ISSN: 2348 - 2117

International Journal of Engineering Technology and Computer Research (IJETCR)

Available Online at www.ijetcr.org

Volume 14; Issue 03; 2026; Page No. 37-46

Enhancing Mechanical Properties and Durability of Plain Cement Concrete with Basalt

Vikash Danwar[1], Mahendra Kr. Singar[2], Ravi Kant Pareek[3]

[1]M. Tech. Scholar, Department of Civil Engineering, Vivekananda Global University, Jaipur
[2]Assistant Professor, Department of Civil Engineering, Vivekananda Global University, Jaipur
[3]Associate Professor, Department of Civil Engineering, Vivekananda Global University, Jaipur

Conflicts of interest: Nil

Corresponding author: Mr. Vikash Danwar

Abstract

The present study investigates the combined effect of basalt fibers (0–8% by weight of cement) and silica fume (10% cement replacement) as sustainable additives to enhance the mechanical and durability properties of plain cement concrete (PCC) for road construction. Concrete mixes were prepared as C0–C4 corresponding to 0%, 2%, 4%, 6%, and 8% basalt fiber content. A suite of tests including compressive, split tensile, and flexural strength, water absorption, chloride penetration, freeze–thaw resistance, rebound hammer, and ultrasonic pulse velocity were conducted on laboratory specimens. Results indicate that strength generally improved with fiber addition, with the best overall performance around 6% fiber (C3). At later ages, compressive strength reached ~40 MPa (C3), split tensile strength reached ~6.1 N/mm² (C4), and flexural strength peaked at ~6.4 MPa (C3). Durability improved substantially: water absorption reduced from ~6.0% (C0) to ~3.0% (C4), and freeze–thaw performance improved with reduced mass loss and higher strength retention. Although workability decreased with higher fiber content, it remained manageable using superplasticizer and the densifying effect of silica fume. Overall, the combined use of basalt fibers and silica fume offers a promising approach for producing durable and sustainable PCC for road infrastructure.

Keywords: Basalt Fiber, Silica Fume, Concrete Durability, Mechanical Strength, Water Absorption, Chloride Penetration, Freeze-Thaw Resistance, Sustainable Roads, High-Performance Concrete

Introduction

Plain cement concrete (PCC) is widely used in road construction due to its economy and ease of placement, but its low tensile strength, brittleness, and susceptibility to environmental degradation limit durability and service life. Conventional steel reinforcement mitigates some issues but introduces corrosion and weight concerns. Recent research highlights eco-friendly alternatives such as basalt fibers and silica fume, which enhance strength, durability, and microstructural densification. Although individual benefits of fibers and supplementary cementitious materials are well documented, their combined application in PCC remains insufficiently explored. This study addresses this gap by investigating the synergistic effects of basalt fiber and silica fume on the mechanical performance and durability of sustainable road concrete.

Literature Review

Basalt Fiber Reinforcement in Concrete

Mechanical Properties

Basalt fiber (BF) has gained attention as an eco-friendly reinforcement for improving concrete performance. Studies consistently show that BF has a **limited influence on compressive strength**, particularly at practical dosages. At low fiber contents (≤0.5% by volume), compressive strength either increases slightly or remains unchanged. However, higher fiber contents often reduce compressive strength due to poor fiber dispersion, agglomeration, and increased porosity. Most researchers agree that optimal BF content remains below approximately 1–1.5% by weight of cement.

In contrast, BF has a pronounced effect on **tensile-related properties**. Significant improvements in splitting tensile and flexural strength are widely reported due to the crack-bridging ability of basalt fibers. These fibers enhance post-cracking load capacity, toughness, and ductility, transforming the failure mode from brittle fracture to gradual crack propagation. Relative improvements in flexural strength are typically two to five times greater than compressive strength gains. Optimal performance is commonly observed at fiber volumes of 0.3–0.5%, beyond which workability loss offsets strength benefits.

The addition of BF adversely affects fresh concrete workability. Increasing fiber content and length leads to slump reduction, often requiring superplasticizers or water-binder ratio adjustments. When used together with silica fume, workability challenges become more pronounced, making mix optimization essential.

