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A Study on Hybrid Fiber Reinforced Concrete

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Abstract - *Hybrid fiber reinforced concrete can be defined as concrete that reinforced by two or more types of fibers. This study aims to study the mechanical properties of hybrid fiber reinforced concrete where the fibers used were consists of steel fiber and coconut (coir) fiber. For this purpose five mixes, one normal control mix and four hybrid fiber reinforced concrete mixes were prepared. The volume of steel fiber is kept content as 1% and the volume of coconut fiber varied as 1%, 3%, 5% and 7% Slump Test was carried out for each mix in the fresh state in order to determine the workability of the hybrid fiber reinforced concrete. Meanwhile, compressive test, flexural test and split tensile test were carried out to study the mechanical properties of the hybrid fiber reinforced concrete. From the slump test all specimens show low workability. For the result of Compressive split tensile and Flexural Test, the normal control mix shows normal strength development but all the hybrid fiber reinforced concrete mixes gain their strength higher the normal control mix. The expected outcome which is the strength of hybrid fiber reinforced concrete is higher than the strength of normal concrete did achieved. So, further research need to be carried out with some adjustments of methods or materials.*

***Key Words*: (FRC-Fiber Reinforced Concrete, HFRC-Hybrid Fiber Reinforced Concrete, CFRC-Coconut Fiber Reinforced Concrete, SFRC-Steel Fiber Reinforced Concrete, PCC-Plain Cement Concrete)**

1. INTRODUCTION

Concrete is the most widely used man-made construction material in the world. It is obtained by mixing cementations materials, water, aggregate and sometimes admixtures in required proportions. Fresh concrete or plastic concrete is freshly mixed material which can be moulded into any shape hardens into a rock-like mass known as concrete. The hardening is because of chemical reaction between water and cement, which continues for long period leading to stronger with age. The utility and elegance as well as the durability of concrete structures, built during the first half of the last century with ordinary Portland cement (OPC) and plain round bars of mild steel, the easy availability of the constituent materials (whatever may be their qualities) of concrete and the knowledge that virtually any combination of the constituents leads to a mass of concrete have bred contempt. Cement mortar and concrete made with Portland cement is a kind of most commonly used construction material in the world. These materials have inherently brittle nature and have some dramatic disadvantages such as poor deformability and weak crack resistance in the practical usage. Also their tensile strength and flexural strength is relatively low compared to their compressive strength. Fiber Reinforced Concrete is concrete containing fibrous material which increases its structural integrity. The fiber can make the failure mode more ductile by increasing its tensile strength of concrete [01]. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers each of which lend varying properties to the concrete. In addition, the character of fiber reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities. In a hybrid, two or more different types of fibers are rationally combined to produce a composite that derives benefits from each of the individual fibers and exhibits a synergistic response. The hybrid combination of metallic and non-metallic fibers can offer potential advantages in improving concrete properties as well as reducing the overall cost of concrete production.

1.1 Fiber Reinforced Concrete (FRC)

Fiber reinforced concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinues, discrete, uniformly dispersed suitable fibers. And fiber is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat the fiber is often described by the parameter aspect ratio which is ratio of fiber length to its diameter. Typical aspect ratio varies from 20 to 150. The use of fibers to reinforce a brittle material was done first by Egyptians they used straw to reinforce sun baked bricks and horsehair was used to reinforce plaster. In the early 1900's asbestos fibers were used in concrete. The modern development of steel fiber reinforced concrete may have begun in 1960's. Glass fibers comes into picture by the 1980's and Carbon fibers from 1990's. And now a day's many types of fibers are available as a construction material and among them consumption of steel and polypropylene fibers is large.

Basically fibers can be divided into following two groups

(i) Fibers whose moduli are lower than the cement matrix such as cellulose, nylon, polypropylene etc.
(ii) Fibers with higher moduli than the cement such as asbestos, glass, steel etc.

