Visual Abstract

An assessment of HDPE fillers and fiber wrapping on the strength of reinforced concrete

Basavaraj Gudadappanavar*, D. K. Kulkarni
Research Center, Department of Civil Engineering, SDM College of Engineering & Technology, Dharwad, Visvesvaraya Technological University, Karnataka, India.
gudadappa@gmail.com, dilipkkulkarni@rediffmail.com

P. S. Shivakumar Gouda
Research Center, Department of Mechanical Engineering, SDM College of Engineering & Technology, Dharwad, Visvesvaraya Technological University, Karnataka, India.
ursshivu@gmail.com

ABSTRACT. Fiber-reinforced polymer (FRP) is the most promising technique in the present era to bring sustainability, reliability, and pseudo ductility to concrete structures due to its superior properties. Thermoplastic and thermoset polymers are the most thrown-out synthetic waste that contributes to environmental pollution for a long time. To address this issue an attempt was made to utilize High-Density Polyethylene Fiber (HDPE) fillers of size 40x2 mm has been incorporated in concrete. This investigation aims to estimate the integrity effect of HDPE fillers incorporation and wrapping of concrete with Basalt fiber mats (BFM) and Geo-textile fiber mats (GFM) on split tensile strength, shear strength, and impact resistance as per standards. Results indicate that the addition of an optimum quantity of HDPE has a significant effect on improving the tensile, shear, and impact strengths. Adding HDPE fillers in the range of 0.5 - 1.5% in concrete samples wrapped with Basalt and Geo-textile fiber mats showed an increased tensile strength of up to 14.06% and 7.40% respectively with that conventional concrete. Further, wrapping of concrete using Basalt fiber and geotextile fiber mats showed a 4.16% and 20% increase in shear strength for 0.5% HDPE-incorporated concrete samples. Higher impact resistance was also observed for HDPE-added and fiber-wrapped concrete samples.

KEYWORDS. Fiber Reinforced Polymer, HDPE, Split Tensile Strength, Shear Strength, Impact Resistance.

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INTRODUCTION

Concrete is the most widely used building material due to its superior properties like compressive strength, impact resistance, and durability [1]. But inadequate tensile strength and the catastrophic nature of failure raised to find appropriate techniques to overcome such drawbacks. The incorporation of filler i.e., E-waste, short synthetic fiber, steel fibers, and natural fibers [1-5] slow down the random propagation of cracks. Along with that, Fiber-reinforced composites (FRP) as external jacket [6-8] is promising to enhance their strength due to their superior properties like high tensile strength, impact resistance, stiffness, and flexural strength. Wrapping the HDP (High-Density Polyethylene) sheet enhances the load-carrying capacity [2]. And also, the tensile strength and flexural modulus were increased marginally between 3% and 14% in HDPE-incorporated concrete [3]. Abdulkader Ismail Al- Hadithi [4] found that incorporating Polyethylene Terephthalate (PET) with 1.25% of volume increases the tensile strength by 18.43% and increased shear strength was observed up to 1% of PET addition. F.S. Khalid [5] experimented to estimate the effect of filler shape and size on splitting tensile strength. In this study 3 different types of filler were used i.e., Ring-shaped PET fibers (RPET-5 mm and RPET-10mm), irregular shape PET, and synthetic waste fiber. The tensile strength of RPET-10 FRC increased by 16.9%, 35.1%, and 24.4% for fiber content 0.5%, 1%, and 1.5% respectively compared to irregular PET, synthetic fiber, and pristine concrete specimens. The incorporation of filler in concrete improves the ductility and crack flow pattern. The dynamic tensile strength of flax-fiber-reinforced polymer (FFRP) and glass-fiber-reinforced polymer (GFRP) wrapped with impact strain ranging from 0.1 to 58 s-1 was studied by Wenjie Wang [6]. By increasing the wrapping layers, the tensile strength was enhanced by 29% and 67% in FFRP concrete and 32% and 84% in GFRP concrete. similarly, carbon nanofiber-reinforced concrete (CNFC) showed improved dynamic split tensile strength [7]. Non-Woven Polyethylene Terephthalate (PET) plastic tissue-wrapped concrete samples showed a 15.12% increase in tensile strength compared to reference specimens [8]. The thickness of glass fiber wrapping over the concrete also has a significant effect on improving the strength of concrete structures [9]. A.R. Pradeep [10] reported that the carbon fiber reinforced polymer (CFRP) wrapped sample showed an increase in split tensile strength from 30 to 50%, flexural strength from 10 to 30%, and compressive strength from 15 to 40% as compared to pristine concrete samples. The increase in shear strength is about 2.15 to 2.46 times as a volume fraction of steel fiber increases from 0 to 1.5% compared to plain concrete [11]. The retrofitting of shear damage of reinforced concrete beam shear strength increased between 50% to 111% due to the carbon fiber strip wrapping and the addition of micro-synthetic fibers.[12]. The polypropylene-incorporated and glass fiber-reinforced polymer (GFRP) concrete showed higher impact resistance compared to polypropylene-incorporated and plain concrete [13]. And even, the addition of steel fiber and wrapping of bidirectional carbon fiber-reinforced polymers (CFRPs) to the concrete showed extremely higher impact resistance [14]. Gunasekaran Murali [15] experimented on prepacked aggregate fibrous concrete (PAFC) prepared by incorporating Steel and polypropylene fibers with a dosage of 2.4%. In this study different types of drop weights i.e steel bar, cross knife-like, or line load types were used. The remarkable influence of filler was observed on impact resistance.