Durability and Crack Resistance

Basalt fiber significantly improves crack resistance and durability by bridging microcracks and restricting crack width development. This mechanism delays crack initiation and limits the ingress of water and aggressive ions, thereby enhancing long-term durability. Although quantitative shrinkage data remain limited, consensus indicates that BF effectively reduces plastic and drying shrinkage cracking, particularly in pavement applications.

BF also enhances freeze–thaw resistance, especially under saline conditions. Fiber-reinforced concretes consistently show reduced mass loss, lower surface scaling, and higher residual strength after repeated freeze–thaw cycles. The fibers provide stress redistribution during ice formation, minimizing internal damage. These benefits are particularly relevant for road concretes exposed to de-icing salts.

Chemically, basalt fibers exhibit excellent alkali resistance and long-term stability in cementitious environments. BF-modified concretes often show reduced chloride permeability, largely due to improved crack control. Unlike steel fibers, BF does not corrode, eliminating corrosion-related durability concerns. Under cyclic or fatigue loading, fiber reinforcement slows stiffness degradation and enhances fatigue life, suggesting improved performance for traffic-loaded pavements.

Silica Fume in Concrete

Silica fume (SF) is a highly reactive pozzolanic material widely used to enhance concrete strength and durability through microstructural densification. Typical SF contents range from 5% to 15% by weight of cement. Numerous studies report moderate compressive strength improvements within this range, primarily due to increased calcium silicate hydrate formation and refinement of the interfacial transition zone. Excessive SF content, however, can reduce strength because of increased water demand and reduced workability.

SF also improves tensile and flexural strength, increases elastic modulus, and reduces creep. However, its extremely fine particles significantly reduce workability and may accelerate early hydration, necessitating careful use of chemical admixtures and optimized mix proportions.

Durability and Microstructure

The most significant contribution of SF lies in durability enhancement. By filling capillary pores and refining pore structure, SF substantially reduces permeability and ion transport. Studies consistently report major reductions in water permeability and chloride diffusion in SF-modified concrete. SF also improves resistance to sulfate attack and alkali-related deterioration by consuming calcium hydroxide.

Despite these advantages, SF can increase autogenous and plastic shrinkage due to self-desiccation and may require proper curing to avoid early-age cracking. Overall, an SF content of approximately 10–15% is generally considered optimal for balancing durability and workability.

Combined Basalt Fiber and Silica Fume Effects

Hybrid concrete systems incorporating both basalt fiber and silica fume demonstrate clear synergistic benefits. SF densifies the cement matrix and limits permeability, while BF controls crack initiation and propagation. Studies consistently show that moderate SF content (5–15%) combined with low BF volume fractions (0.1–0.3%) produces the most effective performance.

These hybrid mixes exhibit enhanced compressive, flexural, and tensile strengths, with improvements typically exceeding those achieved by individual additives. More importantly, durability is significantly improved, with substantially reduced chloride diffusion, enhanced freeze–thaw resistance, and improved long-term serviceability under aggressive environmental exposure.

In summary, the literature confirms that basalt fiber and silica fume act complementarily, offering a promising approach for developing high-performance, durable, and sustainable concrete for road and pavement applications.

Research Methodology

Research Design

This study adopts a comprehensive experimental programme to evaluate the performance of plain cement concrete (PCC) incorporating basalt fibers and silica fume. Standardized test procedures in accordance with relevant Indian Standards (IS) were followed to ensure that the results are accurate, reliable, and reproducible. Concrete mixes were prepared with basalt fiber contents of 0%, 2%, 4%, 6%, and 8% (C0–C4), while silica fume was kept constant at 10% as a partial replacement of cement. The combined influence of these additives on the fresh, mechanical, and durability properties of concrete was investigated through laboratory testing.

Materials

Cement

- Type: Ordinary Portland Cement (OPC)
- Grade: 43 Grade
- Fineness: 300 m²/kg
- Specific Gravity: 3.15

Consistency: Standard consistency of the cement ensures proper hydration and setting time.

