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Experimental Investigation on Mechanical Properties of Hybrid Fiber Reinforced Concrete with Admixtures

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Abstract— A composite is termed as hybrid if two or more types of fibers are rationally combined to produce a composite that derives benefits from each of the individual fibers and exhibits a synergistic response. Fiber reinforcement is commonly used to provide toughness and ductility to brittle cementitious matrices. Reinforcing concrete with a single type of fiber may improve the desired properties to a limited extent. This study aims to characterize and quantify the mechanical properties of Basalt fiber and Polypropylene fiber reinforced concrete. The volume percentage of inclusion of both fibers was varied from 0 to 1%. Slump test and compaction factor test were carried out for each mix in the fresh state. Compressive strength at 28 and 90 days, as well as split tensile strength tests, were performed in the hardened state on M25 grade concrete. Various numerical analyses were conducted to quantify the determined mechanical properties and to describe the effects of fiber inclusion on these properties.

Keywords— Composite, Basalt fiber, Polypropylene fiber, mechanical properties, Slump test, Compaction factor test.

I. INTRODUCTION

The term fiber reinforced concrete (FRC) is defined by ACI Committee 544 as concrete made of hydraulic cements containing fine or fine and coarse aggregates and discontinuous discrete fibers [1]. Inherently, concrete is brittle under tensile loading. Mechanical properties of concrete can be improved by reinforcement with randomly oriented short discrete fibers, which prevent and control initiation, propagation, or coalescence of cracks. FRC can continue to sustain considerable loads even at deflections exceeding the fracture deflections of plain concrete. The character and performance of FRC change depending on matrix properties as well as the fiber material, fiber concentration, fiber geometry, fiber orientation, and fiber distribution. FRC can be regarded as a composite material with two phases in which concrete represents the matrix phase and the fiber constitutes the inclusion phase. The volume fraction of fiber inclusion is the most commonly used parameter attributed to the properties of FRC. Fiber count, fiber specific surface area, and fiber spacing are other parameters, which may also be used for this purpose. Another convenient numerical parameter describing a fiber is its aspect ratio, defined as the fiber length divided by its equivalent diameter. Fibers are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact, abrasion, and shatter resistance in concrete. Generally, fibers do not increase the flexural strength of concrete, and so cannot replace moment-resisting or structural reinforcement.

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II. LITERATURE REVIEW

A. Muatapha Abdulhadi [2014] The study on the effect of Basalt and Polypropylene Fibers with different volumes can still be a promising work as there is always a need to overcome the brittleness of concrete. It is observed that the compressive strength for C30 grade of concrete from two different types of fibers at different volume fractions shows a different degree of reduction. Addition of 0.3%, 0.6%, 0.9%, and 1.2% of basalt fiber resulted in different compressive strengths, which were compared to plain concrete. Similarly, the addition of 0.3%, 0.6%, 0.9%, and 1.2% of polypropylene fiber resulted in good compressive strengths, which were compared to plain concrete. It was observed that the incorporation of fiber in the concrete matrix greatly increases splitting tensile strength. Addition of 0.3% and 0.6% volume of basalt fiber increases the splitting strength of concrete and concluded that the optimum dosage for the splitting tensile strength of basalt fiber is in the vicinity of 0.6%. Also, the addition of 0.3% and 0.6% volume of polypropylene fiber increases the splitting strength of concrete. Therefore, the optimum dosage for the splitting tensile strength of polypropylene fiber is in the vicinity of 0.3%.