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

1.2 Types of fibers

Depending upon the parent material used for manufacturing fibers can be broadly classified as;

1. Metallic fibers (e.g. low carbon steel, stainless steel, galvanized iron, aluminum)
2. Mineral fibers (e.g. asbestos, glass, carbon)
3. Synthetic fibers (polyester, nylon, polypropylene, polyethylene)
4. Natural fibers (bamboo, coir, jute, sisal, wood, sugarcane bagasse)

1.3 Hybrid Fiber Reinforced Concrete (HFRC)

The usefulness of hybrid fiber reinforced concrete in various Civil Engineering applications is thus indisputable. Hence this study explores the feasibility of hybrid fiber reinforcement with a given grade of concrete. Hybrid Fiber Reinforced Concrete (HFRC) is formed from a combination of different types of fibers, which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. The hybridization of fibers provides improved specific or synergistic characteristics not obtainable by any of the original fiber acting alone. Until today mainly three types of hybrid composites have been used by the researchers using the combinations of polypropylene-carbon, carbon-steel and steel-polypropylene fibers.

Hybrid fiber reinforced concrete is use of two or more than two fibers in a single concrete matrix to improve overall properties of concrete. In well-designed hybrid composites, there is positive interaction between the fibers and the resulting hybrid performance exceeds the sum of individual fiber performances.

As a research work on FRC has established that addition of various types of fibers such as metallic (steel) and non-metallic fibers (glass, synthetic, natural and carbon) in plain concrete improves strength, toughness, ductility, post-cracking resistance, etc. For optimal result therefore different types of fibers may be combined and the resulting composite is known as hybrid-fiber reinforced concrete in this experiment steel fiber (continuously crimped) and natural fiber (coconut) have been tried.

1.4 Steel fiber

In this experimentation, Flat continuously crimped Steel fibers were used. This is collected from Ryan international factory, The Steel fibers with aspect ratios, its length and width adopted were shown in table 1.

1.5 coconut fiber

The coconut is the fruit of the Cocos nucifera, a tropical plant of the Arecaceae (Palmae) family. It is locally available material nearby kalaburgi.

Table 1: mechanical properties of coconut fiber (As per ACI 544.1R-96) Manual of concrete practice

Table1: properties of steel fiber & coconut fiber

properties	Coconut fiber	properties	Steel fiber
Fiber length(mm)	50-110	Length of fiber	40mm
Fiber diameter(mm)	0.1-0.406	Aspect ratio	50
Specific Gravity	1.12-1.15	Thickness	0.8mm
Elongation (%)	10-25	Width	2.5mm
Modulus of elasticity(ksi)	2750-3770	Tensile strength	1000-1200mpa
Average tensile strength (N/mm^2)	150	Material type	LOW CARBON DRAWN FLATE WIRE

2. REVIEW OF LITERATURE

2.1 LITERATURE SURVEY

- Title: "The mechanical and dynamic properties of coconut fiber reinforced concrete"

By Majid Ali, ET. AlNewzealand [4],the mechanical and dynamic properties of coconut fiber reinforced concrete members were well examined. A comparison between the static and dynamic Moduli was conducted. The influence of 1%, 2%,3% and 5% fiber contents by mass of cement and fiber lengths of 2.5, 5 and 7.5 cm is investigated. Noor Md.sadiqulHasan, et. al from Malaysia, have investigated the physical and mechanical characteristics of concrete after adding coconut fibers on a volume basis.

- Title: "Study of strength and durability of coconut fiber reinforced concrete in aggressive environmental"

By CF. MahyuddinRamli, et. Al [5]. They conducted a micro structural analysis test using a scanning electron microscope for understanding bonding behavior of studied strength and durability of CFRC in aggressive environment. Their aim was to mitigate the development of cracks in marine structures by introducing CF which would provide a localized reinforcing effect. Yalley, et.al. From UK performed various test to study the enhancement of concrete properties after addition of CF. their study focused on the CF obtained from Ghana Africa.

- Title: "The mechanical and dynamic properties of coconut fiber reinforced concrete"

By (Liu et al., 2011) [3] studied the influence of 1%, 2%, 3% and 5% at fiber lengths of 2.5, 5 and 7.5 cm on properties of concrete. For a proper analysis the properties of plain cement concrete was used as reference. It was seen that damping of CFRC beams increases with the increase in fiber content. It was observed that CFRC with a fiber length of 5 cm and fiber content of 5% produced the best results. In this study the optimum percent of coconut fiber added was 5%.