The cement used conforms to IS: 8112-1989 specifications, ensuring that it meets the necessary quality standards for use in concrete. The physical and chemical properties of the cement are thoroughly tested to ensure consistency and performance.

Fine Aggregates

- Type: Natural river sand
- Specific Gravity: 2.65
- Grading Zone: II (as per IS: 383-1970)
- Fineness Modulus: 2.7

The fine aggregates are sourced from natural riverbeds and thoroughly washed and sieved to remove any impurities and oversized particles. The grading of the sand is verified to ensure it falls within the specified limits, which is crucial for achieving the desired workability and strength in the concrete mix.

Coarse Aggregates

- Type: Crushed granite stone
- Specific Gravity: 2.70
- Maximum Size: 20 mm

Coarse aggregates form the bulk of the concrete mix and play a crucial role in its strength, durability, and workability. The aggregates are sieved to ensure a maximum size of 20 mm, conforming to IS: 383-1970 standards.

Basalt Fibers

- Type: Continuous basalt fibers
- Diameter: 13-20 microns

- Length: 12-50 mm
- Specific Gravity: 2.65
- Tensile Strength: 2000-3000 MPa
- Young's Modulus: 85-90 GPa

Basalt fibers are chosen for their superior mechanical properties and resistance to environmental damage. The fibers are alkali-resistant and provide significant reinforcement to the concrete matrix.

Silica Fume

- **Type: Undensified silica fume**
- Specific Gravity: 2.2
- SiO_2 Content: Minimum 85%

Silica fume, used as a partial replacement for cement, improves the density and durability of the concrete matrix. It reacts with calcium hydroxide to form additional calcium silicate hydrate (C-S-H), enhancing the concrete's mechanical and durability properties.

Water

Type: Potable water, free from impurities and contaminants.

pH Value: 6.5-8.5

Specifications: Conforming to IS: 456-2000

Water used in the concrete mix facilitates the hydration of cement and influences the workability and strength of the concrete. It is essential to use clean, potable water to avoid any adverse effects on the concrete properties.

Chemical Admixtures

- Type: Polycarboxylate ether (PCE) based superplasticizer
- Dosage: 0.8% by weight of cement
- Specific Gravity: 1.10
- Water Reduction: 20-25%

Chemical admixtures are added to the concrete mix to enhance its workability, durability, and strength. The primary admixture used in this study is a superplasticizer, which helps reduce the water-cement ratio without compromising workability.

Results and Discussion

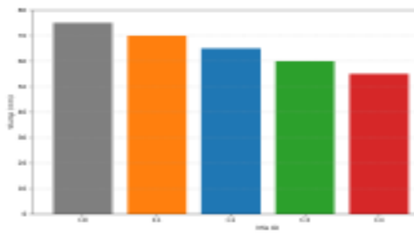
Fresh Concrete Properties

Fresh concrete tests indicate that the incorporation of basalt fibers and silica fume reduces workability progressively with increasing fiber content. The control mix exhibited the highest workability across all tests, while mixes with higher fiber dosages showed reduced slump, flow, passing ability, and increased flow time.

Slump, compaction factor, and flow diameter decreased consistently as fiber content increased, while Vee-Bee and V-Funnel times increased, indicating higher internal resistance and viscosity. L-Box and J-Ring results confirmed reduced passing ability and increased blocking tendency at higher fiber contents. These trends are attributed to fiber interlocking, increased cohesiveness, and matrix densification caused by silica fume. Overall, the results highlight a clear trade-off between workability and fiber dosage, emphasizing the need for optimized mix design where

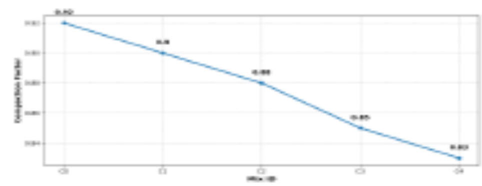
n higher fiber contents are used. These results highlight the workability and consistency of the mixes with varying basalt fiber contents (0%, 2%, 4%, 6%, 8%).

