

Flexural Behaviour of Hybrid Fibre Reinforced Concrete Beam

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Abstract—Concrete is a heterogeneous composite material made up of cement, sand, coarse aggregate and water mixed in a desired proportion to obtain the required strength. Plain concrete does not stand tension as compared to compression. In order to compensate this drawback steel reinforcement are provided in concrete. Now a day, for improving the properties of concrete and also to take up tension different types of fibres are added to concrete. Many studies shows that the addition of small closely spaced and uniformly distributed fibres in concrete would increase the tensile strength, cracking resistance, impact strength and improve other structural properties of concrete. In this thesis work the properties of concrete with the addition of hybrid fibre (combination of polypropylene and steel fibre) was studied. From the fresh and hardened properties of concrete, the optimum percentage of polypropylene fibre in concrete was found out as 0.25% by weight of cement. For finding the optimum percentage of hybrid fibre in concrete, split tensile strength test and flexural strength test were conducted in the laboratory and it was observed that combination of 0.25% of polypropylene fibre by weight of cement and 0.75 % of steel fibre by weight of concrete as the optimum percentage. The flexural behavior of RC beam containing the optimum percentage of polypropylene fibre, steel fibre and hybrid fibre were studied. From the test results it was observed that the hybrid fibre reinforced concrete beam gives the better performance on ductility, energy absorption and load carrying capacity

Keywords—*fibre reinforced concrete; hybrid fibre reinforced concrete; polypropylene fibre; steel fibre*

I. INTRODUCTION

Concrete is the most widely used man made construction material in the world. It is obtained by mixing cementing materials, water and aggregates, and sometimes admixtures in required proportions. The mixture when placed in forms and allowed to cure, hardens into rock-like mass known as concrete. The hardening is caused by chemical reaction between water and cement and it continuous for a long time and consequently the concrete grows stronger with age. The hardened concrete may also be considered as an artificial stone in which the voids of larger particles (coarse aggregate) are filled by the smaller particles (fine aggregate) and the voids of fine aggregate are filled with cement. In a concrete mix, the cementing material and water form a paste

called cement - water paste which in addition to filling the voids of the fine aggregate, coats the surface of the fine and coarse aggregate and binds them together as it cures, thereby cementing the particles of the aggregate together in a compact mass. It is characteristic that the properties of concrete ingredients have a major influence on the fresh and hardened concrete.

Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop. Now a day, the definition of concrete would cover a wide range of products. Concrete is made with several type of cement and also containing pozzolanos, fly ash, blast furnace slag, additives, admixtures, polymers, fibres and so on.

In certain circumstances especially in flexural members where the tensile load is predominant, it is very much essential to increase the tensile capacity of the concrete. So incorporating fibres in concrete holds a great importance in the construction field. Fibers used in concrete pavements are typically made from steel or plastic and are available in a variety of lengths, shapes, sizes, and thicknesses. They are added to fresh concrete during the batching and mixing process[1].

The fibres are being used in the concrete for increasing the tensile strength. The concrete fails before the fibre fails and therefore the fibres will bridge the cracks formed in the concrete during the application of load. The combination of fibre and matrix made the concrete equipped with improved toughening effect. The fibre bridging leads to the energy absorption and there by formation of cracks can be arrested. Adding fibres to concrete greatly increases the toughness of the material [2]. The significance of toughening effect cannot be considerably large, but the combined effect of all such bridging in the whole concrete can contribute a considerable toughening effect to the concrete. The fibre bridging mechanism[3] controls the widening of cracks and thereby reduces the stress intensity at the crack points. Fibres having lower modulus of elasticity are expected to enhance

strain performance whereas fibres having higher modulus of elasticity are expected to enhance the strength performance. Moreover, the addition of hybrid fibres makes the concrete more homogeneous and isotropic and therefore it is transformed from brittle to more ductile material [4].

