An experimental study of changes in performance on retrofitted concrete beams using steel fibers

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ABSTRACT

Many external conditions, like ageing or material degradation amid extremely stressful conditions, as well as mistakes made during the construction phase, can contribute to the failure of a structure, it necessitates the repair and strengthening of reinforced concrete structures. Nowadays, RC buildings are repaired in a different way with different materials. One of the retrofitting options is to use FRC. The cementitious composite employed in Steel fiber reinforced concrete was this research's purpose. It comprises small discrete fibers that behave like internal reinforcement material to improve the performance of the cementitious compound. The major reason for tiny isolated fibers being incorporated into something like a cementitious material is to save costs on cement or concrete. The main rationale for small discrete fibers are injected into cement compound to inhibit elastic cracks, raise tensile strength and deformation capacity, and promote composite toughness. The length and volume of Steel fibers associated in this mix determine the SFRC characteristics. Due to a lack of understanding, design requirements, and building specifications, steel fiber reinforced concrete (SFRC) has only been used in a few constructions in India. As a result, more knowledge on the role of these fibers in concrete mixtures is required. The experimental task involved the performance as mechanical properties of concrete at higher extraction percentages of steel fibers. Being reported in this paper. Compressive strength, split tensile strength, and flexural strength and deflection of beams are among the mechanical parameters studied. As well as the role of steel fiber aspect ratio and volume fraction on certain physical behavior is also seen. The study's major goal, however, was to determine the utility of RC beams reinforced with fibers - reinforced polymer concrete layers, as well as how they deflect under strain. The investigation's goal was to determine whether or not using FRC to reinforce beams enhanced the performance of structures in terms of ultimate load bearing ability, deflected pattern of fracture, and failure mode.

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1 Introduction

Steel fibers of 30 and 60 aspect ratios and the volume fractions of 0.5 %, 1 %, and 1.5% will be used in two unlike aspect ratios. in an experimental study. The concrete mechanical characteristics at various steel fiber volume fractions are included in the experimental work reported in this paper. Mechanical characteristics evaluated with compressive strength, split tensile strength, and flexural strength, as well as the impact of steel fiber aspect ratio and volume fraction on certain mechanical properties. The primary purpose of the research is to determine the significance of fiber reinforced concrete layers in reinforced concrete beams, as well as to investigate their load deflection behaviour.

Because of the high costs and difficulties of reconstructing deteriorating structures, government and commercial groups have been looking for new technologies and materials to extend and increase the life of existing structures. One of the most persuasive ways to increase a structure's structural performance is to use FRC (fiber reinforced concrete). FRC is made up of a random distribution of small discontinuous, internally reinforcing fibers that increase the characteristics of concrete. The purpose of inserting small discrete filaments into a concrete mixture is to improve the composite's toughness and strength (tensile), as well as its cracking deformation properties.

The type of fibers used in the concrete has a significant impact on FRC properties. To strengthen concrete, a variety of short discrete fibers have been employed. Natural organic materials such as cellulose or sisal, Polypropylene, for example, is a synthetic organic substance or carbon, Natural inorganic asbestos and manufactured inorganic materials such as steel or glass are all options. Glass, small discrete steel, polyester, and polypropylene fibers are the frequent reinforcing fibers used in FRC. The diameter, specific gravity, young's modulus, tensile strength, and other qualities of the fibers, and also the extent to which these fibers alter the performance of the cement mix, are utilized to influence the type of fibers used.

1.1 Fiber reinforced concrete

It is a way of composite which comprises short discontinuous fibers that are uniformly distributed and randomly orientated to add structural strength. Steel, glass, synthetic, and natural fibers are examples of diverse types of fibers that give concrete varied properties. Furthermore, various concretes, fibers shapes, morphologies, dispersion, alignment, and concentrations influence the nature of fiber-reinforced concrete. It is not a novel concept to employ fibers or reinforcement. Fibers have been used to reinforce structures since antiquity. Horse hair and straw were once used in mortar and mud bricks.