Slump Test



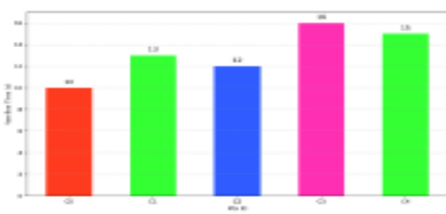
highlighting the effect of increasing basalt fiber content on the workability of fresh concrete

Compaction Factor Test



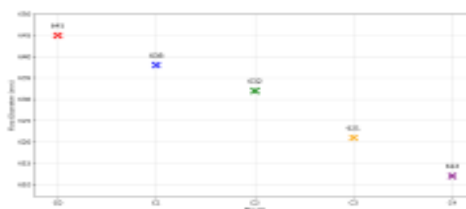
Compaction Factor values for different concrete mixes (C0 to C4)

Vee-Bee Consistometer Test



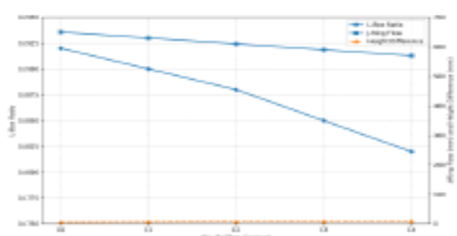
Vee-Bee Time values for different concrete mixes (C0 to C4)

Flow Test



Flow Diameter values for different concrete mixes (C0 to C4)

L-Box and J-Ring Tests



L-Box Ratio values for (C0 to C4)

V-Funnel Test

V-Funnel Time values for (C0 to C4)

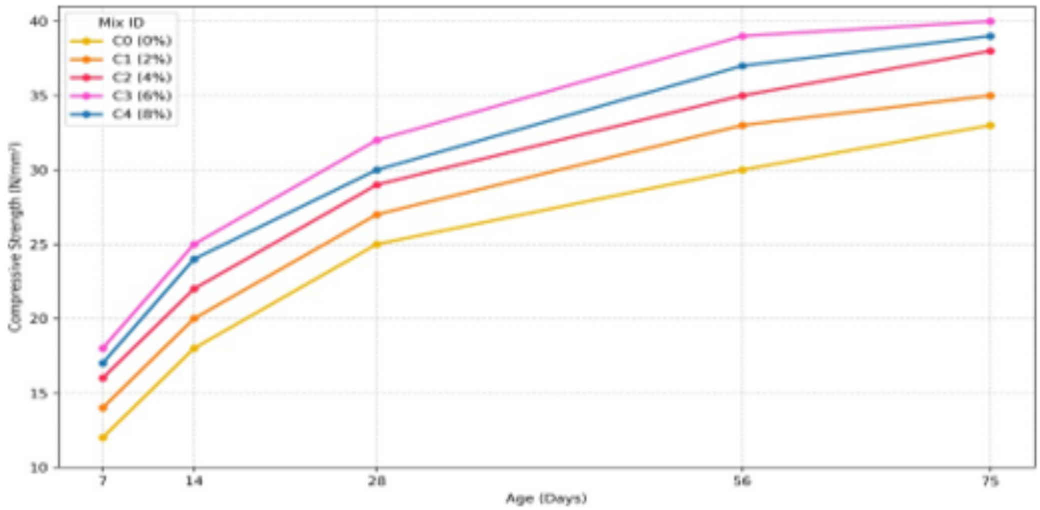
Mechanical Properties

The mechanical properties of the basalt fiber-reinforced concrete were evaluated through compressive strength, tensile strength, and flexural strength tests.

