Studies of Concrete Mechanical Properties with Basalt Fibers

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Abstract. Current situation of construction industry demands competency in inventing new materials to enhance the mechanical properties of concrete in its strength point of view as well as durability. Basalt fibers are formed due to melting crushed volcanic basalt rock in a single stage phase. These are non-toxic and environmentally safe. Basalt fibers (BF) are highly resistant to heat, and possess insulating properties apart from having an elastic structure. In this context, the present study has been taken up to study the performance of concrete blended with basalt fibers and their influence on mechanical properties of concrete. The Basalt fibers of different proportions 0%, 0.1%, 0.3% and 0.5% in volume of concrete added to M40-grade concrete (BFRC) and tested for compressive strength, tensile strength and bending strengths. The results showed that concrete with 0.3% fibers exhibited maximum strength values.

1. Introduction
Concrete, a construction material is most widely used to build in structural elements with or without reinforcement and exhibits low tensile strength and tensile strain. Normally, addition of fibers is one of the methods to improve strength properties of the concrete such as flexural strength, tensile strength, impact strength, abrasion resistance, load bearing capacity, toughness, and deformation capability. Microstructure of concrete with BF showed good bond at early days than later days [1-6]. More recently, many types of fibers such as cellulose, asbestos, steel, cellulose, glass and polypropylenes are being used as reinforcing cement products. Addition of BF to the concrete could provide remarkable improvement in flexural strength, fracture energy and abrasion resistance of plain concrete [7-8]. Basalt is being used as composite material in plain concrete, polypropylene composites, geopolymer concrete, epoxy composites, inorganic binder like phosphate and polysiloxane based matrices by exploiting its bonding capability [9-14]. Basalt fiber is the 21st century green industrial material and has advantage of safety of ecological system, sustainability of nature and several other properties. It can be applied innovatively due to its better chemical and mechanical performances than traditional carbon and glass fiber in many economic and industrial areas, from automotive to aeronautic and from building constructions to energy efficiency. Increase of percentage of weight of BF and Nano clay particles (up to 5%) increase the yield strength and the Young’s modulus of clay reinforced polypropylene due to its reinforcing effect.[15-16].
Properties of PCC or RCC for Pavement concrete slabs are enhanced by addition of basalt fibres due to its physical features and chemical features like resistance to extreme temperature variations and resistance to alkali reactions [17]. Fracture energy is improved by adding basalt fibres and glass fibres at the dosage of 1%. Specifically, composite materials like Cement based or polymeric with basalt fibers of different geometrical features and their configurations can be used in the construction of structures as well as for retrofitting and strengthening of damaged structures [19].

![Fiber Basalt](image)

**Fig.1.1. Fiber Basalt.**

### 2. Methodology

#### 2.1. Objectives

Objectives of the experimental investigation are as follows:

To calculate the Workability, compressive strength, split tensile strength and Flexural strength of Concrete beams with Basalt fiber used to be 0%, 0.05%, 0.1%, 0.3% and 0.5% of the whole volume of the mix compared with the plain concrete of M40 Grade.

#### 2.2. Materials

53 grade Ordinary Portland Cement was used as binding material. The characteristics of cement are shown in Table 1. River sand of size 3mm dia. was used as fine aggregate in BFRC. The specific gravity and fineness modulus of sand is 2.47 and 2.62 respectively. 20 mm size crushed aggregate was used as coarse aggregate and its specific gravity is 2.86. 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 Nickunj Eximp Enterprise Private Limited. The mixing of the BF used to be 0%, 0.05%, 0.1%, 0.3% and 0.5% of the whole volume of the mix added to M40-grade concrete (BFRC). Table 3 shows physical and mechanical characteristics of basalt fibers.

### Table 1. Cement characteristics.

| Chemical characteristics | %   | Physical Characteristics |
|--------------------------|-----|--------------------------|
| CaO                      | 63.40| Specific gravity         | 3.10 |
| SiO₂                     | 19.96| Initial setting time (min)| 30   |
| Al₂O₃                    | 5.17 | Final setting time (min) | 400  |
| Fe₂O₃                    | 3.41 | Compressive strength (MPa) | 3 Days | 30 |
| MgO                      | 1.61 | 7 Days                 | 41   |
| SO₃                      | 2.13 | 28 Days                 | 55   |
| K₂O                      | 0.80 | Loss on ignition        | 1.12 |
| Na₂O                     | 0.13 |                          |      |
2.3 Mixing details and curing process
In mixing of BFRC, dry fine and coarse aggregates, cement, basalt fibers and water had been added to the mixer successively and mixed well for one minute for each addition of ingredient shown Fig.2.1. The duration for concrete mixing was taken as three minutes to ensure uniform dispersion of fiber in the concrete shown Fig.2.2. The concrete was cast in 100 mm x 100 mm x 500 mm prismatic molds for testing bending strength, in 150 mm cube molds for compressive strength testing and separately in 100 mm diameter and 300 mm height of cylinder molds for tensile strength testing. Sample size was taken as 3. The samples were placed for curing after 24 hours for 3 days, 7 days and 28 days.

