Shear resistance of hybrid steel and basalt fiber reinforced concrete

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Abstract. The study aimed at investigating the mechanical properties and shear resistance of hybrid steel and basalt fiber reinforced M-25 grade of concrete. Crimped steel fibers with chopped basalt fiber have been used with varying (0.25%, 0.5%, 0.75%, and 1%) percentage volumetric ratio of concrete. The results indicated that crimped steel fiber performs better under compressive loading and chopped basalt fiber performs better under tensile loading. The beams are observed to fail in shear with majority of cracks developed near the support and some cracks were developed in middle third portion of beam with varying fiber dosage. Beam with 0.75S0.25B hybrid fiber performs and found 29% cheaper than the conventional beam with stirrups.

Keywords: Shear resistance, hybrid fiber, flexural failure, shear failure.

1. Introduction

Concrete is a blending material of aggregate (coarse and fine), cement and water. When water gets added to concrete, it becomes hard and forms a rigid structure like a rock. Concrete is weak in tension and strong in compression, due to which it is most commonly used with reinforcing material for better strength attainment. To overcome weakness of concrete in tension, some other reinforcing materials are also used in concrete. In last few decades, addition of different fibers in concrete has started to enhance and rectify the strength popularly called as Fiber Reinforced Concrete (FRC). The review of the available research papers [1, 5, 6, 7, 8, and 9] indicates that fibers play an effective role in enhancing the mechanical and shear properties of concrete. Hybrid fiber is a promising field of study where metallic and non metallic fibers or fibers with different sizes and shapes are mixed together in concrete mix with varying volumetric ratio of concrete. These fibers are generally distributed forms of some composite materials. When fibers are randomly mixed in concrete, they help to stop crack propagation by their bridging action even at high temperature and provide resistant to brittle failure. As plain concrete is brittle in nature, so fibers are added as reinforcing material in concrete. The combination of two or more fibers in the concrete mix is known as hybrid fiber reinforced concrete. The intention to add more than one fiber is to achieve better mechanical properties as induced by one fiber only. Basalt fiber which is showing better results than glass fiber can be considered as a good hybrid material with steel fiber to study the combined effect on hardened properties of concrete.

The present work has been done with objectives to evaluate the mechanical properties and shear resistance capacity of Hybrid steel and basalt FRC. To investigate the effectiveness of each type of fiber on shear strength, crack patterns and ultimate load carrying capacity of each beam. To determine at what percentage of volumetric ratio among (0.25%, 0.5%, 0.75%, and 1%) of Hybrid fibers as shear reinforcement in beams would provide adequate strength as compared to reinforcing steel used as minimum shear reinforcement.

2. Experimental Methodology

In first phase, cube and cylindrical specimens were cast for 7 days and 28 days curing having hybrid steel and basalt fibers as 0.25%, 0.5%, 0.75% and 1% volumetric ratio of concrete.
The compressive strength of cubes and split tensile strength of cylinder specimens has been evaluated. In second phase, beams were cast for 28 days curing having hybrid steel and basalt fibers as 0.25%, 0.5%, 0.75% and 1% volumetric ratio of concrete. The beam specimens were tested to check the shear behavior of hybrid steel and basalt fibers, their effect on shear strength, crack patterns, mode of failure and ultimate load carrying capacity. The beam specimens were provided with 2 longitudinal bars at bottom as main reinforcement and hybrid steel and basalt fibers were added as secondary reinforcement in such a way that their summation is 1%. 3 beam specimens were also cast without main reinforcement, they are only provided with hybrid steel and basalt fibers and their shear behavior has also been observed. Total 3 specimens were cast for each hybrid percentage of steel and basalt fiber. Fig 1 to Fig 3 gives the detailing of the beams cast for the testing.