Compressive Strength

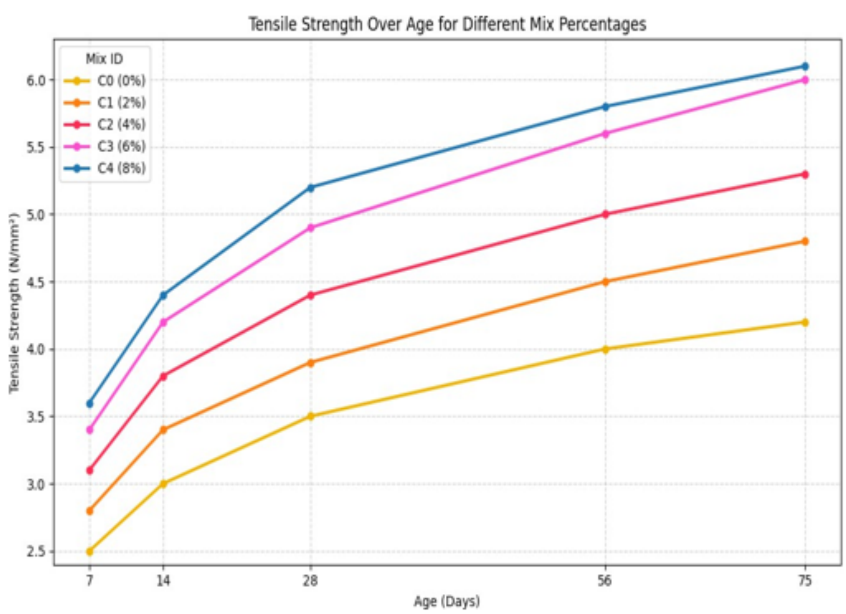
Basalt fiber addition improved compressive strength compared to the control mix at all curing ages. Strength increased with fiber content up to an optimum level (approximately 6%), beyond which a slight reduction or plateau was observed. The decrease at higher fiber content is attributed to reduced workability, increased internal friction, and less effective compaction. These results indicate that moderate basalt fiber content provides optimal compressive performance.

Compressive Strength values for different concrete mixes (C0 to C4)



Tensile Strength: - Split tensile strength showed a consistent and significant increase with increasing basalt fiber content at all curing ages. The improvement is primarily due to the crack-bridging action of basalt fibers, which restricts microcrack propagation and enhances stress transfer across the matrix. However, excessive fiber addition may lead to diminishing returns due to poor workability, fiber agglomeration, and weakened fiber–matrix bonding. The results emphasize the importance of optimizing fiber dosage to maximize tensile performance without compromising overall concrete quality.

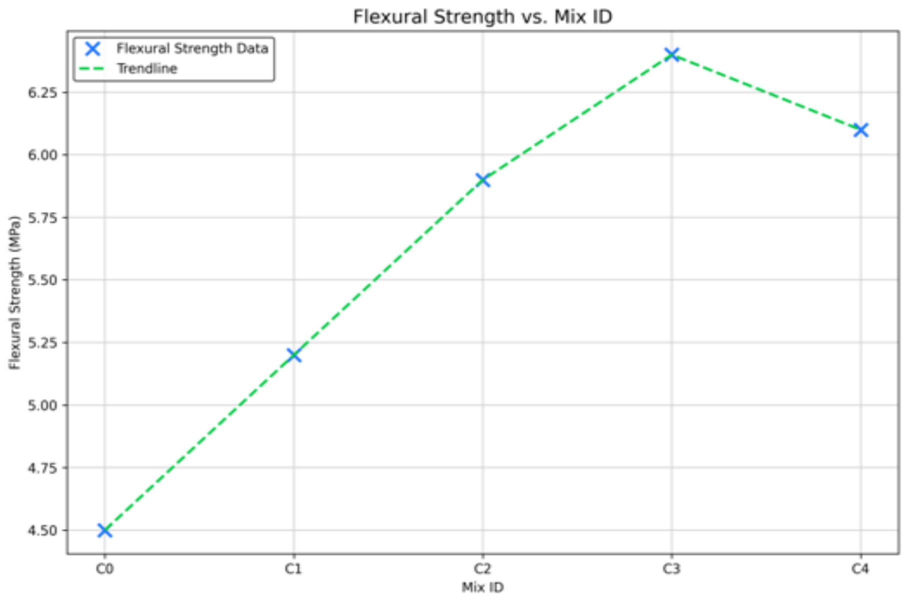
Tensile Strength values for different concrete mixes (C0 to C4)



Flexural Strength

Flexural strength improved markedly with the incorporation of basalt fibers, reaching a maximum at an intermediate fiber content. The enhanced performance is attributed to improved post-cracking behavior and effective stress redistribution provided by the fibers. At higher fiber contents, a slight reduction in flexural strength was observed, likely due to fiber crowding, reduced workability, and compaction inefficiencies. These findings confirm that an optimal fiber dosage is critical for achieving maximum flexural resistance, particularly for pavement and slab applications.