Through many studies, it was observed that the incorporation of different fillers leads to enhanced ductility of the concrete structure, and also wrapping of different fibers on the concrete structure helps to enhance its durability and strength [16-19]. This study aims to investigate the effect of the incorporation of HDPE fillers, Basalt, and Geo-textile fiber mat wrapping of concrete for Split tensile, Shear, and impact strengths. The M30 grade concrete was prepared, and samples were cast and tested as per the procedure given in the test standards.

MATERIALS

The HDPE bottles were collected from Hubballi Dharwad municipal corporation (HDMC). The bi-directional basalt fiber was supplied by Nickunj Eximp Entp Pvt. Ltd. Mumbai. The Geo-Textile fiber was supplied by a local supplier. The physical and mechanical properties of fibers are listed in Tab. 1. The Portland cement of grade 43 was procured from a local supplier. The properties of cement were determined by conducting tests in the laboratory, the fineness of 4.63, the normal consistency of 32%, with a 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 with a fineness modulus of 7.38 for coarse aggregate and similarly a specific gravity of 2.61, and the fineness modulus of 2.18 for fine aggregates were obtained from the lab test. The Poly-Naphthalene Condensate type was used as a superplasticizer 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.

Fibers	Density (kg/m^3)	Tensile Strength (MPa)	Youngs Modulus (GPa)	Elongation at Break (%)
Basalt	2650	3100 - 4840	84	3.15
Geo-Textile	400	643	30	1.6

Table 1: Physical and mechanical properties of fibers.

SAMPLE PREPARATION

The concrete mixing process is as follows. Initially, mixing of coarse aggregate, fine aggregate, and cement were mixed as per the M30 grade of concrete. The blending ratios for different compositions are listed in Tab. 2. Further, a chopped size of 40*2*1 mm(L*W*t) HDPE was added to perform the mixture by varying the proportion from 0.5% to 3%. To enhance the workability of the concrete the mixture of water and superplasticizer solution was poured into the concrete as per the blending ratio proportion. The mixing process was carried out to form the homogenous concrete. For each composition, three samples were tested. The prepared fresh concrete was poured into the mold to cast a split tensile sample with the dimension of 300*150 mm as per standard which is shown in Fig. 2. Similarly, shear and impact test samples were prepared by pouring the fresh concrete into the mold as per the standard. A vibrator was used to bring the proper compaction in the concrete samples. The casted samples were de-molded from the mold after 24 hrs and further samples were soaked in water for 28 days for curing purposes. Cured samples were kept at room temperature for 24 hours for drying. And further, Basalt and Geo-textile fiber mats were wrapped using an epoxy binder. The process of preparing the concrete samples is shown in Fig. 1.

