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Structural Behaviour of Coir Fiber Added Concrete

Shibi Varghese[1], Eldhose M Manjummekudiyil[2], Arun Das[3]
[1,2] Department of Civil Engineering, MACE Kothamangalam, Ernakulam dist, Kerala, India
[3] Department of Civil Engineering, VJCET Vazhakulam, Ernakulam dist, Kerala, India

Abstract:- Concrete is the most widely used construction material. Apart from its excellent properties concrete is very poor in tensile strength. To improve its tensile strength, fibers are added to concrete which is known as fiber added concrete. In our study we focused on structural behaviour of coir fiber added concrete. Coir is abundantly available at low cost in the tropical areas especially Kerala. In this study coir fiber of aspect ratio 50 is randomly dispersed in M20 concrete for the preparation of 48 specimens. Two different varieties of concrete with different fiber cement ratio (0.5% and 1.5%) were casted. The specimens were tested for its compressive strength, splitting tensile strength, flexural strength and modulus of elasticity. From the test results obtained it can be seen that compressive strength, splitting tensile strength, flexural strength are greater than those of PCC. The optimum percentage f/c ratio may be occurring very near to 0.5%. From the cost benefit analysis coir fiber is proved to be far economical than any other fibers for a strength comparable to that obtained for 0.5% fiber cement ratio coir fiber added concrete. This study also focus on the comparative study among presently using fiber added concrete which their structural strength and cost of production.

Keywords:- Coir Fiber Added Concrete; Aspect ratio; Fiber Cement Ratio; Splitting Tensile Strength; Compressive Strength; Flexural Strength

I. INTRODUCTION

Construction industry has undergone a rapid change in the last century especially with the advancement of different types of concrete. The advancement finds their position in the limitations of ordinary concrete. Concrete with the development of technology has undergone several changes not in its composition, but also in its performance and application. Apart from its excellent properties, concrete shows a rather low performance when subjected to tensile stress. Even a simple concrete bar under bending conditions has zones with high compressive as well as high tensile stresses. The traditional solution to this problem is reinforced concrete, where reinforcing bars or prestressed steel bars inside the concrete elements are capable of absorbing the appearing tensile stresses. Another rather recent development is steel fiber reinforced concrete (SFRC). By adding fibers while mixing the concrete, a so-called homogenous reinforcement is created. This does not notably increase the mechanical properties before failure, but governs the post-failure behaviour. Thus, plain concrete, which is a quasi-brittle material, is turned to the pseudo ductile fiber reinforced concrete. Fiber reinforced concrete is a concrete containing fibrous material which increases its structural integrity.

There are different varieties of fiber reinforced concrete, like steel, glass, polymer, carbon etc. In this study, we have focused on one variety of natural fiber i.e. coir which is very abundant in Kerala. Being the coir fibers are very cheap, replacement of the presently used fibers is very economical. Commonly added fibers like steel and polymer fibers require a series of processes before they can be used. These fibers are also costly and increase the construction cost. Coir is abundant in Kerala and can be used in its natural form, without any treatment. Moreover, coir is usually cheap and its use in the construction industry would promote small – scale industries in a large way. The main objective of this work is to study the structural behaviour of natural fiber (coir) – added concrete. This work aims to improve the ductility of concrete by adding coir in its natural form. This study is expected to determine the maximum percentage by weight of coir to be added to the concrete to get maximum performance. The tests conducted are compressive strength, the test on flexural strength by conducting experiments on specimens by varying percentage of fiber content and the test on splitting tensile strength. These test results are compared with standard results, available for steel fibers and polymer fiber – added concrete.

