Durability Studies on the Hybrid Fiber reinforced Geopolymer concrete made of M-sand under ambient curing

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Abstract. In the recent decade, there have been a lot of significant developments made in the area of Geopolymer concrete. Geopolymer concrete has been proved for its remarkable durability properties but when alterations are done to the conventional geopolymer concrete through the incorporation of fibers, the durability of the fiber reinforced concrete is uncertain. In this analysis, high elasticity modulus and low elasticity modulus fibers were inserted into geopolymer concrete made of M-sand. As ambient curing is favored in this study, geopolymer concrete is GGBS dependent. As an alkali solution, a mixture of sodium hydroxide solution and sodium silicate solution is used. Durability properties such as water absorption, sorptivity, rapid chloride penetration test, resistance to HCL attack, resistance to H₂SO₄ attack, resistance to sulphate and marine attack are determined in this study. Significant observance has been made with respect to different proportions of glass fiber and polypropylene fiber. Glass fibers yielded fairer results compared to the polypropylene fibers. This study reviews the scope of the use of hybrid fibers made of M-sand in Geopolymer concrete.

1. Introduction:
Current Era witness the hefty developments in Infrastructure all around leading to the increased consumption of concrete as the building material [1]. It has been reported that concrete has frail chemical resistance and depicts poor durability properties under aggressive environmental conditions [2]. Moreover one tonne of carbon dioxide liberates for the production of one tonne cement leading to air pollution. Cement manufacturing also involves utilization of large amount of raw materials that has to be mined leading to land pollution[3].Geo-polymer concrete, manufactured from the wastes such asflyash and Ground Granulated Blast Furnace Slag (GGBS) helps to mitigate the air pollution and land pollution caused due to the production of cement concrete [4].Polymerization reaction takes place in the alumino silicate resource material and alkali solution to yield strength and other
engineering properties against hydration process of conventional concrete [5]. Better compressive strength, split tensile strength, flexural strength, better acid resistance and other resilience properties are exhibited in geo-polymer concrete. [6-9]. Only limitation of Geo-polymer concrete can be its brittle nature.

Fiber reinforced concrete seeks to pay attention to its structural quality in the modern era [10-16]. Precisely fibers are categorized in to high and low modulus fiber based upon its strength and energy absorption capabilities [29-36]. There has been a remarkable advance in the field of sustainable concrete to make in the current decade to increase its engineering properties to replace traditional cement concrete by industry rejects in the building materials [37-43]. Fiber reinforced concrete has fibrous material which reduces the brittleness of cement concrete and improves its engineering properties based upon the type of fiber being used [44-47]. Hence it can be recommended to incorporate fibers in the Geo-polymer concrete. The introduction of fibers into geo-polymer concrete has been found to increase concrete ductility and post-cracking behavior. [17]. But the influence of fibers in affecting the durability of the Geo-polymer concrete is bewildered.

On the other hand, the acute demand for river sand to be used as a fine aggregate is a significant issue faced by the infrastructuredomain. Also mining of river sand leads to major environmental issues [18-19]. Out of many alternatives for river sand, M-sand is found to be advantageous along with conventional concrete in construction activities [21]. Also M-sand has been found to yield convincing results along with the Geo-polymer concrete and Fibers [18].

In this study, durability of Geo-polymer concrete prepared of M-sand is studied for the various proportions of high and low modulus fibers. In this study Glass fiber and Polypropylene fibers are selected as the high and low modulus fibers respectively. Geo-polymer concrete is prepared of GGBS and are ambient cured. Durability tests such as water absorption, Sorpitivity, Rapid Chloride Penetration test, chloride attack test and sulphate attack test are performed over the hybrid fiber reinforced geopolymer concrete prepared of M-sand.