- Title: "Introduction to mechanical properties of high-strength steel fiber reinforced concrete"

BySong P.S. and Hwang S[6] thebrittleness with low tensile strength and strain capacities of high strength concrete can be overcome by addition of steel fibers. They investigated an experimental study were steel fibers added at the volume of 0.5%, 1.0%, 1.5% and 2.0%. The observation indicate that compressive strength of fiber concrete reached a maximum at 1.5%volume fraction, being 15.3% improvement over the HSC. The split tensile and Flexural Strength improved 98.3% and 126.6% at 2.0% volume fraction.

- Title: "Comparative study of steel fiber reinforced concrete over control concrete"

By Vikrant S Vairagade, Kavita S. Kene, Tejas R Patil[2] This paper deals with Experimental investigation for M-20 grade of concrete to study the compressive strength, and tensile strength of steel fiber reinforced concrete (SFRC) containing fibers of 0% and 0.5% volume fraction of hook end Steel fibers of 50 and 53.85 aspect ratio were used.

A result data obtained has been analyzed and compared with a control specimen (0% fiber). A relationship between Compressive strength vs. days, and tensile strength vs. days represented graphically. Result data clearly shows percentage increase in7 and 28 days Compressive strength and Tensile strength for M-20 Grade of Concrete.

2.2 LITERATURE REVIEW

Steel fibers enhance strength of FRC under almost all types of loading but fail to demonstrate deformability [7]. On the other hand, non-metallic fibers such as Coconut fibers demonstrate superb deformation under different types of loading with moderate strength enhancement Therefore, the objective of the present study was to evaluate the mechanical properties of FRC having hybrid combinations of a metallic fiber (steel fiber) and a non-metallic fiber (Coconut fiber). As a research work on FRC has established that addition of various types of fibers such as metallic (steel) and non-metallic fibers (glass, synthetic, natural and carbon) in plain concrete improves strength, toughness, ductility, post-cracking resistance, etc. For optimal result therefore different types of fibers may be combined and the resulting composite is known as hybrid-fiber reinforced concrete in this experiment steel fiber (continuously crimped) and natural fiber (coconut) have been tried.

2.3 SCOPE AND OBJECTIVE OF PRESENT WORK

OBJECTIVES: The aim of this study is to investigate the effect of hybridisation (metallic and non-metallic fibres) of fibres on properties of concrete

The objectives of this research are

a. To study the workability of hybrid fibre reinforced concrete.
b. To study the mechanical properties of hybrid fibre reinforced concrete.

3. METHODOLOGY

3.1 COLLECTIONS OF RAW MATERIALS

The materials used in this study are

Portland cement (OPC): ultratech cement

Sand: Aggregates passing through 4.75mm IS sieve

Coarse aggregate: Aggregates passing through 20mm IS sieve

Coconut fiber: locally available in kalaburgi

Steel fiber: Collected from Ryan international factory

Water: Collected from local fresh water sources

Admixture: PAR PLAST-LW

3.2 TESTS ON MATERIAL

Tests on Cement

Cement is an important constituent in concrete. The process of manufacture of cement consist of grinding the raw materials mixing them intimately in certain proportions and burning them in kiln at a temperature 13000C to 15000C. To determine the various properties of cement different tests are done.

The tests done are

1. Standard Consistency

2. Initial Setting Time

3. Final Setting Time

4. Fineness of Cement

5. Density of Cement

Tests on Coarse Aggregate

Aggregates are important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. The aggregates occupy 70-80 percent of the volume of concrete; their impact on various characteristics and properties of concrete is considerable. To determine the various properties of aggregates different tests are done.

1. Bulk density of coarse aggregates

2. Specific gravity of coarse aggregates

3. Sieve analysis of coarse aggregates

Tests on Fine Aggregate

1. Bulk density of fine aggregates

2. Specific gravity of fine aggregates

3. Sieve analysis of fine aggregates

3.3MIX DESIGN

Mix design is defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. A Mix design was conducted as per IS 10262-2009 to arrive at M 25 mix concrete.

3.4MIXING OF CONCRETE

The coarse aggregate and fine aggregate were weighed and the concrete mixture was prepared by hand mixing on a water tight platform. On the water tight platform cement and fine aggregates are mixed thoroughly until a uniform colour is obtained, to this mixture coarse aggregate was added and mixed thoroughly. Then water is added carefully making sure no water is lost during mixing. While adding water care should be taken to add it in stages so as to prevent bleeding which may affect the strength formation of concrete rising of water required for hydration to the surface. Clean and oiled mould for each category and filled in three layers. Each layer is tamped by 25 blows using standard tamping rod. The finishing was stopped as soon as the cement slurry appeared on the top surface of the mould.

