Experimental Study on the Behaviour of Hybrid Fiber Reinforced Geopolymer Concrete under Ambient Curing Condition

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Abstract. Recent studies have shown that Geopolymer concrete is one of the emerging building materials worldwide. Various studies have been conducted on the Geopolymer concrete and the engineering properties of the material have been improved drastically. Geopolymer concrete is found to be comparatively brittle than the ordinary conventional concrete. To counteract this effect fibers are incorporated in to the Geopolymer concrete. In this research work, glass fibers and polypropylene fibers are added to the Geopolymer concrete in various proportions and its influence was studied over the fresh and hardened properties of concrete such as workability, compressive strength, split tensile strength, flexural strength and ductility factor. The Geopolymer concrete in this study is GGBS based as it involves ambient curing. The various materials were proportioned based on the Rangans mix design. Fair results have been obtained in the study and it was found that the brittleness could be controlled in the Geopolymer concrete by appropriate proportioning of fiber.

Keywords: Geopolymer concrete, Glass fiber, Polypropylene fiber, hybrid fiber, GGBS

1. Introduction
Geopolymer concrete is one among the rapidly developing construction materials in the decade. Many research works are being perpetrated in the discipline of geopolymer concrete to make it more versatile like ordinary cement concrete [1]. Geopolymer is made from waste material such as flyash, Ground Granulated Blast Furnace(GGBS) etc which are byproduct of thermal power plant and steel plant [2-4]. When these alumino silicate source materials are activated with the help of alkali solution, polymerization reaction take place and the concrete is formed without the use of cement [5-7]. Geopolymer diminish green house emission and also possess good mechanical and durability properties. Geopolymer concrete exhibits reduced shrinkage and low creep compared with the cement concrete [8-11]. Geopolymer concrete posses great resistance to acid attack. Geopolymer concrete made of M-sand exhibits better performance at elevated temperatures with fair thermal properties [12]. The only cons of this hybrid engineering material is that it is comparatively brittle than the conventional concrete and shows cracks with the increase in the application of tensile load [13-15].

Fiber has introduced to the world the possibility of having a high performance concrete in the arena. Augmentation of fibers in ordinary conventional concrete increases its engineering properties such as compressive strength, split tensile strength, flexural strength, post cracking behavior and its durability [16]. Various natural and synthetic fibers like steel, polypropylene, glass, banana, sisal, jute fiber, etc. can be used in concrete. In general the fibers are classified in to high modulus fiber and low modulus fiber. Precisely high modulus fiber incorporates high tensile strength, compressive strength, impact resistance where as the low modulus fibers increases the flexural strength, ductility and post cracking behavior. The extent of variation of properties depends not only on the type of fibers, but also on the fiber dosage [17].
Glass fibers being high modulus fibers impart high tensile strength. This increases dimensional stability and ability to resist heat, fire and chemicals [18]. Glass fibers are useful because of their high ratio of surface area to weight. Polypropylene fiber being a low modulus fiber imparts high flexural strength, low coefficient of friction and improves the post cracking behavior of concrete. Polypropylene fibers reduce the plastic shrinkage crack due to their flexibility and ability [19-22].

In this research work, effort has been made to reduce the brittleness of Geopolymer concrete by utilizing fibers in Geopolymer Concrete. Different proportions of glass and polypropylene fibers are augmented to the geopolymer concrete and it is tested for both fresh and mechanical properties such as compressive strength, split tensile strength, flexural strength and durability properties. Also in this work, M-sand was utilized to overcome the scarcity problems of river sand. Results are tabulated and conclusions were interpreted clearly for the effect of various dosages of hybrid fibers on geopolymer concrete. The tests also reveal the significance of M-sand as fine aggregate in the hybrid fiber reinforced Geopolymer Concrete.

2. Materials
The hybrid Fiber reinforced Geopolymer concrete made in this experimental work was synthesized with the GGBS, alkaline solution, M-sand, Coarse aggregate, glass fibers and polypropylene fibers. The various material properties of the ingredients are briefed below.

