 [16] over cubical specimens of size 100 x 100 x 100 mm. The cubes were tested for compression testing at the age of 7, and 28 days. The average compressive strength of fiber reinforced geopolymer concrete specimens are tabulated in Table 2.

Table 2. Mechanical Properties Test Result

| Specimen name | Fiber volume fraction | Specimen name | Compressive strength (Mpa) | Split Tensile strength (Mpa) | Flexural Strength (Mpa) |
|---------------|-----------------------|---------------|----------------------------|-----------------------------|-------------------------|
|               |                       |               | 7 days | 28 days | 7 days | 28 days | 28 days |
| GPC           | 0                     | GPC           | 36.5   | 43      | 3.1    | 3.6     | 6.1     |
| SFRGPC1       | 0.25                  | SFRGPC1       | 40     | 46.9    | 3.5    | 4.1     | 6.5     |
| SFRGPC2       | 0.50                  | SFRGPC2       | 43.5   | 51.4    | 3.9    | 4.5     | 6.8     |
| SFRGPC3       | 0.75                  | SFRGPC3       | 47     | 55.3    | 4.1    | 4.8     | 7.1     |
| SFRGPC4       | 1                     | SFRGPC4       | 49.2   | 58      | 4.4    | 5.1     | 7.4     |
| SFRGPC5       | 1.25                  | SFRGPC5       | 47.9   | 56.3    | 4.1    | 4.9     | 7.2     |

Compressive strength of SFRGPC and Control specimens are compared in Figure 1.
From Figure 1, it is evident that there is a gradual increase in compressive strength of Geopolymer with the augmentation of steel fibers for various proportions. From Table SFRGPC of different volume fraction SFRGPC1, SFRGPC2, SFRGPC3, SFRGPC4 shows an increase in compressive strength of about 10%, 20%, 29%, 35% at 7 days and about 10%, 20%, 30% and 35% at 28 days respectively than control specimen GPC. The increase in strength is attributed to the improved microstructure of the matrix with reduced porosity. The increase in compressive strength is due to the improved structural integrity provided by the increased fiber content. The decrease in strength after the optimum percentage is due to the excess fiber content that affects the adhesion inside the matrix. Some research work carried out in the vicinity of steel fiber reinforced concrete reported increase in compressive strength with volume fractions ranging from 0.5% to 2.0% [17].

3.2 Split tensile strength:
Split tensile strength test was carried out over cylindrical specimens of 150 mm diameter and 300 mm length after 7 days and 28 days as per IS : 5816 -1999 [18]. The average Tensile strength of fiber reinforced geopolymer concrete specimens are tabulated in Table 2.
augmentation of steel fibers for various proportions. From Table 2, it is inferred that SFRGPC of different volume fraction SFRGPC1, SFRGPC2, SFRGPC3, SFRGPC4 shows an increase in Split tensile strength of about 13%, 25%, 33%, 42% at 7 days and 14%, 25%, 35%, 42% at 28 days respectively than control GPC. From Table 2, it is clear that steel fiber reinforced geopolymer concrete specimens gains about 86 percent of the 28 days strength at 7 days. Prateek et al., stated that the maximum split tensile strength of SFRGPC is achieved at 14 days under ambient curing when compared with conventional concrete [19].

3.3 Flexural Strength Test:
Flexural strength was determined by testing the prismatic specimens of size of 500 X 100 X 100 as per IS : 516 -1959 [16]. The average values are tabulated in Table 2. The average values are plotted in the graph for better interpretation. The variation of flexural strength for the various percentages of steel fiber are depicted in Figure 3.

From Table 2, it is inferred that SFRGPC of different volume fraction SFRGPC1, SFRGPC2, SFRGPC3, SFRGPC4 shows an increase in flexural strength of 7%,12%,17%,22% at 28 days than control GPC. The increase in flexural strength of the specimens is due to the bridging effect exhibited by the fibers. The fibers act as a bridge and transfer the stress across them there by increasing the flexural strength capacity of the section. Islam et al claimed that the addition of 0.5% steel fibers enhanced the splitting tensile and flexural strength of geopolymer concrete by about 19%–38% and 13%–44%, respectively[20].