3.5CASTING AND CURING

Concrete was cast in pre-oiled cast iron moulds (Fig.3.1).These specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition. After that these were demoulded with care so that no edges were broken and were placed in the tank at the ambient temperature for curing. After demoulding the specimen by loosening the screws of the steel mould, the cubes were placed in the water for 7 days and 28 days.

Figure 3.1: cast iron moulds

3.6 TESTING OF SPECIMEN

The remoulded specimens after being cured for sufficient time period are taken out and dried in sunlight and tested under standard testing apparatus.

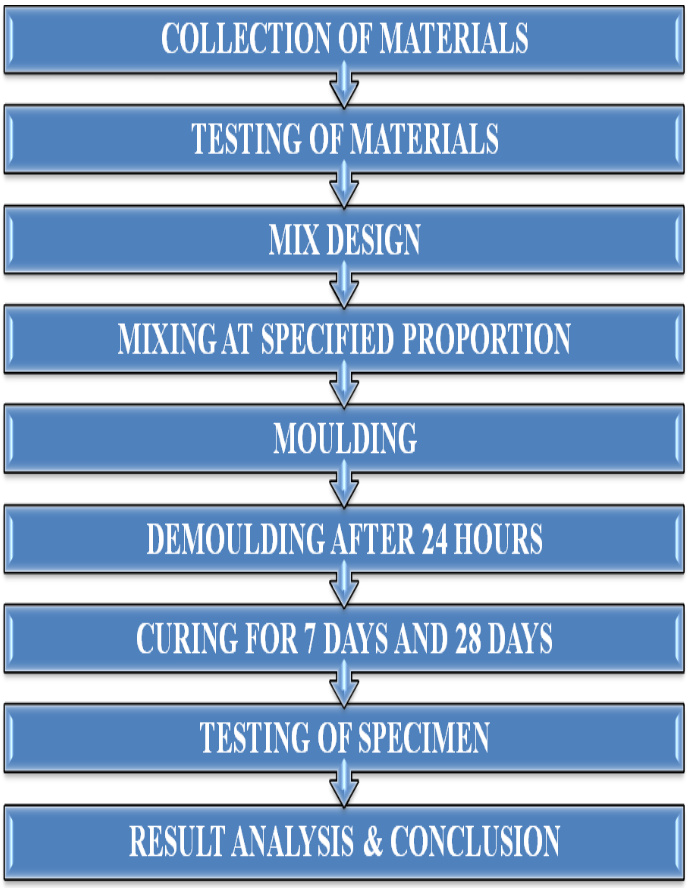


Figure 3.5: flow chart

4. CASTING AND TESTING OF CONCRETE SPECIMEN

4.1 TESTS ON FRESH CONCRETE

4.1.1 SLUMP TEST

Slump test is the most commonly used method of measuring consistency of concrete. It is used conveniently as a control test and gives an indication of the uniformity of concrete. Additional information on workability and quality of concrete can be obtained by observing the manner in which concrete slumps. The apparatus for conducting the slump test essentially consists of a metallic mould in the form of frustum of a cone having the internal dimensions of bottom diameter 20 cm, top diameter 10 cm and a height of 30 cm as shown in Figure 4.1.

Figure 4.1: slump testing apparatus

4.2 TESTS ON HARDENED CONCRETE

4.2.1 COMPRESSIVE STRENGTH TEST

Compressive strength is the capacity of a material or structure to withstand axial loads tending to reduce the size. It is measured using the Universal Testing machine. Concrete can be made to have high compressive strength, e.g. many concrete structures have compressive strengths in excess of 50 MPa. Here the compressive strength of concrete cubes for the plain concrete and fiber reinforced concrete are found out using Compression testing machine. Three cubes were cast for each percentage of fibers and the average of the three compressive strength values was taken. A Compression testing machine is shown in Figure 4.2.

