Mechanical properties of hybrid polypropylene-steel fibre-reinforced concrete composite

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Abstract. Fibres are materials with axial resistance to load that can withstand tensile stresses also when they are mixed in concrete. Recent research shows that the use of fibres improves the mechanical properties in terms of tensile strength and use of hybrid fibres, the mechanical properties further get improved. This paper presents an experimental investigation to quantify the improved Mechanical Properties for different amounts of mono fibres as hook end steel fibres and hybrid fibres that is a combination of hook end steel and polypropylene fibres. Compressive and splitting tensile strengths, modulus of rupture, and modulus of elasticity are studied. Steel fibres are used in the volume fractions of 0%, 0.1%, 0.3%, 0.5%, 0.7%, 0.9%, 1%, 1.25% and polypropylene fibres in a fixed quantity of 400 gm/m³ in M35 grade concrete. From the results, all the Mechanical properties improve with an increase in the fibre content up to an optimum volume fraction of 0.9%. Addition of steel fibres and polypropylene fibres improves flexural strength and split tensile strengths significantly. However, compressive strength and elastic modulus are slightly improved. It is also observed that the addition of fibres increases the post-peak behaviour of the concrete.

1. Introduction
Concrete is a Strong, reliable, easily mouldable and most sought-after construction. Over seven billion tons of concrete are manufactured on this planet yearly. Fiber Reinforced Concrete (FRC) is a cement composite made with cement, fine aggregate, coarse aggregate, water and fibres. The idea of adding fibres to concrete and other building materials is there since olden days when horsehair has been utilized in mortar and straw in mud blocks. In the 1900s, asbestos strands have been used in concrete. In the 1950s, the idea of utilizing composite materials came into construction practice and FRC had begun to be one of the research areas of interest for concrete technologists. As it was discovered that using asbestos as fibre in concrete is resulting in health hazards for construction workers, the focal point of exploration moved towards finding a substitute for the substance in concrete and other structural materials in place of asbestos. In the 1960s, researchers started studying the use of steel, glass and other manufactured fibres like synthetic, polypropylene and glass in concrete.

Concrete is weak in tension and its tensile strength is around one-tenth of its compressive strength. To overcome this disadvantage, concrete can be reinforced with little randomly dispersed fibres. The collaboration of fibres and concrete ingredients improves numerous properties of concrete like flexibility and reduced crack initiation and propagation because of plastic shrinkage and drying shrinkage. They also reduce permeability and void ratio of concrete. The value of FRC in different Structural Building applications is consequently unquestionable.
The use of SFRC (Steel Fiber Reinforced Concrete) has opened numerous new areas of applications especially in precast, cast in situ, and shotcrete applications. The advantages of SFRC have now been perceived and used in a precast application where designers are searching for more slender segments and progressively complex shapes. Applications include sea- defence, walls and blocks, blast-resistant storage cabins, piles, coffins Pipes, prefabricated storage tanks, highway kerbs, building panels, composite panels and ducts etc. Precast fibre reinforced solid covers and frames are effectively being utilized in India, Europe and USA.

In the ongoing research, Hybrid Fiber Reinforced Concrete (HFRC) in which more than one type of fibre is added to concrete is prominently being utilized in various applications with promising results. The utilization of at least two kinds of fibres resulting in an appropriate blend is found to improve the general properties of concrete thereby bringing about a superior concrete. The process of combination of fibres is sometimes called hybridization.

To optimise overall system behaviour, the mixing of at least two distinct kinds of fibres (diverse in material and or geometry) is getting increasingly normal. The expectation is that the adoption of two or more fibres in concrete would improve the behaviour much superior to that resulted by individual fibres due to synergy between the fibre types. Banthia and Gupta, 2004 [1] characterized this synergy in three categories depending on the mechanisms involved.

1. Fibre constitutive response: One fibre is stiffer and stronger providing strength, while the other is more ductile and provides toughness at high strains.
2. Fibre dimensions: One fibre is very small and controls the formation of microcracks at early stages of loading; the other fibre is larger and provides a bridging mechanism across macrocracks to control the propagation of cracks formed if any.
3. Fibre function: One type of fibre improved fresh mix properties suitable for the required application while the second improved the strength or toughness in the hardened composite.