Figure 1. Beam with conventional minimum steel reinforcement with stirrups

Figure 2. Beam with conventional minimum steel reinforcement without stirrups having uniformly distributed fibers

Figure 3. Beam with uniformly distributed fibers only

Thereinforcement details of beams are given in Table 1 and Figure 4 gives the details of Fiber dosages and specimens.

| S. No. | Total Specimens | Main Reinforcement | Shear Reinforcement | Shear span to depth ratio (a/h) |
|-------|----------------|-------------------|---------------------|--------------------------------|
|       |                |                   | Vertical Stirrups   | Crimped Steel fiber (%) volume fraction | Chopped Basalt fiber (%) volume fraction |
| 1.    | 3              | 2-10mm diameter bars at bottom face and top face | 5-6mm diameter stirrups @ 80mm c/c | 0% | 0% | 1.33 |
| 2.    | 3              | 2-10mm diameter bars at | Nil | 0.25% | 0.75% | 1.33 |
3. Materials Used

Cement

OPC of grade 43 is used in this experimental work. The recommendations stated in IS: 4031(1999) were followed in determining the physical properties of cement.

Aggregate

In this experimental work two types of aggregates are used i.e. coarse and fine. The maximum size of coarse aggregate used is 20mm with specific gravity 2.80. The fine aggregate from zone 3 with specific gravity 2.6 has been used.
Steel and Basalt Fiber

The crimped steel fiber with aspect ratio 50 and chopped basalt fiber with aspect ratio 300 is used in the experimental work. The properties of steel and basalt fiber are given in Table 2.

### Table 2. Properties of Steel and Basalt Fiber

| Parameters                  | Steel Fiber | Basalt Fiber |
|-----------------------------|-------------|--------------|
| Fiber Length (mm)           | 50          | 3            |
| Equivalent Diameter (mm)    | 1           | 0.01         |
| Aspect Ratio                | 50          | 300          |
| Elastic Modulus (GPa)       | 200         | 85           |
| Tensile Strength (MPa)      | 1000        | 2900         |
| Density (kg/m³)             | 7850        | 2700         |
| Wearing Temperature (°C)    | -           | -260…+700    |
| Elongation at break (%)     | 0.5–3.5     | 3.1          |
| Water absorption (%)        | -           | ≤ 0.02       |

Mix Design

The mix design of M25 grade of concrete has been done as per IS 10262-2009. The design mix is given in Table 3.

### Table 3. Mix Proportions for 1m³

| Material          | Mix-1 | Mix-2 | Mix-3 | Mix-4 | Mix-5 | Mix-6 | Mix-7 |
|-------------------|-------|-------|-------|-------|-------|-------|-------|
| Cement            | 438.13| 438.13| 438.13| 438.13| 438.13| 438.13| 438.13|
| Sand              | 584.77| 584.77| 584.77| 584.77| 584.77| 584.77| 584.77|
| Coarse aggregate  | 1173.71| 1173.71| 1173.71| 1173.71| 1173.71| 1173.71| 1173.71|
| Water             | 197.16| 197.16| 197.16| 197.16| 197.16| 197.16| 197.16|
| W/C               | 0.45  | 0.45  | 0.45  | 0.45  | 0.45  | 0.45  | 0.45  |
| Steel fiber dosage| 0%    | 0.25% | 0.5%  | 0.75% | 1%    | 0%    | 1%(78.5) |
| Basalt fiber dosage| 0%   | 0.75% | 0.5%  | 0.25% | 1%    | 1%    | 0%    |

4. Results and Discussions
**Fresh concrete property**

Fresh concrete properties can be derived by different ways such as flow table test, slump cone test, etc. In this study, slump cone test has been carried out as per IS: 1199 to measure the workability of fresh concrete mix. Table 4 gives the slump values of different mixes.

| Table 4. Workability of different mixes |
|----------------------------------------|
| **Type of concrete mix** | **Slump value in mm** |
| Control mix | 105 |
| 0.25S0.75B | 95 |
| 0.5S0.5B | 90 |
| 0.75S0.25B | 80 |
| 1S1B | 65 |
| 0S1B | 100 |
| 1S0B | 70 |

From Table 4, it is observed that the workability of control mix is highest and the workability reduces when fibers are added to them. The workability is reduced from 105mm to 65mm but the concrete mix is still workable. As the steel fiber dosage is increasing the workability is decreasing because of fiber large dimension, it is reducing the flow ability of fresh concrete and there is sudden increase in the workability when steel fiber proportion becomes zero. From the above trend, it is also observed that chopped basalt fiber does not have much effect on the workability because of its small size. The workability is reduced from 105mm to 100mm when basalt fiber proportion is maximum.