2. Materials
In this study, geopolymer concrete is synthesized using GGBS as it is cured in the field (ambient cured). GGBS is collected from the nearby industry sited at Salem and specific gravity is 2.9. M-Sand is used as the fine aggregate which is collected from the quarry sited at Madurai. Various test results are conducted upon the M-sand to understand the properties of the acquired material. It comes upon the zone-III category having specific gravity of 2.3, the bulk density of the M-Sand is 1702 kg/m³. The fineness modulus of the M-sand is 2.36. The Coarse aggregate of 20mm size used in the project is acquired from the nearby local industry located at Madurai with specific gravity of 2.9 and bulk density of 1456 kg/m³. The fineness modulus of the aggregate is 6.10. The Sodium hydroxide pellets is acquired from the chemical industry located upon Madurai. Sodium hydroxide of 13 Molarity is used in the solution and its specific gravity is found to be 1.47. The sodium silicate is obtained from the chemical industry located upon the Madurai which is having the specific gravity of 1.6. The metallic and non-metallic fibers are used the Glass fibres used of length 6mm, diameter 0.1mm. Aspect ratio of the glass fibre is 60. The polypropylene fibre is of length 20mm, diameter of 0.2mm with aspect ratio of 10.

3. Methodology
The aim of this paper is to determine the durability of hybrid fiber reinforced geopolymer concrete for different glass and polypropylene fiber proportions. The mix design was found on the suggested mix design by Rangan for Geopolymer concrete. [21]. Mix proportions of various specimens are tabulated in Table 1. As an alkaline solution, a mixture of sodium silicate and sodium hydroxide solution is used and must be ready one day earlier to casting. The addition of alkaline solution is accompanied by the first dry mixing of all materials including fibers in the mixer. For around 4 to 5 minutes, the mixing is carried out. The hybrid fiber reinforced geopolymer concrete prepared of M-sand is casted in to
specimens of standard sizes for various durability tests as tabulated in Table 2. Durability experiments are performed to arrive at the conclusion and the findings are analyzed.

Table 1. Mix proportion of the hybrid fiber reinforced Geopolymer concrete specimens

| Specimen No. | GGBS (Kg/m³) | Fine Aggregate (Kg/m³) | Coarse Aggregate (Kg/m³) | Sodium Hydroxide (Kg/m³) | Sodium Silicate (Kg/m³) | Glass Fiber (Kg/m³) | Polypropylene Fiber (Kg/m³) |
|--------------|--------------|------------------------|--------------------------|--------------------------|------------------------|---------------------|-----------------------------|
| HFGPC A     | 630          | 442.15                 | 836.07                   | 109.8                    | 274.5                  | 25                  | 0                           |
| HFGPC B     | 630          | 442.15                 | 836.07                   | 109.8                    | 274.5                  | 18.75               | 2.2                         |
| HFGPC C     | 630          | 442.15                 | 836.07                   | 109.8                    | 274.5                  | 12.5                | 4.4                         |
| HFGPC D     | 630          | 442.15                 | 836.07                   | 109.8                    | 274.5                  | 6.25                | 6.6                         |
| HFGPC E     | 630          | 442.15                 | 836.07                   | 109.8                    | 274.5                  | 0                  | 8.8                         |

Table 2. Specimen size and number of cubes to be casted for testing of hybrid fiber reinforced Geopolymer concrete specimens

| Specimen Type | Water absorption test | Sorptivity test | Rapid chloride penetration | Acid resistance test | Sulphate resistance test | Marine attack test |
|---------------|-----------------------|-----------------|---------------------------|----------------------|-------------------------|-------------------|
| Specimen Type | Size | Cube (100 x 100 mm) | Disc (100 x 50 mm) | Cube (100 x 100 mm) | Cube (100 x 100 mm) | Cube (100 x 100 mm) |
| HFRGPC A     | 3    | 3                | 3 | 3 | 6 | 3 | 3 |
| HFRGPC B     | 3    | 3                | 3 | 3 | 6 | 3 | 3 |
| HFRGPC C     | 3    | 3                | 3 | 3 | 6 | 3 | 3 |
| HFRGPC D     | 3    | 3                | 3 | 3 | 6 | 3 | 3 |
| HFRGPC E     | 3    | 3                | 3 | 3 | 6 | 3 | 3 |

4. Tests Results and Discussions

4.1. Water Absorption test
Water absorption of the HFRGPC made of M-sand was determined based on ASTM-C642-2006 and the results are tabulated in Table 3 [23]. The values are also compared with CEB standards to ascertain the quality of Geopolymer concrete [23]. Figure 1 shows the variance of the potential of water absorption for different fiber addition proportions.