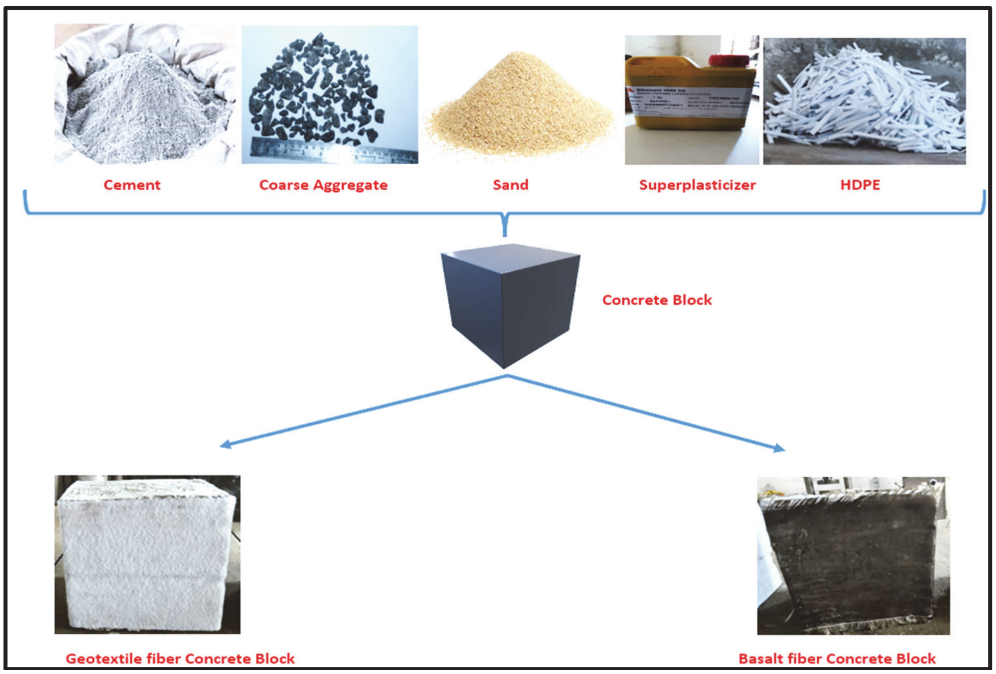

Figure 1: Process of sample preparation.

Test	Materials (3Specimens) Cement (kg)	Sand (kg)	Coarse Aggregate (kg)	Water (ml)	Superplasticizer (ml)
Tensile Strength	6.53	16.731	24.306	2940	52.29
Shear Strength	3.16	8.10	11.77	1424.25	25.31
Impact Strength	1.305	3.340	4.85	587.25	10.45

Table 2: Mixing proportion to prepare the concrete samples.

EXPERIMENTAL

Split tensile test

The split tensile test was performed as per IS: 5816-1999 [20] standard. The sample dimensions and loading configuration is shown in Fig. 2. The 200kN capacity compression testing machine was used to perform the test and the maximum load for each sample is noted to find the tensile strength of concrete samples using Eqn. 1.

$$\text{Tensile strength } \sigma_t = \frac{2P}{\pi HD} \tag{1}$$

where P, H, and D denote Load, the height of the specimen, and the diameter of the specimen respectively.

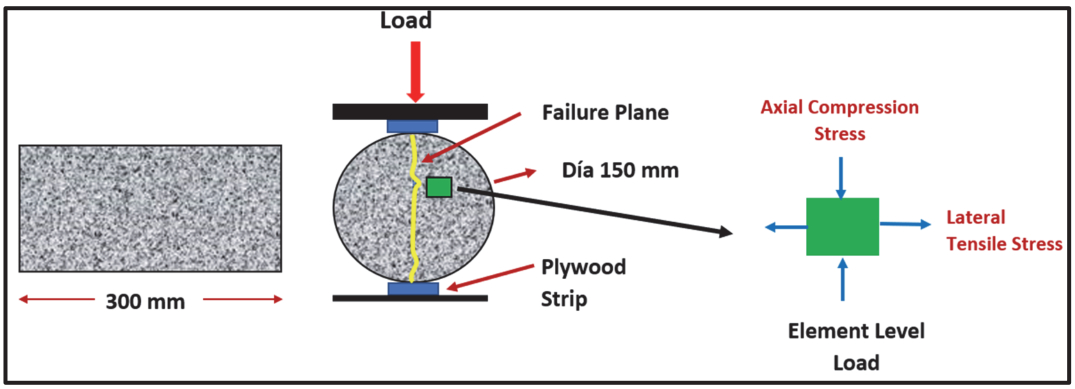

Figure 2: Schematic of sample dimension and compressive loading configuration.

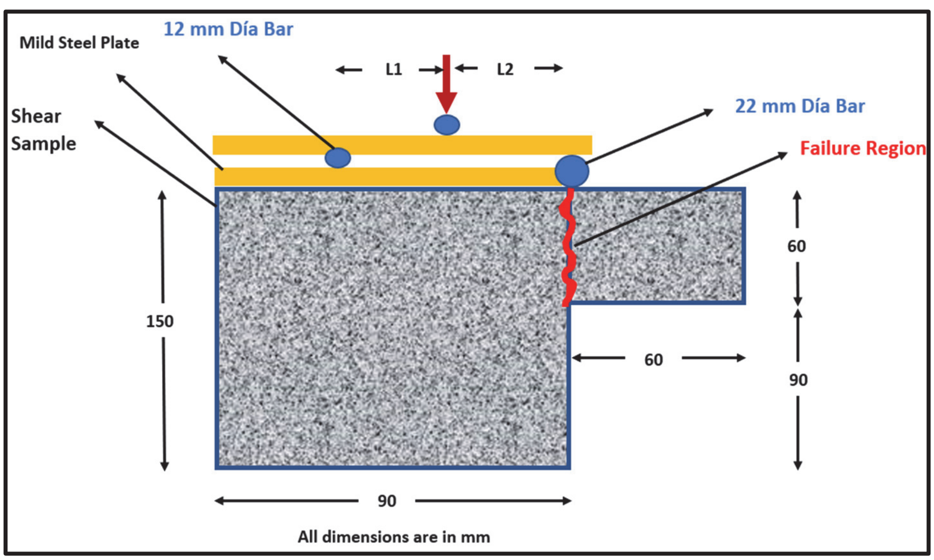

Figure 3: Schematic of shear test sample and its loading points.