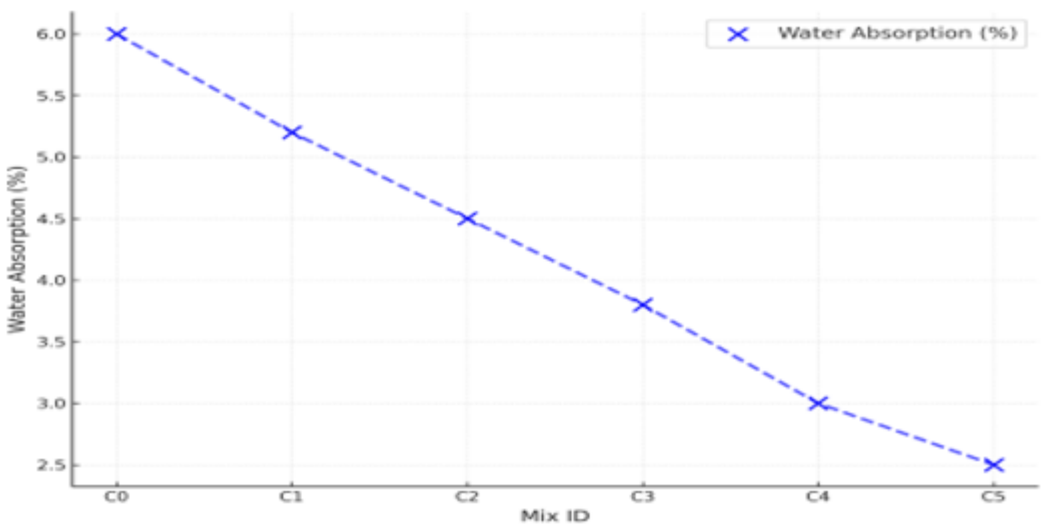
Flexural Strength values for different concrete mixes (C0 to C4)



Durability Tests

Water Absorption Test

The water absorption test evaluates the porosity and permeability of concrete.

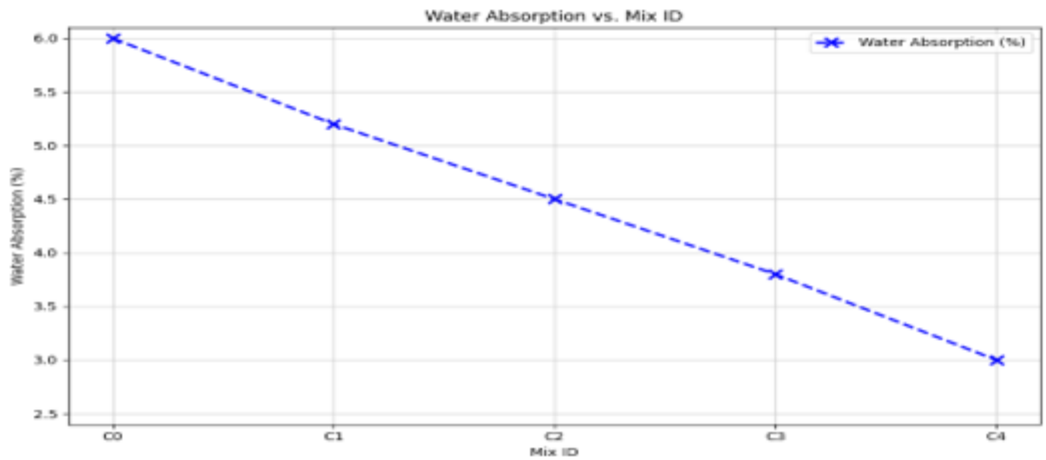


Water Absorption values for different concrete mixes (C0 to C4)

The water absorption decreases with higher fiber content, indicating reduced porosity and permeability.