Table 2. Mix proportions of BFRC for One Cubic Meter

| Grade of Concrete | Cement (kg) | Water (Litres) | Fine Aggregate (kg) | Coarse Aggregate (kg) |
|-------------------|-------------|----------------|---------------------|-----------------------|
| M40               | 438.13      | 197.16         | 598.60              | 1180.17               |

Table 3. Properties of Basalt fibers.

| Fibre | Length (mm) | Density (g/cc) | Modulus of Elasticity (GPa) | Tensile Strength (MPa) | Break Elongation (%) | Absorption of Water |
|-------|-------------|----------------|-----------------------------|------------------------|----------------------|---------------------|
| BF    | 12          | 2.63           | 75-90                       | 3200-3850              | 3.1                  | < 0.5               |

Fig. 2.1. Dry mix of concrete with basalt fiber

Fig.2.2. Concrete mixing
2.4 Testing methods
The cubes of BFRC were tested for compressive strength and the split tensile strength according to the Indian standard IS 516–1959 [20] shown Fig.2.3. and Fig.2.4. respectively. The bending strength at 3, 7 and 28 days was tested using the third-point loading. The 400 mm bending span is used. The load was regulated by displacement up to the samples failed at a rate of 0.2 mm/min.

3. Results and discussion

3.1. Workability of BFRC
The BFRC's slump as shown in Table 4. The table indicates that the slump decreases due to the addition of fiber to some extent. The slump for the normal concrete is 165 mm. If BF adds 0.05%, 0.1%, 0.3% and 0.5% to volume mixtures, the workability of BFRC decreases to 147 mm, 125 mm, 84 mm and 59 mm respectively. It shown that adding fibers to the concrete leads to a reduction in the concrete's workability. It may be to the large surface areas of basalt which accumulate more cement paste to cover over and this lead to raise the viscosity of mix. Hence it contributes to decreases in slump.

3.2. Compressive strength of BFRC
The value of the compressive strength and strength ratio of BFRC samples at 3, 7 and 28 days is shown in Table 4. In this experiment, the compressive strength of basalt FRC is not clearly improved.
Sivakumar and Santhanam [20] 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. Similar to normal concrete, the compressive strength of concrete reinforced with BF with volume mixtures of 0.05%, 0.1%, 0.3% and 0.5% at 3 days increase by 9.26%, 19.86%, 27.37% and 18.28% respectively. At a later age, FRC's compressive strength improves relative to the previous
The compressive strength of BFRC is reduced at 7 and 28 days. At 7 and 28 days, the BF reinforced concrete compressive strength ranges from 4.21% to 11.41% and 3.36% to 9.82% respectively. The reduction in the fiber concrete's compressive strength is at 28 days. Due to the aging of the interface between the concrete mix and fibers, the binding potential is decreased. However, BFRC 3 (0.3%) showing higher compressive strength than the remaining mixes including PC.

### Table 4. Compressive Strength of different BFRC mixes.

| Mixture no. | $V_m$ (%) | Slump (mm) | Compressive strength (MPa) | 3 Day | 7 Day | 28 Day |
|-------------|-----------|------------|---------------------------|-------|-------|--------|
|             |           |            | Measured (MPa) | Strength ratio (%) | Measured (MPa) | Strength ratio (%) | Measured (MPa) | Strength ratio (%) |
| PC          | -         | 165        | 17.72            |                | 31.37            |                | 44.28            |                |
| BFRC1       | 0.05      | 147        | 19.36            | 9.26            | 32.69            | 4.21            | 45.77            | 3.36            |
| BFRC2       | 0.1       | 125        | 21.24            | 19.86           | 34.14            | 8.83            | 47.47            | 7.21            |
| BFRC3       | 0.3       | 84         | 22.57            | 27.37           | 34.95            | 11.41           | 48.63            | 9.82            |
| BFRC4       | 0.5       | 59         | 20.96            | 18.28           | 32.94            | 5               | 46.12            | 4.16            |

Note: Strength ratio (%) = \([(Fibre concrete strength - normal concrete strength) / normal concrete strength]\) x 100%.

