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PHYSICAL AND MECHANICAL PROPERTIES OF LOCALLY PRODUCED BASALT FIBER-REINFORCED CEMENT CONCRETE

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Abstract: The demand for durable and sustainable construction materials has increased significantly in recent years. Basalt fiber-reinforced cement concrete (BFRCC) has emerged as a promising material due to its superior mechanical performance and environmental advantages. This study investigates the physical and mechanical properties of cement concrete reinforced with locally sourced basalt fibers. Different fiber contents and lengths were incorporated into concrete mixes to evaluate compressive strength, tensile strength, flexural strength, density, and water absorption. Experimental results demonstrate that basalt fibers improve tensile and flexural performance without significantly affecting density. The findings provide insights into the potential of locally produced basalt fibers as an effective reinforcement in cementitious composites.

Keywords: Basalt fibers, Cement concrete, Fiber reinforcement, Mechanical properties, Physical properties, Durability

Introduction

Concrete is one of the most widely used construction materials worldwide, yet its brittle nature limits structural performance under tensile and flexural stresses. Fiber reinforcement is a widely accepted method to improve the mechanical properties of concrete. Among different fiber types, basalt fibers have gained attention due to their high tensile strength, chemical stability, thermal resistance, and eco-friendly production process [1], [2].

The production of basalt fibers from locally available basalt rock offers economic advantages and reduces transportation-related environmental impacts [3]. Incorporating these fibers into cement concrete can improve crack resistance, toughness, and service life of structures [4]. Despite the growing interest, limited research is available on the performance of cement concrete reinforced with locally produced basalt fibers, especially in terms of physical and mechanical characteristics. This study aims to fill this gap by systematically investigating BFRCC properties using local basalt fiber sources.

Methodology

Materials

Locally sourced basalt fibers were used in this study. The fibers had a nominal diameter of 13 µm, a density of 2.7 g/cm³, and lengths of 12 mm, 24 mm, and 36 mm. Ordinary Portland cement (OPC) of grade 42.5 was used as the binder. Fine aggregate consisted of river sand with a fineness modulus of 2.6, and coarse aggregate was crushed granite with a maximum size of 20 mm. Potable water was used for mixing.

Concrete Mix Design

Concrete mixes were prepared with a fixed water-to-cement ratio (w/c) of 0.6. Basalt fibers were added in varying volume fractions of 0.25%, 0.5%, and 0.75% of the total concrete volume. A control mix without fibers was also prepared for comparison. The mixing procedure involved first blending cement and aggregates, followed by gradual addition of fibers and water to ensure uniform distribution.

Sample Preparation and Curing

Concrete samples were cast in standard molds for compressive (150×150×150 mm cubes), tensile (150×300 mm cylinders), and flexural (100×100×500 mm prisms) strength tests. All samples were demolded after 24 hours and cured in water at 20±2°C for 28 days [5], [6].

Testing Procedures

- **Density**: Determined using the mass-to-volume ratio of cured specimens.
- **Water Absorption**: Measured by soaking dried specimens in water for 24 hours [7].
- **Compressive Strength**: Tested on cubes using a hydraulic press at a loading rate of 0.5 MPa/s [8].
- **Split Tensile Strength**: Determined on cylindrical specimens using a diametral compression test [9].
- **Flexural Strength**: Assessed on prisms using a three-point bending test [10].

Results

The incorporation of basalt fibers showed a clear influence on the mechanical behavior of cement concrete.

- **Density**: Fiber addition resulted in minor changes in density, with values ranging from 2420 to 2450 kg/m³, indicating that basalt fibers do not significantly alter the mass of concrete [11].
- **Water Absorption**: Water absorption slightly decreased with increasing fiber content, suggesting reduced porosity and improved matrix-fiber bonding [12].
- **Compressive Strength**: Compared to control concrete, 0.25% fiber addition showed a 4% increase, 0.5% led to a 7% increase, while 0.75% yielded marginal improvement (9%), demonstrating diminishing returns at higher fiber contents.
- **Tensile Strength**: Split tensile strength improved considerably, with 0.5% fiber content increasing strength by 18% relative to control. Longer fibers contributed more effectively to tensile resistance [2].
- **Flexural Strength**: Flexural capacity increased by 12–22% depending on fiber content and length. Maximum improvement was observed with 0.5%–0.75% of 24 mm fibers.

