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Studying The Properties Of Concrete Using Basalt Fiber For Sustainable Development

Mohd Shahnawaz Isha, Syed Mohd Subuktageen, Nawab Ali Siddiqui, And Anwar Ahmad, Juned Ahmad
Department of Civil Engineering, Integral university, Lucknow (226026), U.P, India

Abstract: In response to the evolving needs of the construction industry, there is a growing emphasis on developing new materials that can enhance the mechanical properties, strength, and durability of concrete. Basalt fiber-reinforced concrete, as a relatively new type of fiber-reinforced concrete, has shown promising mechanical performance. However, basalt fibers are being considered superior to these because of their comparable mechanical strength, higher durability than glass fibers, lesser cost than carbon fibers, sustainability due to abundant raw material, and environment-friendly production process. Hence, the number of studies on Basalt fiber-reinforced concrete are increasing over the years. This research paper covers the properties of Basalt fiber-reinforced concrete. Basalt fibers are produced by melting crushed volcanic basalt rock through a single-stage process. These are non-toxic and environmentally safe. Basalt fibers are highly resistant to heat, and possess insulating properties apart from having an elastic structure. The objective of this study is to investigate the effects of incorporating basalt fibers into concrete and evaluate their impact on the mechanical properties of the concrete. The Basalt fibers of different proportions 0%, 0.25%, 0.75% and 1.25% in volume of concrete added to M35-grade concrete and tested for compressive strength, tensile strength, flexural strength, rebound hammer and ultra pulse velocity. The results showed that concrete with 0.25% fibers exhibited maximum strength values.

Keywords: Basalt Fiber Reinforced concrete, Compressive strength, split tensile strength, Flexural strength, Ultra pulse velocity, Bridging Functions.

1. Introduction

Concrete, a commonly used construction material, is primarily utilized in structural elements, both with and without reinforcement. However, it has inherent limitations in terms of its low tensile strength and limited ability to withstand tensile strain. The synthesis and enhancement of mechanical properties in quaternary epoxy-based polymer concrete using basalt fiber and clay nanoparticles, showing that basalt fiber improves properties and thermal stability, while nanoparticles enhance certain strengths but reduce tensile strength [1]. The reinforcement effects of basalt fiber on concrete, demonstrating that its inclusion enhances ductility and improves compressive and split tensile strength at different ages, offering valuable insights for the application of basalt fiber in concrete projects [2]. The effects of basalt fiber volume fraction and length on the mechanical properties of fiber reinforced concrete, revealing that the addition of basalt fiber significantly improves tensile strength, flexural strength, and toughness index, while the compressive strength remains relatively unchanged, and the length of basalt fiber has an influence on these properties [3-4]. The effects of incorporating basalt fiber in self-compacting concrete (SCC), showing that while the workability decreases, the mechanical properties of SCC, such as flexural strength and splitting tensile strength, are improved, with optimal results observed at a volume fraction of 0.5% and fiber lengths of 12mm and 24mm, and the response surface method is employed to optimize strength and durability properties by minimizing rapid chloride permeability and water penetration depth [5]. The effects of incorporating short discrete basalt fibers into magnesium phosphate cement (MPC) composites, revealing a decrease in workability but improvements in compressive strength, splitting tensile strength, flexural strength, and fracture toughness, with no significant influence of fiber length observed, and basalt fiber reinforced MPCs demonstrating superior mechanical properties compared to glass fiber reinforced MPCs [6]. A new type of hybrid fiber reinforced concrete, $CaCO_3$ whisker-steel fiber-basalt fiber reinforced concrete, revealing that an increase in basalt fiber content up to 0.68% enhances the mechanical properties, while beyond this percentage, the properties decrease, and the resistance against cracking is observed through SEM analysis [7]. High-performance concrete reinforced with basalt fiber and polypropylene fibers, revealing that the addition of single basalt fibers or polypropylene fibers enhances flexural strength and splitting tensile strength, with the best synergy effect observed at a basalt fiber content of 0.15% and a polypropylene fiber content of 0.033%, resulting in significant improvements in compressive strength, flexural strength, and splitting tensile strength compared to HPC without fibers [8]. High-performance concrete (HPC) reinforced with basalt fiber and polypropylene fibers, revealing that the addition of single basalt fibers or polypropylene fibers enhances flexural strength and splitting tensile strength, with the best synergy effect observed at a basalt fiber content of 0.15% and a polypropylene fiber content of 0.033%, resulting in significant improvements in compressive strength, flexural strength, and splitting tensile strength compared to HPC without fibers [9]. The impact of basalt fiber on the mechanical properties, chloride content, and water absorption of coral aggregate concrete, finding that an optimal fiber content of 0.05% leads to increased mechanical properties and water absorption resistance, with 9.87% and 1.36% increases in compressive strength and splitting tensile strength, respectively, at 28 days, and further investigation suggests the enhancement mechanism of BF through various analyses [10].