2. Literature review
The interaction of many fibres and their combinations has already been studied by many researchers. Zhihong and Dorel [2] studied the characteristics of various fibres and their effect on the behaviour of the concrete composites when they are used as reinforcements in concrete. Song and Hwang [3] evaluated some of the mechanical properties of concrete for the various percentage of steel fibres in the volume fraction of 0.5%, 1%, 1.5%, 2%. The Compressive strength is observed to be maximum at 1.5% of volume fraction and is about 15.3% increment. But the Split tensile strength and Modulus of Rupture have got maximum values at 2% of volume fraction, and the improvements are observed to be around 98% and 126% respectively. John et al. [4] observed that the microfibres have been delayed the development of macro cracks so the composite exhibited greater strength and resistance to cracks than the similar matrix which is reinforced with macro fibres only. Yurtseven et al. [5] prepared nine mixes to study the mechanical properties of HFRC. Four types of different fibres have been used in combinations. Among them, two are macro steel fibres and two are microfibres. The volume percentage of fibres has been kept constant at 1.5%. for HFRC the percentage of macro fibres is 1% and the remaining percentage is contributed by microfibres. the compressive strength, split tensile strength, modulus of rupture has been evaluated after 28 days. and these values are compared with the numerical model values to find the effect of the fibre inclusion. The analysis is given that the steel fibres contribute to the strength of the concrete and the microfibres contribute to the ductility of the concrete. Thomas and Ramaswamy [6] conducted an experimental investigation and analytical models have been derived based on the regression analysis to evaluate the influence of adding the fibres on mechanical properties of concrete. Hsie et al. [7] used two types of polypropylene fibres to prepare the HFRC. One is stapled fibres and other is monofilament fibres. The monofilament fibres are used in the quantity of 3 kg/m³, 6 kg/m³, 9 kg/m³. The stapled fibres are used in the quantity of 0.6 kg/m³. From the study, it is observed that the HFRC is showing improved properties when compared with the single fibre reinforced concrete. Staple fibres have good dispersion capacity and fineness so, they can control the premature cracks. The monofilament fibres have high Young’s Modulus and stiffness and these are similar to steel fibres. so,
they can withstand more stress during loading. As, the combination can disperse throughout the mixture the drying shrinkage strain of concrete can be reduced. Bencardino et al. [8] prepared the standard cylindrical specimens of plain and steel fibre reinforced concrete for the volume fractions of 1%, 1.6%, 2%. Tests have been done under compression for stress-strain curves and compared with the numerical model results to evaluate the actual stress-strain relations of fibre reinforced concrete. Padmanabha Rao et al. [9] used two types of hooked steel fibres and one type of twisted steel fibres as reinforcement in the concrete. The various mechanical properties like compressive strength, split tensile strength, first crack load, ultimate load, Elastic modulus, toughness is evaluated to know the type and content of the fibre. From the study, it is found that the compressive strength and Elastic modulus are slightly increased with the steel fibre reinforcement in the concrete but the flexural strength is significantly increased with the steel fibre reinforcement. Singh et al. [10] used HFRC in combinations of steel fibre and polypropylene fibres in the volume fraction of 1-0, 0.75-0.25, 0.5-0.5, 0.25-0.75, 0-1 respectively. The mechanical properties like compressive strength, split tensile strength and flexural toughness have been evaluated. From the results, it is been observed that the combination of 0.75% of steel fibres with 0.25% of polypropylene fibres have given the good improvement in compressive strength, flexural toughness as well as split tensile strength. Gencel et al. [11] added monofilament polypropylene fibres to the self- compacting concrete. The study was done with two cement contents of 350 and 450 kg/m³ as well as with four fibre contents of 3, 6, 9 and 12 kg/m³. The results have shown that the compressive strength, split tensile strength, Elastic modulus, flexural strength have increased significantly up to 9 kg/m³ of fibres. Amir et al. [12] studied the hardened properties of concrete like compressive strength, split tensile strength, flexural strength with the addition of steel fibres and synthetic fibres separately. From the results, it is observed that the steel fibres were found to be effective for flexural strength at an early stage. But at 28 days, the compressive strength, split tensile strength and flexural strength are almost same for two types of fibre reinforced concretes.