Shear test

The shear test for L-shaped samples was prepared by inserting a wooden cube of dimension 60x90x150mm into the cube mold of size 150x150x150 mm. The 1000kN UTM was used to perform the test. The loading points and failure region are shown in Fig. 3. The maximum load was noted to find the failure load and shear strength which are calculated as per Eqn. 2 and Eqn. 3.

$$\text{Failure Load}\left(F\right) = \frac{PL_1}{\left(L_1 + L_2\right)} \tag{2}$$

$$\text{Shear Strength} = \frac{F \times 1000}{A} \quad (3)$$

where, P= Load (kN), A= Area of shear surface i.e., 60x150 mm², L1=25mm, L2=25mm

Impact test

The impact test on the concrete specimen is to measure the ability of impact absorption due to external load. For evaluating impact strength, cylindrical specimens of 150mm diameter and 60mm height were prepared. Samples were tested on Schruder's impact testing machine which is shown in Fig. 4. Several blows were required to cause the first crack and final failure and then readings were noted down. The number of blows was used and recorded to find the impact energy using Eqn. 4.

$$\text{Impact Energy} = W \times h \times n \quad (4)$$

where, w = Weight of the hammer = 45.4N, h = Height of fall = 0.457 m, and n = Number of blows required to cause a first crack or final failure

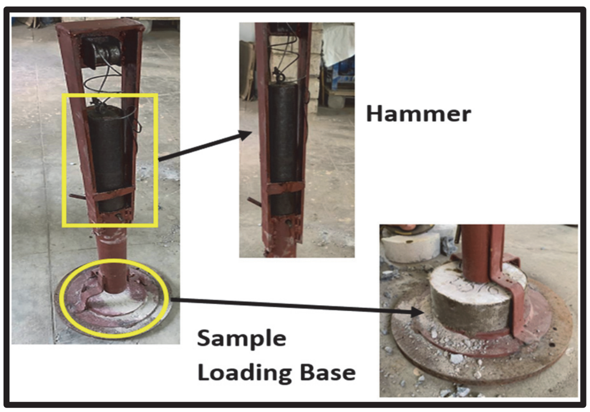

Figure 4: Impact test setup.

RESULTS AND DISCUSSION

Split tensile strength

Fig. 5a illustrates the split tensile strength of HDPE-incorporated concrete samples by varying the range from 0 to 3 % with a 0.5% interval. From Fig. 5a it was observed that 0.5%, 1%, and 1.5 % HDPE-incorporated concrete samples showed an increase in tensile strength of more than 3.67%,7.35%, and 3.89% respectively as compared to plain concrete. Good cohesion even after the first failure was observed up to 1.5% addition of HDPE fillers. But a further increase in the percentage of HDPE leads to a drop in the strength of the concrete due to the poor bonding leading to random propagation of cracks. The increase in tensile strength with different polymer addition was reported in many studies [1-5]. And the authors highlighted that the increase in the tensile strength depends on the optimal quantity of polymers/plastics in concrete. Even fiber wrapping along with HDPE incorporation has a significant effect on tensile strength which is shown in Fig. 5b. From Fig. 5b it was observed that 0.5%, 1%, and 1.5% HDPE filler incorporated concrete wrapped with BFM increased in the tensile strength by more than 9.37%,14.06%, and 7.81% respectively when compared to plain concrete samples. And it was also observed that 0.5%, 1%, and 1.5% of HDPE-filled concrete wrapped with GFM gave increased tensile strength by more than 3.7%,7.40%, and 3.8% respectively when compared to plain concrete samples. In addition to this, the concrete samples without HDPE addition and wrapping showed brittle nature of failure with samples split into two halves are shown in Fig. 6a. But HDPE incorporated samples did not split into two halves even after taking more load than conventional concrete samples. Contrarily, concrete samples wrapped with FRP were not separated which are shown in Figs. 6b and 6c. This indicates that the FRP-wrapped concrete samples could withstand the larger split loads. Comparing the BFM and GFM-wrapped concrete tensile strength, BFM-wrapped samples showed almost a 45% increase in the tensile strength for 1 % incorporation of HDPE. This is caused by the attractive mechanical properties of Basalt fiber compared to Geo-Textile fiber which is given in Tab. 1.

