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RESEARCH ARTICLE

Influence of Basalt and Geo-Textile Fiber Wrapping on Compressive and Flexural Strengths of HDPE-filled Reinforced Concrete

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Abstract

Objectives: To investigate the combined effect of filler and Fiber Reinforced Polymer (FRP) wrapping on the compression and flexural behavior of concrete beam structure. **Methods:** In this study, High-Density Polyethylene Fiber **(**HDPE) is used as filler in concrete ranging from 0.5 to 3% in the M30 grade concrete. The Basalt and Geotextile FRP mats were wrapped on to the concrete beams to estimate the influence of HDPE filler and fiber wrapping on compression and flexural strengths. **Findings:** The addition of 0.5 % and 1% of HDPE fillers in M30 grade concrete has a significant impact on compressive strength by up to 6% and flexural strength by 20% when compared to conventional concrete. **Improvement:** Wrapping concrete beam samples with Basalt and Geotextile fiber along with HDPE fillers exhibits an increase in compressive strength by 30% and Flexural strength by 60% with respect to pristine concrete beam samples. **Novelty:** Inadequate studies were found on the effect of filler and FRP wrapping on the compression and flexural strength of concrete beams. Hence, a new method of avoiding the complete failure of concrete beams by adopting a filler/fiber wrapping technique to enhance the load-carrying capacity in the concrete. Further, a greater attention was made through morphological studies to know the cumulative effect of both constituents on the strength of concrete samples.

Keywords: HDPE; Basalt Fiber; Geo-Textile fabric; Compressive Strength; Flexural Strength

1 Introduction

Fiber Reinforced Polymer (FRP) composites have a unique and border application in the civil engineering sector. The incorporation of short fibers and electronic wastes has a significant benefit over the overall performance of conventional concrete like tensile strength, compression strength, durability, load bearing capacity, and post crack. [1–6] Also, a poor tensile and flexural response of the geo-polymer concrete composites [7] and Cement-tailings matrix composites (CTMC) [8] can be enhanced with the inclusion of natural and synthetic fibers. The banana skin power (BSP) as cement replacement and coir fiber (CF) as filler in self-compacting concrete (SCC) showed enhancement up to 7% in compression strength for 0.4% of BSP and 0.5% of CF adding in SSC. [9] Tamrin et al. [2] reported that the size and percentage of HDPE incorporation have a significant effect on concrete strength. Investigation revealed that an increase in compression strength was reported for 5 % HDPE and a size of 5*20 mm. In addition to this, replacing 30% of coarse aggregate with HDPE showed the same nature of failure pattern compare to the reference beam under flexural loading [10]. The incorporation of a compatible dosage of short basalt fiber enhances the crack resistance performance, concrete's compressive strength, and flexural strength [11]. In addition to this, basalt-macro polypropylene hybrid fiber reinforced concrete showed up to 10% and 20% improvement in compression and flexural strength respectively [12]. The polypropylene incorporated and GFRP-wrapped concrete showed higher impact resistance along with decreased crack propagation rate and damage intensity [13]. Wrapping of Fiber Reinforced Polymer [FRP] enhances the load-carrying capacity and deflection [14]. The effect of BFRP wrapping on the bottom and vertical side of the beam on flexural performance was studied by Sara Kadhim et.al [15]. The author reported that the ductility of BFRP-wrapped beams is less than the reference beam. But, the toughness of all BFRP-wrapped beams was higher than the reference beam by 8-78%. The Near-Surface Mounted Carbon-Fiber-Reinforced Polymer Strips (NSM-CFRP) technique reduced the possibility of debonding of CFRP. Also, the NSM-CFRP technique enhances the flexural capacity in the range of 10.36% and 52.28% compared to the pristine sample [16].Bo Wang [17] summarized the effect of different FRP (Flax, glass, and basalt) wrapping, thickness, and layer arrangement on wooden block flexural behavior. The author suggested that the proper surface preparation of wood can provide good load transfer between the wood to FRP. Even in concrete strengthened with sisal FRP debonding of sisal FRP can be overcome by selecting a compatible resin system [18]. The effect of wrapping width and thickness of jute fiber on the concrete surface was studied by Yaseen A. Salih et al. [19]The author reported that increasing the width of the wrapping has a significant effect on load-carrying capacity compared to the thickness of the wrapping. The proper adhesion between jute fiber and concrete surface results in better compression strength compared to polypropylene fiber-wrapped concrete samples [20].