2.1. Conclusions from literature
Most of the research projects investigating mechanical properties by mixing of either steel fibres or polypropylene fibres.

A limited number of mostly experimental studies were conducted to investigate the mechanical properties of hybrid fibre reinforced concrete with a combination of micro polypropylene as well as macro steel fibres. Hence the present study has been done by using the combination of steel fibres and polypropylene fibres in concrete. When compared to other micro fibres, polyester is more available fibres as they are the by-product in the textile industry.

3. The objective of the work
The main objective of the work is to evaluate the improvement in various Mechanical Properties (Compressive Strength, Split Tensile Strength, Modulus of Rupture, Elastic Modulus) of concrete by adding macro steel and micro polypropylene fibres in different proportions.

4. Scope of the work
In this study, two types of fibres are used, one is steel fibres and other is polyester fibres. For HFRC, the polyester fibres are taken in fixed quantity as 400gm/m³ of concrete. For SFRC and HFRC the steel fibres are varied in percentages (0%, 0.1%, 0.3%, 0.5%, 0.7%, 0.9%, 1%, 1.25%).

For SFRC for each percentage of steel fibres, 5 specimens of cubes (15 cm × 15 cm × 15 cm), 6 specimens of cylinders (3 for split and 3 for the stress-strain curve of size 15 cm × 30 cm), 3 specimens of prisms (50 cm × 10 cm × 10 cm) are cast.

For HFRC also the same specimens are cast but for 0.7%, 0.9%, 1%, 1.25% of steel fibres only. By studying the results, an attempt is made to know the optimum percentage of fibres to be added to achieve good strength as well as the improvement in the mechanical properties by altering the percentage of steel fibres.
5. Experimental program
5.1. Material details: Ordinary Portland cement conforming to IS 12269 1983 [13] with specific gravity 3.15, Zone II fine aggregate with specific gravity 2.74 and crushed coarse aggregate of a combination of 4.75 mm size passing and 10 mm retained proportion and 10 mm passing -20 mm retained proportion with specific gravity 2.74 was used in the mix. A combination of Duraflex hook end Steel fibres and Recron 3S polyester fibres are used in this study. Potable water was used for mixing.

5.1.1. Fibbers
a) Duraflex Hook ends steel fibres (figure 1).
Duraflex (Hook End Steel) Fibbers are unglued and loose fibres made of high strength steel (> 100 MPa) developed for convenient and cost-effective mixing in concrete as reinforcement. The Fibers are as per ASTMA820 [14] M04 Type I Standards. These fibres in concrete enhance one or more of the following properties of concrete.
• ductility
• overall efficiency
• load-bearing capacity
• flexural Strength
• microcracking Mechanism
• mechanical anchorage substantially
• impact Resistance
• fatigue strength
• flexibility with various types of Portland cement, admixtures and shotcrete mix designs
These fibres are loose and unglued and hence requires less labour and time to place in concrete than with glued steel fibre. It also results in even distribution in the concrete mix in a fast and convenient manner thus effective in avoiding balling, it also reduces overall cost significantly. Table 1 presents the properties of Duraflex hooked end Steel fibres.

| Length | Diameter | Aspect ratio | Young’s modulus (N/mm²) |
|--------|----------|--------------|-------------------------|
| 50 mm  | 0.9 mm   | 55           | 210000                  |

Applications. These fibres are presently being used in Shotcrete in Mines/Tunnels, Industrial Floorings, Pavements, Highways, Roadways and Bridges, Precast Structures and elements, Seismic Resistant structures (Dams), Explosive and Impact resistance Structures.

Figure 1. Duraflex hook end steel fibres

Figure 2. Recron 3S polyester fibres
Recron 3S polyester fibres (figure 2) Recron 3S polyester fibres used in this study belong to the thermoplastic polymer group and are available in monofilament form. They are a by-product from the textile industry and are temperature sensitive and hydrophobic in nature. These non-biodegradable fibres unlike glass, steel or carbon fibres and belong to the low-modulus fibres group. They are added to the concrete as 0.1 % by volume to

- control cracking due to plastic and drying shrinkage in concrete.
- improve the abrasion resistance of concrete.
- reduce the water permeability.
- reduce rebound loss
- increase ductility.