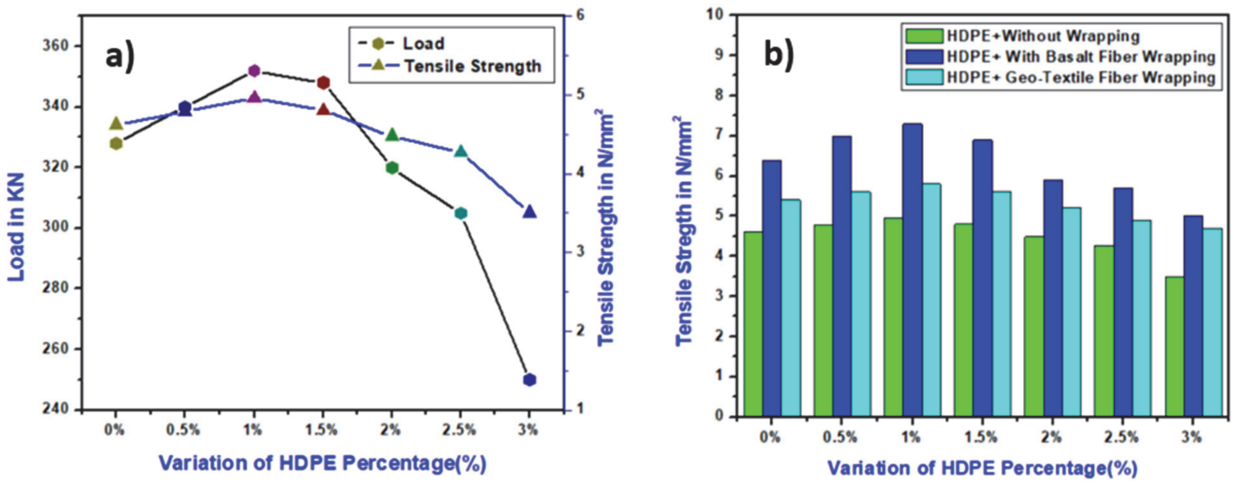

Figure 5: Tensile Strength of concrete samples (a) Tensile strength versus HDPE proportion (b) Tensile strength of fiber-wrapped samples versus HDPE proportion.

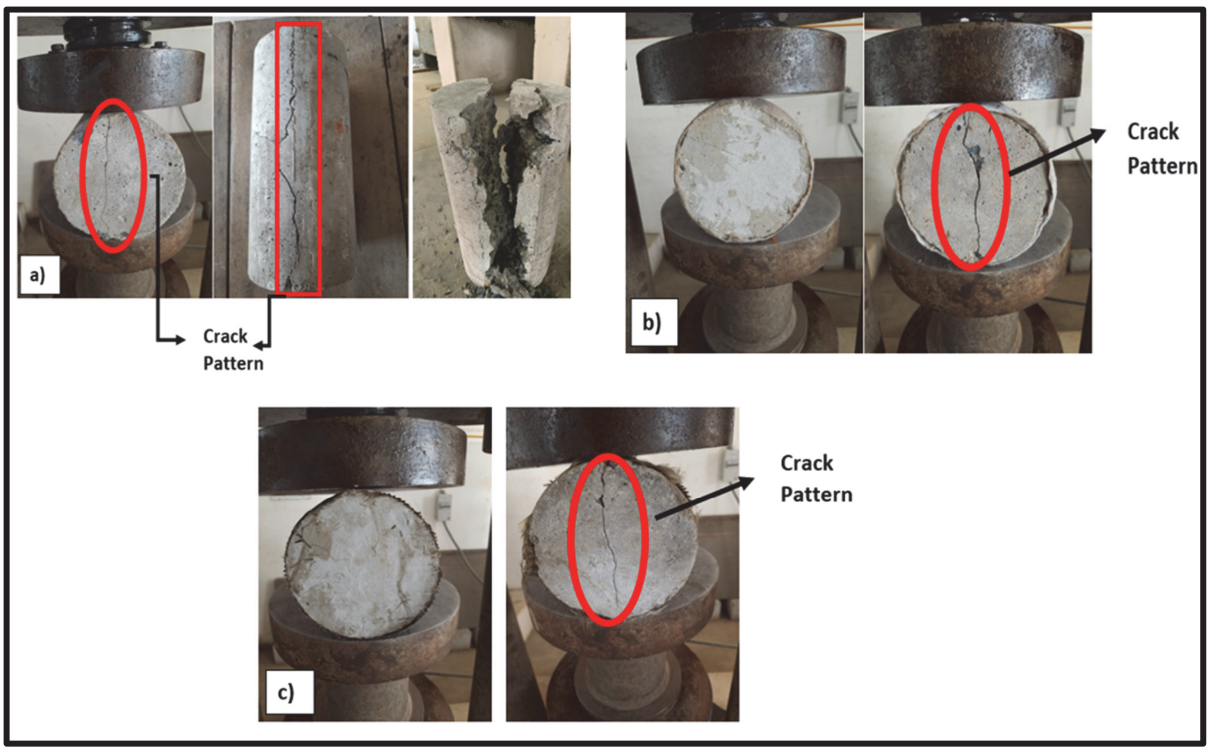

Figure 6: Cracked samples under split Tensile Test (a) pristine concrete (b) Geo-Textile wrapped concrete and (c) Basalt fiber wrapped concrete.