**Compressive Strength of hybrid fiber reinforced concrete**

The compressive strength results are given in Table 5. At 7 days, maximum compressive strength is 20.49MPa which is observed in control mix. When hybrid fiber percentage varies from 0.25S0.75B, 0.5S0.5B and 0.75S0.25B, the compressive strength reduces by 50.4%, 49.5% and 36.4%. This may be due to cohesive decrease between the cement and aggregates. In the hybrid fibers when cramped steel fiber changes from 0.25%, 0.5% and 0.75%, the compressive strength increases by 1.74% and 20.63% with respect to each other. At 28 days, maximum compressive strength is 40.52MPa which is observed in 0.75S0.25B mix and is 21.9% more than control mix. When hybrid fiber percentage varies from 0.25S0.75B, 0.5S0.5B and 0.75S0.25B, the compressive strength increases by 9.03%, 17.15% and 21.89% respectively with respect to control mix. In the hybrid fibers when cramped steel fiber changes from 0.25% to 0.5% to 0.75%, the compressive strength is increased by 8.9% and 5.7% respectively. The maximum compressive strength at 7 days is 20.49MPa and at 28 days is 40.52MPa, hence 49.4% increase is observed in maximum compressive strength of concrete and it is obtained in 0.75S0.25B.

| Table 5. Compressive strength of cubes at 7 days and 28 days |
|-----------------------------------------------|
| **S. No.** | HyFRC Mix | Steel fiber dosage | Basalt fiber dosage | 7 days Compressive Strength (MPa) | 28 days Compressive Strength (MPa) |
|-----------------|-----------|-------------------|-------------------|----------------|----------------|
| 1. | Control mix | 0% | 0% | 20.49 | 31.65 |
| 2. | 0.25S0.75B | 0.25% | 0.75% | 10.17 | 34.79 |
| 3. | 0.5S0.5B | 0.5% | 0.5% | 10.35 | 38.2 |
| 4. | 0.75S0.25B | 0.75% | 0.25% | 13.04 | 40.52 |
**Split Tensile Strength**

The split tensile strength results are given in Table 6. At 7 days, maximum split tensile strength is 2.73MPa which is observed in 0.25S0.75B mix which is 23.4% more than control mix. When hybrid fiber percentage changes from 0.25S0.75B, 0.5S0.5B and 0.7S0.25B, the split tensile strength is increased by 23.4%, 17.4% and 15.1% respectively with respect to control mix. In the hybrid fibers when chopped basalt fiber increases from 0.25%, 0.5% and 0.75%, the split tensile strength increases by 2.8% and 7.3% respectively. At 28 days, maximum split tensile strength is 3.33MPa which is observed in 0.25S0.75B mix which is 14.1% more than control mix. When hybrid fiber percentage changes from 0.25S0.75B, 0.5S0.5B and 0.75S0.25B, the split tensile strength increases by 14.1%, 8.9% and 5.9% respectively with respect to control mix. In the hybrid fibers when chopped basalt fiber increases from 0.25%, 0.5% and 0.75%, the split tensile strength increases by 3.2% and 5.7% respectively. The maximum split tensile strength at 7 days is 2.73MPa and at 28 days is 3.33MPa, hence 18% increase is observed in maximum split tensile strength of concrete and is obtained in 0.25S0.75B due to high tensile strength of basalt fiber.

**Table 6. Split Tensile Strength of cylinders at 7 days and 28 days**

| S. No. | HyFRC Mix | 7 days Split Tensile Strength (MPa) | 28 days Split Tensile Strength (MPa) |
|--------|-----------|----------------------------------|-----------------------------------|
| 1.     | Control mix | 2.09             | 2.86                               |
| 2.     | 0.25S0.75B | 2.73             | 3.33                               |
| 3.     | 0.5S0.5B   | 2.53             | 3.14                               |
| 4.     | 0.75S0.25B | 2.46             | 3.04                               |