Early in the twentieth century, Concrete contained asbestos fibers. FRC was among the hot topics when the concept of composite materials was first introduced in the 1950s. A substitute for asbestos was required. Despite the fact that these approaches are occasionally useful and productive, they are frequently ineffective or uneconomical in achieving the desired results. After the substance's health hazards were discovered, it was utilized in concrete and other construction materials. By the mid-19th century, concrete had included steel, glass (GFRC), and synthetic fibers such as polypropylene fibers. The development of new fiber-reinforced concrete is still ongoing.

Concrete fibers have an impact. Concrete fibers are often utilized to minimize cracks caused by plastic shrinkage and drying shrinkage. They also lower concrete's permeability, resulting in less water bleeding. Impact, abrasion, and shatter resistance are all improved in concrete with certain types of fibers. The volume fraction refers to the amount of fiber introduced to a cementitious material as a percentage of the overall volume of the composite (concrete with fibers) (V_f). The value of V_f is normally between 0.1 and 3%.

The AR (aspect ratio) is obtained by the ratio of length of the fiber (l) by the diameter of the fiber (d). An analogous diameter is used to calculate the aspect ratio of fibers with a quasi-circular cross section. If the modulus of elasticity of fibers is larger, the mix of concrete or mortar serve to play the vital role to enhance the tensile strength of materials like concrete or mortars. When aspect ratio of fiber is increased, the matrix's flexural strength and toughness are usually segmented. Longer fibers, on the other hand, have a tendency to "lump" up in the mix and cause workability issues.

According to a recent study, adding fibers to concrete provides a slight impact resistance effect. This finding is significant because it contradicts the widely held belief that adding fibers to concrete improves ductility. Micro fibers beat longer fibers in terms of impact resistance, according to the study, Steel and polymeric fiber blends are frequently utilized in building projects to combine the structural merits of steel fibers with polymeric fibers providing resilience to explosive spalling and plastic shrinkage. In certain instances, in reinforced concrete, steel fiber or macro synthetic fibers can fully change conventional steel reinforcing bar ("rebar").

1.2 Properties of fiber reinforced concrete

The adding up of fibers to mix affects its mechanical qualities, which are significantly dependent on the type and percentage of fiber used. It was discovered that fibers with a high aspect ratio are more effective. Crimped-end fibers have the same properties as straight fibers but use 40% less strands for the same length and diameter. Any engineering material's performance is determined by its physical and mechanical properties, as well as its durability and cost. As a result, it is vital to research the qualities of such a material.

1.2.1 Compressive strength

A solid material's maximum compressive stress tolerance without cracking when subjected to a progressively applied force is known as compressive strength. Compressive strength is calculated using the symbols below:

F / A = Compressive strength

F implies force acting on cross sectional area A.

Fibers have a minor effect on concrete's static compressive strength, with improvements ranging from almost nothing to about 25%. Steel fibers have little impact on compressive strength in members with traditional reinforcement in conjunction to steel fibers. The fibers, on the other hand, improve the material's ductility or energy absorption post cracking.

1.2.2 Tensile strength

Direct tensile strength improvements of up to 133 percent for smooth, straight steel fibers can be achieved when fibers are aligned in the tensile stress direction. On the other hand, the gain in strength for mostly randomly dispersed fibers is substantially smaller, ranging from zero to around 60% in some circumstances, with many investigations finding intermediate values. The results of the SFRC splitting-tension test are equivalent. Incorporating fibers to boost direct tensile strength is unlikely to be beneficial on its own.

1.2.3 Flexural strength

Steel fibers have been discovered to have a much bigger impact on SFRC Flexural strength, which is greater than compressive or tensile strength, with recorded improvements of over 100%. Flexural strength growth is influenced by both fiber volume and fiber aspect ratio, with a larger aspect ratio resulting in a bigger gain in strength.