1.1 Research Significance

In existing literature, the mechanical performance of a concrete structure with the combined effect of filler reinforcement and externally wrapped FRP fabric was inadequate. Thus, the present study investigates the effect of HDPE as filler and Basalt and Geo-Textile fabrics as an external jacket for improving flexural and compression strength was undertaken. The experimental results were comprehensively discussed by comparing them with the previous studies.

2 Methodology

2.1 Materials

The HDPE bottles were collected from Hubballi Dharwad municipal corporation [HDMC], Karnataka, India. The bi-directional Basalt fiber was supplied by Nickunj Eximp Entp Pvt. Ltd. Mumbai, India. The Geo-Textile fiber was supplied by a local supplier. The physical and mechanical properties of fibers are listed in Table 1. The Portland cement grade of 43 was procured from a local supplier. The properties of cement tested in the laboratory, the fineness of 4.63, the normal consistency of 32%, and the specific gravity of 3.12 were reported. The coarse and fine aggregate was procured from a local supplier and the test was performed in the laboratory. The specific gravity of 2.74, fineness modulus of 7.38 for coarse aggregate and specific gravity of 2.61, and fineness modulus of 2.18 for fine aggregates were obtained from the lab test. The Poly-Naphthalene Condensate was used as a super plasticizer which is having a specific gravity of 1.1 – 1.2. Water used for concrete mix is potable drinking water, no Chlorides are found, pH was 7.8 and all other parameters are within the permissible limits.

Table 1. Mechanical properties of Fibers

Fibers	Density [kg/m^3]	Tensile Strength [MPa]	Tensile Modulus [GPa]	Elongation at Break [%]
Basalt	2650	3100-4840	84	3.15
Geo-Textile	134	643	30	1.60

2.2 Mixing and Sample Preparation

The mixing process started with mixing coarse, and fine aggregates and cement as per the M30 grade of concrete. Further, chopped HDPE fibers were added to the mixture by varying the proportion from 0 to 3%. The prepared solution of water and super plasticizer was poured over the mixture. The 1% of super plasticizer by weight of cement was added to form the solution. Further, uniform and slow mixing were carried out to form homogeneous concrete. The fresher concrete was poured in a mold to cast the compression test sample with a size of 150x150x150mm as per IS 516-1959 [21] standard. Similarly, concrete was poured in a mold to cast a flexural test sample with a size of 100x100x500mm as per IS: 516-1959 [21] standard. The specimens are de-molded after 24 hours and further samples were soaked in water for 28 days for curing purposes. Further samples were dried at room temperature for 1 day. The cured sample surface was cleaned using a cotton cloth to remove the unwanted contaminants from the surface. Further, basalt and geotextile fiber were wrapped using epoxy resin to achieve the proper bonding. The process of manufacturing the sample is shown in Figure 1.

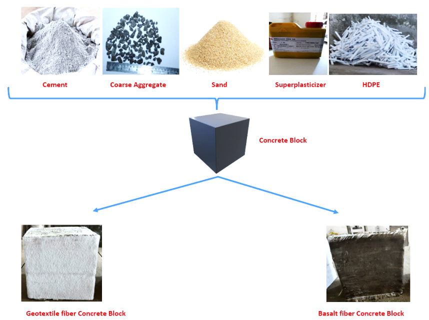

Fig 1. Schematic of Sample Preparation Procedure

2.3 Experimetal

2.3.1 ***Compression Test***

The compressive strength test was performed as per IS 516-1959 [21] using a 2000KN capacity compression machine which is shown inFigure 2. The M30 grade concrete sample with a size of 150X150X150mm was used to perform the compression test. For each composition i.e by varying the percentage of HDPE in the concrete mixture, and wrapping of basalt and geotextile fibers 3 samples were tested. The schematic mode of loading on the sample is shown in Figure 2. The static loading was applied over the sample until failure and drop in load were observed. Based on obtained maximum load the compression strength was calculated using the formula.

$$\text{Compressive Strength } \sigma_c = P/A \quad (1)$$

Where P and A denotes load at failure of specimen and cross-section area respectively.