II. OCCURRENCE, DISTRIBUTION AND TYPE OF COIR

Coir is a versatile hard fiber obtained from the husk of coconut. Coir fibers are categorized in two ways. One distinction is based on whether they are recovered from ripe or immature coconut husks. The husks of fully ripened coconuts yield brown coir which is strong and highly resistant to abrasion, its method of processing also protects it from the damaging ultraviolet component of sunlight. On the other hand, white coir comes from the husks of coconuts harvested shortly before they ripen. Actually light brown or white in color, this fiber is softer and less strong than brown coir. Both brown and white coir consist of fibers ranging in length from 4-12 in (10-30 cm). It is the only natural fiber resistant to salt water and it is highly resistant to abrasion. It is Strong and nearly impervious to the weather.

Coir fiber is in great demand for its toughness, strength, resilience to dampness, rot resistance, durability, natural resilience, porous, hygroscopic, biodegradable, renewable, recyclable etc. it can withstand huge amount of weight and rubbing and recovers as soon as the weight is removed from it.

The coir fiber is one of the hardest natural fibers because of its high content of lignin. Coir is much more advantageous in different application for erosion control, reinforcement and stabilization of soil and is preferred to any other natural fibers. Of all natural fibers coir processes the greatest tearing strength, retained as such even in very wet conditions. The chemical constituents have found to be cellulose, lignin, hemi cellulose and pectin. Higher lignin content makes the fiber stiffer and tougher. The physical and chemical properties of coir are shown in table 1 and 2. Coir fiber is much coarser than most of the other natural fibers. However, the extent of elongation of coir is not approached by any of the best fiber and this fact is of greater advantage in its utilization in the preparation of materials which are expected to with stand the stresses resulting from operation involving repeated tension, bending and relaxation.

TABLE 1 TENSILE PROPERTIES OF VARIOUS COIR FIBERS

Type of coir Fiber	**Diameter**	**Peak load(N)**	**Break load(N)**
Anjengo fiber (retted)	0.248	8.46	8.21
Vycom fiber (retted)	0.236	6.85	6.77
Brown fiber (non retted)	0.218	6.72	6.55
Green Husk fiber (non retted)	0.260	8.79	8.66

TABLE 2 CHEMICAL PROPERTIES AND PHYSICAL PROPERTIES OF COIR

Substances	**Percentage**	**Properties**	**Values**
Lignin	45.84	Length of single fiber	10-30 cm
Cellulose	43.44	Diameter	0.1-1.5 mm
Hemi-cellulose	0.25	Density	1.4 g/cc
Pectins	3.00	Rigidity modulus	1.8924 dyne/cm^2
Water soluble	5.25	Breaking elongation	30%
Ash	2.22	Swelling in water	5%
		Porosity	40%

III. EXPERIMENTAL STUDY

Materials Used

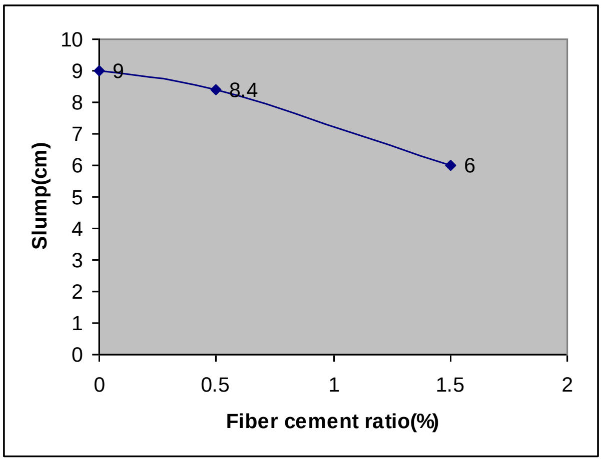
The common ingredients of fiber added concrete are cement, coarse and fine aggregates, fibers and water. Ordinary Portland cement of grade 43 conforming to IS 12269 was used for this study. This grade was selected due to the fact that the available test results for different varieties of fibers are obtained after conducting tests on this grade of cement. Locally available river sand has been used as the fine aggregate. Sand is collected from the local market, was washed and dried before use. It was sieved using 4.75 mm sieve. Locally available crushed granite aggregate of 20 mm downsize conforming to IS 383 was used. In the present investigation, potable water was used for mixing and curing. The brown fiber, collected from the local market (Defibering Unit, Industrial Estate, Angamaly, Kerala, India) was used for the study. It was manually cut into pieces of approximate length 40 mm each. Aspect ratio is defined as the ratio of the length of the fiber used to the mean lateral dimension (diameter) of the fiber. The coir fiber was cut into an approximate length of 40 mm so as to obtain an aspect ratio of 50.