Chloride Penetration Test

The chloride penetration test evaluates the resistance of concrete to chloride ion ingress

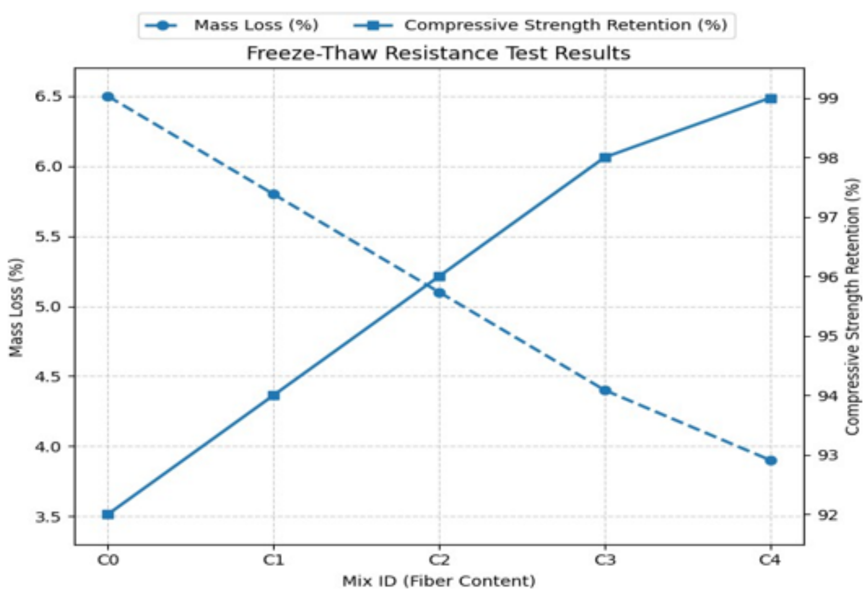


Chloride Penetration values for different concrete mixes (C0 to C4)

The charge passed decreases with higher fiber content, indicating improved resistance to chloride ion ingress.

Freeze-Thaw Resistance Test

The freeze-thaw resistance test evaluates the durability of concrete under cyclic freezing and thawing conditions.



Freeze-Thaw Resistance values for different concrete mixes (C0 to C4)

Discussion

The experimental results confirm that the incorporation of basalt fibers and silica fume significantly influences the fresh, mechanical, and durability performance of plain cement concrete (PCC), with behavior strongly governed by fiber dosage. Increasing basalt fiber content reduced workability due to higher internal friction and matrix densification, even with the use of superplasticizers. Mechanical performance improved markedly with fiber addition. Compressive and flexural strengths increased up to an optimum fiber content of approximately 6% (C3), beyond which a slight reduction or plateau was observed due to reduced compaction efficiency and fiber crowding. In contrast, split tensile strength increased consistently with fiber content and curing age, highlighting the effective crack-bridging mechanism of basalt fibers.

Durability performance showed substantial improvement with fiber and silica fume incorporation. Water absorption decreased significantly, indicating reduced porosity and improved impermeability, while freeze–thaw resistance improved through lower mass loss and higher strength retention. Non-destructive test results further confirmed enhanced surface hardness and internal uniformity. Overall, an optimal balance of workability, strength, and durability was achieved at moderate basalt fiber content within the investigated range.

Conclusion

This study confirms that incorporating silica fume (10% cement replacement) together with basalt fibers (0–8%) improves the overall performance of plain cement concrete (PCC) for road applications. Fresh concrete results showed a reduction in workability with increasing basalt fiber dosage. The slump decreased from 75 mm (C0) to 55 mm (C4), and the compaction factor reduced from 0.92 to 0.83, indicating increased cohesiveness and internal friction in fiber-rich mixes. However, workable mixes were still achievable using a PCE-based superplasticizer along with the densifying effect of silica fume.

