Structural performance of hybrid fiber geopolymer concrete beams

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Abstract: This research work aims at investigating the structural properties of hybrid fiber reinforced geopolymer concrete specimens such as load-deflection behaviour, stiffness, ductility, toughness index. In this research work, effort has been made towards reducing the brittleness of geopolymer concrete by the addition of glass (high modulus) and polypropylene (low modulus) fibers inside GGBS based geopolymer concrete made of M-sand. The glass and polypropylene fibers were added in various proportions such as 1/0, 0.75/0.25, 0.5/0.5, 0.25/0.75, 0/1. The research work recorded enhancement of structural properties of geopolymer concrete under ambient curing. This work paved way for the utilization of fibers inside geopolymer concrete and replace cement concrete in all facets.

Keywords: Hybrid fiber, Geopolymer concrete, Ambient curing.

1. INTRODUCTION

Geopolymer concrete (GPC), introduced by Davidovits in 1974 has witnessed different facets of development over years in order to replace the conventional cement concrete in construction industry. Geopolymer concrete is made of aluminosilicate source material and alkaline solution. Alumino silicate source material may be of natural origin like Metakaolin [1-6] or industrial by products like flyash, GGBS[7-10]. Flyash based geopolymer concrete developed strength only under heat curing[11-12]. Curing condition and curing period are the significant aspects which influence the strength and setting time of Geopolymer concrete[12-14] [15]. Geopolymer Concrete has better compressive, tensile, flexural, acid resistance properties than the cement concrete. Geopolymer concrete also exhibits better engineering properties when expressed to elevated temperature [16,17].

Geopolymer concrete finds its application in many precast arena such as boat ramp, wall panels, bridge girders, sleepers, paver blocks[18,19]. Two important limitations of geopolymer concrete is its synthesis method and the failure mode[9,20]. Synthesis of flyash based Geopolymer concrete is strictly through heat curing and thus is difficult to synthesis in cast in situ construction. Also the mode of failure of geopolymer specimens is more brittle when compared to cement concrete specimens which can be observed through the fracture planes. For the effective implementation of GPC specimens in the place of cement concrete specimens these limitations has to be rectified[21,22,23,24,25,26,27,28,29]

On the contemporary, Fiber reinforced concrete gains attention owing to its increased structural integrity obtained through the addition of fibers in to the cement concrete. Fibers added in to the concrete are briefly divided into two types such as high modulus and low modulus depending upon
the modulus of elasticity. Fibers may be of natural origin or sometimes synthetic. Incorporation of different types of fibers augment different types of alterations inside the matrix. Some research works concentrate on the utilization of combined high and low modulus fibers inside matrix.

Incorporation of GGBS was found to support the synthesis of GPC without the employance of heat curing conditions. Hence, work has been concentrated towards improving the ductility of GPC by the addition of glass (high modulus) and polypropylene (low modulus) fibers inside GGBS based GPC made of M-sand. The glass and polypropylene fibers were added in various proportions such as 1/0, 0.75/0.25, 0.5/0.5, 0.25/0.75, 0/1. The structural properties of the beam such as load-deflection behaviour, stiffness, ductility, toughness index are investigated in this research work.

2. EXPERIMENTAL STUDY

2.1 Materials

In this work, Geopolymer concrete specimens are GGBS based and are ambient cured. GGBS utilized in this work is brought from JSW cements. Alkaline solution used in this study is the concoction of NaOH and Na$_2$SiO$_3$ solution. Sodium hydroxide solution of 13 molarity is used in this work. Coarse aggregate of 10mm size obtained from the local quarry is utilized in this work. M-Sand used here is obtained from locally available crushing stone. High modulus glass fibers and low modulus polypropylene fibers are utilized in this work. The properties of the various materials are tabulated in Table 1.

| Table 1. Material Properties |
|-----------------------------|
| S.No | Properties          | Materials | Value |
| 1    | Specific Gravity    | GGBS      | 2.90  |
|      | M-Sand              | 2.62      |
|      | Coarse Aggregate    | 2.70      |
| 2    | Fineness Modulus    | M-Sand    | 2.36  |
|      | Coarse Aggregates   | 6.10      |
| 3    | Bulk Density        | M-Sand    | 1702k$_g$ |
|      | Coarse Aggregates   | 1456k$_g$ |
| 4    | Length              | Glass Fiber | 6.0mm |
|      | Polypropylene       | 20mm      |
| 5    | Diameter            | Glass Fiber | 0.1mm |
|      | Polypropylene       | 0.2mm     |
| 6    | Aspect ratio        | Glass Fiber | 60    |
|      | Polypropylene       | 100       |

2.2 Specimen Specifications

GGBS and M-sand were mixed in mixer, trailed by the augmentation of fiber, coarse aggregate and the activator solution. All the ingredients were mixed in pannmixer for about 4 to 5 minutes. The beam specimens of size 150 X 150 X 3000 mm were casted using steel moulds to find the structural properties of the beam. All the specimens were ambient cured. The mix ingredients of the various specimen types are tabulated in Table 2.