Figure 4.2: compression testing machine

4.2.2 SPLIT TENSILE STRENGTH TEST

Tensile strength is the capacity of a material or structure to withstand tension. It is measured on concrete cylinders of standard dimensions using a Universal Testing machine. Both conventional and fiber reinforced specimens were tested at varying percentages of fiber and the average value was obtained

4.2.3 FLEXURAL STRENGTH TEST

Flexural strength of concrete is considered as an index of tensile strength of concrete. Tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and many other reasons. Beam tests are conducted to determine flexural strength of concrete Figure 4.3. In flexural tests on beam theoretical maximum tensile strength is obtained at bottom of beam and is called modulus of rupture, which depends on dimension of beam and position of loading

Figure 4.3: flexure testing machine

4.3 EXPERIMENTAL PROCEDURE

4.3.1 MIX DESIGN

Mix design is defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The mix design must consider the environment that the concrete will be in exposure to sea water, trucks, cars, forklifts, foot traffic or extremes of hot and cold. A Mix design was conducted as per IS 10262-2009 to arrive at M 25 mix concrete.

4.3.2 CASTING PROCEDURE

4.3.2.1 Casting of Concrete Cubes

Concrete is mixed by hand (Fig 4.4) Concrete is a mixture of Cement, Water, Coarse and Fine Aggregates and Admixtures. The proportion of each material in the mixture affects the properties of the final hardened concrete. These proportions are best measured by weight. Measurement by volume is not as accurate, but is suitable for minor projects. The dry ingredients are mixed and water is added slowly until the concrete is workable. This mixture may need to be modified depending on the aggregate used to provide a concrete of the right workability. The mix should not be too stiff or too sloppy. It is difficult to form good test specimens if it is too stiff. If it is too sloppy, water may separate (bleed) from the mixture.

Figure 4.4: mixing of concrete

For casting, all the moulds were cleaned and oiled properly. There were securely tightened to correct dimension before casting. Care was taken that there is no gaps left, where there is any possibility of leakage of slurry. Careful procedure was adopted in the batching, mixing and casting operation. The coarse aggregate and fine aggregate were weighed first. The concrete mixture was prepared by hand mixing on a water tight platform. On the water tight platform cement and fine aggregates are mixed thoroughly until a uniform color is obtained, to this mixture coarse aggregate was added and mixed thoroughly. Then water is added carefully making sure no water is lost during mixing. While adding water care should be taken to add it in stages so as to prevent bleeding which may affect the strength formation of concrete rising of water required for hydration to the surface. Clean and oiled mould for each and filled in three layers and finishing is done by using trowel.

These specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition. After that these were demoulded with care so that no edges were broken and were placed in the tank at the ambient temperature for curing. After demoulding the specimen by loosening the screws of the steel mould, the cubes were placed in the water for 7 days and 28 days

Figure 5.6: finishing of moulds

5. TEST RESULTS

5.1 SLUMP TEST

TABLE 5.1: slump test on trial mixes

Trial	w/c ratio	Slump value(mm)	Remarks
Trial 1	0.4	40	Target Slump not achieved
Trial 2	0.45	85	Target Slump achieved Desired Slump value is obtained
Trial 3	0.5	120	(Slump >100mm)

INFERENCE

From the table it is observed that the desired slump value is obtained for trial 2 at water cement ratio = 0.45. (For standard m-25mix) Hence we fix it as the design ratio. Trial 1 and 3 yielded very low and very high slump values which may be either due to inadequate paste available for binding the mix or due to improper mixing procedure

TABLE 5.2: slump test values

Mix No	Steel fiber (SF) (%)	Coconut fiber (SF) (%)	Obtained slump values
M_1	0%	0%	80
M_2	1%	1%	27
M_3	1%	3%	25
M_4	1%	5%	23
M_5	1%	7%	23

From the table it is observed that the workability drastically decreases when coconut fiber content is increased in concrete.