Shear strength

Fig. 7 illustrates the effect of HDPE incorporation in concrete on shear strength. From Fig. 7 it was observed that 0.5% HDPE fiber-reinforced concrete gains shear strength of more than 10.52% when compared to plain concrete samples. Further increase in HDPE in concrete has a decrease in shear strength was noticed. This is due to the poor shear resistance between cement and HDPE and the localization of stresses at the loading point which was shown in Fig. 8a From Fig. 7b it was observed that 0.5% HDPE fiber-reinforced concrete wrapped with BFM and GFM showed an increase in shear strength of more than 4.16% and 20% respectively when compared to fiber-wrapped and pristine concrete samples. The wrapping with external fiber jackets leads to resisting the sudden catastrophic failure under the shear mode of loading which is shown in Figs. 8b and 8c.

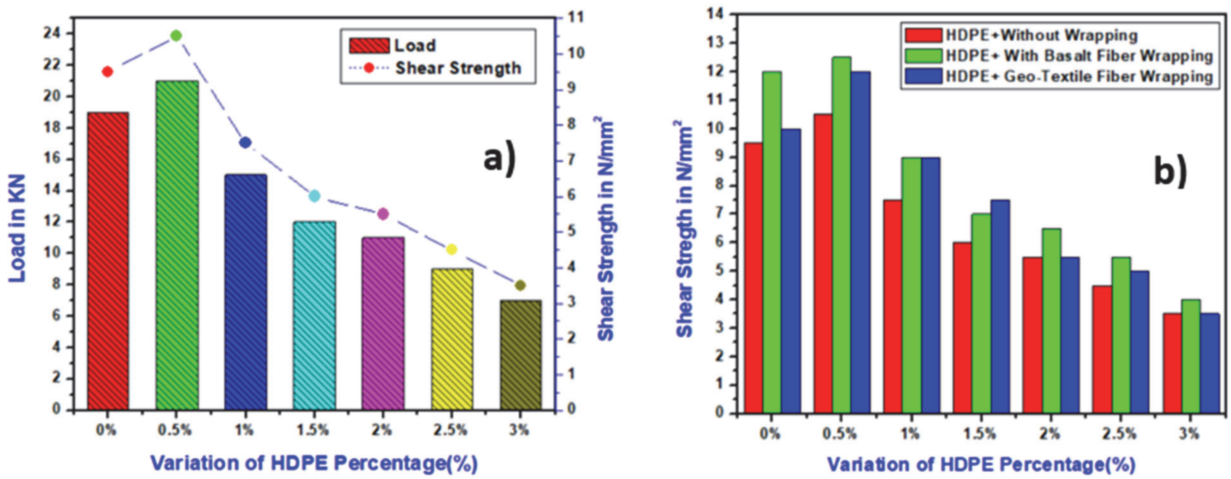

Figure 7: Variation of Shear Strength values in concrete (a) Shear strength versus HDPE proportion (b) shear Strength of fiber wrapped versus HDPE proportion.

