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International Journal for Modern Trends in Science and Technology
Volume 12, Issue 08, pages 01-07.
ISSN: 2455-3778 online
Available online at: http://www.ijmtst.com/vol12issue06.html
DOI: https://doi.org/10.5281/zenodo.21863688

Retrofitting of Beam – Column Joints using Confined High – Performance Hybrid Fiber Reinforced Concrete

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To Cite this Article
Vangapandu Ajay & B.V. Suresh Kumar (2026). Retrofitting of Beam – Column Joints using Confined High – Performance Hybrid Fiber Reinforced Concrete. International Journal for Modern Trends in Science and Technology, 12(08), 01-07. https://doi.org/10.5281/zenodo.21863688

Article Info
Received: 08 July 2026; Revised: 29 July 2026; Accepted: 06 August 2026.

KEYWORDS

Basalt fiber, fiber-reinforced concrete, M30 concrete, compressive strength, split tensile strength, micro-silica, nano-silica, sustainable concrete.

ABSTRACT

The Earth is getting rapidly heated up mostly due to the carbon dioxide emissions. It is believed that one ton of cement produces one ton of carbon dioxide. Adding basalt fibre to concrete improves its characteristics like high tensile strength, Compressive strength extended operating temperatures, better chemical resistance and environmental friendliness. The present study is concentrated on strength characteristics of basalt fibre reinforced concrete. This combination in the concrete causes shrinkage and decreases the tensile strength. To overcome this, varying percentages of basalt fibre (0.1%, 0.2%, 0.3% and 0.4%) is added. It is also found out that, generally addition of basalt fibre in concrete reduces the compressive strength and increases the split tensile strength. So, the combination of basalt fibre reinforced concrete with considered ideal. Specimens containing basalt fibre (0.1%, 0.2%, 0.3% and 0.4%) are casted and are tested for compressive and split tensile strength. It is observed that the strength values are improved compared to cement concrete. The tensile strength values increased comparatively whereas compressive strength decreased with increase of basalt fibres content.

1. Introduction

Concrete is one of the most widely used construction materials because of its high compressive strength, durability, versatility, and availability. However, conventional concrete has relatively low tensile strength and exhibits brittle behavior under tensile and cracking stresses. Furthermore, the production of Portland cement is associated with significant carbon dioxide emissions. Consequently, considerable research has focused on developing modified concrete mixtures capable of achieving improved mechanical performance while reducing the environmental burden associated with conventional concrete.

Fiber-reinforced concrete is a composite material in which discrete fibers are distributed throughout the cementitious matrix. The incorporation of fibers can improve tensile resistance, crack bridging, toughness, durability, and post-cracking behavior. The source document identifies several fibers used in concrete, including basalt, steel, glass, carbon, polypropylene, and other synthetic or natural fibers.

Basalt fiber has attracted attention as a reinforcing material because of its high tensile strength, elastic modulus, thermal stability, and resistance to chemical attack. Basalt fibers are manufactured by melting basalt rock and extruding the molten material into fine filaments. The material is similar to glass fiber in some respects while offering favorable mechanical and environmental characteristics. The fibers used in the present investigation were reported to have a length of approximately 12 mm and a filament diameter in the range of 9–23 μm.

Previous studies reported in the source document demonstrate that basalt fibers can enhance the tensile and flexural performance of concrete. Studies have also investigated combinations of basalt fiber with micro-silica and nano-silica, indicating that supplementary cementitious materials can further modify the strength and durability characteristics of concrete.

The present investigation focuses specifically on the effect of relatively low basalt fiber contents on the compressive and split tensile strengths of M30 concrete. The selected fiber contents were 0%, 0.1%, 0.2%, 0.3%, and 0.4%. The study evaluates the strength development at 7 and 28 days and compares the fiber-reinforced mixtures with conventional cement concrete.

2. Literature Review

The mechanical performance of fiber-reinforced concrete has been investigated extensively using different fiber types and combinations of supplementary cementitious materials. Nili et al. investigated the combined use of micro-silica and colloidal nano-silica and reported improved compressive strength compared with reference concrete. The study reported that a combination of micro-silica and nano-silica could improve strength and electrical resistance.

