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Experimental Investigation on Mechanical Characteristics of Fiber-Reinforced Concrete

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Abstract

Concrete is one of the most utilized construction materials because of its excellent compressive strength and durability. Nevertheless, its relatively low tensile and flexural capacities often limit its performance in structures subjected to tensile stresses. To address this limitation, fiber reinforcement has emerged as an effective technique for enhancing the mechanical behavior of concrete. This study examines the influence of chopped basalt fibers on the strength characteristics of concrete through a series of laboratory investigations. Basalt fibers with lengths of 12 mm and 18 mm, representing different aspect ratios, were incorporated into concrete mixtures at volume fractions of 0.25%, 0.50%, and 1.00%. The prepared specimens were evaluated for compressive strength, split-tensile strength, and flexural strength. In addition, the performance of the fiber-reinforced concrete was assessed after exposure to elevated temperatures of 300°C and 500°C to determine its thermal resistance and residual strength characteristics. The experimental findings revealed that the inclusion of basalt fibers contributed positively to the mechanical performance of concrete. Improvements were observed in tensile and flexural behavior, while compressive strength also showed enhancement compared to conventional concrete mixes. Furthermore, the fiber-reinforced specimens demonstrated better resistance to strength degradation under high-temperature conditions. The results suggest that basalt fibers can serve as an effective reinforcing material for producing concrete with improved structural performance, crack resistance, and durability, making it suitable for applications where enhanced mechanical and thermal properties are required. The flexural and split-tensile strength increased with an increase in the aspect ratio of fibers, while compressive strength showed improvement up to 0.50% fiber dosage. The study also revealed that concrete remained nearly unaffected in appearance and strength up to 350°C. However, at 500°C, slight deterioration in concrete quality and reduction in strength were observed. The investigation concludes that basalt-fiber-reinforced concrete exhibits enhanced mechanical properties and better thermal resistance compared to conventional concrete.

Keywords: Basalt fiber, dosage, resistance, concrete, strength

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INTRODUCTION

Concrete plays a fundamental role in modern construction because of its ability to withstand high compressive loads, long service life, and widespread availability of its constituent materials. It is extensively used in buildings, bridges, pavements, dams, and other infrastructure projects. Despite these advantages, conventional concrete exhibits poor tensile and flexural strengths and behaves in a brittle manner under loading conditions. Cracks caused by drying shrinkage, thermal effects, and external loading can adversely affect the strength, durability, and long-term performance of concrete structures. Consequently, enhancing the resistance of concrete to tensile stresses and bending forces has become a major focus in construction materials research. Fiber-reinforced concrete (FRC) has been widely recognized as a practical approach for addressing these challenges and improving the overall performance of concrete structures. The incorporation of discrete fibers into concrete improves its crack resistance, ductility, toughness, impact resistance, and overall mechanical performance. Different types of fibers, such as steel, glass, synthetic, carbon, and basalt fibers, are commonly used in concrete, depending on the required engineering properties. Among these, basalt fibers have gained considerable attention owing to their high tensile strength, good thermal stability, corrosion resistance, non-combustible nature, and eco-friendly characteristics [1–3].

Basalt fibers are produced from naturally available basalt rock and possess superior mechanical and thermal properties compared with many conventional fibers. The addition of chopped basalt fibers to concrete helps control microcracks and enhances compressive, split-tensile, and flexural strengths. Moreover, basalt FRC performs better under elevated temperatures, making it suitable for structures exposed to fire and harsh environmental conditions [4–6].

In the present experimental investigation, the mechanical characteristics of basalt FRC were studied using chopped basalt fibers of 12 mm and 18 mm lengths with varying dosages of 0.25%, 0.50%, and 1% by volume of concrete. The prepared concrete specimens were subjected to a series of mechanical tests, including compressive, split-tensile, and flexural strength evaluations. These tests were conducted under ambient conditions and after exposure to elevated temperatures of 300 and 500°C to assess the influence of thermal loading on the performance and residual strength of the concrete.