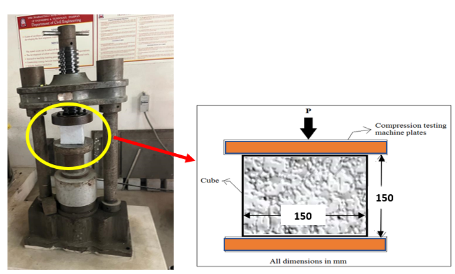

Fig 2. Sample loaded in a Compression Test Machine

2.3.2 ***Flexural Test***

The flexural strength test was performed as per IS 516-1959 [21] using a 1000kN universal testing machine [UTM]. A sample size of 100x100x500mm was used to perform the flexural test. The pure two-point bending load was applied over the sample with a displacement rate of 3mm/min. The position of the loading arm and support points are shown in Figure 3. Static loading was applied until the drop in load was observed. The flexural strength of reinforced concrete was calculated using Equation (2).

$$Flexural\ Strength\ \sigma_s = \frac{PL}{BD^2} \tag{2}$$

Where P, L, B, and D denote Load, length of prism, breadth of the prism, and depth of prism respectively.

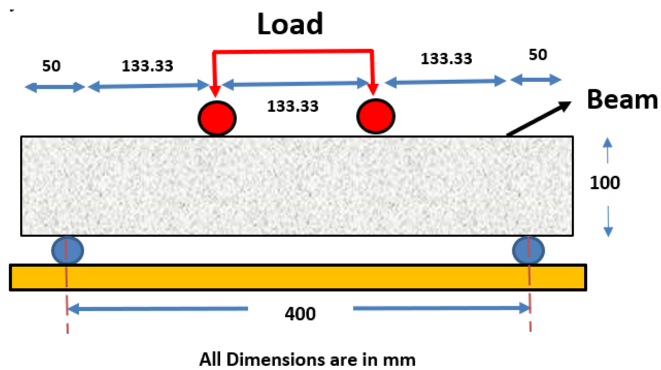

Fig 3. Schematic Diagram of Loading Points and Dimensions of Flexural Test Sample

3 Results and Discussion

3.1 Compression Test

The effect of the addition of HDPE on compression strength values is shown in Figure 4(a). The graph replicates that the addition of HDPE filler has a marginal variation in compression strength. It is observed that 0.5% and 1% of HDPE fiber-reinforced concrete have gained higher compressive strength by 3.26% and 5.22% when compared to plain concrete. The drop in compression strength was observed in a further increase of HDPE incorporation in concrete. Previous research has discovered a similar relationship between filler addition in concrete and compression strength, and the optimal level of filler reinforcement can prevent brittle failure and improve concrete ductility [1,2,22–25]. Besides that, Han Wu et. al [11] reported that using basalt short fibers as a filler above the optimum level can reduce compression strength. Furthermore, hybrid reinforced concrete of basalt-macro polypropylene demonstrated ductile failure [12]. Interestingly, when 30% of coarse aggregate was replaced with HDPE in concrete beams, the crack manner and failure time were relatively similar to the reference beam [10]. And even replacing the pulverized plastic as fine aggregate in concrete showed improvement of 2.27 N/mm^2 compare to conventional concrete [26].