Fig.1.1. Fiber Basalt.

2. Methodology

2.1. Objectives

Objectives of the experimental investigation are as follows:

- Evaluate the effect of adding basalt fiber on Compressive Strength, Flexure Strength and Split tensile Strength of Concrete at 7, 28 days.
- To study UPV on Convectional Concrete and Fiber Reinforced Concrete at 7 & 28 days.
- With 0%, 0.25%, 0.75% and 1.25% of Basalt Fiber in Concrete of M35 Grade.

2.2. Materials

43 grade Portland Pozzolana Cement was used as binding material. Table 1 presents the properties and characteristics

of cement. River sand of Zone I was used as fine aggregate in Basalt fiber reinforced concrete. The specific gravity and fineness modulus of sand is 2.51 and 3.286 respectively. 20 mm size crushed aggregate was used as coarse aggregate and its specific gravity is 2.6150. Table 2 describes the details of the mix of proportions.

Fibers: Fiber of 12mm length and diameter of 20 μm were used. The chopped BF was supplied by Hayael Aerospace India Private Limited. The mixing of the BF used to be 0%, 0.25%, 0.75% and 1.25% of the whole volume of the mix added to M35-grade concrete. Table 3 shows physical and mechanical characteristics of basalt fibers. The Basalt Fiber is shown in Fig.1.1.

Table 1. Cement characteristics.

Chemical characteristics %		**Physical Characteristics**		
CaO	63.4	Specific gravity	2.72	
SiO_2	19.96	Initial setting time (min)	137	
Al_2O_3	5.17	Final setting time (min)	400	
Fe_2O_3	3.41	Fineness of cement	2.33%	
MgO	1.61	Fly ash Content	35%	
SO_3	2.13	**Mechanical properties**		
K_2O	0.8	Compressive strength (MPa)	3 Days	17
Na_2O	0.13		7 Days	28.5
Loss on ignition	1.12		28 Days	46

2.3. Mixing details and curing process

During the mixing process of Basalt Fiber Reinforced Concrete, the dry fine and coarse aggregates, cement, basalt fibers, and water were sequentially added to the mixer. Each ingredient was mixed for one minute to ensure proper blending. The overall mixing duration was three minutes to ensure the uniform dispersion of fibers in the concrete. The resulting concrete was then cast into prismatic molds measuring 100 mm x 100 mm x 500 mm for flexural strength testing, 150 mm cube molds for compressive strength testing, and cylindrical molds measuring 100 mm in diameter and 300 mm in height for tensile strength testing. Sample number was taken as 3. The samples were placed for curing after 24 hours for 7 days and 28 days.

The details of all five mixtures used in this study are presented in Table 4. The fiber content refers to the proportion of fiber volume compared to the volume of the concrete matrix. The proportions of BF in the five mixtures were 0%, 0.25%, 0.75%, and 1.25%, and these mixtures were denoted as BF0, BF0.25, BF0.75, and BF1.25, respectively. For all the mixtures, the water–binder ratio is 0.4.

Table 2. Mix proportions for One Cubic Meter

Grade of Concrete	Cement (kg)	Water (Liters)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Admixture (ml)
M35	428.8	182.97	616.47	1053.13	2544

Table 3. Properties of Basalt fibers.

