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Experimental Analysis of Behaviour of Joints in Fibre Reinforced Concrete Pavements

Akhil S[1], Priya Grace Itti Eipe[2]

[1]*PG Scholar, Department of Civil Engineering, SVNCE.*
[2]*Professor and Head of the Department, Department of Civil Engineering, SVNCE, Kerala.*

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Abstract - *The behaviour of the fiber reinforced concrete pavement was analyzed in this study by means of experimental tests. Slabs connected by a dowel bar representing a pavement joint system were used for testing. Steel, polypropylene and coir fibers were used in the study. After analyzing the fresh and hardened concrete properties of each type of specimens, their optimum fiber dosage were found. Concrete slabs were then made with optimum dosage of each fiber and also with control mix were tested. For measuring the vertical deflections, two LVDT's were used. Steel fiber was found to be the strongest followed by coir and polypropylene. FRC specimens were found to be stronger than control specimen, transfer load effectively and reduce crack formation. Reduced cracks ensures pavement durability, reduced maintenance, improved performance and ride quality.*

Key Words: FRC, Steel fibre, Polypropylene fibre, Coir fibre, Rigid pavement, Construction joint

1. INTRODUCTION

A long lasting, reliable and economical transportation system is a critical component for the continuous movement of goods and services. Extensive research on highway pavements is needed to address current problems as well as develop new designs and techniques for future pavement applications.

Bitumen has been widely used in the construction of flexible pavements for a long time; however, due to high temperature in summer season, the bitumen becomes soft resulting in bleeding, rutting and segregation finally leading to failure of pavement. In winter season, due to low temperature, the bitumen becomes brittle resulting in cracking, ravelling and unevenness, which makes the pavement unsuitable for use. In rainy season, water enters the pavement resulting in potholes and sometimes total removal of bituminous layer. In hilly areas, due to sub-zero temperature, the freeze-thaw cycle takes place. Due to freezing and melting of ice in bituminous voids, volume expansion occur. This leads to pavements failure. India imports nearly 70% of the petroleum crude from which bitumen is obtained and the continuous rise in cost of bitumen is a serious problem faced by the construction industry. The demand for bitumen in the coming years is likely to grow steeply, far outstripping the availability. Hence, it will be in India's interest to explore alternative binders. Cement is available in sufficient quantity in India. Thus, cement concrete roads should be the obvious choice in future road programmes.

Rigid pavements, though costly in initial investment, are cheap in long run because of low maintenance costs. Besides the easy availability of cement, concrete roads have a long life and are practically maintenance-free. Another major advantage of concrete roads is the savings in fuel by commercial vehicles to an extent of 14-20%. The fuel savings themselves can support a large programme of concreting. Cement concrete roads save a substantial quantity of stone aggregates and this factor must be considered when a choice pavement is made, Concrete roads can also withstand extreme weather conditions – wide ranging temperatures, heavy rainfall and water logging. Hence, though cement concrete roads may cost slightly more than a flexible pavement initially, they are economical when whole-life-costing is considered.

Fibre reinforced concrete (FRC) is defined as a composite material consisting of concrete reinforced with discrete randomly but uniformly dispersed short length fibres. The fibres can be made of steel, polymer or natural materials. FRC is considered as a material of improved properties and not as reinforced cement concrete where reinforcement is provided for local strengthening of concrete in tension region. Several research has been done on the use of fibre in concrete, Bentur and Mindess [1] (2007); Rossi, [2]; Banthia and Gupta [3]; Kanalli et.al, [4], for improving some specific properties of the concrete. The concept of using fibres in a brittle matrix was first recorded with the ancient Egyptians who used the hair of animals and straw as reinforcement for mud bricks and walls in housing, Balaguru and Shah, [5]. This dates back to 1500 B.C.

Since in FRC, fibres are distributed uniformly in concrete, it has better properties to resist internal stresses due to shrinkage. As fibres improve specific material properties of the concrete, impact resistance, flexural strength, toughness, fatigue resistance, ductility also improves. Fibres generally used in cement concrete pavements are steel fibres, organic fibres like coir and jute, glass fibres, polymer fibres such as polypropylene and polyester, nylon fibre etc.