![Flexural strength graph](Figure 3. Flexural strength graph)

3.4 Ductility Factor:
Ductility measures the flexibility of the prism specimens. Ductility factor for the various dosages are determined by testing the prismatic specimens using Universal Testing Machine as per IS : 516 -1959 [16] The ductility index $\mu$ is then calculated as the ratio of ultimate deflection to the yield deflection. The ultimate and yielding deflections determined were tabulated in Table 3.

From Figure 4, it is inferred that SFRGPC of different volume fraction SFRGPC1, SFRGPC2, SFRGPC3, SFRGPC4 shows an increase in Ductility factor of 5%,13%,15%,18% at 28 days than control GPC . It is inferred that the presence of steel fibers increased the ductility of the specimens till 1 percent beyond which it reduced. There was a significant increase in ultimate deflection than the yield deflection thereby increasing the overall ductility of the geopolymer concrete specimens. Jang et al. [21] claimed increase in ductility of the Steel fiber reinforced concrete with an increase in fiber content. Utilization of steel fiber as transverse reinforcement proved to enhance the confinement and
ductility.

![Figure 4. Ductility Factor graph](image)

### Table 3. Ductility factor test result

| Specimen name | Ultimate deflection(δu) | Yield deflection(δy) | Ductility factor μ = (δu/δy) |
|---------------|--------------------------|----------------------|------------------------------|
| GPC           | 3.16                     | 2.65                 | 1.19                         |
| SFRGPC1       | 3.35                     | 2.71                 | 1.24                         |
| SFRGPC2       | 3.7                      | 2.77                 | 1.34                         |
| SFRGPC3       | 3.8                      | 2.8                  | 1.35                         |
| SFRGPC4       | 3.92                     | 2.82                 | 1.4                           |
| SFRGPC5       | 3.98                     | 2.97                 | 1.34                         |

### 3.5 Impact strength test:
Impact strength of the steel fiber reinforced geopolymer concrete specimens were determined as per ACI Committee 544[23] over specimens of 152 mm diameter and 62 mm thickness. The impact resistance of the concrete was determined using instrumented drop-weight testing equipment. The number of blows required to cause initial crack and ultimate failure are noted for the different dosages of steel fiber and are tabulated in Table 4.

### Table 4. Impact Strength test result

| Specimen name | Number of blows for first crack | Number of blows for ultimate crack | Impact Strength (Nm) |
|---------------|---------------------------------|------------------------------------|----------------------|
| GPC           | 3                               | 3                                  | 587.0711             |
| SFRGPC1       | 4                               | 6                                  | 1174.142             |
| SFRGPC2       | 7                               | 9                                  | 1761.213             |
| SFRGPC3       | 8                               | 11                                 | 2152.594             |
| SFRGPC4       | 11                              | 14                                 | 2739.665             |
| SFRGPC5       | 12                              | 16                                 | 3131.046             |
Figure 4. Impact Strength Graph

GPC specimen without any fiber content exhibited first crack and suffered ultimate failure at the same number of blows. From Figure 4, it is evident that impact energy increases with increase in the steel fiber content. This increase is due to the reason that steel fibers have high tensile strength and modulus of Elasticity than the concrete. This increases the integrity of the matrix thereby increasing the impact strength. Zhang[22] stated that incorporating steel fiber into concrete improved the impact resistance and increased the maximum bending load and fracture energy under impact loading considerably.

4. CONCLUSION

From the above discussions the following conclusions could be drawn,

- With the increase in the steel fiber content, there has been a significant increase in the mechanical properties of the Geopolymer concrete. Compressive strength increased about 35 percent, split tensile strength increased about 42 percent and flexural strength about 22 percent.
- Addition of steel fibers increased the ductility of the concrete. However the increase in the ultimate deflection was more than the increase in the yield deflection. Post yielding behaviour of Geopolymer concrete increased at the optimum utilization of steel fibers in the matrix.
- Impact strength measured the real performance of steel fibers. Addition of steel fibers increased the impact strength about 433.33 percent.

This paves way for the effective utilization of steel fibers in Geopolymer concrete by reducing its brittleness and increasing the energy absorption capacity with the overall increase in the mechanical properties.

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