Fiber	Length (mm)	Density (g/cc)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)	Break Elongation	Absorption of water
BF	12	2.7	85-90	3200-3850	3.15%	3.6%

Fig. 2.1. Slump test

Fig.2.2. Casted Specimens

Table 4. Properties of Basalt fibers

Mix proportions of concrete						
Specimen	**Cement (kg/m3)**	**FA (kg/m3)**	**CA (kg/m3)**	**Water (kg/m3)**	**Admixture (ml)**	**BF (kg/m3)**
BF0	428.8	616.4	1053.13	182.9	2544	-
BF0.25	428.8	616.4	1053.13	182.9	2544	1.072
BF0.75	428.8	616.4	1053.13	182.9	2544	3.216
BF1.25	428.8	616.4	1053.13	182.9	2544	5.36

Fig. 2.3. Compressive strength test

Fig. 2.4. Flexural strength test

Fig. 2.5. Split tensile strength test

Fig. 2.6. Compression testing machine

Fig. 2.7. Ultra Pulse Velocity

Fig. 2.8. Split tensile test apparatus

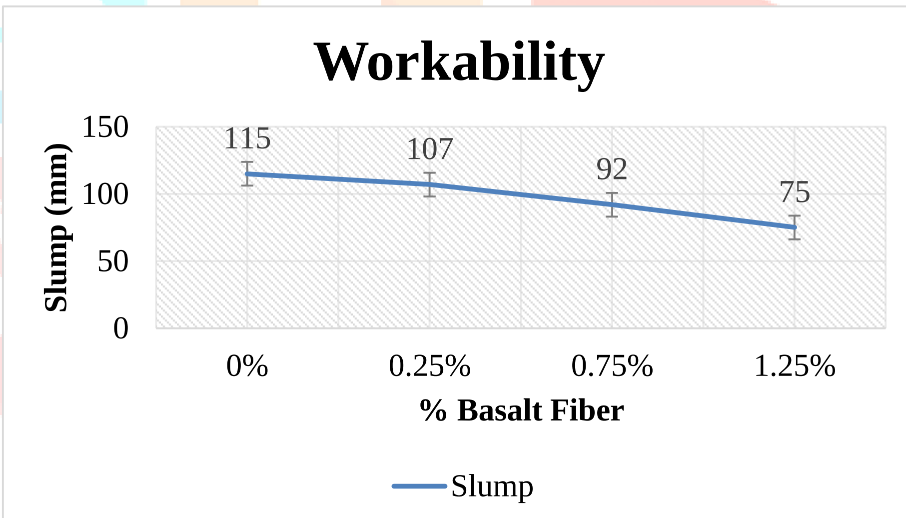
2.4. Testing methods

The cubes, prisms, and cylinders of Basalt Fiber Reinforced Concrete were tested for compressive strength (according to the Indian standard IS 516–1959), flexural strength (according to the Indian standard IS 516–1959) and the split tensile strength (according to the Indian standard IS 5816-1999) shown Fig.2.3. Fig.2.4 and Fig.2.5 respectively. All the specimens are shown in Fig.2.2. The flexural strength was tested using the third-point loading. The 400 mm bending span is used. All samples are tested at 7 and 28 days. The load was regulated by displacement up to the samples failed at a Pace rate of 5.2, 0.11, 2 in compression, flexural, and split tensile test respectively. The cubes were tested for Ultra Pulse Velocity (according to the Indian standard IS 516–Part 5 Sec-1).

3. Results and discussion

3.1. Workability of Basalt Fiber Reinforced Concrete

The Basalt Fiber Reinforced Concrete's slump as shown in Table 5. The inclusion of fiber in the concrete mixture leads to a certain reduction in slump. The slump for the normal concrete is 115 mm. If BF adds 0.25%, 0.75%, and 1.25% to volume mixtures, the workability of Basalt fiber reinforced concrete decreases to 107 mm, 92 mm, and 75 mm respectively. It shown that adding fibers to the concrete leads to a reduction in the concrete's workability. The decrease in slump can be attributed to the increased surface area of basalt fibers, which results in a higher accumulation of cement paste. The Slump test is shown in Fig. 2.1. This increased paste coverage leads to an increase in the viscosity of the concrete mix. Hence it contributes to decreases in slump. This is due to the interlocking effect of the fibers, water absorption, and increased viscosity of the mix.