2.1. GGBS
GGBS is the slag powder obtained from the residue of the blast furnace during the manufacture of iron. In this work GGBS obtained from Salem Steel Plant was used as the alumina silicate base material. The specific gravity of GGBS was calculated using pycnometer test as 2.9.

2.2. Alkaline Solution
A concoction of sodium hydroxide solution and sodium silicate solution was used as alkali activated solution. The molarity of 13 was selected from the previous works held by the researcher. Molarity of 13M was prepared by dissolving 520 grams of NaOH pellets in a liter of distilled water. The alkali solution was prepared one day prior to casting of specimens and is mixed well. The specific gravity of sodium hydroxide solution is 2.1 and that of sodium silicate solution is 1.5.

2.3. M-sand
Manufactured sand (M-Sand) is an alternative of Ennore sand for the manufacture of concrete. Manufactured sand is produced by crushing hard granite stone to fine particles with less than 4.75mm. It falls under zone 3 having fineness modulus of 2.3, bulk density of 1702kg/m³ and specific gravity is 2.8

2.4. Coarse Aggregate
Locally available Coarse aggregates of 20mm size was used. Specific gravity of the coarse aggregate was determined to be 2.7.

2.5. Glass Fiber
Glass fiber used here is of length 6mm and diameter is 0.1 mm. Aspect ratio= length of fiber / diameter of fiber = 6/0.1 = 60

2.6. Polypropylene Fiber
Polypropylene fiber is one of the low cost and abundantly available polymers with high chemical resistance. It has high boiling point about 165 c making it suitable to be used under any condition. The fiber length of 20mm and diameter is of 0.1mm was used. It is cut into 6 mm in length and utilized in the experimental work. Aspect ratio= length of fiber / diameter of fiber = 6/0.1 = 60
Experimental Program
The experimental program consists of casting and testing the specimens. Mix design for the geopolymer concrete of grade 40 was based on the Rangans mix design which was similar to the code-10262 [23]. The total number of specimens casted in this experimental work is listed in the table no1.

| S.no | Specimen name | Glass | Polypropylene | Compression test | Split tensile | Prism |
|------|---------------|-------|---------------|------------------|--------------|-------|
| 1    | GPCA          | 0     | 1             | 6                | 6            | 3     |
| 2    | HGPCA         | 0.25  | 0.75          | 6                | 6            | 3     |
| 3    | HGPCB         | 0.5   | 0.5           | 6                | 6            | 3     |
| 4    | HGPCCC        | 0.75  | 0.25          | 6                | 6            | 3     |
| 5    | GPCB          | 1     | 0             | 6                | 6            | 3     |

At first, GGBS and M-sand was mixed in the pan mixer. It is then followed by the addition of coarse aggregate, then by the fibers and the alkaline solution. The mixer is operated for about five minutes. The concrete is then poured into the desired steel moulds. The specimens are then ambient cured for 28 days.

The cubical specimen of size 100X100X100mm were casted for measuring compression strength, cylinder specimens with 100mm diameter and 200mm length were casted for split tensile strength test and prism specimen of size 200X200X500 were casted for flexural strength test and ductility factor test.

4. Test Results and Discussions
4.1. Compaction Factor Test
Workability of hybrid fiber reinforced geopolymer concrete was assessed using the compaction factor test. The test was carried out for the various proportions of fibers and the results are tabulated in table2.

| S.No | Specimen name | Compaction factor |
|------|---------------|-------------------|
| 1    | GPCA          | 0.76              |
| 2    | HGPCA         | 0.78              |
| 3    | HGPCB         | 0.78              |
| 4    | HGPCCC        | 0.80              |
| 5    | GPCB          | 0.81              |

It is observed from table 2 that the compaction factor value increases with increase of glass fibers and decrease of polypropylene fibers. This mainly due to the total volume of fiber content. Volume of glass fiber is less than the volume of polypropylene fiber for the given weight of fibers. Here GPCB contains less amount of fibers than all other specimens. This is the reason for increased workability of GPCB. The variation of the workability is clearly depicted in figure 1.
4.2. Compressive Strength Test
Cubical specimens of size 100X100X100mm were tested in the compression testing machine after seven days and twenty eight days of ambient curing and the results are tabulated in table 3.