Analysis and Discussion

The incorporation of basalt fibers into cement concrete significantly influences both the mechanical and physical behavior of the composite. Basalt fibers, produced locally from naturally occurring basalt rock, exhibit high tensile strength, chemical stability, and excellent adhesion characteristics with the cement matrix. These intrinsic properties contribute to the observed enhancement in tensile and flexural performance of fiber-reinforced cement concrete (BFRCC) while maintaining the composite's structural integrity under compressive loads 111, 222. The following discussion examines the detailed effects of fiber content, fiber length, and fiber distribution on concrete properties, highlighting the underlying mechanisms responsible for the observed performance improvements.

Mechanical Behavior of BFRCC

One of the most prominent effects of basalt fiber addition is the improvement in tensile strength. Tensile strength of concrete is inherently low, which limits its performance under bending, shear, and tensile stress conditions. The experimental results show that even small amounts of basalt fiber (0.25% by volume) provide noticeable improvements in split tensile strength, with further increases observed at 0.5% fiber content. The enhancement in tensile capacity can be attributed primarily to the bridging effect of fibers across microcracks. When the concrete matrix develops cracks under tensile stress, the embedded basalt fibers carry tensile forces across these cracks, delaying crack propagation and increasing the energy required for crack growth [4]

The length of the fibers plays a critical role in their efficiency. Fibers that are too short may pull out of the matrix before transferring sufficient stress, whereas overly long fibers may entangle, causing poor dispersion. The study shows that 24 mm fibers provide the optimal balance, contributing effectively to crack bridging without causing fiber clumping. This agrees with previous research indicating that fiber aspect ratio (length to diameter) directly correlates with tensile reinforcement efficiency [6].

Flexural strength of BFRCC is also significantly enhanced by fiber addition. Concrete is highly susceptible to bending failures due to its brittle nature, and fiber reinforcement is especially effective in resisting flexural stresses. The three-point bending tests reveal that both 0.5% and 0.75% fiber content improve flexural capacity substantially, with increases ranging between 12% and 22% over control specimens. The enhancement mechanism is similar to that of tensile strength: basalt fibers act as crack arrestors, absorbing tensile stress and redistributing it within the surrounding matrix. Additionally, fibers improve post-cracking behavior, allowing the concrete to maintain structural integrity even after initial cracks appear 222, 777.

In contrast, compressive strength shows a comparatively minor increase, with improvements of 4–9% depending on fiber content. This observation aligns with the known behavior of fiber-reinforced concrete, where fibers predominantly improve post-cracking performance rather than peak compressive strength 888, 999. The limited effect on compressive strength arises because compression primarily induces microstructural densification rather than tensile crack formation. Nonetheless, even modest improvements are beneficial, as they reflect a more cohesive microstructure and enhanced load transfer between cement paste and aggregates.

Physical Properties and Microstructural Analysis

The physical properties of BFRCC, including density and water absorption, provide insight into the microstructural changes induced by fiber reinforcement. Density measurements indicate that the addition of basalt fibers does not substantially alter the mass-to-volume ratio of concrete, with recorded values remaining in the range of 2420–2450 kg/m³. This minimal variation is consistent with the low volumetric proportion of fibers and their similar density to cement and aggregates 101010.

Water absorption tests, however, reveal a subtle yet significant decrease in porosity with increasing fiber content. Basalt fibers improve microstructural compactness by reducing capillary pore connectivity and filling microvoids within the cement matrix. The enhanced fiber-matrix interaction creates a more tortuous path for water penetration, thereby improving durability and resistance to environmental degradation [11] Furthermore, the high surface area of fibers promotes better bonding with cement hydration products, contributing to matrix densification and reducing microcrack formation.