Mix Proportion and Preparation of Specimen

The mix proportion used for the fibre added concrete is $M_{20.}$ The ratio of mixing is 1:1.5:3. The water cement ratio used for this concrete is 0.6. Fiber cement ratio (f/c) is the percentage by weight of the fibre added to the weight of cement added in the concrete. The different fibre cement ratio used for the testing are 0.5% and 1.5%. The specimens are casted for the two fiber cement ratios 6 specimens for each experiment.

Hand mixing was employed for mixing. The cement and fine aggregate were properly mixed until it obtained a uniform colour. Then the fibre was uniformly distributed to the mix. Then the coarse aggregate was added and was distributed uniformly. Water was then added and mixed till it appeared to be homogeneous and of desired consistency. Vibrators were used for the compaction. The casted specimens were marked. Specimens were removed from the moulds after 24hours and kept submerged in fresh water for 28 days.

Slump test was conducted in the laboratory for determining the consistency of concrete confirming to IS: 1199. The variation of slump with fiber cement ratio obtained from the slump test is furnished in the fig 1as graph. This test is intended for measuring workability of concrete mix. As per IS : 456 Clause 7.1, if the slump is less than 25mm, the degree of workability is very low and hence it can be used in blinding concrete, shallow sections, pavements using pavers.



FIG,1 VARIATION OF SLUMP WITH F/C RATIO

Testing of Specimen

The test conducted on hardened concrete after 28 days of curing are compressive strength test on concrete cubes, flexural strength test on concrete beam, splitting tensile strength test and modulus of elasticity test in concrete cylinders.

Splitting Tensile Strength test is carried out by placing a cylindrical specimen horizontally between the loading surface of the compression testing machine and a load is applied without shock and increased continuously at normal rate within the range $1.2N/mm^2$ – $2.4N/mm^2$ /min until the failure of cylinder along the vertical diameter. The loading condition produces high compressive stresses immediately below the two generators to which the load is applied. In order to reduce the magnitude of the high compressive stresses near the application of the load, narrow packing strips of plywood are placed between the specimens and loading platens of the testing machine. The measured splitting tensile strength of the specimen is calculated to the nearest $0.05N/mm^2$.

Compressive Strength Test of cubes was carried out in a compression testing machine as per IS 516 guidelines. The load is applied without shock and increased continuously at a rate of approximately 140 kg/sq.cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen is then be recorded and the appearance of the concrete and any unusual features in the type of failure is be noted.

In Flexural Strength Test specimens stored in water at a temperature of 24° to 30°C for 48 hours before testing and tested immediately on removal from the water whilst they are still in a wet condition. The load is applied without shock and increasing continuously at a rate such that the extreme fibre stress increases at approximately 7 kg/sq.cm/min. The appearance of the fractured faces of concrete and any unusual features in the type of failure is noted. The flexural strength of the specimen is expressed as the modulus of rupture.

Modulus of Elasticity test specimens consist of concrete cylinders 15.0 cm in diameter and 30.0 cm long. The three test specimens for compressive strength are first tested in accordance with IS 516 and the average compressive strength is recorded. Immediately on removing the cylinder or prism from the water and while it is still in a wet condition, the extensometers is attached at the ends. The load is applied continuously and without shock at a rate of 140 kg/sq.cm/min until an average stress of (C + 5) kg/sq.cm is reached, where C is one-third of the average compressive strength of the cubes calculated to the nearest 5 kg/sq.cm. The load is maintained at this stress for at least one minute and then reduced gradually to an average stress of 1.5 kg/sq.cm when extensometer readings are taken. The load is applied a second time at the same rate until an average stress of (C + 1.5) kg/sq.cm is reached. The load is maintained at this figure while extensometer readings are taken. The load is again be reduced gradually and readings again taken at 1.5 kg/sq.cm. The load is then be applied a third time and extensometer readings taken at ten approximately equal increments of stress up to an average stress of (C + 1.5) kg/sq.cm.

