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Comparative Study Of Concrete Properties Using Fiber Reinforced Polymer

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Abstract: *Concrete, a building material with low tensile strength and tensile strain, is most frequently utilized to produce structural elements with or without reinforcement. The insertion of fibers is typically one way to increase the concrete's strength characteristics, including its flexural, tensile, impact, abrasion, load-bearing, tough, and deformation capabilities. Concrete, a building material with low tensile strength and tensile strain, is most frequently utilized to produce structural elements with or without reinforcement. Adding fibres is typically one way to increase the concrete's strength characteristics, such its flexural strength, toughness, and abrasion resistance, load bearing capacity, tensile strength, impact strength, and deformation capability. The effectiveness of basalt fibers in concrete has been the subject of very few studies. Consequently, a more thorough investigation into BFRC is needed. Characterization of the basalt fibers and the mechanical characteristics of BFRC with various volume fractions will be presented in this work. The effectiveness of basalt fibers in concrete has been the subject of very few studies. Consequently, a more thorough investigation into BFRC is needed. This research focuses on characterizing basalt fibers and BFRC's mechanical characteristics with varying volume fractions.*
keywords: *Concrete, Basalt Fiber, BFRC, Tensile Strength, Flexural Strength, Fiber Reinforcement*

1. INTRODUCTION

The cementitious materials are characterized by low tensile strength, strain capacity, and fracture toughness but termed to be brittle materials. The reinforcement in the form of continuous steel bars and stirrups are used to resist imposed tensile and shear stresses in reinforced concrete and makes a stable and usable structural material [1]. In the last five decades, another kind of reinforcement called fibers have been used to overcome the brittleness and named as Fiber Reinforced Concrete (FRC) when discontinuous and randomly distributed fibers are intruded to produce a new structural material with improved strength, ductility, and durability [1].
The term Fiber Reinforced Concrete (FRC) is defined as concrete made of hydraulic cement, fine aggregate, coarse aggregate, water and discontinuous discrete fibers. The fibers added are not a substitute for control reinforcement [2]. The basic difference between steel reinforcement and discrete steel fibers is that the continuous steel bars are used to increase the tensile and shear capacities of concrete while the addition of discontinuous fibers improves the post cracking response by controlling the crack opening and propagation [2]. Conventional steel reinforcement, such as Fe 500 grade steel, has long been the standard in reinforced concrete structures due to its high tensile strength and ductility [3]. However, steel is susceptible to corrosion, especially in aggressive environments such as coastal regions, marine structures, and areas exposed to de-icing salts, industrial chemicals, or groundwater. Corrosion not only shortens the service life of reinforced concrete structures but also leads to increased maintenance and repair costs [3]

2. Research Significance

This research is significant as it investigates the use of Basalt Fiber Reinforced Polymer (BFRP) in enhancing concrete properties, addressing its inherent weaknesses like low tensile strength and brittleness. While FRPs are gaining popularity, limited studies focus on basalt fibers in structural applications. This study compares the mechanical behavior of conventional and BFRP concrete in compression, tension, and flexure, and evaluates the axial capacity of BFRP-reinforced columns. Using Finite Element Modeling (FEM), it also predicts structural responses. The findings aim to promote durable, corrosion-resistant, and sustainable alternatives to steel reinforcement, contributing to advanced material use in modern construction.

3. Basalt Fiber

During recent times, several research works are being carried out on a development of modern continuous fibers from basalt stones. Basalt has its source from volcanic magma and flood volcanoes which are a very hot fluid or semi-fluid material under the earth's crust. [4] It gets solidified in open air. Basalt fiber is a variety of volcanic rocks, which are dark gray in color, and it formed from the molten lava after solidification. Basalt rock-beds with a thickness of 200 m have been found in the East Asian countries. Basalt rock is a volcanic rock which can be divided into small particles [5]. It can then be formed into continuous or chopped fibers called basalt fibers. Basalt is quarried, crushed, washed and then melted at 1500°C. The molten rock is then extruded through small nozzles to produce continuous filaments of basalt fiber [6].

Fig 1 Basalt fiber [6].