Table 3. Water absorption results of the Geopolymer specimens

| Specimen type | Oven(g) | Initial (g) | Final (g) | Initial Water absorption capacity (%) | Saturated Water absorption capacity (%) | Standards |
|---------------|---------|-------------|-----------|---------------------------------------|----------------------------------------|-----------|
| HFRGPCA-1G    | 2386    | 2415        | 2457      | 1.20                                  | 2.97                                   | Excellent |
| HFRGPCB       | 2365    | 2397        | 2436      | 1.33                                  | 3.00                                   | Excellent |
| HFRGPCC       | 2350    | 2387        | 2424      | 1.55                                  | 3.14                                   | Excellent |
| HFRGPCD       | 2324    | 2361        | 2400      | 1.56                                  | 3.27                                   | Excellent |
| HFRGPCE1P     | 2304    | 2350        | 2392      | 1.95                                  | 3.81                                   | Excellent |

From Table 3. It is evident that, as compared to the other specimens, HFRGPCE shows optimum water absorption. It is evident from Figure 1 that HFRGPC’s water absorption ability increases with an increase in the content of polypropylene fibers. But all the hybrid Fiber reinforced geopolymer concrete specimens were found to be in good standards.
4.2. Sorptivity test
In order to determine the ability of water penetration into the HFRGPC pores as per ASTM-C642-82[24], the sorptivity test was performed. [24]. The change in mass of the specimen was observed for 30, 60, 90 and 120 minutes and sorptivity values are calculated and provided in Table 4. Figure 2 depicts clearly the change in rate of penetration of water for various specimen types.

| Specimen type | Mass (kg) | Time (min) | Sorptivity (mm/min) |
|---------------|-----------|------------|---------------------|
| HFRGPC A      | 4.01      | 30         | 0.09                |
|               | 5.4       | 60         | 0.08                |
|               | 5.8       | 90         | 0.07                |
|               | 6.2       | 120        | 0.07                |
| HFRGPC B      | 4.24      | 30         | 0.09                |
|               | 5.6       | 60         | 0.09                |
|               | 5.8       | 90         | 0.07                |
|               | 6.3       | 120        | 0.07                |
| HFRGPC C      | 4.56      | 30         | 0.10                |
|               | 5.85      | 60         | 0.09                |
|               | 6.02      | 90         | 0.08                |
|               | 6.5       | 120        | 0.07                |
| HFRGPC D      | 4.8       | 30         | 0.11                |
|               | 6.2       | 60         | 0.10                |
|               | 6.5       | 90         | 0.08                |
|               | 6.9       | 120        | 0.08                |
| HFRGPC E      | 5.3       | 30         | 0.12                |
|               | 6.6       | 60         | 0.10                |
|               | 6.9       | 90         | 0.09                |
|               | 7.5       | 120        | 0.08                |

From Figure 2, it is observed that HGPCA specimens have lowest sorptivity values. This is attributed due to the fact that HGPCA is a dense concrete with the optimum fiber content. With the increase in time, the sorptivity values decrease. This is due to the reason that the secondary absorption decreases with the time.
4.3. Rapid Chloride Penetration Test

The Rapid Chloride Penetration Test was carried out to assess the electrical conductance of the hybrid fiber reinforced geopolymer concrete prepared of M-sand concrete in accordance with ASTM C1202-2012 [25]. This also tests the rate at which chloride ions penetrate into the concrete. In Table 5, the charges passed through the various specimens are tabulated and are contrasted with the standards. The electrical resistivity variance of the different specimen forms is shown in Figure 3.