IV. RESULTS AND DISCUSSION

Concrete mix of various fiber cement ratios that is 0.5% and 1.5% was made. Six specimens of concrete cubes for compressive strength test, six beams for flexural strength test, twelve cylinders for splitting tensile strength and six cylinders for modulus of elasticity test were casted, cured and tested for each fiber cement ratio varieties. Some test results which are done earlier using various fibers in M20 concrete using 43 grade OPC is given below in table 3.

TABLE 3 STRENGTH COMPARISON OF VARIOUS FIBER ADDED CONCRETE[3]

Type of fiber	**Volume Fraction (%)**	**Compressive strength (N/mm^2)**	**Splitting tensile strength(N/mm^2)**	**Modulus of rupture (N/mm^2)**
Plain Concrete M 20	0	21.42	2.88	3.25
Steel fiber (ST3C)	0.5	22.55	**3.16**	3.79
	1.0	**23.68**	3.52	4.41
	1.5	26.42	3.87	**4.82**
Polymer fiber (Recron)	0.5	21.51	3.13	3.47
	1.0	23.31	3.40	3.95
	1.5	25.10	3.70	4.16
	2.0	24.82	3.63	4.28
Glass	0.5	21.04	3.07	3.41
	1.0	21.98	3.42	3.77
	1.5	23.87	3.63	4.23
	2.0	23.68	3.52	3.36
Jute	0.5	21.42	2.99	3.77
	1.0	22.46	3.11	4.05
	1.5	23.31	3.31	4.07
	2.0	23.50	3.35	3.38

Splitting Tensile Strength

Twelve cylinders of sizes 150mm diameter and 300mm height were kept for each fiber cement ratio tested in a compression testing machine as per IS 5816 - 1999 for determining split tensile strength and the test results are shown in table 4

TABLE 4 SPLITTING TENSILE TEST RESULT OF COIR FIBER ADDED CONCRETE

Fiber cement ratio (%)	**Avg.Max.Load (tonnes)**	**Splitting tensile strength(N/mm^2)**
0.5	22.22	3.14
1.5	15.32	2.17

In general it can be seen that with increase in fiber content there is increase in tensile strength of concrete. From the above table it is understood that the tensile strength increases up to 0.5% fiber cement ratio then decreases. Figure 2 is the graph showing the variation of splitting tensile strength with fiber cement ratio.
Even after the splitting of the cylinder if we apply more load to the specimen the specimen will not break and more over it take some more load. This may be due to the post cracking integrity of the fiber added concrete while using coir fiber in the concrete. Split tensile strength of coir fiber added concrete is greater than plain

cement concrete by 9.03% for 0.5% fiber content variety. Increase in strength is because in fiber added concrete, fiber bridges between concrete matrix which holds the matrix together. After matrix crack initiation, the stresses are absorbed by bridging fibers, and the bending moments are redistributed. The concrete element does not fail spontaneously when the matrix is cracked; the deformation energy is absorbed and the material becomes pseudo-ductile. The split tensile strength of fiber added concrete is greater than that of plain cement concrete by 9.03% for coir fiber. Figure 3 shows the percentage increase of tensile strength of the concrete while using different types of fibers.

From table 3 tensile strength of 0.5 % volume fraction of steel fiber added concrete is 3.16 N/mm^2, this strength can be obtained by coir fiber added concrete of 0.5% f/c ratio. Tensile strength of coir fiber added concrete of 0.5% f/c ratio is also comparable with other fiber added concrete.