Shah and Rangan [6], in their study on mechanical properties of FRC, conducted uni-axial compression test on fibre reinforced concrete specimens. The results showed an increase in strength of 6% to 17% compressive strength, 18% to 47% split tensile strength, 22% to 63% flexural strength and 8% to 25% modulus of elasticity respectively. Byung Hwan Oh [7], studied about the mechanical properties of concrete. The results showed an increase in strength of 6% to 17% compressive strength, 14% to 49% split tensile strength, 25% to 55% flexural strength and 13% to 27% modulus of elasticity respectively. Kukreja et.al [8] conducted some experiments and reported that, based on the results of three methods such as split tensile test, direct tensile test and flexural test, split tensile strength test was recommended for fibrous concrete. Also increase in tensile strength, post cracking strength and toughness was reported.

Ramakrishna and Sundrarajan [9], compared the theoretical and experimental investigations on the compressive strength and elastic modulus of coir and sisal fibre reinforced concretes for various volume fractions. It was observed that both the experimental and analytical values of elastic modulus had shown 15% discrepancy, which can be regarded as comparatively small.

Shakor and Pimplikar [10] carried out a study on concrete with glass fibre and without glass fibre and they conducted various trial tests to indicate the differences in compressive strength and flexural strength by using cubes of varying sizes. Experimental test results indicated the tremendous potential of GFRC as an alternative construction material.

Joints are used in concrete pavements in order to control cracking due to thermal and environmental conditions. Joints may be parallel to traffic, longitudinal joints, or perpendicular to traffic, transverse joints. There are three types of transverse joints that are typically used in concrete pavements: contraction joints, construction joints, and expansion or isolation joints. Dowel bars are the standard for mechanical load transfer devices used in PCC pavements today. They provide vertical shear reinforcement while allowing for expansion and contraction of the joint or crack. They are smooth bars that are placed across the pavement discontinuity, parallel to the major axis of the roadway, Darter et.al, [11].

2. EXPERIMENTAL SET UP

In this experimental study, fresh concrete workability and mechanical properties of concrete like compressive strength, split tensile strength, flexural strength and modulus of elasticity were tested and determined. Fibre contents used are 0%, 0.25%, 0.50%, 0.75%, 1% and 1.25%. The optimum value of each fibre dosage was calculated. Slabs are made with the optimum fibre content of each fibre. The slab specimens casted was of 1000mm x 500mm, with 170mm thickness. The dowel bar used was a 25mm thick and 500mm long steel bar. A point load was applied at the edge of slab by means of hydraulic jack.

2.1 Fibres

Fibres used for the study were hooked-end steel fibre, polypropylene & natural coconut fibre. The properties of fibres are presented in the table 1.

Table- 1: Properties of fibres

Properties of fibres	Steel	Polypropylene	Coir
Diameter (mm)	0.5	0.44	0.25
Aspect ratio	60	113.6	120
Specific gravity	7.8	0.91	0.7

2.2 Mix design

All the mixes were prepared according to M25 grade concrete. The specifications according to IRC 44-2008 was followed. The purpose of design is to achieve the minimum demanded strength, durability and to make the concrete in the most economical manner. The mix design obtained is shown in table 2.

Table- 2: M-25 Mix design

Cement	Fine aggregate	Coarse aggregate
1	1.8	3.4

2.3 Test Specimen Preparation

Test specimens were casted with three different fibres and five different percentages (0.25%, 0.50%, 0.75%, 1% and 1.25%) and one set of control specimens without fibre content were also casted. Optimum fibre content was determined. A total of 230 specimens were casted. The test specimen details is shown in table 3.

Table -3: Test specimen details

Specimen	Test	No.
Cube	Compressive Strength	104
Cylinder	Split tensile Strength	42
Beam	Flexural strength	42
Cylinder	Modulus of elasticity	42
Total		230

2.4 Specimen Casting

The experiment consisted of casting a pair of concrete slabs having a length of 1m, width 0.5m and thickness 0.17m, with optimum dosage of each fibre. Dowel bars of length 50cm and outer diameter 25mm were used. The dowel bar was embedded and kept in concrete at one end and the other end was kept free to expand or contract in a sleeve by providing a thin film of bitumen over it. The embedded length of the dowel bar was 30 cm in the concrete.