Polypropylene (PP) is a popular fibre due to its properties like low density, easy process ability, excellent orientation characteristics, superior tensile properties, good chemical resistance, hydrophobicity and resistance to micro-organisms. Polypropylene fibers in general are effective in controlling plastic shrinkage cracking in concrete[5] These properties have resulted the use of PP fibre in the manufacture of carpets, rugs, apparel, home furnishings, geotextiles, strappings, personal hygiene products, medical drapes and various other applications. Recently their applicability is extended to structural elements also.

Polypropylene fibres are non-polar and hence do not cling together. The bundles of fibre added to concrete spread easily and uniformly into the concrete matrix. The advantages of using polypropylene fibre in concrete are as follows.

- It is chemically inert, alkali resistant and free from corrosion
- PP fibre is more workable, lighter in mass and cheaper than steel fibres
- Polypropylene has hydrophobic surface that prevents it from being wet by the cement paste. The hydrophobic nature of the polypropylene fibre does not affect the mixing water requirements of concrete
- Cohesiveness is more
- Water demand is nil for polypropylene fibre
- Light, easy to spread into place
- Greater fatigue strength

Several manufacturers currently produce polypropylene fibre specifically for the use in concrete as a form of secondary reinforcement as they possess many properties that make them particularly adaptable for use in concrete. Polypropylene Fibre Reinforced Concrete (PFRC) can be used under the following circumstances

- Rigid highway pavements
- Runways and taxiways in airports
- Blast resistant structures
- Structures subjected to dynamic loading
- Intake structures, spillways etc.

The development of micro cracks leads to the corrosion of reinforcement thereby results in the failure of concrete. The micro cracks are invisible to the naked eye and formed due to the stresses developed during shrinkage and by static and low energy impact loading. By using polypropylene fibre as a secondary reinforcement material, the micro cracks can be arrested to a great extent. From the past studies the introduction of polypropylene fibre in concrete mix substantially reduces the shrinkage stresses of structural members. The other major factor that affects the properties of fibre reinforced concrete is the bond strength of fibre with

cement paste. Due to the abrasive action of aggregates, bundles of polypropylene fibres added to concrete are separated into millions of individual strands. The fibres are distributed throughout the entire matrix, providing same property in all directions. When the structure is subjected to the peak tensile load in normal concrete (NC), brittle failure occurs. The fibre reinforced concrete structure also fails at the peak tensile load but do not deform and can maintain the load to very large deformations. The fibres in the matrix bridges the cracks and can maintain pull out process, such that the deformation can continue only with the increase of load.

Reinforcing fibres stretch more than concrete under loading. So, the composite behaviour of fibre reinforced concrete is assumed to behave as conventional reinforced concrete until it reaches its first crack load. After reaching first crack load, the fibre reinforcement takes over and holds the concrete together. Reinforcing fibres do not have a deformed surface unlike larger steel reinforcing bars with non-smooth surface which helps mechanical bonding. This condition limits performance to a point far less than the yield strength of the fibre itself. This is important because some fibres pull out easier than others and will affect the toughness of the PFRC.

Toughness is based on the total energy absorbed prior to complete failure. The main properties influencing toughness and maximum loading of fibre reinforced concrete are based on the type of fibres used, percentage of the fibre, the aspect ratio and the orientation of the fibre in the matrix. The other factors that control the performance of the fibre reinforced concrete are physical properties and the bond strength between fibres and matrix. The chemical properties of the fibre in terms of their inertness or reactivity with the surrounding environment to form chemical bond play an important role in determining the bonding characteristics of the fibre and the composite.

Concrete containing hydraulic cement, water, fine and coarse aggregate and discontinuous discrete steel fibres is called Steel Fibre Reinforced Concrete (SFRC). Fibres of various shapes and sizes produced from steel are being used.[6]. Steel fibres are the most commonly used fibre in structural and non-structural applications. The behaviour of concrete under post cracking can be improved by the incorporation of steel fibre in concrete. Although in the fibre-reinforced concrete the ultimate tensile strength do not increase appreciably, but the tensile strain increases at failure points. Compared to plain concrete, steel fibre-reinforced concrete is much tougher and more resistant to impact.