The Basalt fiber shown in Figure 1 is an inorganic fiber material. It is a natural material and originates from volcanic rock. It is commonly known as basalt roving or continuous filament fiber. When the continuous length is chopped into various lengths, it is called as basalt chopped strands fiber which has varying colours such as brown, gold or grey [7].

3.1 Basalt Fiber-Reinforced Concrete (BFRC)

- Basalt fibers are added to concrete mixes as chopped fibers or in the form of basalt fiber-reinforced plastic (BFRP) rebars[7]..
- BFRC exhibits improved mechanical properties, including increased tensile strength, deformation capacity, and energy absorption capabilities compared to plain concrete [7].
- It can enhance the durability of concrete structures by improving crack resistance and preventing corrosion, particularly in marine or aggressive environments [7].
- BFRC offers a sustainable alternative to steel reinforcement, addressing concerns about corrosion, environmental impact, and long-term maintenance [7].

4. Related Work

Farid Abed et al. (2021) studied the flexural behavior of BFRP-RC beams using normal and high-strength concrete. Fourteen beams were tested using a four-point loading setup. The study revealed that reinforcement ratio had minimal impact on deflection and strain pre-cracking, but higher reinforcement ratios reduced deflection post-cracking due to increased stiffness [8].

Shahaji Patil et al. (2022) highlighted basalt fibers as a promising alternative to steel reinforcement, emphasizing their superior mechanical and thermal stability. The study suggested that basalt rebars improve concrete strength after 28 days and hold potential for broader structural applications due to their durability and light weight [9].

Yu Tang et al. (2022) examined concrete columns reinforced with BFRP bars and spirals under compression. Results showed that reduced spiral spacing enhanced compressive strength and delayed failure by limiting lateral deformation. A new design method was proposed, offering improved prediction accuracy for FRP-RC columns [10].

Ehab T. Al-Rousan et al. (2023) provided a comprehensive review on BFRC, noting its durability, environmental benefits, and mechanical performance. The study emphasized the need for further investigation into BF dosage and length for optimized concrete properties [11].

Fkrat Latif Hamid et al. (2023) tested short and slender columns with BFRP under axial and flexural loads. The study found BFRP effective for both concentric and eccentric loading, though failure modes varied by load type and slenderness. A validated analytical model was proposed for design predictions [12].

Shui Liu et al. (2023) explored the performance of slender hybrid-RC columns (steel and BFRP). Higher reinforcement ratios improved load capacity and stiffness. The study proposed strength prediction equations, affirming hybrid reinforcement as a viable alternative in slender columns [13].

Sheikmohammed S et al. (2024) investigated compressive and flexural strength of concrete with partial replacement by basalt fibers. The study confirmed improved mechanical properties and emphasized the importance of fiber-reinforced alternatives to enhance conventional concrete's performance [14].

P. Sujitha Magdalene & B. Karthikeyan (2024) analyzed hybrid fiber use in ultra-high-performance concrete. Results showed 3% basalt fiber combined with 1% steel fiber yielded a 23.03% strength increase. Excessive fiber content, however, hindered workability and matrix bonding [15].

Mahdis Jalalpour Barforoush et al. (2025) studied the mechanical and radiation shielding effects of basalt fibers in high-performance concrete with magnetite aggregates. Results showed basalt improved compressive, tensile, and elastic modulus values, and enhanced radiation shielding with magnetite presence [16].

4.1 GAP Identification

- A review of existing literature reveals that Basalt Fiber Reinforcement (BFR) exhibits excellent tensile strength, corrosion resistance, and durability when used in concrete structures.
- Studies show that Basalt Fiber Reinforcement (BFR) enhances concrete's tensile strength, durability, and resistance to corrosion, making it suitable for harsh environments.
- It also reduces structural weight and improves crack control. However, research is limited regarding its bond behavior with concrete, long-term durability, and performance under full-scale structural loading.
- Additionally, standardized design codes are lacking. These gaps highlight the need for further investigation into the structural and practical applicability of BFR in concrete construction.