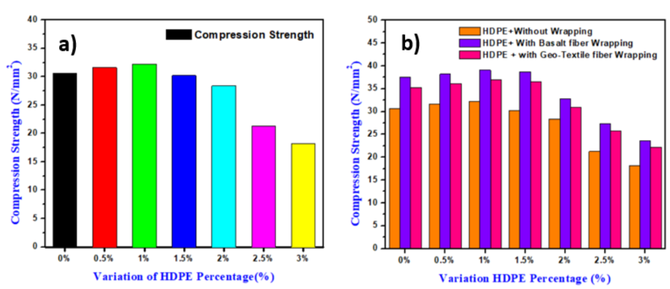

Fig 4. Compressive Strength of concrete (a) compressive strength versus HDPE proportions (b) Compressive strength of fiber wrapped versus HDPE proportion

Fiber wrapping with the addition of HDPE fillers in concrete for different proportions has a significant effect on compression strength which is shown in Figure 4(b). The width and thickness of the fabric coverage area have a significant effect on load-carrying capacity in concrete beams strengthened with FRP [19,27]. In this study, all the faces of concrete samples were wrapped with fabric. It is observed that 0%, 0.5% 1%,1.5%,2%,2.5%, and 3% filled HDPE fiber reinforced concrete wrapped with Basalt

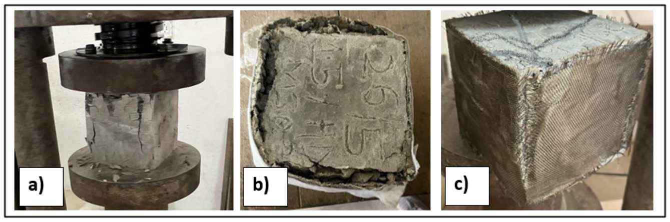

Fig 5. Crack Patterns of concrete samples (a) Plain Concrete (b) Geo-FRP Wrapped and (c) BFRP Wrapped

fiber increases the compressive strength by 23%, 21%, 22%, 28%,16%, 29%, and 30% respectively. Similarly, the Geotextile fiber-wrapped HDPE incorporated samples showed an increase in compression strength by 15%,14%,15%, 21%, 9%, 20%, and 22% respectively compared to HDPE incorporated concrete without wrapping of fibers. A catastrophic failure in plain concrete was observed in the loading direction and is depicted in Figure 5(a). Enhancing the strength of concrete can be achieved by the wrapping technique, but reduced ductility was observed with this technique [15,18,19,28]. This is due to brittle failure of concrete and hence transfer of load to FRP wrapped jacket. The incorporation of HDPE can prevent such random load transfer, which leads to improving the ductility and reducing the debonding between fiber and concrete. Even a delay in the development of cracks without FRP failure was noted in beams strengthened with polypropylene fibers [20].Even with comparing the compression strength of Basalt and Geotextile fibers wrapped samples basalt fiber-wrapped composite showed a significant effect on compressive strength. This is due to the superior mechanical properties of Basalt fiber. The dispersed cracks were observed in Basalt and Geo textile-wrapped polymer concretes which are shown in Figure 5 (b) and Figure 5(c).

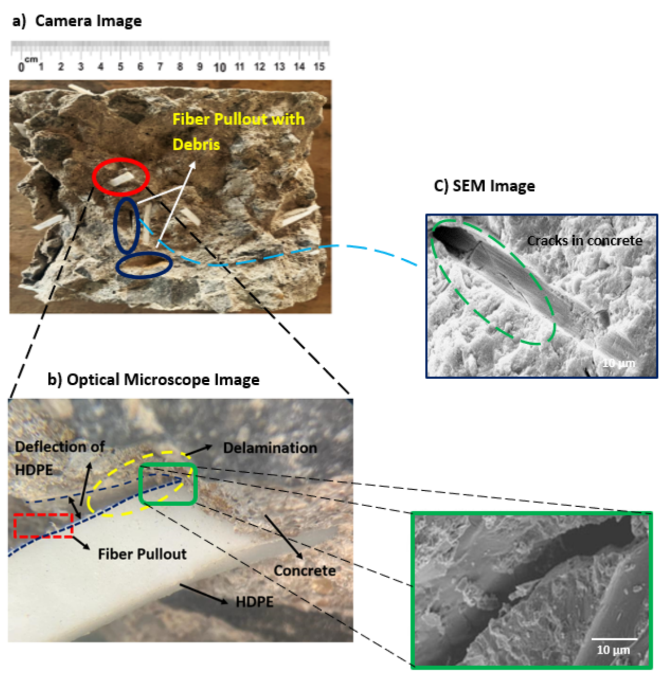

Fig 6. HDPE Incorporated Concrete Fractured Images under compressive load (a) Camera Image (b) Optical Microscope Image and (c) SEM Images