Table 5. Chloride penetration values upon hybrid fiber reinforced geopolymer concrete

| Specimen type | Charge Passed (c) | Standard as per ASTM |
|---------------|------------------|----------------------|
| HFRGPCA       | 1990.8           | Low                  |
| HFRGPCB       | 2169             | Moderate             |
| HFRGPCC       | 2245.5           | Moderate             |
| HFRGPCD       | 2383.2           | Moderate             |
| HFRGPCE       | 2580.3           | Moderate             |

Figure 2. Variation of Sorptivity values between the concrete specimens.

Figure 3. Variations on the charge passed on the hybrid fiber reinforced geopolymer concrete.
Figure 3 clearly shows that HFRGPCE exhibits highest resistance for chloride penetration and HFRGPACA possess lowest electrical resistance for chloride penetration. Presence of fibers increases the resistance of the concrete. Also, with the rise in polypropylene content, it is obvious that electrical resistance increases slightly.

4.4. Acid resistance test

To assess the resistance of HFRGPC specimens made of M-sand to hydrochloric acid and sulphuric acid, an acid resistance test was carried out in compliance with ASTM C267-2001 [26]. The mass losses of specimens are measured after 28 days of immersion in to the 5% HCl and H2SO4 and the values are provided in Table 6. The activity of different HFRGPC samples for acid attacks is clearly shown in Figure 4. From table 6 it is clear that all the hybrid fiber specimen possesses better resistance to hydrochloric acid and sulphuric acid.

| Specimen type | Mass loss percentage after immersion for 28 days |
|---------------|--------------------------------------------------|
|               | HCl | H2SO4 | Na2SO4 | Marine water    |
| HFRGPCA       | 0.16 | 0.20 | 0.04   | 0.25            |
| HFRGPCB       | 0.16 | 0.21 | 0.08   | 0.25            |
| HFRGPCC       | 0.17 | 0.21 | 0.08   | 0.25            |
| HFRGPCD       | 0.17 | 0.21 | 0.08   | 0.23            |
| HFRGPCE       | 0.17 | 0.21 | 0.08   | 0.26            |

Figure 4. Variation of mass loss among the exposure to HCL and H2SO4

4.5. Sulphate resistance test

Sulphate resistance was performed as per ASTM C1012-2015 [27] to measure the resistance of HFRGPC specimens made of M-sand to sulphate attack. The mass losses of specimens made of M-sand after 28 days of immersion in to the sodium sulphate solution are provided in Table 6. The variation of the sulphate attack resistance of various HFRGPC specimens is clearly illustrated in Figure 5. It is evident from Table 6 and Figure 5 that all hybrid fiber specimens have stronger resistance to sulfate attacks.
4.6. Marine Attack test
In order to find out the applicability of Geopolymer concrete in offshore structures, a marine attack test was conducted in compliance with ASTM D1141-1998[28]. Mass losses of M-sand specimens prepared in the laboratory after 28 days of immersion in marine water are reported in Table 6. The change in actions of HFRGPC specimens to marine assault is clearly seen in Figure 6. It is evident from Table 6 that all the reinforced hybrid fiber geopolymer concrete specimens show greater resistance to marine attack.

5. Conclusion
- Geopolymer concrete reinforced with glass fibers exhibited least Water absorption capacity than the other hybrid fiber reinforced geopolymer concrete samples.
- Rate of penetration of water through the pores depends upon the surface texture and Geopolymer concrete with glass fibers outperforms the other hybrid fiber reinforced geopolymer concrete samples.
- Geopolymer concrete reinforced with glass fibers resisted the entry of charges in to the concrete than the other types of geopolymer concrete.
- All the hybrid fiber reinforced geopolymer concrete exhibited excellent resistance to acid attack, sulphate attack and marine attack. There is no significant variation between the type of fibers used inside the geopolymer concrete. Irrespective of the type f fiber and its proportion being utilized in to the geopolymer concrete, all the types exhibited excellent properties.
All the hybrid fiber reinforced geopolymer concrete exhibited fair durability properties as per standards in all the tests. The fiber-reinforced geopolymer concrete made of M-sand unleashes a lot of scope in this research paper.

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