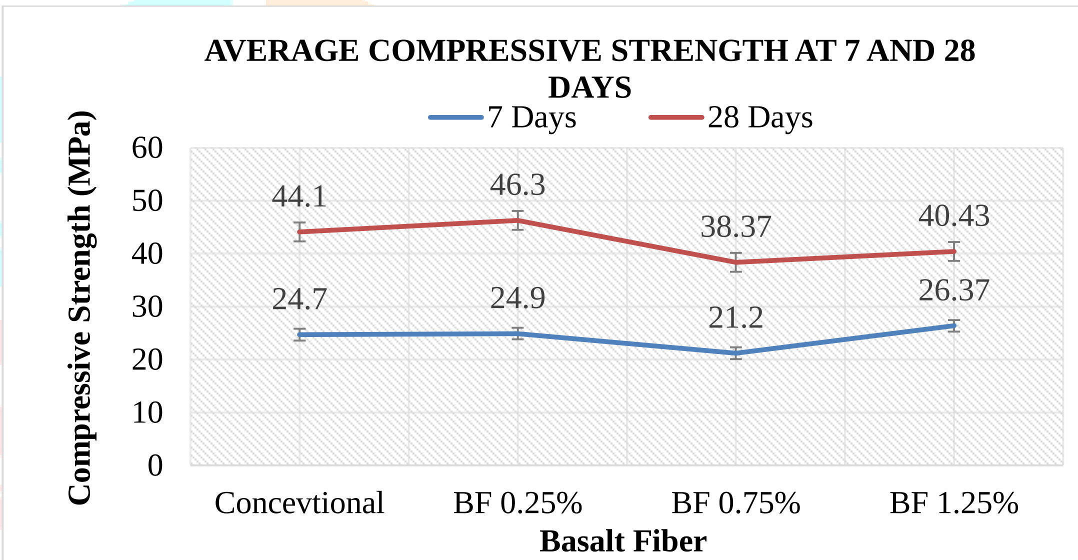
3.2. Compressive strength of Basalt Fiber Reinforced Concrete

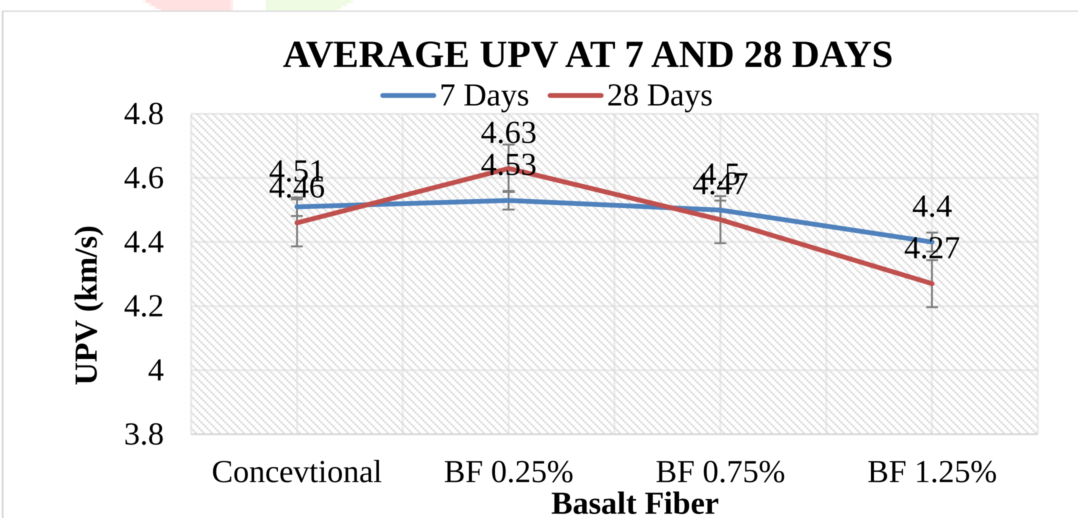
The value of the compressive strength and strength ratio of Basalt Fiber Reinforced Concrete samples at 7 and 28 days is shown in Table 5. In this experiment, the compressive strength of Basalt Fiber Reinforced Concrete is not clearly improved. The test is performed on 3000kn compression testing machine shown in Fig.2.6.