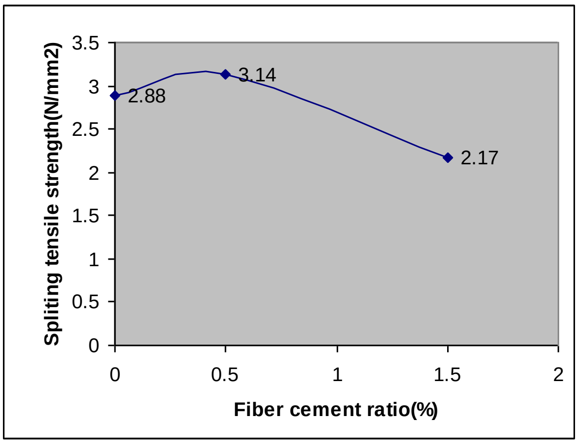


FIG. 2 VARIATION OF SPLITTING TENSILE STRENGTH WITH FIBER CEMENT RATIO

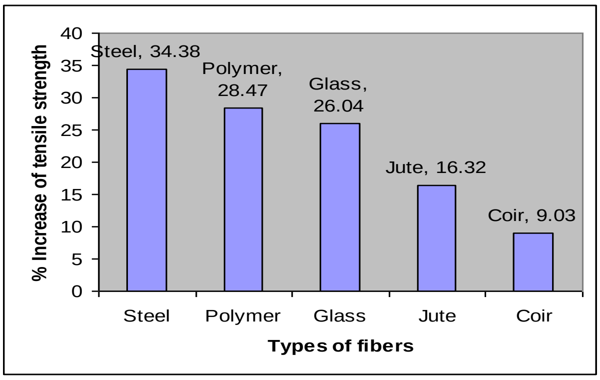


FIG. 3 PERCENTAGE INCREASE OF TENSILE STRENGTH OF DIFFERENT TYPES OF FIBERS

Compressive Strength

Six cubes of size 150x150x150 mm were tested in compression testing machine for each verity of fiber cement ratio to determine the 28th day compressive strength of concrete. The specimens were tested as per IS 516 - 1959. The table V shows the Average compressive strength of sample cubes after 28 days for various f/c ratio.

TABLE 5 COMPRESSIVE STRENGTH TEST RESULT OF COIR FIBER ADDED CONCRETE

Fiber cement ratio (%)	**Avg.Max.Load (tonnes)**	**Compressive strength(N/mm^2)**
0.5	52.6	23.38
1.5	47.5	21.11

Concrete mix of f/c ratio 0.5% is showing an increase of 9.15% in compressive strength when compared to that PCC. Figure 4 is the graph showing the variation of compressive strength with f/c ratio.

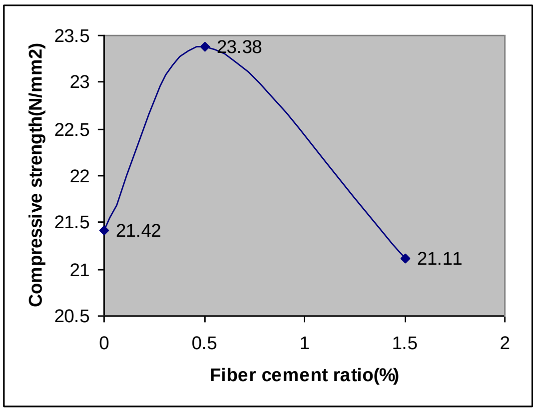


FIG. 4 VARIATION OF COMPRESSIVE STRENGTH WITH F/C RATIO

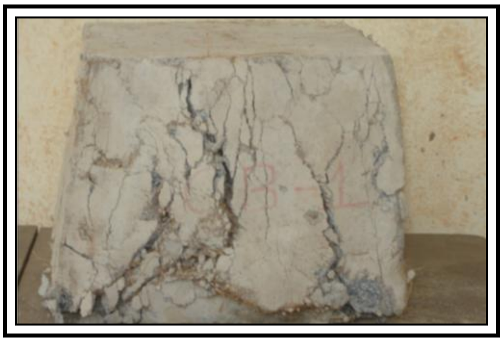


FIG. 5 CUBE AFTER COMPRESSION TEST

After the breaking load in compression test of the cube if we apply more load to the specimen the specimen will not break and more over it take some more load. This may be due to bridging of the fibers in the matrix causes the post cracking integrity of the fiber added concrete while using coir fiber in the concrete. The figure 5 shows the cube specimen after compressive strength test.