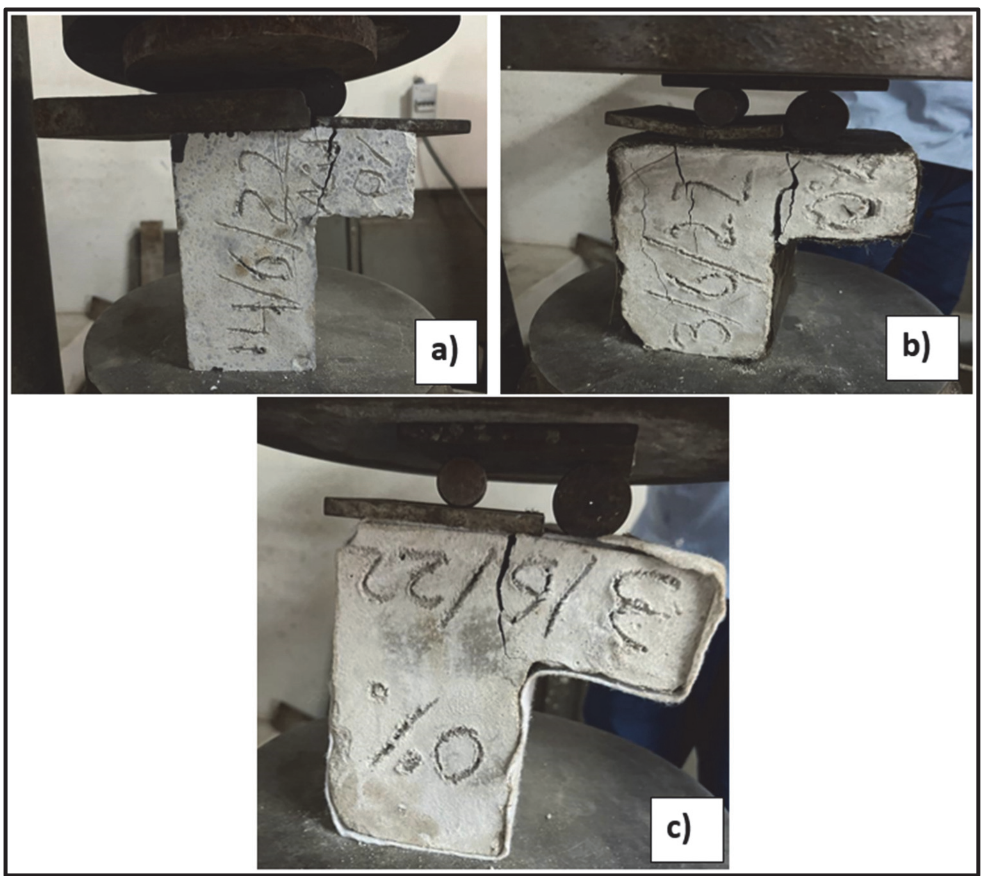

Figure 8: Cracked concrete samples under Shear Test (a) Plain Concrete (b) BFM wrapped and (c) GFM wrapped samples.

Impact resistance

The effect of adding HDPE in concrete on impact resistance is shown in Figs. 9a and 9b. From Figs. 9a and 9b, it was observed that 0.5%, 1%, and 1.5 % HDPE fiber-reinforced concrete gains an impact strength of more than 33.33%, 61.11%, and 77.77% for the first crack on the specimen and 31.81%,54.54% and 68.18% for the final failure respectively when compared to plain concrete. The energy-absorbing of HDPE-filled concrete is higher and leads to take a greater number of blows required to develop the initial crack and final failure. Due to the poor resistance to impact the plain concrete samples have broken into many pieces which is shown in Fig. 11 a.

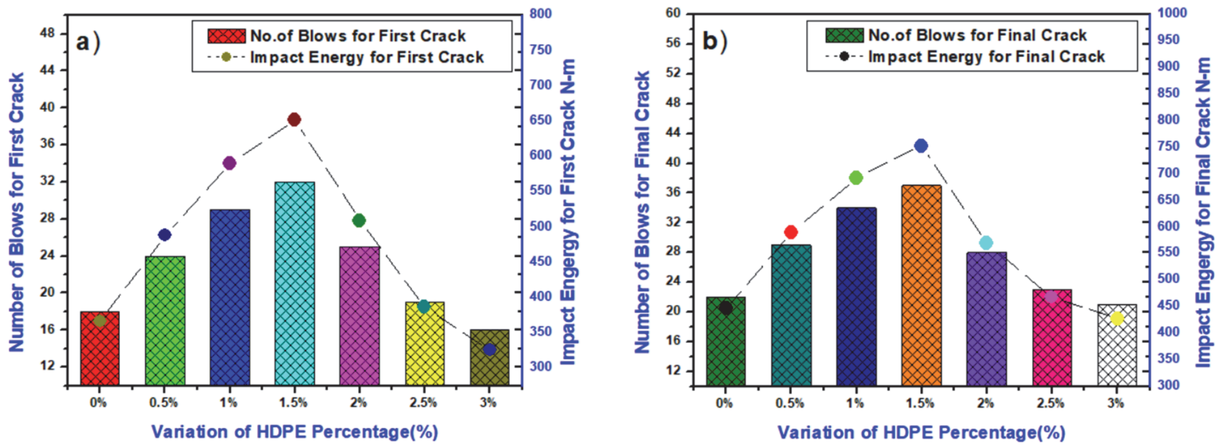

Figure 9. Variation of impact energy and number of blows (a) first crack (b) final failure.

Fig. 10 illustrates the effect of fillers and fiber wrapping on impact resistance. From Fig. 10 it was observed that 0.5%, 1%, and 1.5% HDPE fiber-reinforced concrete wrapped with BFM gave an increased impact strength of more than 18.58%, 37.03%, and 44.44% for the initial crack on the samples and 15.33%, 25.00%, and 32.69% for the final failure respectively when compared to plain concrete. Similarly, it was observed that 0.5%, 1%, and 1.5% HDPE fiber-reinforced concrete wrapped with GFM showed an increased impact resistance of more than 33.33%,57.14%, and 71.42% for the first crack and 22.22%, 33.33%, and 41.66% for the final failure on the specimens respectively when compared to plain concrete. The impact resistance tested samples with the initial and final crack for Basalt and Geo-textile fiber wrapped are shown in Fig. 11b and 11c. It was also seen that the wrapping helps to withstand higher impact loads. This is due to the resistance offered by the fiber jacket.