Hybrid Fibre Reinforced Concrete (HFRC) is a combination of different types of fibres, which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. Fibre Reinforced Concrete (FRC) is containing fibrous material, which increases its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres each of which lend varying properties to the concrete. In addition, the properties of fibre reinforced concrete changes with different types of concrete, fibre

materials, geometric conditions, distribution, orientation, and densities. In HFRC, two or more different types of fibres are rationally combined to produce a composite that derives benefits from each of the individual fibres and exhibits a synergistic response. The hybrid combination of metallic and non-metallic fibres can offer potential advantages in improving the properties of concrete. The use of different types of fiber in a suitable combination may potentially improve the mechanical properties of concrete and result in synergic performance [7].

The present study is to determine the structural properties of concrete added with steel fibre and polypropylene fibre.

II. AIM OF THE STUDY.

In the thesis work, a detailed experimental investigation was conducted and the objective of the study includes:

1. To design M20 mix
2. To find the optimum percentage of polypropylene fibre in M20 mix.
3. To study the fresh and hardened properties of PFRC.
4. To find the optimum percentage of hybrid fibre reinforced concrete (polypropylene and steel) in M20 mix.
5. To study the flexural behaviour of RC beam containing control concrete, beam containing optimum percentage of polypropylene fibre, steel fibre and hybrid fibre reinforced concrete

III. METHODOLGY

The mix proportion for the M20 was to be found out by preparing various trial mixes by keeping water cement ratio constant and varying cement content. Using mix proportion so obtained, the optimum dosage of polypropylene fibre was to be found out by conducting test on hardened properties of concrete such as cylinder compressive strength test, cube compressive strength test, split tensile strength test, flexural strength test.

The optimum percentage of steel fibre was taken as 1% as obtained from the literature study [8-10]. The optimum dosage of the hybrid fibre in concrete was to be found out by choosing three different volume fraction of polypropylene fibre and three different fraction of steel fibre. The volume fractions to be adopted for the polypropylene fibre were 0.15%, 0.2% and 0.25%, and the volume fractions adopted for the steel fibre were 0.5%, 0.75% and 1%. Flexural strength test and split tensile strength test were to be studied for various combinations of fibre volume fractions for obtaining the optimum hybrid fibre percentage. The other hardened properties such as cube compressive strength, cylinder compressive strength and modulus of elasticity of mix with optimum hybrid fibre percentage would be studied.

The flexural behaviour of reinforced concrete beam containing the optimum percentage of polypropylene fibre, steel fibre and hybrid fibre would be studied under two point loading. Deflection at mid span, reading from the LVDT fixed

at top and bottom of the beam corresponding to each increment of load was to be measured. From the observations from the experiment, load deflection graph, energy absorption, ductility factor, crack patterns were to be studied.

IV. EXPERIMENTAL INVESTIGATION

A. Materials

Pozzolana Portland Cement, sand, coarse aggregate, Polypropylene fibre (Recron 3S) and water were used for making the various concrete mixes considered in this study. Pozzolana Portland cement of 43 grade (Shankar) was used in the investigation. The specific gravity of cement is 3.15. Water suitable for drinking was used for mixing and curing of concrete specimens. M sand (<4.75mm) having fineness modulus 3.056 and specific gravity 2.51 was used as fine aggregate. Fine aggregate used conforms to Zone I grade of IS 383:1970 Specification. The coarse aggregate having specific gravity 2.926 and fineness modulus 7.168 was used. Admixture was used to get the required workability. The admixture used was conplast sp430 manufactured by FOSROC chemicals. Polypropylene fibre used in the present study is 'RECRON 3S' of Reliance Industries Limited. These fibres are monofilament fibres with length of 12 mm and thickness of 18 microns were used. The steel fibres used are of crimped type having aspect ratio 25. The reinforcement details of the beam used for the study are shown in the Fig 1.