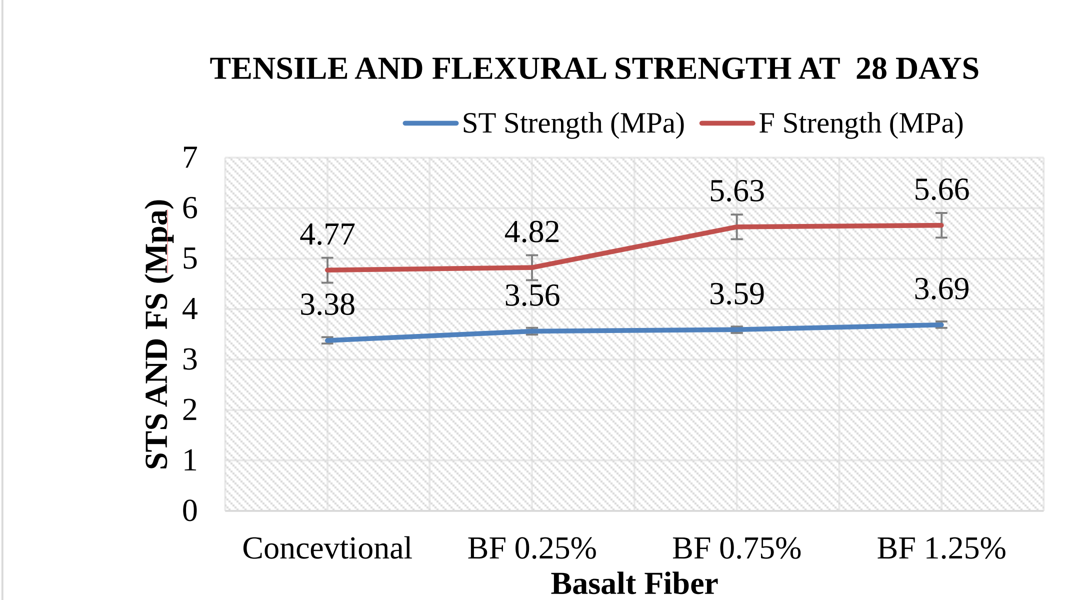
Sivakumar and Santhanam [11] concluded that the polyester, nylon, and GFRC compressive increased by 1.8%, 6.3%, and 3.0% respectively, at usage of fiber of 0.6 kg / m3 for 28 days. The compressive strength of concrete reinforced with basalt fibers at volume mixtures of 0.05%, 0.1%, 0.3%, and 0.5% increased by approximately 9.26%, 19.86%, 27.37%, and 18.28% respectively compared to normal concrete at 3 days. At a later age, Fiber Reinforced Concrete's compressive strength improves relative to the previous age. The compressive strength of Basalt Fiber Reinforced Concrete is reduced at 7 and 28 days. At 7 and 28 days, the compressive strength of basalt fiber reinforced concrete ranged from approximately 4.21% to 11.41% and 3.36% to 9.82% higher, respectively, compared to normal concrete. The decrease in compressive strength of fiber concrete is observed at the 28-day mark. As the concrete mix and fibers age, the bonding capability between them diminishes, resulting in a decrease in the binding potential. However, Basalt Fiber Reinforced Concrete 3 (0.3%) showing higher compressive strength than the remaining mixes including Plain Concrete.

Table 5. Compression, UPV, Split tensile, Flexural Strength for All Specimens

Specimen	Workability (Mm)	Compressive Strength (MPa)		UPV (Km/S)		Split Tensile Strength (MPa)	Flexural Strength (MPa)
		7th day	28th day	7th day	28th day	28th day	28th day
BF0	115	24.7	44.1	4.51	4.46	3.38	4.77
BF0.25	107	24.9	46.3	4.53	4.63	3.56	4.82
BF0.75	92	21.2	38.37	4.5	4.47	3.59	5.63
BF1.25	75	26.37	40.43	4.4	4.27	3.69	5.66







Note: The strength ratio is calculated by subtracting the strength of normal concrete from the strength of fiber concrete, dividing the result by the strength of normal concrete, and then multiplying by 100%.