The compressive strength increases for increase in f/c ratio up to 0.5% and then shows a decrease. The increase in compressive strength is due to bridging of fibers within the matrix. The decrease in compressive strength may be due to formation of weak zones by bundling of large amount of fibers in the matrix. Figure 6 shows the percentage increase of compressive strength of the concrete while using different types of fibers. Tensile strength of 1.0 % volume fraction of steel fiber added concrete is23.68 N/mm^2, this strength can be obtained by coir fiber added concrete of 0.5% f/c ratio. To get the same compressive strength by using other fibers we have to use more than 1.5% volume fraction.

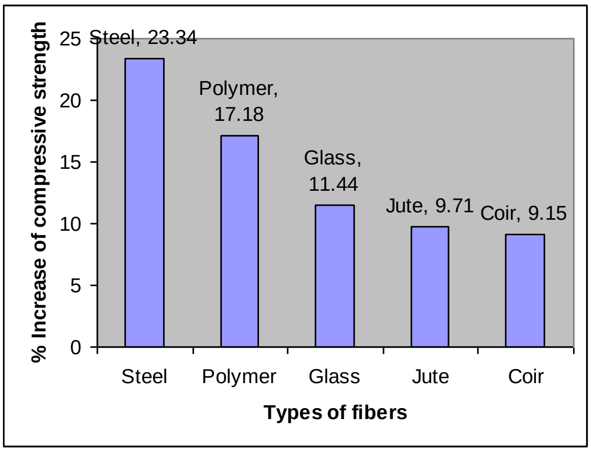


FIG. 6 PERCENTAGE INCREASE OF COMPRESSIVE STRENGTH OF DIFFERENT TYPES OF FIBERS

Flexural Strength Standard beam specimens of size 100x100x500 mm were used for finding flexural strength of the concrete. Six of these specimens were kept for each f/c ratio and tested Universal testing machine as per IS: 516 - 1959 for determining flexural strength and the test results are shown in tables 6

TABLE 6 FLEXURAL STRENGTH TEST RESULT OF COIR FIBER ADDED CONCRETE

Fiber cement ratio (%)	Avg.Max.Load (tonnes)	Flexural strength(N/mm^2)
0.5	1.19	4.75
1.5	1.08	4.32

The specimen of fiber content is showing an increase of 46.15% when compared to that of PCC. Figure 7 is the graph showing the variation of flexural strength with f/c ratio. Flexural strength of 1.5 % volume fraction of steel fiber added concrete is 4.82 N/mm^2, this strength can be obtained by coir fiber added concrete of 0.5% f/c ratio. Maximum Flexural strength that can be achieved by other fiber added concrete is comparatively lesser than coir fiber added concrete.

When PCC beam is subjected to bending test the breaking is suddenly at a particular load. But when coir fiber added concrete beam is tested even after the breaking load the specimen did not break into two more over it takes more load it may be due to the phenomenon called tension stiffening due to bridging of fibers within the matrix. The fibers incorporated in the concrete matrix, bridges within the matrix which has positive effect on tension stiffening effect. It is well known that after cracking the fibers between the cracks carries tension and hence stiffness the response of a reinforced concrete member subjected to tension. This stiffening effect, after cracking, is referred to as tension stiffening.

Figure 8 shows the percentage increase of flexural strength of the concrete while using different types of fibers.