| Table 2: Specimen Specifications |
|----------------------------------|
| Mix ID  | GGBS (Kg/m$^3$) | M-sand (Kg/m$^3$) | Coarse Aggregate (Kg/m$^3$) | NaOH (Kg/m$^3$) | Na$_2$SiO$_3$(Kg/m$^3$) | Glass Fiber (percent) | Polypropylene Fiber (percent) |
|--------|-----------------|-------------------|-----------------------------|-----------------|------------------------|------------------------|-----------------------------|
| PFRGPC | 550             | 481.21            | 1030.2                      | 95.86           | 239.64                 | 0                      | 1                           |
| HFRGPCA| 550             | 481.21            | 1030.2                      | 95.86           | 239.64                 | 0.25                   | 0.75                        |
| HFRGPCB| 550             | 481.21            | 1030.2                      | 95.86           | 239.64                 | 0.5                    | 0.5                         |
| HFRGPPC| 550             | 481.21            | 1030.2                      | 95.86           | 239.64                 | 0.75                   | 0.25                        |
| GFRGPC | 550             | 481.21            | 1030.2                      | 95.86           | 239.64                 | 1                      | 0                           |
3. RESULTS AND DISCUSSION

The effect of combined behaviour of glass and polypropylene fibers over the geopolymer beam was investigated. Glass and Polypropylene fibers were added in different proportions such as 0/1, 0.25/0.75, 0.5/0.5, 0.75/0.25 and 1/0. Structural properties of the beam such as load-deflection behaviour, ductility, stiffness and toughness index of the specimens were investigated in this study.

3.1. Load-deflection behaviour

Steel and polypropylene Fiber reinforced geopolymer beam specimens were subjected to two point loading using loading frame of 500 KN capacity. The deflections were measured using strain gauge at three points such as under the loads and at mid span. The load and corresponding deflection for the various fiber dosages are tabulated in Table 3.

| Load | Deflection | Load | Deflection | Load | Deflection | Load | Deflection | Load | Deflection |
|------|------------|------|------------|------|------------|------|------------|------|------------|
| 0    | 0          | 0    | 0          | 0    | 0          | 0    | 0          | 0    | 0          |
| 2.5  | 0.4        | 2.5  | 0.2        | 2.5  | 0.2        | 2.5  | 0.2        | 2.5  | 0.2        |
| 5    | 0.9        | 5    | 0.8        | 5    | 0.8        | 5    | 0.8        | 5    | 0.8        |
| 7.5  | 1.4        | 7.5  | 1.3        | 7.5  | 1.3        | 7.5  | 1.3        | 7.5  | 1.3        |
| 10   | 2.6        | 10   | 1.7        | 10   | 1.7        | 10   | 1.7        | 10   | 1.7        |
| 12.5 | 3.5        | 12.5 | 2.4        | 12.5 | 2.4        | 12.5 | 2.4        | 12.5 | 2.4        |
| 15   | 4.2        | 15   | 2.9        | 15   | 2.9        | 15   | 2.9        | 15   | 2.9        |
| 17.5 | 5.3        | 17.5 | 3.5        | 17.5 | 3.5        | 17.5 | 3.5        | 17.5 | 3.5        |
| 20   | 6.5        | 20   | 4.2        | 20   | 4.2        | 20   | 4.2        | 20   | 4.2        |
| 25   | 8.5        | 25   | 5.2        | 25   | 5.2        | 25   | 5.2        | 25   | 5.2        |
| 27.5 | 9.2        | 27.5 | 5.9        | 27.5 | 5.9        | 27.5 | 5.9        | 27.5 | 5.9        |
| 30   | 10.6       | 30   | 6.6        | 30   | 6.6        | 30   | 6.6        | 30   | 6.6        |
| 32.5 | 11.5       | 32.5 | 7.1        | 32.5 | 7.1        | 32.5 | 7.1        | 32.5 | 7.1        |
| 35   | 15.3       | 35   | 8.6        | 35   | 8.6        | 35   | 8.6        | 35   | 8.6        |
| 37.5 | 16.7       | 37.5 | 11.4       | 37.5 | 11.4       | 37.5 | 11.4       | 37.5 | 11.4       |
| 40   | 17.2       | 40   | 13.7       | 40   | 15.2       | 40   | 15.2       | 40   | 15.2       |
| 40.2 | 18.7       | 42.1 | 15.4       | 42.1 | 17.3       | 42.1 | 21.4       | 42.1 | 19.5       |
|      | 42.4       | 44.5 | 19.5       | 47.3 | 21.5       | 45.6 | 20.4       |

The load deflection behaviour of the beams are depicted in Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5.