5. Problem Statement

Concrete is a widely used construction material known for its high compressive strength but low tensile strength and ductility, limiting its effectiveness in tension-dominated applications. Fiber reinforcement has been explored to overcome these limitations, with previous studies indicating that basalt fiber additions in the range of 1–1.5% can enhance mechanical performance. However, limited research has investigated the effects of higher basalt fiber content. There remains a significant knowledge gap regarding the behavior of Basalt Fiber Reinforced Concrete (BFRC) at increased fiber volume fractions. This study aims to address this gap by evaluating the mechanical properties of BFRC with basalt fiber replacements of 1%, 3%, and 5%, providing a more comprehensive understanding of its potential as a high-performance construction material.

- Cubes for compressive strength (150 mm x 150 mm x 150 mm)
- Cylinders for split tensile strength (150 mm diameter × 300 mm height)
- Beams for flexural strength (100 mm × 100 mm × 500 mm)

6. METHODOLOGY

Fig 2 Methodology

6.1 Material Preparation

6.1.1 Concrete Mix Design:

Table 1 Mix Design for 1 M^3

Material	Quantity (kg/m³)
Cement	413 kg
Fine Aggregate	661 kg
Coarse Aggregate	953 kg
Water-Cement Ratio	0.45

1) Sample Calculation for Cube Casting

Cylinder Size: D=150 mm

L=300 mm

Volume = $\pi r^2 h$

= 0.0053 m^3 (wet Volume)

Dry Volume add 54% in wet volume

=1.54 x 0.0053

=0.00816 m^3

Cement = 0.00816x 413 = 3.37 Kg

Sand = 0.00816 x 661 = 5.39 Kg

Coarse Agg = 0.00816 x 953 = 7.78 Kg

2) Sample Calculation for Cylinder Casting
Sample Calculation for Beam Casting:
Beam Size: L x B x H
150 x 150 x 1200 mm
Volume = 0.15 x 0.15 x 1.2
= 0.027 $\mathbf{m^3}$ (wet Volume)
Dry Volume add 54% in wet volume
=1.54 x 0.027
=0.04158 $\mathbf{m^3}$
Cement = 0.04158 x 445 = 18.5 Kg
Sand = 0.04158 x 630 =26.19 Kg
Coarse Agg = 0.04158 x 1210 = 50.31 Kg

3) Sample Calculation for Beam Casting
Beam Size: L x B x H
100 x 500 x 100 mm
Volume = 0.1 x 0.5 x 0.1
= 0.005 $\mathbf{m^3}$ (wet Volume)
Dry Volume add 54% in wet volume
= 1.54 x 0.005
= 0.0077 $\mathbf{m^3}$
Cement = 0.0077 x 413 = 3.18 Kg
Sand = 0.0077 x 661 = 5.09 Kg
Coarse agg = 0.0077 x 953 = 7.34 Kg

Table 2 Material Quantity for one Specimen

Material	One Cube	One Cylinder	One Beam
Cement	2.15	3.37	3.18
Sand	3.44	5.39	5.09
Agg	4.95	7.78	7.34
Water	0.97	1.52	1.43

Table 3 BFRP Quantity (in kg) for Cube, Beam, and Cylinder at Different % Additions

BFRP %	Cube Volume = 0.003375 m^3	Beam Volume = 0.005 m^3	Cylinder Volume ≈ 0.0053 m^3
0%	0.000 kg	0.000 kg	0.000 kg
1%	0.089 kg	0.133 kg	0.140 kg
3%	0.268 kg	0.398 kg	0.421 kg
5%	0.447 kg	0.663 kg	0.702 kg