| S.No | Specimen name | Compressive strength (MPa) |
|------|---------------|---------------------------|
|      |               | 7 days | 28 days |
| 1    | GPCA          | 24.96  | 39      |
| 2    | HGPCA         | 29.64  | 46.2    |
| 3    | HGPCB         | 31.8   | 54.24   |
| 4    | HGPCCC        | 34.56  | 58.2    |
| 5    | GPCB          | 35.4   | 61.02   |

The variation of the behavior is well depicted in figure 2. From table 3, it is witnessed that GPCB exhibits the maximum characteristic strength. The variation of the compressive strength for fiber proportions can be well understood from figure 2.
4.3. Split tensile Strength Test

Cylindrical specimens of size 200X100mm were tested for the split tensile strength in the universal testing machine after seven days curing and twenty eight days curing. The results are tabulated in table 4.

| S.No | Specimen name | Split tensile strength (MPa) |
|------|---------------|-----------------------------|
|      |               | 7 days | 28 days |
| 1    | GPCA          | 2.52   | 3.36   |
| 2    | HGPCA         | 2.52   | 4.2    |
| 3    | HGPCB         | 2.64   | 4.56   |
| 4    | HGPCC         | 3      | 5.16   |
| 5    | GPCB          | 3.20   | 5.28   |

The change in the behavior with the variation of the fiber dosage is well understood from figure 3.

4.4. Flexural Strength Test

Prism specimens of size 500X200X200mm were tested after twenty eight days of ambient curing and the results are tabulated in table 5. The tabulated values are then plotted in the graph for better understanding of the influence of dosage values over the behavior of hybrid fiber reinforced Geopolymer concrete.

| S.No | Specimen name | Flexural strength(MPa) |
|------|---------------|------------------------|
| 1    | GPCA          | 4.56                   |
| 2    | HGPCA         | 6.12                   |
| 3    | HGPCB         | 6.48                   |
| 4    | HGPCC         | 7.14                   |
| 5    | GPCB          | 7.24                   |

From table 5 it is observed that GPCB exhibits the maximum flexural strength. The fluctuations of the flexural strength of geopolymer concrete specimen for the different fiber dosage are well depicted in the figure 4.
4.5. Ductility Factor Test

Ductility of the specimens was measured by observing the initial deflection value and the final ultimate deflection value. This test truly measures the utility of fibers in the geopolymer concrete. Table 6 shows the Ductility factor values for various fiber dosages.

| S.No | Specimen name | Ductility factor |
|------|---------------|-----------------|
| 1    | GPCA          | 1.58            |
| 2    | HGPCA         | 1.60            |
| 3    | HGPCB         | 1.63            |
| 4    | HGPCCC        | 1.70            |
| 5    | GPCB          | 1.64            |

The variation of the ductility for the fiber dosage is depicted in the figure 5.

The hardened mechanical properties are highly influenced by the type of fibers present inside the matrix. In this work, both high modulus fiber and low modulus fibers are utilized. The glass fiber which is a high modulus fiber imparts more compressive strength, split tensile strength and flexural strength for the Geopolymer concrete specimen made of M-sand. It is because of this fact GPCB exhibits more compressive strength, split tensile strength, flexural strength compare to other specimen. The presence of polypropylene fiber which is a low modulus fiber increases the ductility of the
specimen. But GPCA and HGPCB specimen contains more amount of fiber content, which reduces their matrix integrity and stiffness leading to early attainment of ultimate stress. It is because of the fact HGPCB exhibits more ductility factor than any other specimens.

5. Conclusion

Based on the above discussions, the following conclusions are be drawn

- River sand could be effectively replaced with M-sand in geopolymer concrete, thereby completely eliminating the mining activity for river sand.
- Workability of the geopolymer concrete decreases with increases in the fiber content irrespective of the type of fiber utilized.
- The glass fiber imparts more compressive strength, split tensile strength, flexural strength to the concrete specimen.
- The polypropylene fiber increases the post cracking behavior and increases the yield stress of the specimens.
- Engineering properties such as compressive strength, split tensile strength, flexural strength and ductility can be increased with the appropriate combination of both high and low modulus fibers in geopolymer concrete.

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