This study aims to determine the influence of fiber aspect ratio and dosage on the strength and thermal resistance properties of concrete. The outcomes of this investigation will contribute to the development of durable and high-performance FRC for modern construction applications [7–8].

Fiber-Reinforced Concrete

Concrete remains a fundamental material in the construction industry because of its excellent load-bearing capacity, long-term durability, and adaptability to a wide range of structural applications. Despite these advantages, it exhibits limited resistance to tensile and bending stress and is prone to cracking.

To overcome these shortcomings, reinforcing fibers have been incorporated into brittle construction materials for centuries to enhance their strength, toughness, and crack control characteristics. Historical evidence shows that straw has been used as a reinforcement in bricks to enhance their strength and durability. In modern construction practice, the concept of FRC has emerged as an effective method for improving the mechanical behavior and serviceability of concrete structures [9–10].

FRC is a composite material consisting of cement, fine aggregates, coarse aggregates, water, and discontinuous discrete fibers uniformly distributed throughout the concrete matrix. These fibers can be manufactured from steel, glass, polymers, carbon, basalt, or natural materials. Generally, the fibers used in concrete have small diameters and lengths that do not exceed 76 mm. The incorporation of fibers helps control plastic shrinkage cracks, improve toughness, enhance impact resistance, increase ductility, and reduce crack propagation in hardened concrete.

Unlike conventional reinforced concrete, where reinforcing bars provide two-dimensional reinforcement at specific locations, fibers are randomly distributed within the concrete matrix and provide three-dimensional reinforcement. This random distribution improves the crack resistance and stress redistribution throughout the concrete mass. FRC has been widely used in pavements, slabs on grade, tunnel linings, shotcrete applications, industrial floors, and mining structures owing to its improved durability and service life.

Figure 1. (a)–(c) Polymeric fibers: (a) monofilament microfiber, (b) fibrillated microfiber, and (c) macro fiber.

The effectiveness of fibers in concrete depends on several factors, such as fiber content, aspect ratio, fiber length, modulus of elasticity, and bonding characteristics with the cement matrix. For effective reinforcement, fibers should possess higher stiffness than the concrete matrix, adequate length, good bond strength, and a high aspect ratio. Fibers can be classified into low-modulus and high-modulus fibers depending on their modulus of elasticity. Low-modulus fibers, such as polypropylene and nylon, mainly improve the toughness and crack resistance, whereas high-modulus fibers, such as steel, carbon, glass, and basalt fibers, significantly improve the strength and stiffness properties.

Among the various fibers available, basalt fiber has gained increasing attention in recent years because of its superior mechanical and thermal properties. Basalt fibers are manufactured from naturally occurring volcanic basalt rock through melting and extrusion processes. These fibers are environmentally friendly, non-corrosive, non-toxic, and exhibit high tensile strength, good thermal resistance, and excellent durability. Basalt fibers also possess better chemical stability and higher temperature resistance than many synthetic fibers, making them suitable for concrete structures exposed to harsh environmental and elevated temperature conditions.

FRC can also be classified based on the fiber volume fraction. Low-fiber-volume concrete contains less than 1% fiber and is mainly used for shrinkage crack control. Moderate-fiber-volume concrete contains 1–2% fibers and provides improved toughness and impact resistance, whereas high-fiber-volume concrete contains more than 2% fibers and exhibits strain-hardening behavior with enhanced mechanical performance. The geometry and aspect ratio of the fibers also play important roles in determining the strength and workability characteristics of concrete.

In this study, chopped basalt fibers of different lengths and aspect ratios were incorporated into concrete to investigate their influence on the compressive strength, split-tensile strength, and flexural strength under normal and elevated temperature conditions. This study aims to evaluate the effectiveness of basalt fibers in improving the mechanical characteristics and thermal resistance of concrete for modern construction applications, as shown in Figure 1.