7. RESULT AND DISCUSSION

7.1 Density of Concrete

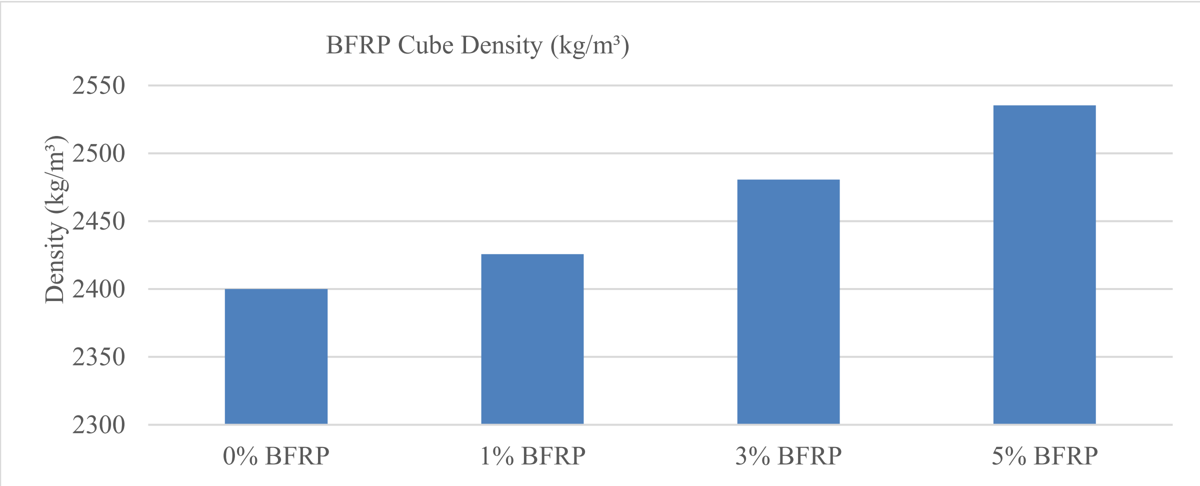
In fiber-reinforced concrete, such as with basalt fibers, density may vary due to changes in material composition. Measuring cube density helps assess the impact of fibers and ensures the concrete meets structural requirements. Density check of cubes after 28 days of curing.

$$\text{Density} = \frac{\text{Weight of the Measure}}{\text{Volume of the Measure}}$$

Cube volume = 0.150 × 0.150 × 0.150 = 0.003375 m^3

Table 4 Results for Density of concrete

BFRP %	Total Mass (kg)	Density (kg/m^3)
0%	8.11	2402
1%	8.189	2425
3%	8.368	2480
5%	8.547	2535



Graph 1 Density of concrete

As the BFRP content increases from 0% to 5%, both the total mass and density of the concrete cubes rise. This indicates that adding basalt fibers makes the mix denser and more compact. The highest density (2535 kg/m^3) is observed at 5% BFRP, showing that fiber addition improves material packing and reduces voids.

7.2 Compressive Strength

Prior to testing, test models of size 150mm X 150mm X 150mm were discarded, dismantled, and treated in water for required time. The largest load used in the sample is recorded, and the compressive strength of the template is compiled as follows.

Fig 3 Laboratory compression testing machine setup

The machine applies a controlled load to the specimen until failure occurs, and the compressive strength is calculated based on the failure load and cross-sectional area.

Table 5 Cube breaking Loads

BFRP %	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
0%	587.25	560.25	569.25
1%	614.25	600.75	625.5
3%	643.5	654.75	636.75
5%	612	596.25	605.25

Compressive Strength =Load / Cross sectional Area
Where
P = Load (KN)
A = Cross-sectional Area
Sample Calculation:
If,
P = 587.25 KN,
A = 150 X 150 mm2.
Compressive Strength = 26.1 Mpa
Table 6 Compressive Strength of concrete 28 Days

BFRP %	Cube 1 (MPa)	Cube 2 (MPa)	Cube 3 (MPa)	Average (MPa)
0%	26.1	24.9	25.3	25.43
1%	27.3	26.7	27.8	27.27
3%	28.6	29.1	28.3	28.67
5%	27.2	26.5	26.9	26.87