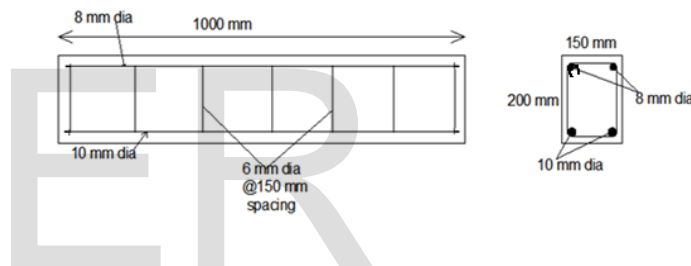


Fig 1 Reinforcement Details of RC Beam Used For the Study

B. Mix Proportion

The mix proportion (Water: Cement: Fine aggregate: Coarse aggregate) was arrived at based on IS: 102626 (2009) and the proportion is 0.5:1: 1.91: 3.36.

C. Prepration of test specimens

For finding the optimum percentage of polypropylene fibre in M20 concrete, various percentages of polypropylene fibre were adopted for the study which includes 0%, 0.1%, 0.15%, 0.2%, 0.25%, 0.3% by the weight of cement. Mixing of concrete was done in the laboratory type pan mixer. For determining the fresh properties of concrete, slump test was conducted for each mix to assess the workability.

Tests were conducted in the laboratory to determine the mechanical properties such as compressive strength, split tensile strength, flexural strength and modulus of elasticity which are used to determine the optimum percentage of polypropylene fibre in concrete The specimens used for the hardened test on concrete to determine the

optimum dosage of polypropylene fibre were tabulated in the table 1

TABLE 1 SPECIMENS USED TO DETERMINE THE OPTIMUM PERCENTAGE OF POLYPROPYLENE FIBRE

Sl. No	Experiment	Specimen	Dimension (mm)	Nos.
1	Cube comp: strength	Cube	150 x 150 x 150	18
2	Cylinder comp: strength	Cylinder	Ht. 300, dia 150	18
3	Split tensile strength	Cylinder	Ht. 300, dia 150	18
4	Flexural strength	Beam	100 x 100 x 500	18

For determining the optimum percentage of hybrid fibre in M20 concrete, different combinations of polypropylene fibre and steel fibre were chosen. The three volume fractions of polypropylene such as 0.15%, 0.2% and 0.25% (weight of cement) and three volume fraction of steel fibre such as 0.5%, 0.75% and 1% (weight of the concrete) were adopted as the different combinations. Split tensile strength and flexural strength were done to determine the optimum percentage of hybrid fibre. The details of specimen for finding the optimum dosage of hybrid fibre were given in the table 2

TABLE 2 SPECIMENS USED TO DETERMINE THE OPTIMUM PERCENTAGE OF HYBRID FIBRE

Sl. No	Experiment	Specimen	Dimension (mm)	Nos.
1	Split tensile strength	Cylinder	Height 300, dia 150	36
2	Flexural strength	Beam	100 x 100 x 500	36

With the optimum dosage of hybrid fibre, the hardened properties such as cube compressive strength, cylinder compressive strength and modulus of elasticity of hybrid fibre with optimum dosage were also determined. The details of specimens for the same is given in the table 3

TABLE 3 SPECIMENS USED TO DETERMINE THE HARDENED PROPERTIES WITH OPTIMUM DOSAGE OF HYBRID FIBRE

Sl. No	Experiment	Specimen	Dimension (mm)	No s.
1	Cube comp: strength	Cube	150x150x150	3
2	Cylinder comp: strength	cylinder	Ht 300, dia 150	3

V. RESULTS AND DISCUSSIONS

A. Fresh Properties

The result of slump test for various percentages of PP fibre is given in the table 4