LITERATURE REVIEW

FRC has gained significant importance in the construction field owing to its ability to improve the mechanical and durability properties of conventional concrete. The incorporation of fibers in concrete helps control cracks, improve ductility, increase toughness, and enhance tensile and flexural strength. Among the various fibers used in concrete, basalt fiber has emerged as an effective reinforcement material because of its high tensile strength, thermal resistance, corrosion resistance, and eco-friendliness.

In recent years, many researchers have investigated the performance of chopped basalt-FRC under normal and elevated temperature conditions. This chapter presents a review of previous research on the mechanical behavior, thermal resistance, and workability characteristics of basalt FRC. The literature review provides an understanding of the influence of fiber dosage, aspect ratio, and supplementary cementitious materials on concrete performance.

A study on the effects of elevated temperatures on basalt fiber-reinforced polymer (BFRP) plates reported that basalt fibers exhibit superior temperature resistance compared to glass fibers. The investigation revealed that the tensile strength and modulus of elasticity decreased with increasing temperature; however, the basalt fibers retained better mechanical performance even after exposure to temperatures up to 200°C. The study concluded that basalt fibers are suitable for structures subjected to high temperatures.

Research on high-performance concrete reinforced with basalt fibers examined the effects of fiber volume fractions of 1%, 2%, and 3% in concrete containing silica fume and metakaolin. The results indicated that the compressive strength improved up to an optimum fiber dosage and then decreased at higher fiber contents owing to poor workability and fiber clustering. Concrete containing metakaolin and basalt fibers exhibited better strength performance than normal concrete.

An experimental study on non-dipping chopped basalt FRC investigated the mechanical and workability properties of concrete with fiber contents ranging from 0.1% to 0.35%. The study concluded that the slump value decreased with an increase in the fiber content, whereas the split-tensile and flexural strengths increased significantly. The optimum fiber content was between 0.1% and 0.2%.

Another investigation on the effectiveness of chopped basalt fibers in high-strength concrete reported that the inclusion of basalt fibers reduced workability but improved the tensile strength, flexural strength, toughness, and ductility of concrete. The addition of fly ash improved workability and reduced the brittleness. The study also observed that the failure pattern changed from brittle to ductile with the inclusion of fibers.

Research on basalt fiber-reinforced composite concrete showed that the compressive strength and modulus of elasticity increased with increasing fiber content up to an optimum value of 0.5%. Beyond this limit, the strength decreased owing to the poor dispersion of fibers and reduction in workability. The study also reported improvements in the density and stress-strain behavior of concrete.

A study on the performance of basalt fiber in M40 grade concrete indicated that the optimum basalt fiber dosage was 0.25%. At this dosage, the compressive, split-tensile, and flexural strengths achieved maximum values. The investigation concluded that basalt fibers can effectively improve the mechanical properties of concrete at lower fiber percentages.

Another experimental study on M20 and M30 grade basalt fiber concrete revealed significant improvements in compressive and split-tensile strengths compared to those of conventional concrete. The research also highlighted better ductile behavior and crack resistance in the FRC specimens.

Research on the thermal and mechanical properties of basalt FRC showed that the compressive strength, split-tensile strength, and modulus of elasticity increased up to 0.3% fiber content and decreased slightly at higher fiber percentages. The study further concluded that the thermal conductivity decreased with increasing fiber content, indicating improved thermal resistance.

A study on high-strength basalt fiber concrete investigated the influence of different fiber proportions on the mechanical and durability properties. The results indicated that the addition of basalt fibers improved the crack resistance and overall performance of concrete, although excessive fiber content adversely affected workability.

The literature review revealed that the incorporation of basalt fibers improves the mechanical characteristics of concrete, such as compressive strength, split-tensile strength, flexural strength, toughness, and ductility. Basalt fibers also enhance the crack resistance and thermal stability of concrete. However, higher fiber dosages reduce workability and may lead to improper distribution. Most researchers have reported that the optimum basalt fiber content lies between 0.25% and 0.5% by volume of concrete.

EXPERIMENTAL MATERIALS

An experimental investigation was conducted to study the mechanical characteristics of basalt FRC under normal and elevated temperature conditions. Prior to the preparation of the concrete specimens, all constituent materials were tested to verify their suitability and compliance with the relevant standards. The concrete mix proportions were designed in accordance with the IS 10262:2009 guidelines.