1.2.4 Modulus of elasticity

With the rise in fiber content of FRC, the modulus of elasticity increases marginally. A 3% increase in the modulus of elasticity was observed for every 1% rise in fiber content by volume, according to research.

1.2.5 Other properties

Fiber reinforced concrete's toughness, fatigue, strength, impact resistance, durability, torsion, shear, and other properties. When fibers are added to concrete, the mixture's hardness is increased by 10 to 40 times that of regular concrete. Concrete's impact resistance is also improved by using fibers. Fibrous concrete is 5 to 10 times stronger than ordinary concrete in terms of impact resistance. The amount of fiber utilized, on the other hand, determines the impact resistance.

The use of fibers reduces the weaknesses that cause plain concrete beams to break quickly. While reducing fracture breadth, it enhances stiffness, torsional strength, ductility, rotational capacity, and the number of cracks per unit area.

Fibers have an impact on the shear properties of concrete. The inclusion of these fibers increases the shear strength of reinforced beams by approximately 100%. Shear-friction strength, first fracture strength, and ultimate strength all improve with the addition of distributed unequally fibers. The aspect ratio (L/D) is obtained by dividing the fiber length by the comparable fiber diameter, is a useful parameter for defining a fiber. For lengths of 6 to 75mm, the typical aspect ratio is around 30 to 150.

2 Objectives

The motivation behind this review is to check whether stringy cement with variable angle proportion steel filaments might be used to support and retrofit built up concrete beams. Therefore, any design needing repair ought to pick this procedure, which has the most un-natural effect, cost, and other development related limitations. Therefore, the motivation behind this review is to expand a definitive exhibition of RC beams while additionally thinking about financial and functional limitations.

The following objectives have been identified for the study: -

- To examine the effect of adding steel fibers with differing aspect ratios to substantial strength characteristics.
- The purpose of this study was to see how shifted steel fiber rates affected significant strength characteristics.
- To check the structural performance of fiber steel beams and concrete beams when it comes to the initial crack load and the failure mechanism.
- Deflection behavior of the beam under loading condition.

- To study the structural behavior of deteriorated concrete beams retrofitted with steel fibers and to compare the stability analysis of steel fiber reinforced concrete beams and concrete beams retrofitted with steel fibers.

3 TEST PROGRAM

The test program as follows was planned –

- To obtain the flexural strength of the beam and then to strengthen them with layer of steel fibrous concrete to evaluate its effects on the flexural strength of the beam.
- To determine the qualities of the constituent materials of the concrete utilized in the study according to applicable Indian Standard norms. To design concrete mix for selecting reference mix.
- To mold cubes and cylinders containing steel fibers of different aspect ratio with different percentages and concrete's compressive and split tensile strength as a result of steel fibers was investigated using the above-mentioned specified mix.
- To cast plain concrete beams containing steel fibers of different aspect ratio with different percentages with above mentioned mix to Identify the impact of steel fibers on the flexural strength of the beam and determine the appropriate aspect ratio and percentage of steel fiber to deploy in retrofitting reinforced concrete beams.
- To load beam under monotonically increasing load till it fail in flexure.
- To load beam which is retrofitted with layer of steel fibrous concrete till it fails.
- To retrofit beam after first crack appears and then loading again.
- To measure deflection of all beams.

These are the tests which will be performed in structural lab to measure cubes' compressive strength, cylinders' split tensile strength, and beams' flexural strength and then, beam will be retrofitted and will measure its strength. All beams will be examined for changes in maximum load bearing, failure modes, and deflections.

4 METHODOLOGY

As per design mix for M30 in given below table 1.

Table 1. Design Mix of M30

Materials	Water (liters)	Cement (kg)	Fine Aggregates (kg)	Coarse Aggregates (kg)
Quantity/m^3	137.5	361.87	434.25	832.50

After 28 days of curing, three experimental mixes were made with varying % of steel fibers and compressive strength was measured. Finally, the trial combination that produced a strength that was near to the characteristic strength was chosen.