The optical microscope and SEM image of HDPE filled concrete fractured specimen is shown in Figure 6. The optical image with 100X resolution for 1 % HDPE filled sample has fiber pullout from the surface of the concrete. This was caused due to a fine aggregate of sand particles attached to the surface of HDPE fillers after curing and delamination between the HDPE and concrete was also observed in Figure 6(b). Further, the delaminated HDPE fillers tend to deflect under the action of compressive loading. Due to this, the varied loads sustained by HDPE fillers help to prevent the brittle nature of the failure. Furthermore, there has been a HDPE fiber pullout was seen in Figure 6(c), this pullout of fibers is due to improper curing of concrete.

3.2 Flexural Test

Figure 7 shows the flexural strength values of HDPE filled with and without fiber-wrapped concrete samples. From Figure 7 (a), it was observed for 0.5%, and 1% HDPE filled fiber reinforced concrete gain a maximum flexural strength of 16%, and 20% respectively when compared to plain concrete. This reveals that the incorporation of the right quantity of HDPE leads to an increase in strength. This is due to the attractive tensile properties of HDPE fillers. Further increase in the percentage of HDPE fillers leads to a significant drop in compression strength. This is due to the excessive volume fraction of HDPE fillers and leads to poor bonding.

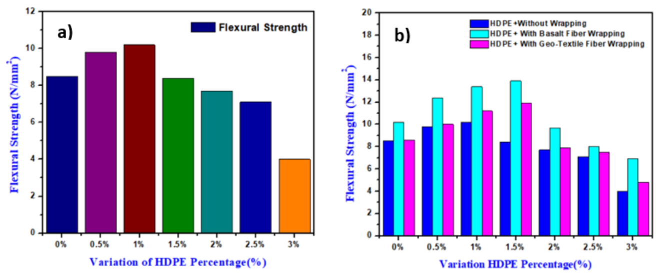

Fig 7. Flexural Strength of concrete (a) Flexural strength versus HDPE proportion and (b) Flexural strength of fiber wrapped versus HDPE proportion

Figure 7(b) illustrates the effect of HDPE filler and fiber wrapping on the flexural strength of the concrete beam samples. Figure 7(b) indicates for 0%, 0.5% 1%, 1.5%, 2%, 2.5%, and 3% HDPE filler incorporated reinforced concrete samples wrapped with basalt fiber showed a flexural strength of 20%, 26%, 32%, 59%, 26%, 13%, and 15% higher as compared to without wrapped reinforced concrete samples. And even, the carbon fiber wrapped for lower concrete strength beam ultimate load carrying capacity is better than the beam designed for moderate and high concrete strength [29].

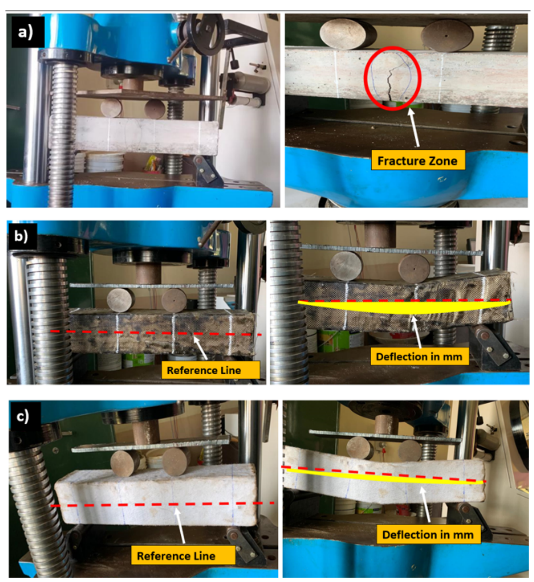

Fig 8. Flexural test on concrete(a) Plain concrete(b)BFRP wrappingand (c) Geo-FRP wrapping