**Shear Strength**

The beams were tested under 4 points bending manually and ultimate load and ultimate deflection was measured. The ultimate load, ultimate deflection, ultimate shear, ultimate bending moment with predominant mode of failure and crack patterns are shown in Table 7. Fig.3 gives the details of the cracking pattern as observed after testing. The ultimate load carrying capacity, ultimate shear load, ultimate bending moment is found in hybrid mix having maximum steel fiber dosage i.e., 0.75S0.25B due to the more load bearing capacity of steel fiber. The ultimate deflection is found in the hybrid mix which is having maximum basalt fiber i.e., 0.25S0.75B due to more tensile strength of basalt fiber which increases the flexural strength. It is visually observed that crack width reduces in beams which are having more basalt fiber percentage in hybrid mix. This may be due to small size of basalt fiber which is behaving as a crack arrestor when cracks are initiated. When only steel fiber is added along with longitudinal reinforcement, diagonal tension failure is observed because when load is increased, it is transferred to steel fiber which takes some shear and bound the concrete in lateral direction which suddenly increases the ultimate load carrying capacity and crack width also increases. It is also observed that the beams with hybrid fibers, first fails in flexure then in shear, which is desired.

The crack pattern observed in the hybrid mixes shows that the beam is failing first in flexure than in shear which is desired. In the control beam when steel reinforcement fails, concrete shows crushing which shows inability of stirrups to reduce crack. The beams with 1S1B without any longitudinal reinforcement fail in flexure at early load, which shows that fibers are not much effective without longitudinal reinforcement. It is also observed that the crack width reduces with increase in the basalt fiber dosage due to the delayed initiation of cracks.
Table 7. Effect of fiber dosage on shear and flexural response of beams

| S. No. | Hybrid FRC mix | a/h ratio | Ultimate load (kN) | Deflection at Ultimate load (mm) | Ultimate Shear (kN) | Ultimate Bending Moment (kN-m) | Predominant Mode of Failure |
|--------|----------------|-----------|--------------------|----------------------------------|---------------------|-------------------------------|-----------------------------|
| 1.     | Control Mix    | 1.33      | 28.27              | 2.19                             | 14.13               | 2.12                          | Shear-Compression failure   |
| 2.     | 0.25S0.75B     | 1.33      | 40.27              | 3.71                             | 20.13               | 3.02                          | Shear Flexural failure      |
| 3.     | 0.5S0.5B       | 1.33      | 43.08              | 2.67                             | 21.54               | 3.23                          | Shear Flexural failure      |
| 4.     | 0.75S0.25B     | 1.33      | 52.94              | 3.25                             | 26.48               | 3.97                          | Shear Flexural failure      |
| 5.     | 1S1B           | 1.33      | 25.48              | 3.00                             | 12.74               | 1.91                          | Flexural failure            |
| 6.     | 0S1B           | 1.33      | 35.22              | 3.19                             | 17.61               | 2.64                          | Web Shear failure           |
| 7.     | 1S0B           | 1.33      | 37.98              | 3.33                             | 18.99               | 2.85                          | Diagonal Tension failure     |

Figure 7. Crack patterns of beams with different fiber dosages

(a) Control beam
(b) Beam with 0.25S0.75B
(c) Beam with 0.5S0.5B
(d) Beam with 0.75S0.25B
(e) Beam with 0S1B
(f) Beam with 1S0B
Effect of Fiber Dosage on Ultimate Load

The variation in ultimate load carrying capacity of beams with different dosage of hybrid fibers when shear span to depth ratio is kept constant is given in Table 7. It is observed that with increase in quantity of steel fiber content in hybrid fibers when added along with longitudinal reinforcement, the ultimate load carrying capacity increases. When fibers are added without longitudinal reinforcement, sudden drop in load carrying capacity is observed as beams become weaker in flexural strength and flexural failure is observed. Maximum load carrying capacity is observed with hybrid fiber dosage of 0.75S0.25B which is 41.86% more than control mix. If the individual fiber effect on the ultimate load carrying capacity is observed then beam with 1% steel fiber dosage shows 25.57% more load carrying capacity with respect to nominal mix.

Effect of Fiber Dosage on Ultimate Deflection of Beams

The variation in ultimate deflection of beams with different dosage of hybrid fibers when shear span to depth ratio is kept constant is given in Table 7. It is observed that beams which are added with fibers experience more deflection as compared to conventional beams. Maximum deflection is observed with hybrid fiber dosage of 0.25S0.75B which is 41% more than control mix. When hybrid steel and basalt fiber dosage is kept equal with and without longitudinal reinforcement then sudden drop in the deflection is observed.