B. Dan-Yang Su. [2021] This study investigates the mechanical and dynamic properties of hybrid fiber-reinforced concrete, comprising basalt fiber and polypropylene fiber with fly ash. The splitting tensile strength of concrete is directly proportional to its compressive strength, but the tension-compression ratio is inversely proportional to its strength grade. Adding fiber into concrete can effectively improve the tension-compression ratio of concrete, enhancing its tensile strength, toughness, and resistance to brittle failure. Currently, representative fibers such as steel fiber, polypropylene fiber, and basalt fiber are being used, with basalt fiber being noted for its low price, high elastic modulus, and minimal environmental pollution. The addition of basalt fiber into concrete significantly improves its splitting tensile property and durability, while polypropylene fiber enhances the compressive strength and mitigates brittle failure under compression. Therefore, the hybridization of two types of fibers can complement each other's advantages, leading to a synergistic effect. Hybrid fiber-reinforced concrete (HBPC) exhibits higher static compressive strength and static splitting tensile strength compared to benchmark concrete, with maximum increases of 20.87% and 37.65%, respectively.

C. Ninghui Liang. [2021] This study aims to investigate the hybrid effects of polypropylene fiber and basalt fiber on the fracture toughness of concrete. Thirteen groups of notched concrete beam specimens with different fiber contents and mass ratios were prepared for the three-point bending test. Acoustic emission monitoring data were used to determine the initiation cracking load and instability load of each specimen, and fracture toughness parameters were calculated based on the double-K fracture criterion. The results indicate that increasing the fiber content does not significantly increase the fracture toughness of the concrete. Different fibers exhibit varying impacts on different fracture parameters. Polypropylene fiber enhances unstable toughness, while basalt fiber increases initial fracture toughness to a greater extent. Overall, fiber incorporation improves the fracture toughness parameters of concrete, with different fibers having distinct effects on different fracture parameters.

D. Patil Shweta and Rupali Kavilkar. [2014] Concrete exhibits low tensile strength, limited ductility, and susceptibility to cracking. Fiber-reinforced concrete (FRC) offers higher flexural strength, better tensile strength, modulus of rupture, and crack resistance compared to plain concrete. This study focuses on steel fiber-reinforced concrete and investigates its flexural and compressive strength. Tests were conducted on specimens with varying aspect ratios and percentages of steel fiber. The results show that the addition of steel fiber significantly increases flexural strength. Moreover, at a constant percentage of fiber, increasing the aspect ratio from 40 to 70 leads to a notable increase in flexural strength. The research suggests that steel fiber-reinforced concrete can be effectively utilized for the design of curvilinear forms due to its enhanced properties.

E. Amit Rana. [2013] This project examines the influence of steel fibers on the flexural strength of concrete. Steel fibers are known to provide maximum strength compared to glass and polypropylene fibers. The study aims to determine the optimal quantity of steel fibers required to achieve maximum flexural strength for M25 grade concrete. Experimental results indicate a significant increase in flexural strength with the addition of steel fibers, with even a 1% content resulting in a notable enhancement compared to plain concrete.

F. Murali, A. S. Santhi, and G. Mohan Ganesh. [2014] The study investigates the impact resistance of fiber-reinforced concrete (FRC) incorporated with steel fibers at various dosages. Drop weight tests were performed on plain and fiber-reinforced concrete samples cured for 28 days. Crimped and hooked end steel fibers were added in different proportions, and the results demonstrate the effectiveness of FRC under impact loads, thereby enhancing impact resistance.

III. MATERIALS USED

Cement: Ordinary Portland cement of 53 grades available in the local market was used in the investigation. The cement used has been tested for various proportions as per IS: 4031-1988 and found to conform to various specifications of IS: 12269-1987. The specific gravity was 3.16.

Fine aggregate: River sand procured from Karimnagar was used. The fine aggregate has a specific gravity of 2.62. The sample conforms to zone II, and the fineness modulus is 3.16.

Coarse aggregate: 10-millimeter and 20-millimeter crushed gravel with a specific gravity of 2.69 were used. The coarse aggregate was air-dried in the laboratory, and sieve analysis was carried out.

Water: Potable water was used in the experimental work for both mixing and curing.

Polypropylene fibers: Polypropylene fibers used in this investigation had a diameter of 200 micrometers, tensile strength of 550 Megapascals, Tensile Modulus of 14 Gigapascals with elongation of 12%.