3.3. Tensile strength of Basalt Fiber Reinforced Concrete

The tensile strength of the Basalt Fiber Reinforced Concrete at 28 days for 0%, 0.25%, 0.75% and 1.25% shown in Table 5. In comparison to regular concrete, Basalt Fiber Reinforced Concrete exhibits improved tensile strength, with enhancements of approximately 5.32%, 6.21%, and 9.17% performed through as shown Fig.2.8. Previous research has shown that the inclusion of basalt fiber in concrete leads to an increase in its tensile strength. Song et al. [12] Concluded that at a fiber quantity of 0.6 kg/m^3, the tensile strengths of polypropylene and nylon Fiber Reinforced Concrete were respectively 9.7% and 17.1% higher compared to that of regular concrete. [13] Yurtseven et al. concluded that the incorporation of polypropylene fiber and carbon fiber at a volume fraction of 0.5% in concrete can lead to a significant increase in tensile strength, specifically by 19.5% and 31.6% at 28 days. This improvement is attributed to the synergistic effect of these three types of fibers, which effectively hinder the propagation of micro cracks in the early stage. The strain is then transferred to the joined fibers after the occurrence of flexural cracks, thereby controlling the growth of macro cracks and ultimately enhancing the concrete's tensile strength.

3.4. Flexural strength

The Flexural strength of basalt fiber reinforced concrete was shown in Table 5 for 7 and 28 days. Previous studies have concluded that the addition of fibers to concrete can improve its flexural behavior. Song and Hwang [12] concluded that the incorporation of steel fibers into the concrete mixture resulted in an increase in the bending strength of the material. Sivakumar and Santhanam [11] It was determined that the addition of polypropylene, polyester, and glass fibers at a dosage of 0.6 kg/m^3 resulted in increases of 7.6%, 21.3%, and 14.4% respectively in the bending strength of the reinforced concrete samples compared to regular concrete. This indicates that the incorporation of fiber reinforcement enhances the bending strength of the concrete. The Flexural strength of basalt fiber reinforced concrete at volume mixtures of 0.25%, 0.75%, and 1.25% increases by 1.05%, 18.03%, and 18.66% respectively at 28 days. This increase in flexural strength can be attributed to the continuous tensile stress carried by the basalt fibers in the tension zone, which bridges and crosses the cracks, resulting in higher bending strength for basalt fiber reinforced concrete. Based on these findings, it can be concluded that the increase in bending strength is directly related to the increase in the volume mixtures of basalt fibers.

3.5. Ultra Pulse Velocity

The addition of basalt fiber in concrete can lead to a decrease in ultra pulse velocity (UPV) due to factors such as non-uniform fiber dispersion, weak fiber-matrix interactions, random fiber orientation, altered material properties, and fiber bridging across cracks. However, the specific effect depends on factors like fiber characteristics, bond strength, and fiber content. It is important to conduct comprehensive testing to assess the impact of basalt fiber on concrete properties, including UPV. UPV test as shown as Fig.2.7.

4. Conclusions

The inclusion of Basalt Fiber (BF) in concrete results in decreased workability. The compressive strength of the concrete increased by 4.99% at 0.25% BF, but decreased by 12.99% and 8.32% at 0.75% and 1.25% BF respectively. Ultrasonic Pulse Velocity (UPV) testing showed a slight positive effect at 0.25% BF (3.81% increase) and 0.75% BF (0.22% increase), but a decrease of 4.26% at 1.25% BF. Flexural strength increased by 1.05%, 18.03%, and 18.66% at 0.25%, 0.75%, and 1.25% BF respectively, attributed to the high tensile strength of Basalt Fiber. Tensile strength also increased by 5.32%, 6.21%, and 9.17% at 0.25%, 0.75%, and 1.25% BF respectively, indicating the reinforcing capabilities and improved ductility of Basalt Fiber in concrete. Therefore, Basalt Fiber is considered a beneficial reinforcement material for concrete.

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