### 3.3. Tensile strength of BFRC

Table 5 list the strength ratio of the fiber concrete tensile strength at 28 days. The tensile strength of the BFRC tends to increase relative to the normal concrete. The tensile strength of BFRC increases by 8.38–36.70%.

Previous studies indicated that tensile strength is increased by adding fiber to concrete. Song et al. [21] concluded that the polypropylene and nylon FRC tensile strengths were 9.7% and 17.1% higher than that of normal concrete at quantity of fiber of 0.6 kg / m³, respectively. Yurtseven et al. [22] concluded that adding polypropylene fiber and carbon fiber at a volume of mixtures of 0.5% can increase concrete tensile strength by 19.5% and 31.6% at 28 days. It is due to the joining operation of the three directed dispersed fibers around cracks, which in the early stage effectively prevents the spread of micro cracks. The strain is move to at joining fibers after the flexural crack in the concrete and thus the macro crack growth is regulated and the tensile strength is increased.

### Table 5. Tensile strength of BFRC.

| Mixture no. | $V_m$ (%) | Tensile strength (MPa) |
|-------------|-----------|------------------------|
|              |           | 28 Day | Measured (MPa) | Strength ratio (%) |
| PC          | -         | 3.46              |                |                |
| BFRC1       | 0.0 5    | 3.75              | 8.38            |                |
| BFRC2       | 0.1       | 3.92              | 13.29           |                |
| BFRC3       | 0.3       | 4.73              | 36.70           |                |
| BFRC4       | 0.5       | 4.26              | 23.12           |                |
3.4. Bending strength
The bending strength and strength ratio FRC was reported in Table 6 at 3, 7 and 28 days. Previous studies have demonstrated that adding fiber to concrete could enhance concrete's flexural behavior. Song and Hwang [21] concluded that as steel fibers were added to the mix, the bending strength of concrete increased. Sivakumar and Santhanam [20] concluded that, at a fiber of 0.6 kg / m³, reinforced concrete bending of polypropylene, polyester and glass fiber was 7.6%, 21.3% and 14.4% respectively. FRC samples show an improvement in bending strength relative to normal concrete.

Table 6. Bending strength of Different BFRC mixes.

| Mixture no. | V_m (%) | Bending strength (MPa) | 3 Day | 7 Day | 28 Day |
|-------------|---------|------------------------|-------|-------|--------|
|             |         | Measured (MPa) | Strength ratio (%) | Measured (MPa) | Strength ratio (%) | Measured (MPa) | Strength ratio (%) |
| PC          | -       | 4.78                | 5.24  | 6.16  |
| BFRC1       | 0.05    | 5.21                | 8.99  | 5.73  | 9.35   | 6.58  | 6.82  |
| BFRC2       | 0.1     | 5.56                | 16.32 | 6.03  | 15.07  | 7.05  | 14.45 |
| BFRC3       | 0.3     | 5.97                | 24.89 | 6.67  | 27.29  | 7.32  | 18.83 |
| BFRC4       | 0.5     | 5.71                | 19.47 | 6.17  | 17.75  | 7.13  | 15.75 |

For BF reinforced concrete with the volume mixtures of 0.05%, 0.1%, 3% and 0.5%, the increased bending strength ranges from 8.99% to 24.89%, 9.35% to 27.29% and 6.82 to 18.83 at 3, 7 and 28 days respectively. The BFRC in the tension zone will bear the tensile stress continuously after flexural cracking until the basalt fiber bridging fracture crosses the cracks. Hence, BFRC shows higher bending strength. From the above results, it was concluded that the increase in bending strength due to the increase in BF's volume mixtures. However, when the fiber volume mixtures increase to 0.5 percent in BFRC4, the bending strength decreases slightly compared to BFRC3 with 0.3 percent basalt fiber volume mixtures. It is due to difficulties in fiber dispersion with mixtures of high volume of 0.5%. It is also indicate that normal concrete showed brittle behavior than BFRC.

4. Conclusions
This study demonstrates measurements of mechanical characteristics on BFRC. The results concluded that addition of Basalt Fiber to the concrete implies reduction of concrete workability with increase of fiber quantity. Compared to PC, the BF-reinforced concrete shows better strengths in bending and tension whereas lesser improvement in compression even reduces at a later age. The Strengths in compression, tension and bending of BFRC increase by 3.36-9.82%, 8.38-36.7% and 6.82-18.83% for 28 days respectively compared with the strengths of PC. Mechanical characteristics of BF concrete are increasing with the rise of BF.

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