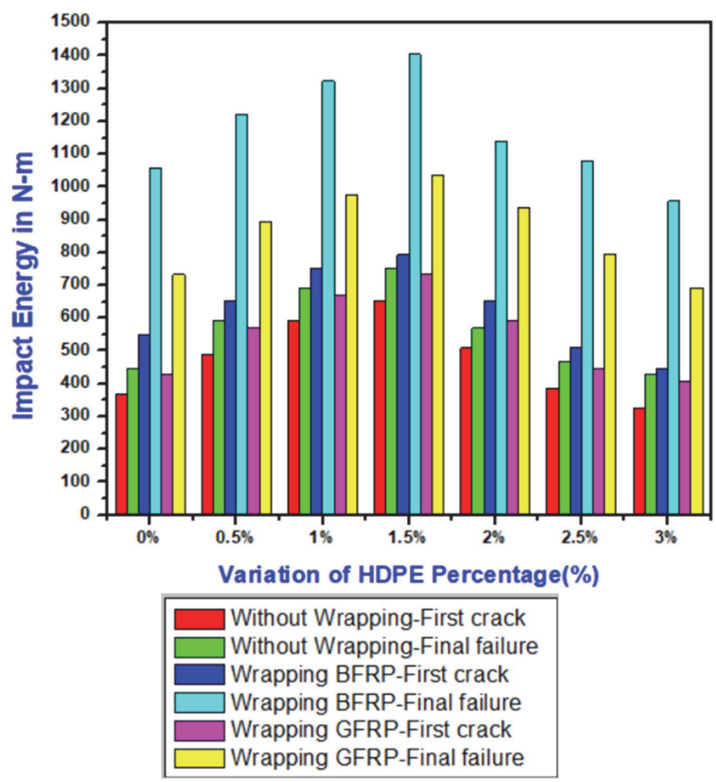

Figure 10: Variation Impact Energy vs wrapping of fibers and HDPE.

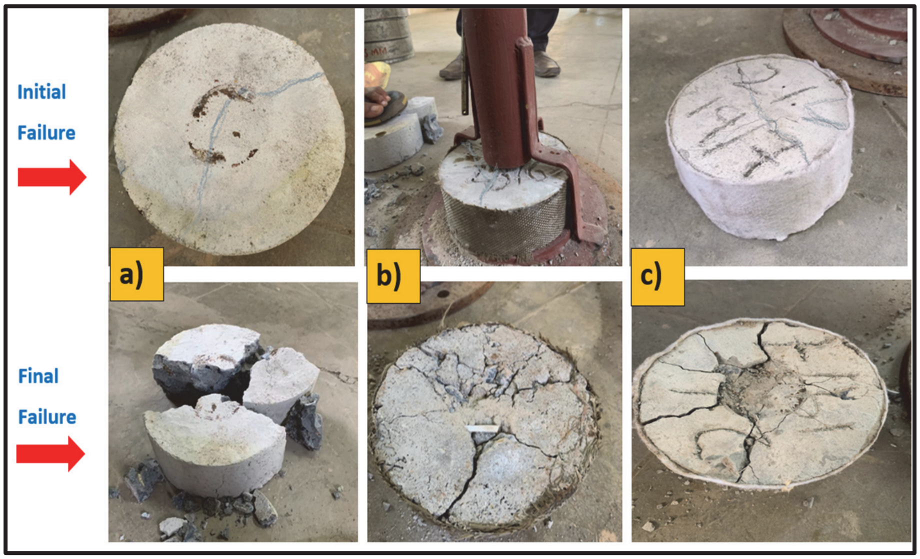

Figure 11: Crack formation during initial and final failure (a) Plain concrete sample (b) Basalt fiber wrapped sample and (c) Geotextile fiber wrapped sample.

Conclusions

In this study, the split tensile, shear strength, and impact resistance of HDPE incorporated, and fiber wrapping on concrete samples were experimentally studied. The following conclusion was drawn from the experimental findings.

- The results revealed that the addition of 0.5%, 1%, and 1.5 % HDPE in concrete showed an increased tensile strength of more than 3.67%,7.35%, and 3.89% respectively compared to plain concrete.
- For 0.5 to 1.5% HDPE incorporated concrete wrapped with BFM increased the tensile strength in the range of 9.37% to 14.10%.
- Similarly, 0.5%, 1%, and 1.5% of HDPE fiber-reinforced concrete wrapped with GFM increased the tensile strength by more than 3.7%, 7.40%, and 3.8% respectively when compared to those without HDPE fillers concrete wrapped with GFM.
- The shear strength is more than 10.52% for 0.5% HDPE-incorporated concrete concerning pristine concrete.
- The wrapping of BFM and GFMs also showed a 4.16% and 20% increase in shear strength for 0.5% HDPE-filled concrete.
- The impact strength is more than 33.33%,61.11%, and 77.77% for the first crack on the concrete, and 31.81%,54.54%, and 68.18% more for the final failure were observed in 0.5 to 1.5% HDPE filled concrete samples.
- The present techniques used in this study are by adding fillers and fiber wrapping will certainly enhance the load-carrying capacity and to overcome the sudden catastrophic failure of the concrete structure. Hence these techniques can be recommended in the development of concrete structures for safety-critical structural design.

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