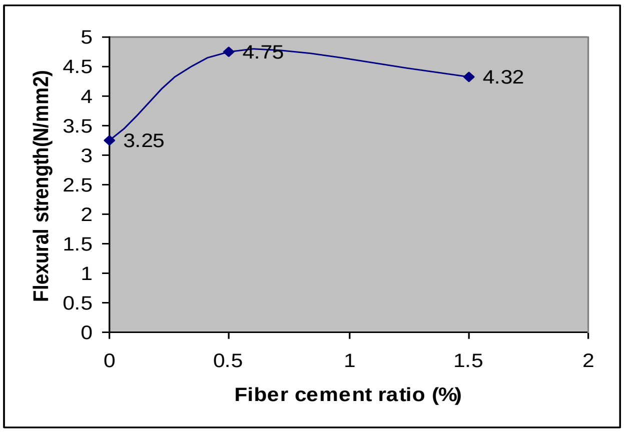


FIG.7 VARIATION OF FLEXURAL STRENGTH WITH F/C RATIO

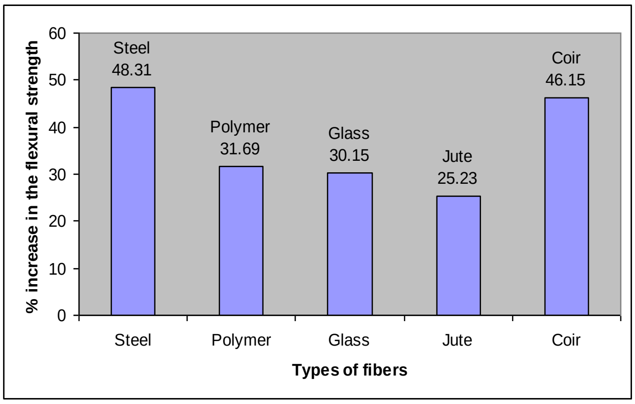


FIG. 8 PERCENTAGE INCREASE IN FLEXURAL STRENGTH FOR DIFFERENT TYPES OF FIBERS

Modulus of Elasticity

Six cylinders of sizes 150mm diameter and 300mm height were casted for each fiber cement ratio. These were tested in a compression testing machine as per IS: 516 - 1957 for determining the modulus of elasticity and the test results are shown in the tables 7

TABLE 7 MODULUS OF ELASTICITY OF COMPOSITE

Fiber cement ratio (%)	Avg. Modulus N/mm^2 (x10^4)
0.5	3.38
1.5	2.94

Modulus of elasticity of the coir fiber added concrete composite is more than that of the ordinary concrete (2.236x10^4 for M20 concrete). Increase in the modulus of elasticity of the fiber added concrete may be due to the tensile property of the fibers added to the concrete. Coir fibers have percentage elongation of 30% which increases the modulus elasticity of the composite.

V. COST BENEFIT ANALYSIS

The cost benefit ratio for any work or test can be defined as the ratio of the cost needed to produce or realize the benefit in required quantities to the corresponding benefit.

In this study, the benefit required is synonymous to the realization of maximum strength attained on testing of the standard specimens, according to Indian Standard provisions, after 28 days of curing in water. The maximum strength attained by the specimens is considered in terms of the splitting tensile strength and the flexural strength on testing after 28 days of curing. After analyzing the test results from the figures and tables, comparing them with the available test results for steel, polymer, glass and jute fiber added concretes, it can be seen that the strengths obtained by 0.5% f/c ratio coir fiber added concrete and those obtained by 0.5% volume fraction steel, polymer, glass and jute fiber added concretes are comparable. The extra cost required for the production of one cubic meter fiber added concrete is calculated. It can be seen that for getting same splitting tensile strength using different types of fibers the cost for the coir fiber added concrete is very less compared to the other fiber added concrete. The cost analysis is shown in the graph as figure 9.