5.2 COMPRESSIVE STRENGTH

30 cubes specimens of size 150mm were used for compression test the test results are summarized in tables below each value is the mean of three test results

$$\text{Compressive strength} = \frac{Max.load}{Area} = \left(\frac{W}{A}\right)$$

Where

W = max load on cube

A = Effected area

$$\text{Density} = \frac{Finalweight}{volume} = \left(\frac{W}{V}\right)$$

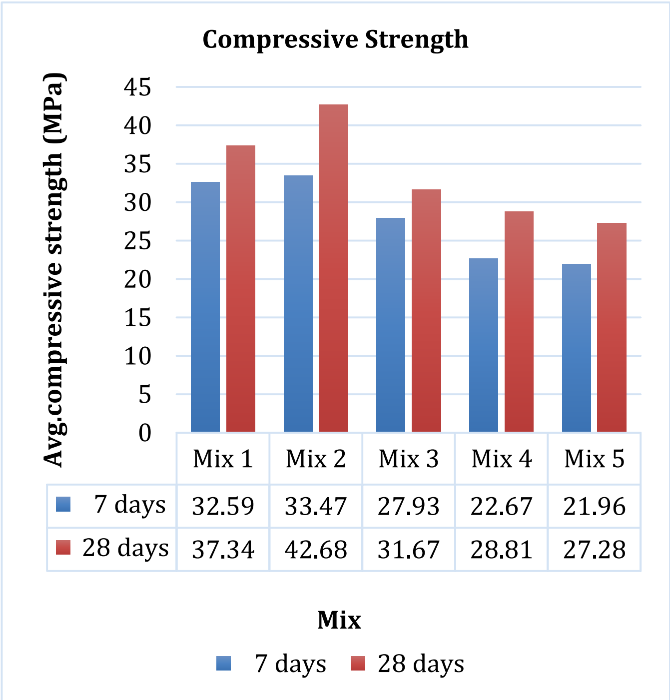
Where

W = Final weight specimen

V = Total volume of mould

TABLE 5.3: average compressive strength

%SF	%CF	Average density (Kg/m3)		Average strength of 7 Days (N/mm2)	Average strength of 28 Days (N/mm2)
		7 Days	28Days		
0%	0%	2601.47	2572.14	32.59	37.34
1%	1%	2640.98	2650.87	33.47	42.68
1%	3%	2494.80	2552.09	27.93	31.67
1%	5%	2531.35	2596.04	22.67	28.81
1%	7%	2540.24	2502.71	21.96	27.28



Graph 5.1: compressive strength v/s mixes of7 & 28 days

5.3 SPLIT TENSILE STRENGTH TEST

A Total 30 standard concrete cylinder of size 150mm dia & 300mm depth were tested for the indirect tensile strength the test results are shown in table below.

Split tensile Strength = (ts) = $\left(\frac{2W}{\Pi LD}\right)$

Where

W = Max load on cylinder

L = Length of cylinder

D = Dia of cylinder

Density = $\frac{Finalweight}{volume} = \left(\frac{W}{V}\right)$

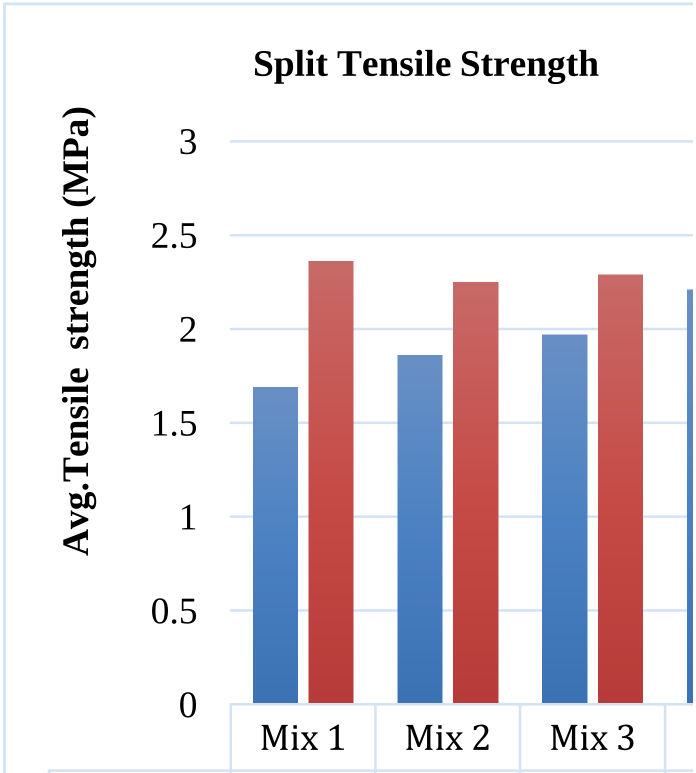
Where

W = Final weight specimen

V = Total volume of mould

Table 5.4: average split tensile strength

%SF	%CF	Average density (Kg/m3)		Average strength of 7 Days (N/mm2)	Average strength of 28 Days (N/mm2)
		7 Days	28 Days		
0%	0%	2560.9	2534.2	1.69	2.36
1%	1%	2552.1	2575.7	1.86	2.25
1%	3%	2562.1	2561.2	1.97	2.29
1%	5%	2556.5	2566.2	2.21	2.41
1%	7%	2542.0	2493.3	2.23	2.60