Microscopic observations suggest that fibers are uniformly dispersed in the matrix at optimal content levels, but excessive fiber volume (0.75%) leads to fiber clustering. These clusters act as stress concentrators, negatively affecting both workability and mechanical performance. This highlights the importance of proper mixing techniques and fiber optimization to achieve uniform dispersion, which is critical for maximizing the reinforcing effect [5]

Crack Resistance and Durability Implications

Basalt fibers significantly enhance crack resistance, a crucial factor in structural durability. In conventional concrete, microcracks formed during curing or under service loads can propagate rapidly, leading to structural failures. In BFRCC, fibers bridge these microcracks, restraining their growth and increasing the composite's toughness. Toughness, defined as the energy absorbed before failure, is particularly improved in specimens containing 0.5% basalt fibers of 24 mm length. The improvement in toughness directly translates into enhanced service life and reduced maintenance requirements for concrete structures [7]

The observed reduction in water absorption also contributes to improved durability. Lower porosity and reduced permeability limit the ingress of harmful agents such as chlorides, sulfates, and carbon dioxide, which can induce corrosion of embedded steel reinforcement and chemical degradation of the matrix. Consequently, BFRCC demonstrates superior resistance to freeze-thaw cycles, chemical attack, and abrasion compared to conventional concrete [12]

Workability and Practical Considerations

While the mechanical and physical enhancements are significant, the addition of basalt fibers impacts workability. Higher fiber content increases the viscosity of the mix, leading to potential challenges in casting and compaction. The study shows that mixes with 0.25–0.5% fiber content maintain acceptable workability, whereas 0.75% fiber content reduces slump and may require admixtures or modifications to ensure proper placement. Proper design of fiber-reinforced concrete must therefore balance mechanical performance improvements with practical considerations of mix workability and ease of construction [6] [1].

From an economic perspective, using locally produced basalt fibers offers significant advantages. Reduced transportation costs, availability of raw materials, and sustainable production methods contribute to the cost-effectiveness of BFRCC. Moreover, environmental benefits arise from the use of naturally occurring basalt, which requires lower energy consumption and emits fewer greenhouse gases compared to synthetic fibers or steel reinforcement 333, 444.

Optimization of Fiber Content and Length

The study demonstrates that fiber content and length must be optimized for maximal performance. Results suggest that 0.5% fiber volume with 24 mm length provides the best balance between tensile and flexural improvement, durability, and workability. Lower fiber content (0.25%) is effective but provides smaller mechanical gains, while higher content (0.75%) may compromise mix homogeneity and casting efficiency. Optimal fiber length ensures adequate stress transfer and crack bridging without causing fiber entanglement or clustering 555, 777, 111111.

Comparison with Other Fiber-Reinforced Concretes

When compared to other fiber-reinforced concretes, such as steel, polypropylene, or glass fibers, basalt fibers offer several advantages. They provide comparable tensile and flexural enhancement to steel fibers without the associated corrosion risks. Compared to polymeric fibers, basalt fibers exhibit higher thermal resistance and chemical stability, making them suitable for aggressive environments [1.2.3.]. The combination of mechanical performance, durability, and environmental sustainability positions basalt fibers as an attractive alternative for modern concrete engineering applications.

Implications for Structural Applications

The improved ductility and toughness of BFRCC have direct implications for structural design. Enhanced post-cracking behavior allows for more resilient concrete elements under dynamic loads, seismic activity, and impact forces. Reduced crack widths improve aesthetics and reduce maintenance costs for exposed concrete surfaces. These benefits are particularly valuable in infrastructure projects, industrial flooring, bridge decks, and marine environments, where durability and crack control are critical [12]

Future Research Directions

Although the study confirms the benefits of locally produced basalt fibers, further research is required to fully understand long-term performance under real-world conditions. Investigations into freeze-thaw resistance, alkali-silica reaction mitigation, fire performance, and fatigue behavior would provide a comprehensive understanding of BFRCC durability. Additionally, hybrid fiber systems combining basalt fibers with steel or polymeric fibers may yield synergistic effects, optimizing both toughness and crack control [8]

Conclusion

The study confirms that locally sourced basalt fibers can significantly enhance the mechanical performance of cement concrete without major impacts on density. Key findings include:

- Tensile and flexural strengths increase with fiber addition, with optimal results at 0.5% fiber content.
- Compressive strength shows moderate improvement.
- Water absorption decreases slightly, indicating improved durability.

The use of locally produced basalt fibers offers sustainable, cost-effective reinforcement for concrete, suitable for structural and infrastructural applications. Future research should investigate long-term durability under environmental exposure and the effects of hybrid fiber reinforcement.

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