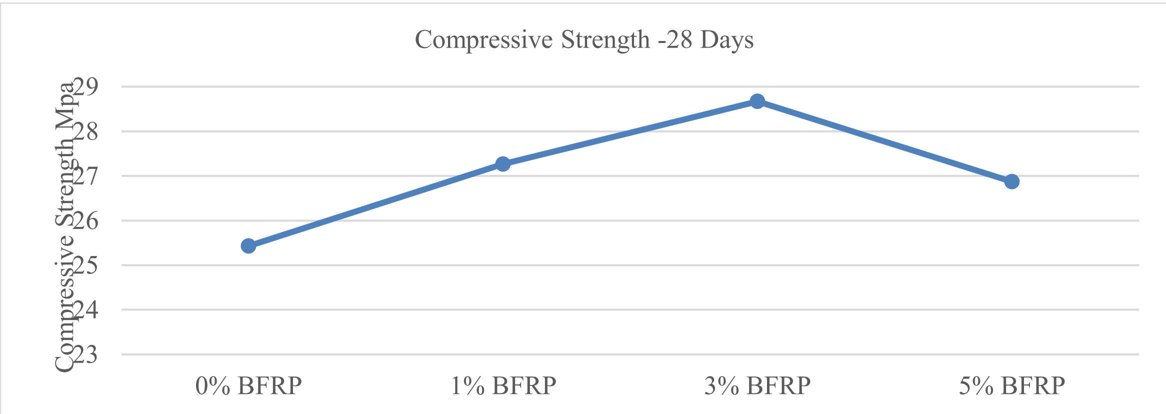


Table 2 Compressive Strength of concrete 28 Days
Compressive strength increased by 7.25% at 1% BFRP and 12.74% at 3%, showing the highest improvement. At 5% BFRP, strength decreased by 6.28% from the 3% peak but was still 5.66% higher than the control. This suggests 3% BFRP is the optimal dosage.

7.3 Flexural Strength Test

Concrete Beam, 500mm X 100mm X 100mm are casted for testing of specimen. All the specimens were prepared in accordance with Indian Standard Specification IS 516-1959.

Fig.4 Flexural Strength
The image shows a flexural testing machine used to determine the flexural strength (modulus of rupture) of concrete beams

Table 7 Beam Failure Loads

BFRP %	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
0%	8	7.75	8.2
1%	8.8	8.6	8.95
3%	9.6	9.78	9.43
5%	9	8.75	9.2

They are using the following formula –
Tensile Strength = PL/$\mathbf{bd^2}$
Where
P= Load (KN)
L= c/c distance between support
b= width of beam
d= depth of beam
Sample Calculation:
If
P=8 KN,
b=100,
L=410mm,
d=100mm
= 3.28 Mpa

Table 8 Flexural Strength of concrete 28 Days

BFRP %	Beam 1 (MPa)	Beam 2 (MPa)	Beam 3 (MPa)	Average (MPa)
0%	3.28	3.1	3.28	3.19
1%	3.52	3.44	3.58	3.51
3%	3.84	3.91	3.77	3.84
5%	3.6	3.5	3.68	3.59

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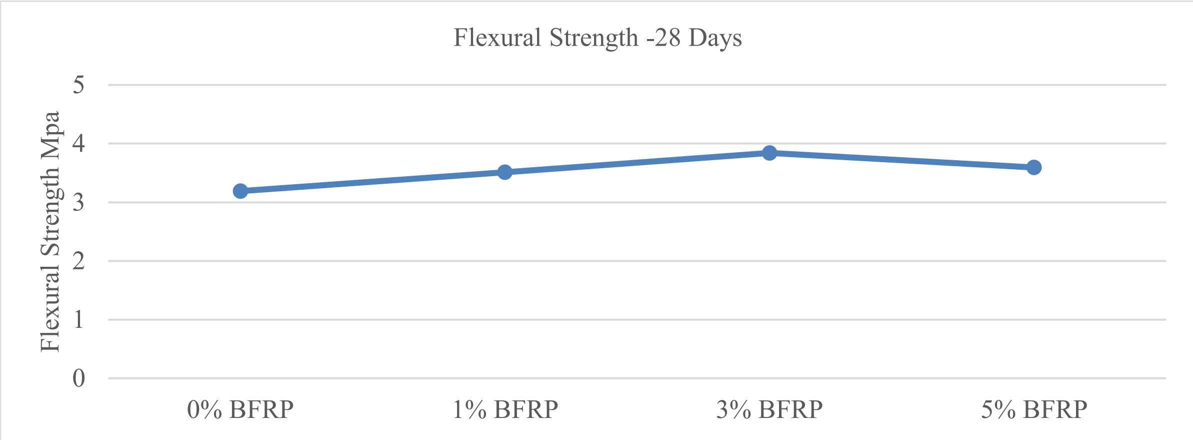


Graph 3 Flexural Strength of concrete 28 Days

Flexural strength increased by 10% at 1% BFRP and 20% at 3%, then dropped slightly at 5% but remained 12.5% higher than the control. The best improvement is at 3% BFRP.