With trial mix at a w/c ratio of 0.38, an appropriate target mean strength of 38.25 MPa was determined based on the testing outcomes of trial mixes 1, 2, and 3 in given table 2.

Split tensile and flexural strength for this concrete mix was found to be 3.32MPa and 4.21Mpa, respectively.

Table 2. Trail Mix of M30 with different % of steel.

S. No	Grade of concrete	Trial mix	Load at failure (kN)	Cube compressive strength(f_{ck}) N/mm^2	Average Compressive strength N/mm^2
1	M30	Mix 1	810	36	35.90
			813	36.13	
			807	35.86	
2	M30	Mix 2	833	37.02	36.76
			822	36.53	
			827	36.75	
3	M30	Mix 3	870	38.66	38.60
			862	38.31	
			873	38.80	

Casting and curing of 1200*230*150 beams took 28 days because the influence of steel fibers on flexural strength was calculated experimentally for the use of steel fibers in retrofitting of RC beams. At various volume fractions, the effects of steel fibers with varying aspect ratios were identified. The fraction of steel fibers utilized when the flexural strength is at its highest should be used for retrofitting reinforced concrete beams.

4.1 Specimen details

All specimens are built using a concrete mix that meets the specifications. Four beams type test specimens of the same shape and size were produced in total. These four beams are separated into three groups.

All of the specimens had the same level of detailing. BR1 and BR2 are the two reference beams in Set 1. Set 2 consists of one BW1 beam. As indicated above, this set beam is encased in Fiber Reinforced Concrete in the arrangement with the highest flexural strength. The FRC layers were kept at the bottom. A beam BL1 is part of Set 3.

4.2 Strengthening of beam

The application of FRC layers to reinforce the beams (sets 2 and 3) was completed. The surface layer was roughened with coarse sandpaper after 28 days of cure and cleaned to remove any dirt and debris. Following the preparation of the surface, the epoxy resin was mixed according to the manufacturer's specifications. Fiber reinforced concrete with the maximum flexural strength predicted above was made according to the design mix, and 40mm layers of FRC were glued to the bottom of the beam with epoxy resin. A consistent color mix was created by mixing 100 parts epoxy and 50 parts hardeners. Epoxy glue was applied using a brush to the prepared concrete surface.

4.3 Loading arrangement

A hydraulic jack and a test cylinder plant were used to apply the load under two-point loading. Because the jack only had a single point load, to convert it to a two-point load, a custom-built loading system formed by two of robust mild steel section welded one on one was utilized. To impart load to the specimen, a 25mm diameter roller was used. A roller was positioned beneath the channel part to convey the supplied force as a two-point load to the beam specimen. Roller was relegated to the far corner of the room. A 25mm thick plate on the roller was used to transfer the weight. A cylinder plant with a capacity of 600kN was used to measure the applied load.

To measure deflections in vertical framing members, dial gauges with magnetic base were used. Dial gauges were placed at center and L/4 distance from support. The least count of these dial gauges was 0.01mm.

5 RESULTS

5.1 Variation in compressive strength of concrete with different percentages of steel fibers and different aspect ratio.

The specimens were allowed to dry after curing for 28 days before being tested for compressive strength. When 1 percent volume fraction of steel fibers was added to concrete, the maximum improvement in compressive strength was found to be 5.36 percent, for aspect ratio 30.

For aspect ratio 60, when 1.5 percent volume fraction of steel fibers was added to concrete, the greatest improvement in compressive strength was found to be 12.5% as shown in figure 1.