The extent of improvement in any property depends on the length, diameter and dosage of the fibre. Table 2 presents the properties of Recron 3S Polyester Fibres

| Property           | Value                                      |
|--------------------|--------------------------------------------|
| Cut length         | 6-12mm                                     |
| Shape              | Special for the improved holding           |
|                    | of cement aggregates                       |
| Tensile strength   | 4000-6000 kg/cm²                           |

5.1.2. Mix Design
The mix proportions adopted in this study are shown in Table 3.

| Description          | Mix proportion (by weight) |
|----------------------|----------------------------|
| Cement               | 1                          |
| Sand (Fine aggregate)| 2                          |
| Coarse aggregate     | 2                          |
| Water                | 0.5                        |

5.1.3 Specimen making procedure:
Locally available potable water was used for mixing concrete. Iron cube, cylinder and beam moulds of standard size are used for casting specimens. Both table and needle vibrator were used to thoroughly compacting the concrete in the moulds. The moulds were sealed by plaster of Paris avoid leakage of cement slurry through the gaps of the joints. The inside edges of all the moulds are oiled before pouring concrete the miller mixed concrete ingredients as per mix design into them. After compacting the concrete in the moulds, the top surface of the specimens was levelled with a trowel. After demoulding the concrete specimens after 24 hours of casting, the specimens are immersion cured in potable water for a period of 28 days for curing.

6. Test setup and testing procedure
6.1. Testing compressive strength
Cubes of size 150 mm are placed under the 3000 kN CTM as shown in figure 3 and the rate of loading is applied at a rate of 5kN/sec. The maximum load that the cube can take under compression will be considered as the compressive strength of the cube.

6.2. Testing for split tensile strength
For testing the split tensile strength of the concrete standard cylinders of diameter 15cm and height 30cm are used. The cylinder specimens are placed under CTM as shown in figure 3. The load is applied at a rate of 5kN/sec. and the maximum load at which the cylinder fails will be noted. The splitting tensile strength of concrete is calculated by using the following formula
Split tensile strength \( T = \frac{2P}{\pi DL} \)

Where,
\( P \) = the maximum load taken by the cylinder at failure
\( D \) = diameter of the specimen
\( L \) = length of the specimen.

6.3. Testing of cylinders for Stress-strain curve
For obtaining the Modulus of Elasticity of concrete, the stress-strain curve for the standard cylinder specimen of diameter 15cm and height 30cm are used. Longitudinal compresso-meter with an attached dial gauge is attached to the cylinder as shown in figure 3 and then is placed under the CTM. The load is applied and the corresponding deflection is noted in the dial gauge. From the recorded values Stress-Strain curves are plotted. The slope of the Stress-Strain curve will give the Young’s Modulus.

6.4. Testing of prisms
Standard prisms of square cross-section 10cm and length 50cm are tested by 4-point loading as shown in figure 3. The load is applied in the UTM and the corresponding deflection is noted. The modulus of rupture will be calculated as \( \frac{3FL}{4BD^2} \)

Where \( F \) is the maximum load at the fracture point, \( L \) is the length between the supports, \( B \) is the width of specimen and \( D \) is the depth of specimen

\[ \text{Figure 3. Specimens under testing for Compressive strength, Splitting tensile strength, Modulus of Elasticity and Flexural strength (respectively)} \]
7. Results and Discussions

The experimental results of all specimens with different combinations of Steel fibre contents are presented in this section. Their behaviour throughout the test is described using recorded data of all the specimens that are tested for their ultimate strengths. 0% of steel fibres specimens are taken as the control specimens for comparison. It is observed that the control specimens had less load carrying capacity values compared to that of the other specimens. The study is to evaluate various mechanical properties. They are compressive strength, Split Tensile Strength, Modulus of Rupture, Stress-Strain Curves, Young’s Modulus. The recorded test results in graphical form are presented along with discussion as follows.

7.1. Compressive strength

It can be observed from figure 4 that for concrete with addition of steel fibres alone, the Compressive strength is following a slight increment profile with the increase in the percentage of steel fibres up to 0.9% of steel fibres. After that a slight decrease in the compressive strength is observed i.e., the addition of steel fibres to the plain concrete is increasing its compressive strength by 9.17% at 0.9% of steel fibres after that no significant improvement even fibres are added.