7.4 Split Tensile Strength

For split tensile strength test, cylinder specimens of dimension 150 mm diameter and 300 mm length were cast. These specimens were tested under compression testing machine. In each category, three cylinders were tested and their average value is reported.

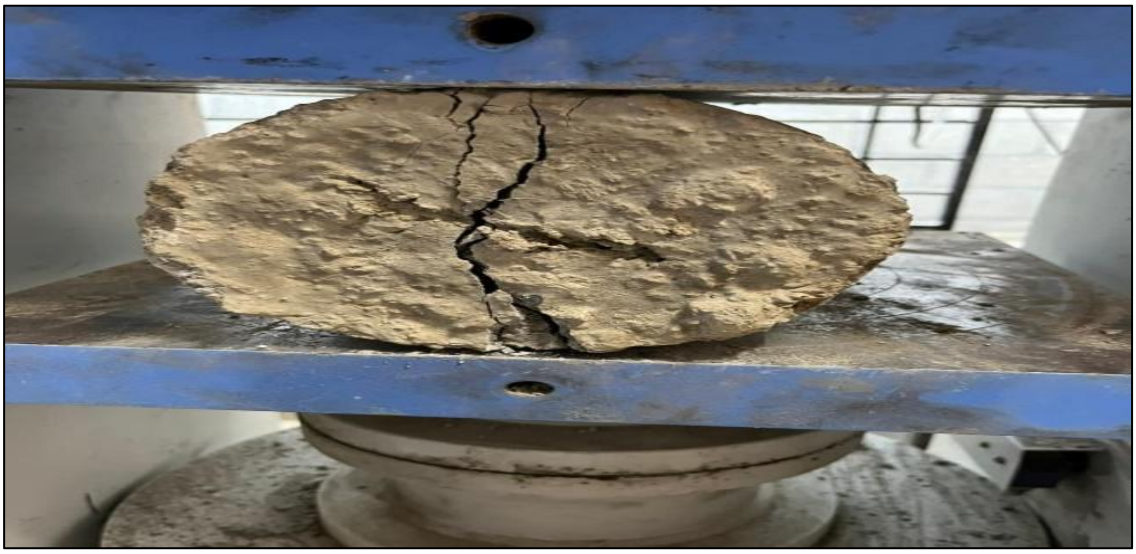


Fig 5 split tensile strength test

The image shows a cylindrical concrete specimen undergoing a split tensile strength test. This test is performed to determine the tensile strength of concrete

Table 9 cylinder Failure Loads

BFRP %	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
0%	180.25	183.78	176.72
1%	190.86	194.39	189.23
3%	208.52	205.01	210.63

5%	198.12	194.39	196.25

They are using the following formula -

Tensile Strength = 2P /π DL

Where,

P = Load (KN)

D = Diameter of Cylinder

L = Length of Cylinder

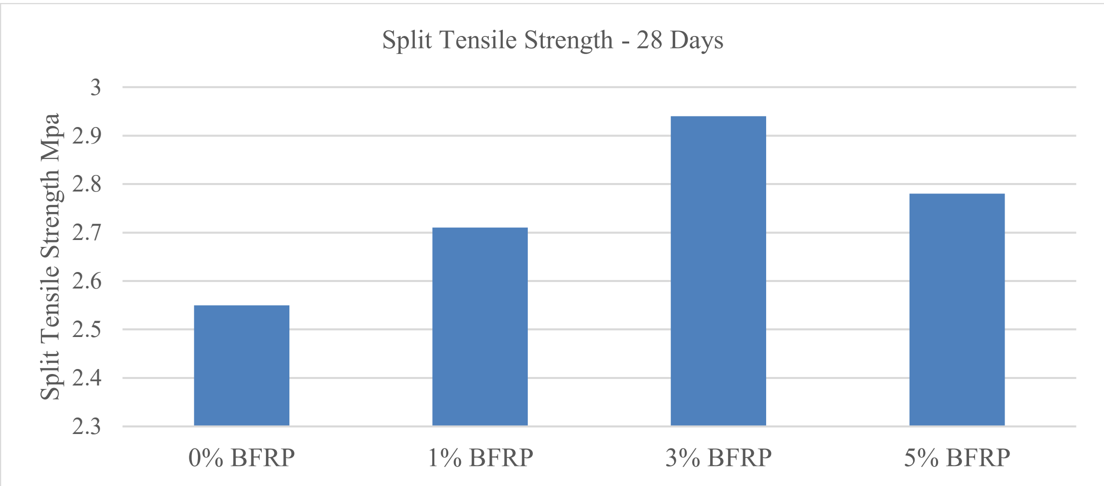
Sample Calculation:

P= 180.25 KN, D=150mm, L=300mm

= 2.55 Mpa

Table 10 split tensile strength of concrete 28 Days

BFRP %	Cylinder 1 (MPa)	Cylinder 2 (MPa)	Cylinder 3 (MPa)	Average (MPa)
0%	2.55	2.6	2.5	2.55
1%	2.7	2.75	2.68	2.71
3%	2.95	2.9	2.98	2.94
5%	2.8	2.75	2.78	2.78



Graph 4 split tensile strength of concrete 28 Days

The split tensile strength of concrete increased with the addition of BFRP up to 3%, rising from 2.55 MPa (control) to 2.94 MPa, a 15.29% improvement. At 1% BFRP, strength increased by 6.27%, while at 5% BFRP, it decreased slightly from the peak to 2.78 MPa, still showing an 8.98% increase over the control. This indicates that 3% BFRP provides the optimal enhancement in split tensile strength.

8. CONCLUSION

1. Improvement in Compressive Strength:

- The addition of Basalt Fiber Reinforced Polymer (BFRP) enhanced the compressive strength of concrete.
- The optimum fiber content was found to be 3%, where the compressive strength increased by approximately 12.7% compared to the control mix without fibers.
- At 5% BFRP, compressive strength slightly decreased from the peak but remained higher than the control, suggesting that excessive fiber content may negatively impact compaction and strength.

2. **Enhancement in Flexural Strength:**
   - Flexural strength showed significant improvement with increasing BFRP content up to 3%, with a maximum increase of 20.4% compared to plain concrete.
   - Beyond 3% BFRP, flexural strength decreased slightly but was still improved compared to the control.
   - This indicates that 3% fiber addition optimizes crack resistance and bending capacity.
3. **Increase in Split Tensile Strength:**
   - Split tensile strength followed a similar trend, improving by 15.3% at 3% BFRP compared to plain concrete.
   - The strength at 5% fiber content dropped slightly from the peak, but remained above the control strength.
   - These results suggest that basalt fibers effectively enhance the tensile properties of concrete up to a certain volume fraction.
4. **Effect on Density:**
   - The density of concrete cubes increased consistently with higher BFRP content, from 2402 kg/m^3 at 0% to 2535 kg/m^3 at 5% BFRP.
   - This increase reflects better material compactness and reduced voids due to fiber addition.
5. **Optimal Fiber Content:**
   - Overall, 3% BFRP was identified as the optimal dosage, providing the best balance of mechanical improvements and manageable workability.
   - Higher fiber percentages (like 5%) may cause fiber agglomeration and reduced mix workability, which can slightly reduce strength gains.
6. **Practical Implications:**
   - Incorporating basalt fibers at the optimal level can improve concrete's performance in structural applications, particularly where enhanced tensile, flexural, and impact resistance are required.
   - Basalt fibers are a promising sustainable alternative to conventional fibers due to their natural origin and mechanical properties

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IS codes

- IS 456:2000 — Code of Practice for Plain and Reinforced Concrete (General guidelines for concrete mix design, construction, and quality control)
- IS 516:1959 — Methods of Tests for Strength of Concrete (Includes procedures for compressive strength, flexural strength, and tensile strength testing)
- IS 383:2016 — Specification for Coarse and Fine Aggregates from Natural Sources for Concrete (Aggregate grading and quality requirements)
- IS 1199:1959 — Methods of Sampling and Analysis of Concrete (Sampling procedures for fresh and hardened concrete)
- IS 5816:1999 — Method of Test for Splitting Tensile Strength of Concrete
- IS 10262:2019 — Concrete Mix Proportioning — Guidelines (Mix design procedures for concrete)