Prasada Rao and Anil Kumar investigated concrete containing micro-silica and nano-silica and reported improvements in compressive, split tensile, and flexural strengths. Their results indicated that a combination of micro-silica and nano-silica provided improved mechanical properties compared with control concrete.

Fathima Irine investigated basalt-fiber-reinforced M30 concrete using different fiber contents and evaluated compressive, split tensile, and flexural strengths. The reported results indicated that basalt fiber could improve the mechanical properties of concrete.

Prakash et al. investigated chopped basalt fibers in M30 concrete over a range of fiber contents and reported improvements in compressive, tensile, flexural, shear, and impact strengths at an optimum fiber dosage. The study also observed a reduction in workability with increasing fiber content.

Ansari and Chandak studied M20 and M30 concrete incorporating basalt fibers at 0.5%, 1%, and 1.5%. Their results indicated that the 1% fiber mixture provided favorable compressive and split tensile strength compared with plain concrete.

Urkhanova et al. investigated mineral-fiber-reinforced concrete containing nano-silica and reported improvements in compressive and flexural performance. The study suggested that nano-silica could contribute to the strengthening of the cementitious matrix and enhance the reinforcing effect of mineral fibers.

Wlodarczyk and Jedrzejewski investigated concrete slabs strengthened with basalt fibers and reported positive effects on load capacity. Their investigation also demonstrated the influence of fiber type on the failure behavior of concrete elements.

The literature reviewed in the source document establishes that basalt fiber is capable of modifying the mechanical behavior of concrete. However, the optimum dosage depends on concrete grade, fiber characteristics, matrix composition, and test conditions. Therefore, the present investigation examines lower fiber dosages between 0% and 0.4% in an M30 concrete matrix containing micro-silica and nano-silica.

3. Materials and Experimental Methodology

3.1 Materials

The materials used in the investigation were cement, fine aggregate, coarse aggregate, water, micro-silica, nano-silica, and basalt fibers. The experimental program followed Indian Standard-based procedures for material characterization and concrete testing.

3.1.1 Cement

53-grade ordinary Portland cement was used. The source document reports a measured specific gravity of

3.14 and a fineness test result corresponding to an average residue of approximately 8.13%.

Figure 1. 53-grade ordinary Portland cement used in the investigation.

3.1.2 Fine Aggregate

Fine aggregate was characterized through specific gravity, water absorption, and fineness modulus tests. The reported specific gravity was 2.69, water absorption was 0.3%, and the fineness modulus was 3.18, with the material classified as Zone II according to the source document.

Figure 2. Fine aggregate used in the concrete mixture.

3.1.3 Coarse Aggregate

Coarse aggregates of nominal sizes 20 mm and 10 mm were used. The reported specific gravities were 2.73 for the 20 mm aggregate and 2.71 for the 10 mm aggregate. Water absorption values of 0.3% and 0.5%, respectively, were reported.

Figure 3. Coarse aggregate used in the investigation.

3.1.4 Basalt Fiber

Basalt fibers were incorporated into the concrete at 0%, 0.1%, 0.2%, 0.3%, and 0.4%. The source document reports that the fibers were approximately 12 mm long and had a filament diameter in the range of 9–23 μm. The reported density was 2.75 g/cm³, tensile strength was 4840 MPa, and elastic modulus was 89 GPa.

3.1.5 Water

Water suitable for concrete mixing and curing was used. The source document states that the water was free from deleterious oils and acids and had a pH value not less than 6.

4. Mix Proportion and Specimen Preparation

4.1 Mix Design

The concrete was designed for M30 grade according to the mix-design procedure described in the source document. The principal mixture consisted of cement, micro-silica, nano-silica, fine aggregate, coarse aggregate, and water. The water-to-cement ratio was maintained at 0.45.

The reported mix proportions were 315 kg/m³ cement, 28 kg/m³ micro-silica, 7 kg/m³ nano-silica, 715.01 kg/m³ fine aggregate, 1235.90 kg/m³ coarse aggregate, and 157.5 kg/m³ water. Basalt fiber quantities corresponding to 0.1%, 0.2%, 0.3%, and 0.4% were 2.45, 4.91, 7.37, and 9.83 kg/m³, respectively.