Basalt fibers: Basalt continuous, staple, and super-thin fibers were used. Basalt continuous fibers (BCF) were used for the production of reinforcing materials and composite products, fabrics, and non-woven materials.

Ground Granulated Blast Furnace Slag: This hydraulic admixture is popular for use as raw material for Portland blast furnace slag cement, admixture for raw concrete, and other applications.

IV. EXPERIMENTAL PROCEDURE

The experimental investigations were conducted on M25 grade concrete with different dosages of Polypropylene fibers and Basalt fibers, with 10% Ground Granulated Blast Furnace Slag replacement. The workability of fresh concrete was assessed using slump cone test and compaction factor test, while hardened properties such as compressive strength, split tensile strength, and flexural strength were evaluated. The combined effect of both fibers on fresh and mechanical properties was experimentally investigated in the study.

The combined effect of fibers on workability was determined by performing slump cone test and compaction factor test as per Indian standards on fresh concrete. The combined effect of the fibers on the mechanical properties of concrete was examined by conducting compressive tests on cubes and split

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tensile strength tests (indirect tension test) as per Indian standard testing procedures for hardened concrete.

Specimens were cast with different dosages of Polypropylene fibers and Basalt fibers, with combined dosages of up to 1%. Dosages of each fiber were incremented at regular intervals of 0.25% from 0 to 1%. Standard cubes of size 150x150x150mm and standard cylinders of 300mm height and 150mm diameter were cast to evaluate compressive strength and split tensile strength, respectively, cured for 7 and 28 days.

The combination of fibers and their dosages used is shown below:

Sl. No.	Basalt Fiber (%)	PolypropyleneFiber (%)	Total Fibercontent (%)
1	0.25	0.75	1
2	0.50	0.50	1
3	0.75	0.25	1

V. RESULTS AND DISCUSSION

Workability: Workability tests were conducted on the fresh concrete using slump cone and compaction factor tests. Slump cone tests were performed according to Indian standards. The results of the slump cone tests for M25 grade concrete with various dosages of both fibers, along with Ground Granulated Blast Furnace Slag, are presented in the tables. It was observed that the slump decreased as the dosage of fibers increased.

Mechanical Properties: Compression tests were conducted using a 2000 Kilonewton compression testing machine, while a 600 Kilonewton UTM was used for the split tensile test. The results of the compressive strength and split tensile strength tests are provided in the tables.

Table 2: Slump Test Values of Concrete with Both Fibers

Combined Dosage of Fibers (1%)	Slump (mm)
0.25 PPF + 0.75 BF	98
0.50 PPF + 0.50 BF	89
0.75 PPF + 0.25 BF	81

Table 3: Compressive Strength of M25 Grade Concrete with Both Fibers (MPa)

Age	0.25 + 0.75	0.50 + 0.50	0.75 + 0.25
At 7 days	20.1	31.2	40.2
At 28 days	26.4	39.1	46.9
Avg.	23.25	35.15	43.55

Table 4: Compressive Strength of M25 Grade Concrete with Both Fibers (MPa)

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Age	0.25 + 0.75	0.50 + 0.50	0.75 + 0.25
At 7 days	2.33	2.87	1.96
At 28 days	3.80	4.67	3.11
Avg.	3.06	3.77	2.53

VI. CONCLUSIONS

The investigation revealed notable effects on the compressive strength of M25 grade concrete with the incorporation of different dosages of two types of fibers. Specifically, the addition of 0.25% Basalt fiber and 0.75% Polypropylene fiber resulted in a decrease in compressive strength compared to the combination of 0.75% Basalt fiber and 0.25% Polypropylene fiber. Moreover, an incremental increase in the percentage of Basalt fiber led to a marginal enhancement in compressive strength. However, it was observed that the tensile strength of fiber-reinforced concrete experienced a reduction compared to conventional concrete. Despite this, the utilization of Basalt chopped fibers proved advantageous, as it contributed to improvements in both compressive and split tensile strength at 28 days.

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