From Figure 7(b) it is observed that 0%, 0.5%, 1%,1.5%, 2%, 2.5%, and 3% HDPE fiber-reinforced concrete wrapped with Geotextile FRP increases the flexural strength by 1.5%, 2%, 10%, 42 %, 3%, 7%, and 20% respectively when compared with HDPE fiber reinforced concrete without wrapped Geotextile fiber. It was also observed that 0%, 0.5%, 1%,1.5%, 2%, 2.5%, and 3% HDPE fiber-reinforced concrete wrapped with BFRP increases the flexural strength by 19%, 24%, 20%, 17%, 23%, 7%, and 42% respectively with that of HDPE fiber reinforced concrete wrapped with Geotextile FRP. Lower ductility of up to 33% for partial side strengthening of concrete beams and 45% for full side strengthening was found as compared to the pristine concrete sample in selective side wrapping of basalt fabric for reinforced concrete beams [15]. In the present study, the addition of HDPE increases the ductility with respect to pristine concrete samples. Further, it will help to overcome the sudden debonding of fiber fabric from concrete. Due to this, uniform transfer of load from concrete to FRP can be achieved under the flexural mode of loading. Figure 8(a) shows that the plain concrete sample under flexural loading has brittle nature of fracture failure and finally breaks into two halves upon ultimate load. Carbon-Fiber Polymer Strips were reinforced by making grooves nearer to the surface of the concrete can prevent the debonding of fiber jackets from the concrete [16]. But this process needs good insight to optimize the depth of groove and volume fraction of fiber and resin to be used. Hence, the present method is one of the simple, quick, and easy to overcome the debonding of FRP fabric at an early stage of load transfer. The lower crack growth and a marginal amount of deflection were observed in HDPE-incorporated and fiber-wrapping concrete samples which are shown in Figure 8(b) and Figure 8(c).

4 Conclusion

In this work, the influence of HDPE fillers and Basalt and Geo-Textile fiber mat wrapping on the compression and flexural strengths of concrete samples were successfully studied experimentally. The following conclusion were drawn from the experimental findings.

- The addition of HDPE fillers of size of 2mm*40mm has a marginal effect on both compression and flexural strength.
- 0.5% and 1% HDPE filled-reinforced concrete beams have higher compressive strength which is more than 4% and 5%, and similarly, the flexural strength is more than 15%, and 20% respectively when compared to 0% HDPE-filled concrete.
- Basalt fiber wrapping with HDPE-filled concrete samples showed an increase in maximum compression strength by 30% to that of only HDPE-filled samples.
- The flexural strength of Basalt fiber wrapping was a maximum of 59% higher as compared to without wrapped reinforced concrete samples.
- HDPE fiber-reinforced concrete wrapped with Geo-textile FRP increases the flexural strength by a maximum of 42% and the compressive strength by 22% when compared with HDPE fiber-reinforced concrete without wrapped Geotextile fiber.
- The improvement in flexural strength was observed due to the superior properties of HDPE fillers with high strain to failure and higher tensile strength. Further, the Basalt and Geo-Textile fibers wrapping has shown better flexural strength when compared to without wrapping. This kind of improvement is due to load transfer to the concrete through the fibers and the superior mechanical properties of the fibers.
- Finally, it was concluded that the Basalt fiber wrapped with 1.5% HDPE-filled concrete samples exhibited significantly improved Flexural and compressive strengths.
- The uniform load transfer from fractured concrete to fiber Jacket was observed. This was due to the superior properties of HDPE under tensile and flexural loading. Hence, the present approach can be recommended in the concrete structures for safety-critical structural design.

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