TABLE .4 SLUMP TEST ON VARIOUS VOLUME FRACTION OF POLYPROPYLENE FIBRE

Volume fraction of fibres Vf (%)	Slump in mm of concrete mix with super plasticizer dosage of			
	0.0%	1.0%	1.5%	2.0%
0	73	--	--	--
0.1	68	68	77	87
0.15	66	66	76	86
0.2	65	65	75	84
0.25	65	65	74	83
0.3	61	61	69	77

From the result of slump test after adding the super plasticizer (SP), it was observed that 1.5% SP at 0.25 % polypropylene gives the slump value 74 mm nearing to that of conventional concrete at all other conditions remaining same. The workability was very much reduced when the Steel Fibre (SF) was introduced into the concrete. The percentage of super plasticizer that obtained for making the polypropylene fibre workable was adopted for the hybrid concrete also and found that the workability of hybrid fibre in concrete increases by a considerable amount. The table 5 shows the slump value obtained for hybrid concrete added with 1.5% super plasticizer

TABLE.5 SLUMP VALUE OF CONCRETE CONTAINING HYBRID FIBRE AT 1.5% SP ADDITION

Specimen designation	Slump value (mm)	Specimen designation	Slump value (mm)
* S ₀ ⁰	73	S _{0.25} ^{0.75}	70
S _{0.15} ^{0.5}	74	S _{0.2} ^{0.75}	72
S ₁ ⁰	64	S _{0.25} ^{0.75}	72
S _{0.25} ¹	63	S _{0.25} ^{0.5}	74
S _{0.2} ¹	62	S _{0.2} ^{0.5}	74
S _{0.15} ¹	62	S _{0.15} ^{0.5}	76

*S denotes specimen and prefix denotes the percentage of steel fibre and suffix denotes the percentage of polypropylene fibre

From the slump values, it was found that 1.5% SP dosage in hybrid fibre reinforced concrete gives the required slump

B. Hardened Properties of concrete with polypropylene

Standard tests were conducted to determine the mechanical properties of PP fibre concrete for finding the optimum percentage of PP fibre in M20 concrete. The test results are tabulated in table 6

TABLE 6. STRENGTH OF CONCRETE MIX WITH VARIOUS PERCENT OF FIBRE

Volume fraction of fibres, Vf (%)	Cube Strength (N/mm ²)	Cylinder Strength (N/mm ²)	Split Tensile Strength (N/mm ²)	Flexural Strength (N/mm ²)	Modulus of Elasticity (N/mm ²)
0	28.40	17.36	2.56	5.87	3.46X 10 ⁴
0.1	28.49	17.52	3.21	5.904	3.46X 10 ⁴
0.15	28.78	17.56	3.46	6.32	3.58X 10 ⁴
0.2	29.52	18.35	3.55	7.28	3.6X 10 ⁴
0.25	30.26	18.93	3.60	7.532	3.66X 10 ⁴
0.3	29.23	18.11	3.70	7.024	3.66X 10 ⁴

From the test results it was observed that the 0.25 percentage polypropylene fibre gives the better compressive strength, flexural strength and modulus of elasticity. The split tensile strength shows the maximum value at 0.3 %. This was because as the fibre content increases the bridging capacity also increases and thereby it enhances the splitting strength. The results from fresh and hardened properties of concrete it was concluded that 0.25% was optimum percentage of polypropylene fibre in concrete.

C. Fresh Properties of concrete with hybrid fibre (polypropylene and steel fibre)

From the literature study it was found that optimum percentage of steel fibre in concrete was 1%. Three volume fractions of polypropylene fibre including the optimum percentage of fibre as 0.15%, 0.2%, 0.25% and three volume fractions of steel fibre including the optimum dosage as 0.5%, 0.75%, and 1% was adopted for the study. For obtaining the hybrid fibre, each Vf of PP fibre is combined with each Vf of steel fibre in concrete. From the nine combinations of PP and steel fibre, the optimum dosage of hybrid fibre in concrete was found out.