Table 1. Mix proportions used in the investigation

Material	0% BF	0.1% BF	0.2% BF	0.3% BF	0.4% BF
Cement (kg/m³)	315	315	315	315	315
Micro-silica (kg/m³)	28	28	28	28	28
Nano-silica (kg/m³)	7	7	7	7	7
Fine aggregate (kg/m³)	715.01	715.01	715.01	715.01	715.01
Coarse aggregate (kg/m³)	1235.90	1235.90	1235.90	1235.90	1235.90
Water (kg/m³)	157.5	157.5	157.5	157.5	157.5
Basalt fiber (kg/m³)	0	2.45	4.91	7.37	9.83
w/c ratio	0.45	0.45	0.45	0.45	0.45

4.2 Batching and Mixing

The constituents were proportioned according to the selected mix design. Basalt fibers were incorporated into the concrete mixture at the specified percentages. Mixing was performed to obtain a relatively uniform distribution of fibers throughout the cementitious matrix.

Figure 6. Mixing of concrete constituents and basalt fibers.

4.3 Casting, Placing and Compaction

Concrete specimens were cast after mixing. The concrete was placed into molds and compacted to minimize entrapped air and obtain homogeneous specimens.

4.4 Curing

The specimens were demolded after approximately 24 h and subsequently subjected to curing. The specimens were tested after 7 and 28 days. The source document reports that ambient-cured specimens were evaluated at these two ages.

5. Experimental Testing

5.1 Compressive Strength Test

Cubic specimens of 100 mm × 100 mm × 100 mm were used for compressive strength evaluation. Three specimens were tested for each mix, and the average value was reported. The maximum load at failure was recorded. The tests were performed at 7 and 28 days using a 200-ton-capacity compression testing machine.
The compressive strength was calculated using:

$$f_c = \frac{P}{A}$$

where is the compressive strength in MPa, is the maximum applied load in N, and is the loaded cross-sectional area in mm².

5.2 Split Tensile Strength Test

Cylindrical specimens measuring 150 mm in diameter and 300 mm in length were used for the split tensile strength test. The cylinder was positioned horizontally between the loading platens, and the load was applied along its diameter until splitting occurred. Plywood strips were used between the specimen and loading surfaces to distribute the load.

The split tensile strength was calculated using:

$$f_{ct} = \frac{2P}{\pi LD}$$

where f_{ct} is the split tensile strength in MPa, P is the maximum applied load in N, L is the cylinder length in mm, and is the cylinder diameter in mm.

6. Results and Discussion

6.1 Compressive Strength

The compressive strength results at 7 and 28 days are presented in Table 2.

Table 2. Compressive strength of M30 basalt-fiber-reinforced concrete

Basalt fiber content	7-day strength (MPa)	28-day strength (MPa)
0%	27.3	35.6
0.1%	33.0	41.6
0.2%	30.6	39.3
0.3%	29.3	37.0
0.4%	28.6	36.3

The 0.1% basalt-fiber mixture produced the highest compressive strength, reaching 33.0 MPa at 7 days and 41.6 MPa at 28 days. With further increase in fiber content, the compressive strength progressively decreased. Nevertheless, all basalt-fiber mixtures exhibited higher compressive strength than the reported conventional cement concrete values of 23.33 MPa at 7 days and 31.67 MPa at 28 days.

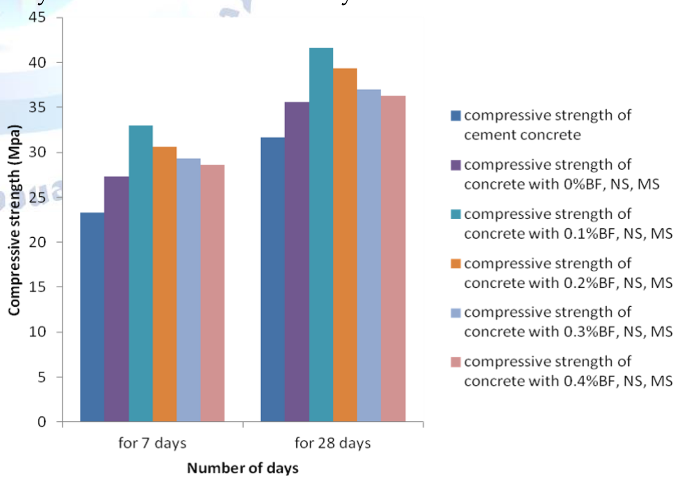

Figure 11. Variation of compressive strength with basalt fiber content at 7 and 28 days.