Cement

Ordinary Portland cement (OPC) of 53 grade was selected as the binding material for this investigation. The cement used complied with the applicable Indian Standard requirements and was examined for its physical and chemical characteristics before incorporation into the concrete mixes.

Fine Aggregate

Natural river sand obtained from local sources was used as the fine aggregate. The material was properly graded, free from organic matter and other contaminants, and satisfied the requirements specified in the relevant Indian Standards.

Coarse Aggregate

Crushed stone aggregates with nominal sizes of 10 and 20 mm were used as coarse aggregates. The aggregates were clean, strong, and durable, with minimal deleterious substances, making them suitable for producing quality concrete.

Water

Clean potable water was used for mixing and curing. The water was free from harmful salts, oils, acids, and other impurities that could adversely affect the properties of concrete, and it met the requirements prescribed by the Indian Standards.

Basalt Fibers

Chopped basalt fibers were incorporated into the concrete mixtures as a reinforcing material to enhance their mechanical performance. Basalt fibers are known for their high tensile capacity, thermal stability, corrosion resistance, and long-term durability. Their inclusion helps improve the crack resistance and contributes to better overall structural behavior of concrete.

Different aspect ratios of basalt fibers were used in the concrete mixes Table 1.

Admixture

A superplasticizer based on modified polycarboxylic ether technology, Master Glenium SKY 8233, was used to improve the workability of the concrete. The admixture is chloride-free and compatible with all cement types.

Tables 1. Physical properties of basalt fiber.

Properties	Value
Tensile Strength	3.84 GPa
Elastic Modulus	89 GPa
Elongation at Break	3.15%
Density	2.7 g/cm³

METHODOLOGY

The present experimental investigation was conducted to study the effect of chopped basalt fibers on the mechanical and durability properties of concrete under normal and elevated temperature conditions. The methodology adopted for this research included the selection and testing of raw materials, concrete mix design, preparation of specimens, curing, and testing of fresh and hardened concrete properties. OPC 53 grade, fine aggregate, coarse aggregate, potable water, chopped basalt fibers, and superplasticizer were used to prepare the concrete mixes. Preliminary tests were conducted on cement, fine aggregates, and coarse aggregates to determine properties such as fineness, setting time, compressive strength, sieve analysis, specific gravity, water absorption, abrasion value, impact value, and fineness modulus, as per the relevant Indian Standard codes.

The concrete mix design for M40 grade concrete was carried out in accordance with the IS 10262:2009 guidelines. The target mean compressive strength was determined using the following relation:

$$f'_{ck}=f_{ck}+1.65s$$

A water-cement ratio of 0.44 was adopted for the concrete mix. Different concrete mixes were prepared by incorporating chopped basalt fibers of 12 and 18 mm lengths with varying fiber dosages of 0.25%, 0.50%, and 1% by volume of concrete. A superplasticizer based on modified polycarboxylic ether was added to improve the workability of the FRC.

Concrete mixing was performed using machine mixing to ensure the uniform distribution of materials and fibers. The fresh concrete was tested for workability using the slump cone test. The concrete specimens were then cast in standard molds for compressive strength, split-tensile strength, and flexural strength tests. Cube, cylindrical, and beam specimens were compacted using tamping rods and vibrators to eliminate air voids. After casting, the specimens were kept for 24 h at room temperature, demolded, and cured in water until the testing age.

The hardened concrete specimens were tested for compressive strength, split-tensile strength, and flexural strength at 7 and 28 days of curing. The compressive strength of the concrete was calculated as follows:

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

where (P) is the failure load and (A) is the loaded area of the specimen. To evaluate the thermal resistance of the basalt-FRC, specimens were exposed to elevated temperatures of 300 and 500°C. After heating, the specimens were cooled naturally and tested to determine their residual mechanical properties. The durability performance of concrete was also evaluated using acid attack tests. The experimental results obtained from all tests were analyzed to study the influence of the basalt fiber dosage, aspect ratio, and elevated temperature on the overall performance of concrete.