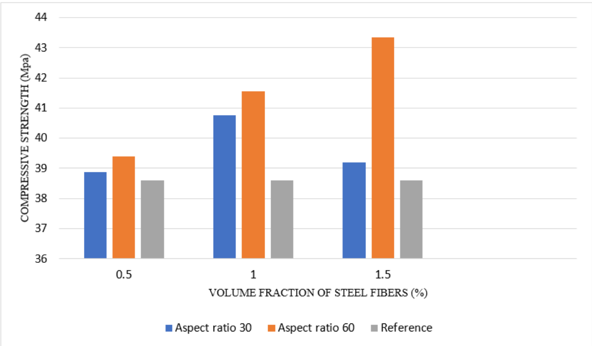

Figure 1: Variation in compressive strength of concrete

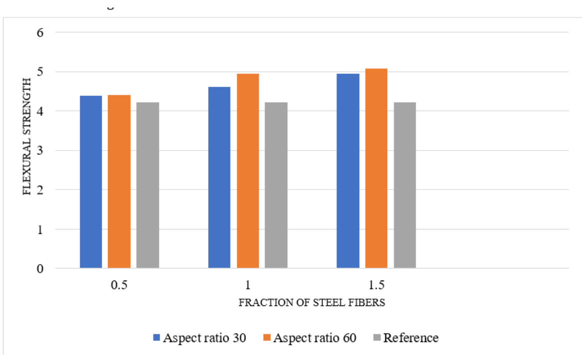

Figure 3: Variation in flexural strength of concrete

5.2 Variation in split tensile strength and flexural strength of concrete at different percentages of steel fibers and different aspect ratio.

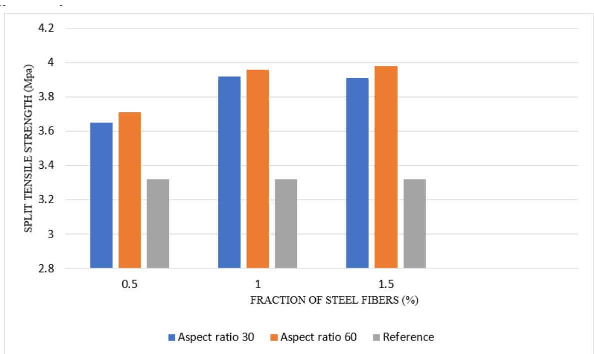

Figure 2: Variation in split tensile strength of concrete

The split tensile strength of concrete containing steel fibers rose considerably as contrasted to concrete lacking steel fibers. This could be due to the fact that as the composite activity between steel fibers and concrete occurs, the tensile strength of the concrete improves effect of Steel fibers on flexural strength of concrete as shown in figure 2 & 3.

5.3 Load deflection behaviour of beams

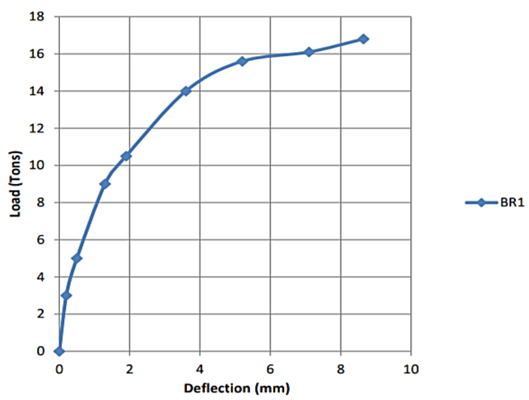

Figure 4: Load deflection behaviour of BR1 beam

As shown in figure 4 the deflection of the reference beams (BR1) rises as the load increases. With a load of 168kN, the highest deflection was 8.65mm. With a dial gauge, the deflection was meticulously recorded.

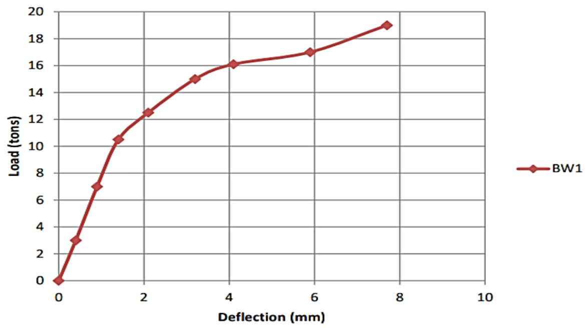

Figure 5: Load deflection behaviour of BW1 beam

The load deflection behaviour of the second set of beams (BW1) with a coating of FRC at the bottom is shown in figure 5 and deflection was considerably decreased when the FRC layer was applied to the bottom of the beam. This behaviour can be observed that fiber-reinforced concrete flexes better than normal concrete. The FRC layer increased the beam's stiffness, which resulted in a decrease in deflection as the load increased.