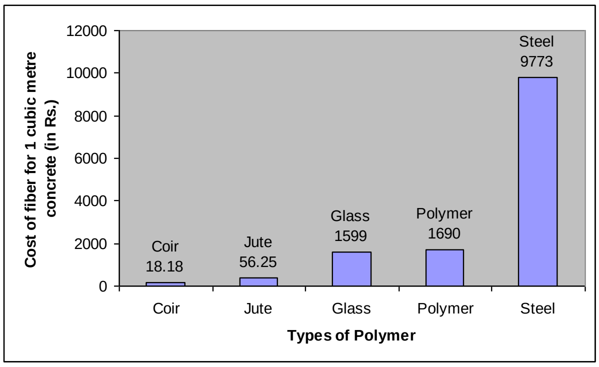


FIG.9 COST OF FIBER FOR 1 CUBIC METER FIBER ADDED CONCRETE

From the graph it is clear that cost for producing coir fiber added concrete to get strength as that for other fiber added concrete is negligible which means it is far cost effective than other fiber added concrete.

VI. CONCLUSIONS

From this study it can be seen that coir fibers can be effectively used in concrete to increase the tensile strength, flexural strength etc. Splitting tensile strength of the ordinary concrete was increased while adding coir fiber to the concrete. The maximum tensile strength that can be obtained by coir fiber added concrete may be very near to 3.14 N/mm^2 which is about 9% more than the ordinary concrete. This strength is obtained when fiber cement ratio is 0.5% while the same strength can be obtained by adding 0.5 volume fraction of steel fibers into the ordinary concrete.

Compressive strength of the coir fiber added concrete also increases with increase in the fiber content to a maximum value and then decreases. Compressive strength is never decreased by the addition of the coir into the concrete. A 9.15 % increase in the compressive strength is obtained as maximum increase for the f/c ratio of 0.5%, Which is Comparable with 1.0% volume fraction of Steel fiber added concrete.

Flexural strength of the ordinary concrete increased up to 4.75 N/mm^2 by the addition of coir fiber into the concrete with 0.5% f/c ratio which shows an increase of 46.15 % in flexural strength which comparable to steel fiber added concrete whose increase percentage is 48%.

Modulus of elasticity of the coir fiber added concrete composite is higher than the ordinary concrete. Modulus of elasticity is increased up to 3.384x 10^4 N/mm^2 for the f/c ratio of 0.5%. This increase in modulus of elasticity may be due to the growth of cement hydration products with in the hollow cellulose fibers which lead to excessive fiber to matrix bonding. Increase in the modulus of elasticity is may be due to the tension stiffening behaviour of fiber added concrete. As the modulus of elasticity increases the tension stiffening by fibers also increases.

Strength of the coir fiber added concrete increases with the fiber content at first and then it is reduced. Maximum value for the compressive strength, tensile strength, flexural strength was obtained for the f/c ratio of 0.5%. So it can be inferred from the study that optimum f/c ratio of coir fiber to the concrete may be 0.5%. Workability of the fresh concrete is getting reduced with the increase in the fiber content. But at the most efficient f/c ratio that is f/c = 0.5% decrease in the slump value is very less.

Coir fiber added concrete very cost effective than any other fiber added concrete. Cost for the production of coir fiber added concrete of strength equal to the strength obtained by 0.5% volume fraction of steel fiber added concrete, polymer fiber added concrete and glass fiber added concrete is negligible.
From the testing of the specimen it can be seen that even after breaking load the concrete did not break more over it took more and more load. This is due to the post cracking integrity of the fiber added concrete which is the property of any fiber added concrete. It can be seen that the post failure integrity or post cracking strength increases with increase in fiber content. But we can see that increase in fiber content beyond a limit will cause decrease in strength of concrete. So the post failure behaviour and strength of concrete need to be compromised for an optimum fiber cement ratio.

The increase in the strength may be due the bridging of fibers and redistribution of moments. The splitting tensile strength and flexural strength increases as the fibers incorporated in the concrete matrix absorb the deformation energy and make the fiber added concrete a pseudo ductile material to an extend.

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