![Figure 4. Comparison of compressive strength](image)

7.2. Split tensile strength

It can be observed from figure 5 that for concrete with addition of steel fibres alone, the Split Tensile Strength is following a slightly increasing profile up to 0.9% of fibres after that a slight decreasing profile i.e., the addition of steel fibres is slightly increasing the split tensile strength when compared with the plain concrete. The split tensile strength is increased by 52% at 0.9% of steel fibres when compared with the 0% of steel fibres. After 0.9% of steel fibres, the increase in the percentage of steel fibres is not significant.

The split tensile strength is slightly increased for HFRC when compared with the SFRC. The split tensile strength is increased by 58.24% for HFRC at 0.9% of steel fibres which is slightly greater than 52% for SFRC i.e., the addition of micro-fibres improving the split tensile strength of concrete.
Figure 5. Comparison of Split tensile strength

7.3 Comparison of peak load

From figure 6, the peak load in the flexure test is increasing with the increase in the percentage of steel fibres. It is maximum at 0.9% of steel fibres. When comparing SFRC with the HFRC the increase in the peak load is more for HFRC. For HFRC the peak load is increased by 218.41% at 0.9% of fibres, which is greater than 174.88% for SFRC at 0.9% of steel fibres when compared with the 0% of steel fibres. i.e. the addition of microfibres will increase the load-carrying capacity in flexure.

Figure 6. Comparison of Peak load
7.4. Individual Load-Deflection behaviour of Hybrid and Steel Fiber Reinforced concrete
From the load-deflection curves shown in figure 7, it is clear that the peak load, as well as the peak deflection, are increasing with an increase in the percentage of steel fibres for both SFRC as well as HFRC when compared with the control specimen. The peak load is increased by 171.28% and deflection by 51.72% at 0.9% of steel fibres for HFRC. Whereas the peak load is increased by 218.41% and the deflection by 60.68% for HFRC at 0.9% of steel fibres.

7.5. Comparative Load-Deflection behaviour of Hybrid and Steel Fiber Reinforced concrete
From all four graphs in figure 8, it is clear that the load-carrying capacity, as well as the deflection, are increasing with the addition of microfibres in HFRC when compare with the SFRC. For 0.7% of steel fibres, HFRC is exhibiting increment of 8.28% in peak load and 7.6% in deflection when comparing with the SFRC. Similarly, at 0.9% of steel fibres HFRC is exhibiting an increment of 15.8% in peak load and 15.9% in deflection, at 1% of steel fibres HFRC is exhibiting increment of 15.3% in peak load and 13.6% in deflection, at 1.25% of steel fibres HFRC is exhibiting increment of 14.65% in peak load and 12.26% in deflection when compare with the SFRC at the same percentage of steel fibres respectively.

Figure 7. Individual Load – deflection behaviour of Hybrid and Steel Fiber Reinforced concrete
7.6. Comparison of Modulus of rupture
From figure 9, it is observed that for concrete with addition of steel fibres alone, the Modulus of Rupture is following an increment profile up to 0.9% of steel fibres after that it is slightly decreasing.

7.7. Comparison of Young’s modulus
Young’s modulus is calculated as the slope of the initial tangent drawn on the stress-strain curves as shown in figures 11 and 12. The value of Young’s modulus is calculated and compared for different amounts of fibres proportions and shown in figure 10. It is observed that for concrete with the addition of steel fibres.
of steel fibres alone, the Elastic Modulus is following the increasing profile up to 0.9% of steel fibres after that a slight decrease in the profile observed. After 0.9% of steel fibres, the Elastic Modulus became constant, i.e., the addition of steel fibres greater than 0.9% is not effective. The Elastic Modulus is increased by 10.15% at 0.9% of steel fibres when compared with the 0% of steel fibres. The modulus of Elasticity is increasing with the increase in the % of steel fibres for both HFRC and SFRC. For SFRC the Modulus of Elasticity is increased by 10.15% and for HFRC it is increased by 12.65% at 0.9% of steel fibres when compared with the 0% of steel fibres. The stress-strain curves for all the combinations of SFRC are presented in figure 11 and for all the combinations of HFRC are presented in figure 12.
Figure 11. Stress-strain curves for finding Young’s modulus of SFRC

e) 0.9% SFRC

\[ y = 16095x - 0.0013 \]

f) 1% SFRC

\[ y = 15835x + 0.0017 \]

g) 1.25% SFRC

\[ y = 15931x - 0.0044 \]