The split tensile strength test and flexural strength test were used to determine the optimum percentage of hybrid fibre in concrete. The test results were tabulated in table 7

TABLE 7 HARDENED PROPERTIES OF HYBRID FIBRE REINFORCED CONCRETE

Specimen designation	Split tensile strength (N/mm ²)	Flexural Strength test (N/mm ²)
S ₀ ⁰	2.97	5.2
S _{0.25} ⁰	3.45	6.13
S ₀ ¹	4	8.0
S _{0.25} ¹	4.04	8.26
S _{0.2} ¹	3.75	8.29
S _{0.15} ¹	3.6	8.03
S _{0.25} ^{0.75}	4.13	8.303
S _{0.2} ^{0.75}	4.01	8.25
S _{0.15} ^{0.75}	3.93	8.15
S _{0.25} ^{0.5}	3.48	7.31
S _{0.2} ^{0.5}	3.28	6.95
S _{0.15} ^{0.5}	3.28	6.86

From the test result it was observed that the combination of 0.75% of steel fibre and 0.25% of polypropylene fibre had given the optimum percentage in concrete. The hardened properties such as cube compressive strength, cylinder compressive strength, modulus of elasticity of concrete with this optimum percentage of hybrid fibre were also determined and tabulated in table 8. The study was continued for RC beams containing this optimum dosage of hybrid fibre in concrete

TABLE 8 HARDENED PROPERTIES OF CONCRETE CONTAINING OPTIMUM PERCENTAGE OF HYBRID FIBRE IN CONCRETE

Specimen designation	Cube compressive strength (N/mm ²)	Cylinder compressive strength (N/mm ²)	Modulus of elasticity (N/mm ²)
S ₀ ⁰	27.23	18.23	3.46 x 10 ⁴
S _{0.25} ⁰	29.34	20.21	3.66 x 10 ⁴
S ₀ ¹	32.71	23.48	3.79x 10 ⁴
S _{0.25} ^{0.75}	34.77	26.83	3.84 x 10 ⁴

The cube compressive strength of PP fibre in concrete was increased by 7.74% as compared to control concrete and for steel fibre and hybrid fibre in concrete, compressive strength increased by 20.12% and 27.69% as compared to normal concrete.

The polypropylene added concrete has 10.86% more cylinder compressive strength than the normal concrete. The steel fibre added concrete and hybrid fibre reinforced concrete has 28.79% and 47.17% more cylinder compressive strength than normal concrete.

D. Load Deflection Graph

Load deflection graph was plotted using the dial gauge readings at mid span of RC beam specimens as shown in Fig 2

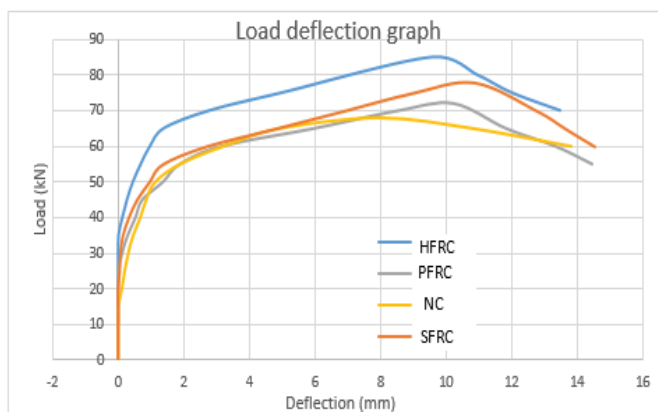


Fig 2 Load Deflection Graph

For all the beam specimens the load deflection curve shows linearity up to first crack and the curve deviates from the linearity on further increment of load. This was due to formation of multiple cracks. On increase of load the steel starts yielding and curve become flat till the ultimate load was reached.