RESULTS AND DISCUSSION

An experimental investigation was conducted to study the effect of chopped basalt fibers on the mechanical and thermal properties of concrete. Different fiber dosages and aspect ratios were used to evaluate the workability, compressive strength, split-tensile strength, flexural strength, and temperature resistance of concrete.

The slump test results showed that the workability of concrete decreased with an increase in fiber content and aspect ratio owing to the higher internal friction and water absorption by the fibers. However, all the mixes remained workable for casting.

The compressive strength of concrete increased with the addition of basalt fibers up to a fiber content of 0.50 %. The maximum 28-day compressive strength obtained was 51.11 MPa for an aspect ratio of 92 and 54.17 MPa for an aspect ratio of 110. Beyond 0.50% fiber content, the strength slightly decreased because of poor workability and improper fiber distribution.

Table 2. Result of M40 aspect ratio of 92.

Volume by %	Compressive strength (MPa)			Split-tensile strength (MPa)	Flexural strength (MPa)
Mix	7 days	14 days	28 days	28 days	28 days
Normal	32.51	35.34	41.7	3.92	4.57
0.25%	33.42	38.92	45.01	4.86	5.23
0.50%	34.73	41.25	51.11	5.67	5.39
1%	31.46	34.69	39.26	4.64	5.38

Table 3. Result of M40 aspect ratio of 110.

Volume by %	Compressive strength (MPa)			Split-tensile strength (MPa)	Flexural strength (MPa)
Mix	7 days	14 days	28 days	28 days	28 days
Normal	32.51	35.34	41.7	3.92	4.57
0.25%	33.46	37.46	43.57	5.83	5.89
0.50%	33.40	41.11	54.17	6.80	7.3
1%	31.56	33.97	41.67	5.56	6.72

The split-tensile and flexural strengths were also significantly improved with the inclusion of the basalt fibers. Higher-aspect-ratio fibers provided better crack-bridging action and improved the ductility of concrete. The maximum split-tensile strength and flexural strength were achieved at a fiber dosage of 0.50 %.

The study further showed that basalt-FRC performed well under elevated temperatures. No major reduction in strength or appearance was observed up to 350°C. However, at 500°C, a slight deterioration in concrete quality and a reduction in strength occurred.

Overall, the results confirmed that the chopped basalt fibers enhanced the mechanical properties, durability, and thermal resistance of concrete, with 0.50% fiber dosage yielding optimum performance, as shown in Tables 2 and 3.

CONCLUSION

The experimental study revealed that incorporating chopped basalt fibers positively influenced the mechanical properties of concrete. Compared with conventional concrete, the fiber-reinforced mixes exhibited improved compressive, split-tensile, and flexural strengths. The findings indicate that basalt fibers contribute to an enhanced load-carrying capacity and crack resistance, resulting in better overall structural performance. Among all the mixes, concrete containing the optimum fiber dosage showed better overall performance owing to effective crack bridging and improved bonding within the concrete matrix.

The workability of concrete decreased with an increase in the fiber content and aspect ratio because of the higher internal friction and reduced flowability of the mix. However, the reduction in workability remained within acceptable limits for casting and compaction.

The study further revealed that increasing the aspect ratio of the basalt fibers improved their compressive, tensile, and flexural strength characteristics. Longer fibers provided better resistance to crack propagation and improved the ductile behavior of concrete.

The effect of elevated temperature on the basalt-FRC was also examined. The concrete specimens remained nearly unaffected in terms of appearance and strength up to a temperature of 350°C. However, when the temperature reached 500°C, slight deterioration in concrete quality and reduction in strength were observed owing to thermal damage within the concrete matrix.

The durability of concrete was also improved with the inclusion of chopped basalt fibers. The fibers helped reduce crack formation and enhanced the resistance of concrete against deterioration, thereby increasing the overall service life of the concrete structure.

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