Mechanical performance improved with basalt fiber addition within the investigated range. The compressive strength trend indicates the best overall performance around C3 (6% basalt fibers), while split tensile strength increased consistently with fiber content and reached the highest value for C4 (8% basalt fibers) due to effective crack-bridging and improved stress transfer. Flexural strength also improved and attained its maximum at C3 (6%), with a slight reduction at C4 (8%), likely due to reduced workability and potential fiber crowding at higher dosage.

Durability characteristics improved markedly. Water absorption reduced from approximately 6.0% (C0) to ~3.0% (C4), indicating a denser and less permeable matrix. Freeze–thaw resistance also improved with higher fiber content, showing lower mass loss and better strength retention. Non-destructive test results further supported the improvement in concrete quality and uniformity. Overall, the combined use of basalt fibers and silica fume enhances the strength and durability of PCC, with C3 (6% basalt fibers) providing the best balance between mechanical performance, durability, and workability within the studied mix range.

References

1. O. Zaid, J. Ahmad, M. S. Siddique, F. Aslam, H. Alabduljabbar, and K. M. Khedher, ‘A step towards sustainable glass fiber reinforced concrete utilizing silica fume and waste coconut shell aggregate’, Sci Rep, vol. 11, no. 1, p. 12822, Jun. 2021, doi: 10.1038/s41598-021-92228-6.
2. J. Ahmad, F. Aslam, O. Zaid, R. Alyousef, H. Alabduljabbar, and A. Manan, ‘Self-Fibers Compacting Concrete Properties Reinforced with Propylene Fibers’, Science and Engineering of Composite Materials, vol. 28, no. 1, pp. 64–72, Jan. 2021, doi: 10.1515/secm-2021-0006.
3. R. Prakash, R. Thenmozhi, S. N. Raman, C. Subramanian, and N. Divyah, ‘Mechanical characterisation of sustainable fibre-reinforced lightweight concrete incorporating waste coconut shell as coarse aggregate and sisal fibre’, Int. J. Environ. Sci. Technol., vol. 18, no. 6, pp. 1579–1590, Jun. 2021, doi: 10.1007/s13762-020-02900-z.
4. H. Dilbas and Ö. Çakır, ‘Influence of basalt fiber on physical and mechanical properties of treated recycled aggregate concrete’, Construction and Building Materials, vol. 254,
5. p. 119216, Sep. 2020, doi: 10.1016/j.conbuildmat.2020.119216.
6. A. Qudoos, H. G. Kim, Atta-ur-Rehman, and J.-S. Ryou, ‘Effect of mechanical processing on the pozzolanic efficiency and the

microstructure development of wheat straw ash blended cement composites', Construction and Building Materials, vol. 193, pp. 481–490, Dec. 2018, doi: 10.1016/j.conbuildmat.2018.10.229.

7. R. Prakash, R. Thenmozhi, S. N. Raman, C. Subramanian, and N. Divyah, 'An investigation of key mechanical and durability properties of coconut shell concrete with partial replacement of fly ash', Structural Concrete, vol. 22, no. S1, pp. E985–E996, 2021, doi: 10.1002/suco.201900162.
8. T. A. Kinjawadekar, S. Patil, and G. Nayak, 'A Critical Review on Glass Fiber-Reinforced Polymer Bars as Reinforcement in Flexural Members', J. Inst. Eng. India Ser. A, vol. 104, no. 2, pp. 501–516, Jun. 2023, doi: 10.1007/s40030-023-00729-6.
9. Z.-D. Li, S.-Q. Huang, Y.-X. Feng, C.-S. Cheng, and B. Fu, 'Enhancing performance of concrete with glass fiber-reinforced polymer short rebars as coarse aggregates by confinement', Journal of Building Engineering, vol. 87, p. 109041, Jun. 2024, doi: 10.1016/j.jobe.2024.109041.
10. D. Yahiaoui, M. Saadi, and T. Bouzid, 'Compressive Behavior of Concrete Containing Glass Fibers and Confined with Glass FRP Composites', International Journal of Concrete Structures and Materials, vol. 16, no. 1, p. 37, Jul. 2022, doi: 10.1186/s40069-022-00525-9.