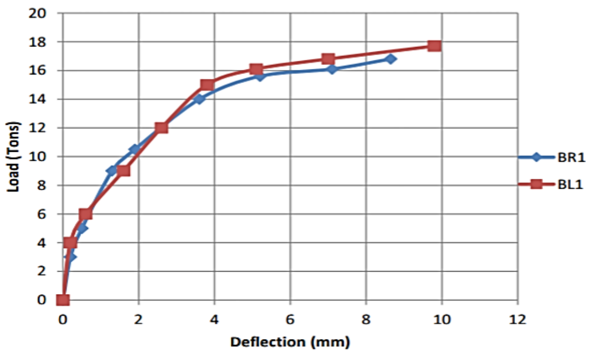

Figure 6: Load deflection behaviour of BR1 and BL1 beam

The load deflection behaviour of a reference beam vs. a damaged reinforced concrete beam fixed with fiber reinforced concrete is shown in figure 6. When the retrofitted beam's deflection was compared to the reference beam's deflection, it was revealed that the retrofitted beam had a higher deflection (13.3 %).

5.4 Effect on ultimate load carrying capacity

When a coating of fibrous concrete was added on the bottom of the beams, the ultimate load rose. The ultimate load value increased by 13.1 % when the bottom of the strengthened beam was coated with a layer of fiber reinforced concrete. This increase in beam load carrying capacity could be attributable to the FRC layer improving the beam's flexural rigidity and it may be inferred that using concrete fibers to boost the beam's ultimate load carrying capability is a realistic option. Beams with an FRC layer have their ultimate load carrying capacity increased by 5.350 %. However, as compared to strengthened beams, the retrofitted beams show a smaller gain because of already established fractures. In reference beams, larger stresses were passed to the fibrous concrete layer, resulting in a reduction in load carrying capability as shown in table 3.

Table 3. Overview of all the experimental outcomes

S. No	Beam	Ultimate load (kN)	Layer of FRC	Centre point deflection (mm)	% increase in ultimate load	Failure pattern
1.	Reference beam (BR2)	168	-	8.65	-	Shear failure
2.	Reference beam (BR1)	161	-	8.30	-	Shear failure
3.	Beam with FRC layer (BW1)	190	At the bottom	7.70	13.10	Shear failure
4.	Beam retrofitted	177	At the bottom	9.40	5.350	Shear failure

Figure 7: Shear failure of BR1 beam

6 CONCLUSIONS

- The compressive strength of typical concrete was enhanced by using steel fibers, by up to 12.25 percent, with aspect ratio 60 having the highest strength at a volume fraction of 1.5 percent. As a result, steel fibers may be easily employed to boost concrete's compressive strength.
- Steel fibers added to concrete improved beam flexural rigidity, resulting in increased beam flexural capacity. When compared to ordinary concrete specimens, maximum flexural strength was observed to be achieved with a maximum improvement in strength of 20.66 percent at 1.5 percent volume fraction of steel fibers at aspect ratio 60.
- Split tensile strength increased in the experimental tests as well. It was revealed that it differed for different aspect ratios at different volume percent ages of steel fibers, with the biggest difference being 19.8% for aspect ratio 60 at 1.5 percent volume fraction.
- According to the findings of this investigation, steel fiber concrete layers can be employed to strengthen reinforced concrete beams with confidence. The ultimate load carrying capacity of a reinforced concrete beam rose by 13.1 percent after a coating of FRC was added to the bottom.
- When steel fibers concrete was used to reinforce and refit reinforced concrete beams, the appearance and propagation of cracks was delayed.

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