The improvement at 0.1% fiber may be associated with effective reinforcement and crack-bridging action at a relatively low fiber concentration. At higher fiber contents, the reduction in compressive strength may be related to difficulties in achieving uniform fiber dispersion and increased internal heterogeneity. The experimental trend reported in the source document confirms that compressive strength decreases as the fiber percentage increases beyond 0.1%.

6.2 Comparison with Conventional Concrete

Table 3. Comparison of compressive strength with cement concrete

BF content	7-day BF concrete (MPa)	28-day BF concrete (MPa)	7-day conventional concrete (MPa)	28-day conventional concrete (MPa)
0%	27.3	35.6	23.33	31.67
0.1%	33.0	41.6	23.33	31.67
0.2%	30.6	39.3	23.33	31.67
0.3%	29.3	37.0	23.33	31.67
0.4%	28.6	36.3	23.33	31.67

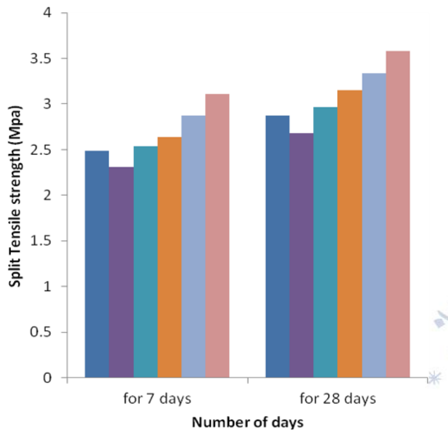

Figure 12. Comparison of compressive strength of conventional concrete and basalt-fiber-reinforced concrete.

At 28 days, the 0.1% BF mixture achieved 41.6 MPa compared with 31.67 MPa for the reported conventional concrete, corresponding to an improvement of approximately 31.3% relative to that comparison value. This calculated percentage differs from the 24% improvement stated in the original thesis; therefore, the numerical comparison should be checked against the original experimental baseline before journal submission. The underlying strength values themselves are directly reported in the source.

6.3 Split Tensile Strength

The split tensile strength results are presented in Table 4.

Table 4. Split tensile strength of M30 basalt-fiber-reinforced concrete

Basalt fiber content	7-day strength (MPa)	28-day strength (MPa)
0%	2.31	2.68
0.1%	2.54	2.97
0.2%	2.64	3.15
0.3%	2.87	3.34
0.4%	3.11	3.58

Unlike compressive strength, split tensile strength increased continuously with basalt fiber content. At 28 days, the tensile strength increased from 2.68 MPa for the 0% fiber mixture to 3.58 MPa for the 0.4% fiber mixture. This represents an increase of approximately 33.6% relative to the 0% BF mixture.

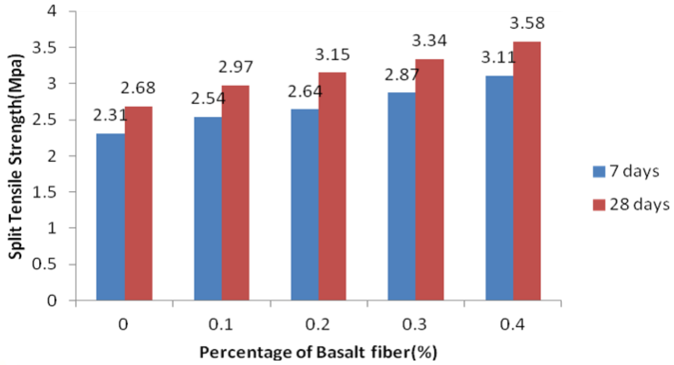

Figure 13. Variation of split tensile strength with basalt fiber content at 7 and 28 days.

The progressive increase in split tensile strength can be attributed to the fiber-bridging mechanism. Distributed basalt fibers can restrain crack propagation and transfer tensile stresses across developing cracks, resulting in improved resistance to tensile failure.

6.4 Comparison of Split Tensile Strength

The source document also provides comparison values for conventional cement concrete. The reported conventional concrete values were 2.49 MPa at 7 days and 2.87 MPa at 28 days.