Effect of Fiber Dosage on Ultimate Shear of Beams

The variation in ultimate shear of beams with different dosage of hybrid fibers when shear span to depth ratio is kept constant is shown in Table 7. It is observed that ultimate shear strength increases with increase in steel fiber dosage in hybrid fibers when they are added with longitudinal reinforcement. When fibers are added without longitudinal reinforcement, sudden drop in shear strength is observed. Maximum shear strength is observed with hybrid fiber dosage of 0.75S0.25B which is 46.64% more than control mix. If the individual fiber effect on the ultimate shear is observed then beam with 1% steel fiber dosage shows 25.60% more shear strength than nominal mix.

Effect of Fiber Dosage on Ultimate Bending Moment of Beams

The variation in ultimate bending moment of beams with different dosage of hybrid fibers when shear span to depth ratio is kept constant is shown in Table 7. It is observed that ultimate bending moment increases with increase in steel fiber dosage in hybrid fibers when they are added with longitudinal reinforcement. When fibers are added without longitudinal reinforcement, sudden drop in bending moment is observed. Maximum bending moment is observed with hybrid fiber dosage of 0.75S0.25B which is 46.6% more than the nominal mix. If the individual fiber effect on the ultimate bending moment is observed then beam with 1% steel fiber dosage shows 25.60% more bending moment than nominal mix.

Cost Comparison

In order to check the feasibility of use of hybrid fiber reinforced concrete beams from the point of view of economy and structural integrity, a cost comparison has been done. From the study, it is observed that the structural performance of beams having 0.25S0.75B and 0.75S0.25B fiber dosages is comparable to conventional beams under compressive, tensile and flexural loading and are about 4.2% and 29% cheaper than beams with conventional minimum steel reinforcement with stirrups respectively.

5. Conclusions

The key conclusions obtained from the experimental study are:

- The workability of hybrid steel and basalt fiber reinforced concrete is found lower than the control mix but the concrete mix is still workable. The basalt fiber does not have much effect on the workability due to its small size. The workability reduces from 105mm to 100mm with addition of 1% basalt fiber.
At 28 days, maximum compressive strength obtained is 40.52MPa in 0.75S0.25B hybrid mix which is 21.9% more than control mix. Crimped steel fiber is more dominating than chopped basalt fiber under compressive loading.

At 28 days, maximum split tensile strength obtained is 3.33MPa in 0.25S0.75B hybrid mix which is 14.1% more than control mix. Chopped basalt fiber is more dominating than crimped steel fiber under tensile loading.

The ultimate load carrying capacity of beam increases with increase in steel fiber dosage in hybrid fibers when they are added with longitudinal reinforcement.

Maximum load carrying capacity is found in hybrid fiber dosage of 0.75S0.25B which is 41.86% more than the control mix. Beam with 1% steel fiber only shows 25.57% more load carrying capacity than control mix.

Beams induced with fibers experience more deflection at ultimate load as compared to conventional beams. Maximum deflection is observed in hybrid fiber dosage of 0.25S0.75B which is 41% more than control mix.

When hybrid steel and basalt fiber dosage is kept equal with and without longitudinal reinforcement there is a sudden drop in the deflection at ultimate load.

The shear load capacity increases with increase in steel fiber dosage in hybrid fibers when they are added with longitudinal reinforcement. Maximum shear carrying capacity is found in hybrid fiber dosage of 0.75S0.25B which is 46.64% more than control mix. Beam with 1% steel fiber only shows 25.60% more shear strength than control mix.

All the beams with hybrid steel and basalt fiber as secondary reinforcement show shear-flexural failure. However when steel fiber is added with longitudinal reinforcement, diagonal tension failure is observed and web shear failure is observed when basalt fiber is added with longitudinal reinforcement.

The width of the cracks reduces when the basalt fiber dosage is increased in the concrete mix.

Beam with 0.75S0.25B hybrid fiber dosage and minimum steel reinforcement is found 29% cheaper than the conventional beam with stirrups.

Hence, hybrid steel and basalt fibers are an alternative to the conventional shear reinforcement as they are handled easily and save cost without affecting structural integrity.

6. References

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