Figure 12. Stress-strain curves for finding Young’s modulus of HFRC

h) 0.7% HYBRID FIBRE

\[ y = 16460x + 3E-05 \]

i) 0.9% HYBRID FIBRE

\[ y = 15895x - 0.0009 \]

j) 1% HYBRID FIBRE

\[ y = 15894x + 0.0037 \]

k) 1.25% HYBRID FIBRE

\[ y = 16931x - 0.0017 \]
8. Conclusions
The Mechanical properties of concrete play a vital role in improving the applicability of concrete. The change in the various mechanical properties has been reported for variation in the percentage of steel fibres and various combinations of hybrid fibres from the analysis of the recorded data. After analysing the results, the following conclusions have been made.

1. The addition of steel fibres to the plain concrete is increasing its compressive strength by 9.17% at 0.9% of steel fibres in SFRC. After that no significant improvement even when fibres are added.
2. For HFRC the compressive strength is increased by 9.82% which is slightly higher than 9.17% at 0.9% of fibres.
3. The split tensile strength is increased by 52% at 0.9% of steel fibres for SFRC. When compared with the 0% of steel fibres. After that, no significant improvement is observed even after fibres are added.
4. The split tensile strength is slightly increased for HFRC when compared with the SFRC. The split tensile strength is increased by 58.24% for HFRC at 0.9% of steel fibres which is slightly greater than 52% for SFRC.5. The peak load in flexure test is increasing with the increase in the percentage of steel fibres. It is maximum at 0.9% of steel fibres. When comparing SFRC with the HFRC the increase in the peak load is more for HFRC. For HFRC the peak load is increased by 218.41% at 0.9% of fibres, which is greater than 174.88% for SFRC at 0.9% of steel fibres when compared with the 0% of steel fibres.
6. The peak load is increased by 171.28% and deflection by 51.72% at 0.9% of steel fibres for HFRC. Whereas the peak load is increased by 218.41% and the deflection by 60.68% for HFRC at 0.9% of steel fibres.
7. The load-carrying capacity, as well as the deflection, are increasing with the addition of microfibres in HFRC when compare with the SFRC. For 0.7% of steel fibres, HFRC is exhibiting increment of .28% in peak load and 7.6% in deflection when comparing with the SFRC. Similarly, at 0.9%of steel fibres HFRC is exhibiting an increment of 15.8% in peak load and 15.9% in deflection, at 1%of steel fibres HFRC is exhibiting increment of 15.3% in peak load and 13.6% in deflection, at 1.25% of steel fibres HFRC is exhibiting an increment of 14.65% in peak load and 12.26% in deflection when compare with the SFRC at the same percentage of steel fibres respectively.
8. The Modulus of Rupture is increased by 171.28% at 0.9% of steel fibres for SFRC when compare with 0% of steel fibres.
9. For SFRC the Modulus of Rupture is increased by 171.28% and for HFRC it is increased by 218.41%. Adding of microfibres is improving the Modulus of rupture by 47.13%.
10. The Elastic Modulus is increased by 10.15% at 0.9% of steel fibres for SFRC when compare with 0% of steel fibres.
11. For SFRC the Modulus of Elasticity is increased by 10.15% and for HFRC it is increased by 12.65% at 0.9% of steel fibres when compared with the 0% of steel fibres.
12. From all the results at 0.9% of steel fibres the maximum increment in all properties will be achieved. So, 0.9% of steel fibres can be taken as an optimum percentage of steel fibres.

9. Future scope
The present study is done on varying the percentage of steel fibres and constant quantity of micro(polyester) fibres as 400gm/m³of concrete. So, the study can be extended to variation of the mechanical properties by varying the number of microfibres along with the steel fibres. The optimum combination of steel fibres, as well as micro-fibres, can be derived. A lot of scope is there for the present study by using various types of micro as well as macro fibres

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