From Table 3, it is observed that HFRGPCC Specimens yielded better post cracking behaviour than the other specimens. The improved post cracking behaviour is due to the presence of both the polypropylene fibers and glass fibers. The contribution to the ultimate load by the polypropylene fibre was more than glass fibre. But at the same time when added in excess it affects the bond inside the matrix. The presence of one fiber enables the optimum utilization of other fiber thereby increasing both the yield and ultimate deflection.
3.2 Ductility
Ductility measures the plastic capacity of the member which determined the inelastic deformation of the member without compromising the strength. Ductility is calculated as per the realistic method [30] as the ratio of ultimate deflection to the yield deflection. The measured deflection values are listed in
Table 4 and the deviation of the values with the change in the quantity of the fiber is depicted in Figure 6.

| Mix ID   | Ultimate deflection | Yield deflection | Ductility factor |
|----------|---------------------|------------------|------------------|
| PFRGPC   | 18.7                | 11.5             | 1.626            |
| HFRGPCA  | 18.8                | 11               | 1.709            |
| HFRGPCB  | 19.5                | 10.2             | 1.912            |
| HFRGPCC  | 21.5                | 9                | 2.389            |
| GFRGPC   | 20.2                | 9.3              | 2.172            |

Figure 6. Deflection and Ductility Variation

Specimen HFRGPCC yields more ductility than the other specimens due to the combined performance of high modulus and low modulus fibers inside the matrix[22]. The presence of glass fibers helps to arrest the macro cracks and low modulus fiber helps to arrest micro cracks [31]. Specimen PFGPC yields least ultimate deflection owing to the presence of excess polypropylene fibers which affects the integrity of the matrix.

3.3 Stiffness
Stiffness relates the load carrying capacity of the member with its deforming capacity. This measures the resistance offered by the beam with limited deformation. The stiffness of the various beams are listed in Table 5 and the deviation of stiffness values for the different dosages of fiber content is depicted in Figure 7.

| Mix ID   | Ultimate Stiffness | Yield Stiffness |
|----------|---------------------|-----------------|
| PFRGPC   | 2.150               | 2.800           |
| HFRGPCA  | 2.255               | 3.091           |
| HFRGPCB  | 2.282               | 3.480           |
| HFRGPCC  | 2.200               | 3.889           |
| GFRGPC   | 2.257               | 3.978           |
From the Table 5, it is inferred that there is a considerable difference in the stiffness property with the variation of the type of fiber. GFRGPC specimens yielded higher stiffness characters than the other specimens. Stiffness values of the hybrid fibers were also found to be greater than the polypropylene fiber reinforced specimens. The reason for the increase in ultimate stiffness and yield stiffness property is due to the fact that Glass fiber exhibits higher stiffness than the polypropylene fibers. The increase in stiffness property vary with the stiffness of the fibers systematically.

3.4 Toughness Index

Toughness measures the energy absorption capacity of the fiber reinforced geopolymer concrete specimens. Toughness of the specimens are measured as per ASTM C1018-1997. The toughness indices of the various beam specimens are tabulated in Table 6.

| Mix ID    | First crack | 3 times the first crack | Toughness Index |
|-----------|-------------|-------------------------|-----------------|
| PFRGPC    | 61.83       | 462.09                  | 7.47            |
| HFRGPCA   | 87.98       | 566.96                  | 6.44            |
| HFRGPCB   | 86.25       | 599.98                  | 6.95            |
| HFRGPCC   | 86.25       | 556.45                  | 6.45            |
| GFRGPC    | 87.90       | 559.71                  | 6.36            |

From Figure 1,2,3,4, and 5, the area of the curve under the first crack and the area under the three
times the first crack has been calculated. Figure 8 depicts the variation of the toughness values for the different composition of glass and polypropylene fibers. It can be inferred from Table 6 that PFRGPC specimens yielded maximum toughness index value due to the presence of large amount of fibers. Hybrid fiber specimens yielded higher load carrying capacity than the mono polypropylene fiber system but when post cracking behaviour is concerned ie) the behaviour after the appearance of first crack is examined, polypropylene fiber exhibited better performance. The reason could be due to the delay of appearance of first crack in the hybrid systems.

4. CONCLUSION

From the discussions, it is inferred that Fibers could be effectively used in geopolymer concrete to enhance its structural properties.

- Utilization of 0.75/0.25 glass and polypropylene fiber inside geopolymer matrix enhanced the load carrying capacity of the concrete than the other combinations by increasing the ultimate deflection values.
- Utilization of 0.75/0.25 glass and polypropylene fiber inside geopolymer matrix enhanced ductility to a greater extent than the other combination due to the combined performance of both the high and low modulus fibers inside the matrix.
- Utilization of 1 percent glass fiber yielded maximum stiffness under ultimate and yield strain conditions.
- Utilization of 1 percent polypropylene fiber yielded maximum toughness index values

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