Graph 5.2: split tensile strength v/s mixes of 7 & 28 days

5.4 FLEXURAL STRENGTH TEST

A total of 30 beams of size 100x 100 x 500mm were tested for flexural strength in all the tested specimen fracture occurred within the central one third of the beam

Flexural strength = fb = $\left(\frac{WL}{BD^2}\right)$

Where, W = max load on prism

L = Length of prism

B = Width of prism

D = Depth of the prism

$$\text{Density} = \frac{Finalweight}{volume} = \left(\frac{W}{V}\right)$$

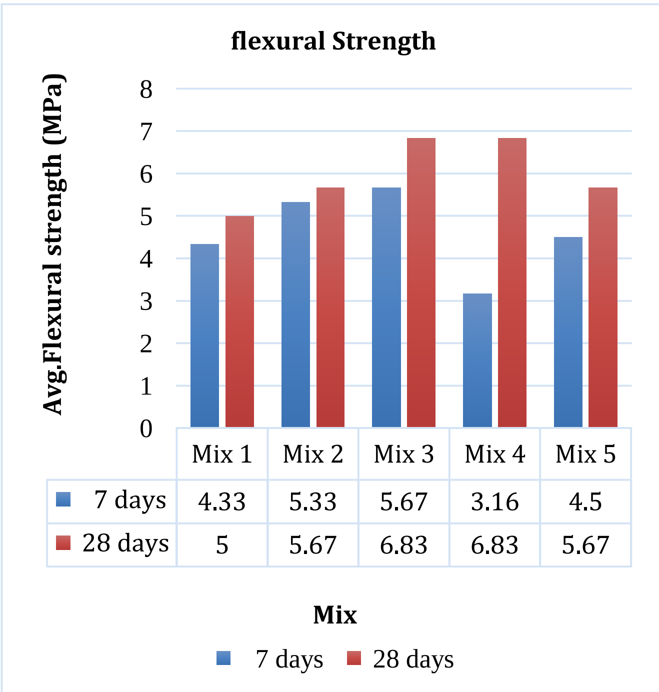
Where

W = Final weight specimen

V = Total volume of mould

Table 5.5: average flexural strength

%SF	%CF	Average density (Kg/m3)		Average strength of 7 Days (N/mm2)	Average strength of 28 Days (N/mm2)
		7 Days	28Days		
0%	0%	2546.6	2641..3	4.33	5
1%	1%	2590	2591.3	5.33	5.67
1%	3%	2458.6	2506	5.67	6.83
1%	5%	2345	2420.3	3.16	6.83
1%	7%	2598.6	2474.6	4.5	5.67



Graph 5.2: flexural strength v/s mixes of 7 & 28 days

6. CONCLUSIONS

Based on the experimental investigations on HFRC, the following observations can be drawn.

1. The brittle mode of failure is changed by the addition of steel fibre & coconut fiber into a more ductile one and such fibres were observed to improve the ductility of the concrete, its post-cracking load carrying capacity, and its energy absorption capacity.

2. The addition of steel fiber and coconut fiber results in an increase of 14.30% compressive strength, 36.6% increase in flexural strength and 10.16% increase in split tensile strength.

3. The improvement in flexural strength reveals that the toughness would be much more than that of non-fibrous concrete which improves ductility and durability of concrete.

4. Addition optimum dosage of 1% of steel fiber and 1% of coconut fiber gives maximum compressive strength up to 42.68%

5. The rate of strength gain for 7 days strength of HFRC is very high as compared to conventional concrete and hence concludes that HFRC has high early Strength and continued strength development.

6. As % of fiber increases the split tensile strength also increases.

7. Workability drastically decreases when coconut fiber content is increased in concrete.

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