Table 5. Comparison of split tensile strength

BF content	7-day BF concrete (MPa)	28-day BF concrete (MPa)	7-day conventional concrete (MPa)	28-day conventional concrete (MPa)
0%	2.31	2.68	2.49	2.87
0.1%	2.54	2.97	2.49	2.87
0.2%	2.64	3.15	2.49	2.87
0.3%	2.87	3.34	2.49	2.87
0.4%	3.11	3.58	2.49	2.87

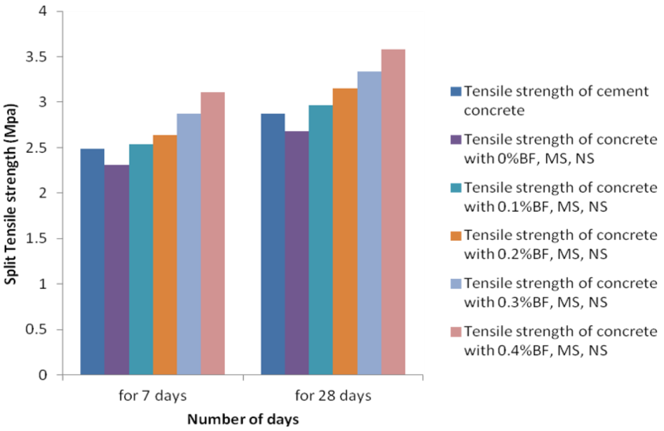

Figure 14. Comparison of split tensile strength between conventional concrete and basalt-fiber-reinforced concrete.

The 0.4% BF mixture produced the highest tensile strength at both ages. At 28 days, its strength was 3.58 MPa compared with 2.87 MPa for the reported conventional concrete. The experimental trend therefore demonstrates that increasing basalt fiber content within the investigated range is beneficial for tensile resistance.

7. Discussion of Optimum Fiber Content

The experimental results indicate that the optimum basalt fiber content depends on the mechanical property being considered. For compressive strength, 0.1% basalt fiber produced the maximum value of 41.6 MPa at 28 days. Increasing the fiber content beyond 0.1% resulted in a gradual reduction in compressive strength.

For split tensile strength, however, the strength increased progressively from 2.68 MPa at 0% fiber to 3.58 MPa at 0.4% fiber. Thus, 0.4% basalt fiber provided the highest tensile performance among the mixtures investigated.

These results demonstrate a strength trade-off associated with increasing fiber dosage. A lower fiber content is more favorable for compressive strength, whereas a higher fiber content provides greater tensile resistance. Therefore, for applications where both compressive and tensile performance are important, the selection of fiber dosage should consider the structural performance requirements rather than a single strength parameter.

8. Conclusions

Based on the experimental investigation, the following conclusions can be drawn:

1. Basalt fibers significantly influence the mechanical properties of M30 concrete.
2. The incorporation of basalt fiber improved the compressive strength compared with the conventional concrete values reported in the source document.
3. The maximum compressive strength was obtained with 0.1% basalt fiber, reaching 33.0 MPa at 7 days and 41.6 MPa at 28 days.
4. Increasing the basalt fiber content beyond 0.1% resulted in a progressive reduction in compressive strength, with 28-day values of 39.3, 37.0, and 36.3 MPa at 0.2%, 0.3%, and 0.4% fiber contents, respectively.
5. Split tensile strength showed an opposite trend, increasing continuously with basalt fiber content.
6. The 28-day split tensile strength increased from 2.68 MPa at 0% BF to 3.58 MPa at 0.4% BF, representing approximately a 33.6% increase relative to the 0% BF mixture.
7. The results indicate that 0.1% basalt fiber is favorable for maximum compressive strength, whereas 0.4% basalt fiber provides the highest split tensile strength within the investigated range.
8. The experimental findings demonstrate the potential of basalt fibers for improving the tensile performance of concrete and modifying the mechanical response of M30 concrete.

Further investigation involving flexural strength, durability, permeability, fracture behavior, and structural-scale beam-column specimens would be required before drawing conclusions regarding actual beam-column joint retrofitting. The original document identifies these areas within its stated scope, but the reported experimental results are limited primarily to compressive and split tensile strength.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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