E. Energy Absorption

The addition of fibre in concrete increase the ductile nature of the concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre added concrete. So the formation of first crack was lagged for fibre reinforced concrete compared to normal concrete. Energy absorbed by each specimen during the test was calculated by the area under the load deflection curve and the results are given in the table 9. Due to the limitations in the experimental set up, the load deflection graph could be plotted only up to 80 % of the peak load, in the descending portion of the curve. Thus, the energy absorption was calculated as the area under the curve up to the peak load and under the descending portion up to 80 % of the peak load. From the test result it was observed that the energy absorption of HFRC, PFRC, SFRC has increased by 41%, 1%, 8% respectively than normal concrete. The energy absorption of HFRC has increased by about 30% and 40% than that of SFRC and PFRC.

TABLE 9 ENERGY ABSORPTION OF BEAM SPECIMENS

Specimen	Energy Absorption (kNmm)
NC	885.87
PFRC	894.35
SFRC	961.97
HFRC	1252.33

F. First Crack Load and Ultimate Load

The first crack load was obtained from the load deflection graph. It is the point where the graph lost its linearity. The first crack load, calculated yield load, ultimate load obtained for each specimens tested are given in the table 10. The first crack load is that load at which the load deflection curve deviates from the initial straight line and ultimate load is the peak load obtained during the flexural test.

TABLE 10. FIRST CRACK LOAD, CALCULATED YIELD LOAD AND ULTIMATE LOAD OF BEAM SPECIMENS

Specimen	First crack load (kN)	Yield load(kN)	Ultimate load(kN)
NC	15	64	68
PFRC	25	70	72
SFRC	30	74	78
HFRC	35	75	85

From the result it was seen that the first crack on HFRC beam specimen was formed at 35 kN, this was because the energy absorption capacity of the HFRC was more compared to PFRC, SFRC and NC. The HFRC beam specimen has more yielding capacity compared to other specimens. It was seen that the after the yielding occur for HFRC, the specimen continue in the yielding stage for more time compared to PFRC, SFRC and NC. The HFRC specimens has 25% , 18.05% and 8.9% more ultimate load carrying capacity than NC, PFRC and SFRC specimens respectively.

G. Moment Curvature

The moment curvature graph was plotted for beam specimens as shown in the Fig 3

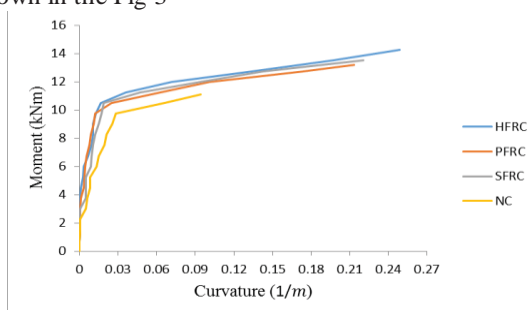


Fig 3 Moment Curvature Plot

The beams were subjected to two point loading. The LVDTs were placed one on the compression face and other over the tension face. The test set up was as shown in the figure 4. The compressive strain(ϵ_c) and tension steel strain(ϵ_s) were obtained from the LVDTs. The curvature ϕ was obtained from the equation $\phi = (\epsilon_c + \epsilon_s)/d$, where d is the effective depth. The maximum bending moment for two point loading at one third span is $M = PL/6$, where P is the applied load and L is the effective span. The moment curvature is obtained by plotting moment for each 10 kN increment of load in y axis and corresponding ϕ along x axis. The moment curvature of a beam will go through three stages, first stage uncracked stage, second is cracked stage and then ultimate strength stage. From the graph it was seen that curve was linear up to first crack moment. On the increment of load, the value of moment also increases and as a result the strain at the outer surfaces increases and thereby moment curvature increases. This can be seen from the graph that curve shifts from linearity after first crack moment. The moment curvature plot shows a similar profile as that of the load-deflection curve with a linear portion up to initial crack, nonlinear bending behaviour till the yield point and there after large deformations beyond yield load for HFRC beams. For NC specimen, the moment curvature plot indicates lower moment carrying capacity

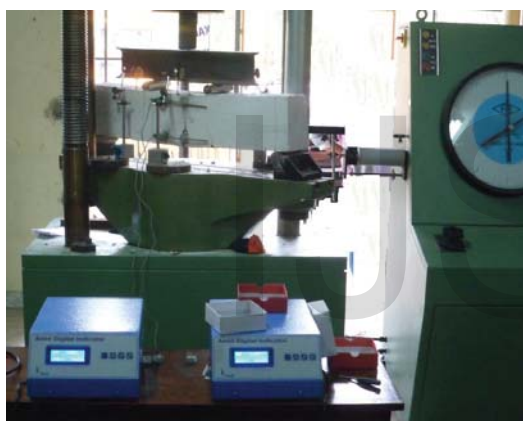


Fig. 4 Test set up for beam testing

H. Ductility Indices

The ductility indices of the beam specimens are shown in table 11.

TABLE 11. DUCTILITY INDICES OF BEAM SPECIMENS

Specimen	Displacement Ductility	Curvature Ductility
NC	1.09	1.08
PFRC	1.19	1.76
SFRC	1.36	1.819
HFRC	1.65	3.7

The result shows that the addition of fibre on concrete increased the ductility and the hybrid fibre reinforced concrete is more ductile compared to other beam specimens.

I. Crack Pattern and Failure

The failure patterns of crack developed in each beam specimen during testing were marked as shown in the Figs.5, 6, 7, 8.



Fig. 5 Crack Pattern of NC Beams

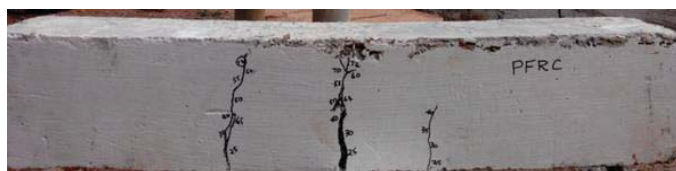


Fig. 6 Crack Pattern of PFRC Beams



Fig. 7 Crack Pattern of SFRC Beams



Fig.8 Crack Pattern of HFRC Beams

It was observed that for NC beam specimen, up to 15 kN load the concrete was in the uncracked stage. Beyond 15 kN concrete starts transferring load to reinforcing steel and steel begin to resist the strain. The cracked stage occurs after 15 kN. So the initial crack was found to be at 15 kN.

PFRC beam was in uncracked stage till 25 kN there after cracked stage began and for SFRC the cracked stage starts at 30 kN and for HFRC it was 35 kN. From the crack pattern, it was observed that the crack formed for all the beam specimens except SFRC beam were in the mid span. For the HFRC beam it was seen that the crack width is large at the tension zone and it was shortening in its width when the crack propagates upward. This was due to the reason that the developments of major cracks are controlled by the synergetic bridging activity of polypropylene and steel fibre. It was observed that, once the fibre matrix bond breaks, the rate of crack propagation increases till the ultimate load was reached

VI. CONCLUSIONS

The following conclusions were derived from the experimental investigation.

- The optimum percentage of Polypropylene fibre in concrete was found to be 0.25% by weight of cement.

- The optimum percentage of hybrid fibre in concrete was found to be 0.25 % polypropylene fibre by weight of cement and 0.75% steel fibre by weight of concrete.
- The split tensile strength of HFRC was increased by 41%, 19% and 3% over NC, PFRC and SFRC respectively.
- The flexural strength of HFRC was increased by 59%, 35% and 4% over NC, PFRC and SFRC respectively.
- All hardened properties of HFRC shows significant improvement compared to Normal concrete.
- From the study on flexural behavior of HFRC, PFRC, SFRC and normal concrete, it was observed that the energy absorption for HFRC, PFRC, and SFRC had increased by 41 %, 1% and 8% than normal concrete.
- The ductility of concrete had been increased by the addition of fibre in concrete and the test results shows that HFRC beam specimens were more ductile compared to other beams
- The energy absorption for HFRC was increased by 41%, 40% and 30% compared to NC, PFRC and SFRC respectively
- The ultimate load carrying capacity of HFRC beam specimen was increased by 25 % as compared to NC beam specimen

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