2.5 Tests on Joined Concrete Slabs

Rectangular concrete blocks of size 300x200x150 were loaded in compression and their stiffness was measured. From the load-displacement curve shown in chart 1, it can be noted that the behaviour is almost linear-elastic. The average stiffness of the single block was equal to 3.85kN/mm. The obtained stiffness of simulated subgrade was equal to 0.08 N/mm^3. Therefore, they could be used to simulate the subgrade. The concrete slabs were placed on top of the simulated subgrade with the dowel bar inserted in the sleeve and leaving a 25mm gap at the joint. LVDTs were attached to the loaded edge portion of the slab. Single point hydraulic load was then applied towards the edge of the slab casted with the dowel bar. The whole assembly was setup on a hydraulic loading frame of capacity 100 tonnes. The test was conducted on all three fiber reinforced concrete slabs and on normal conventional concrete slabs.

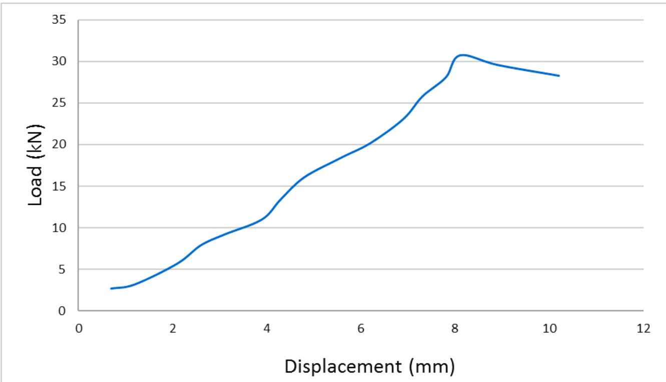

Chart-1: Load vs Displacement graph for concrete blocks used to simulate subgrade

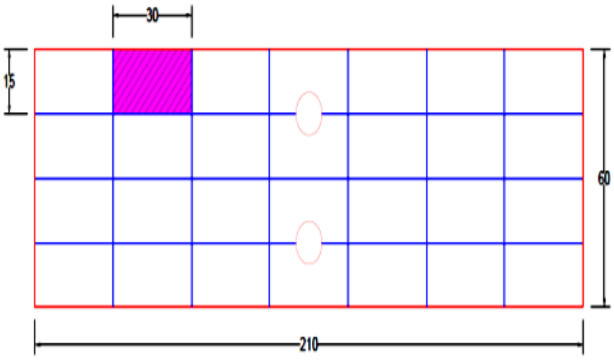

Fig – 1: Layout of concrete blocks used to simulate subgrade

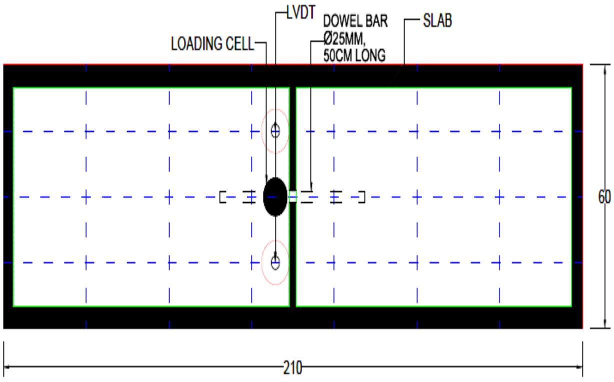

Fig – 2: Slab layout for testing.

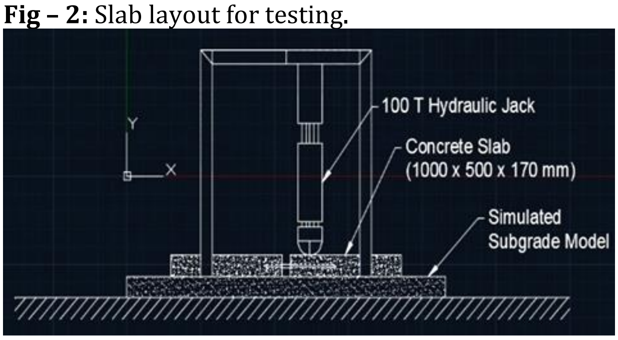

Fig – 3: Representative diagram of testing of joined concrete slabs

3. RESULTS AND DISCUSSION

The workability properties and mechanical strength properties have been discussed here. Comparison of experimental values for all the fibre concrete mixes with varying fibre content were done and the optimum fibre content was determined. Finally, the structural properties of slabs joined by a dowel bar, under point loading is also discussed.

3.1 Workability Tests

The tests commonly employed to measure workability are slump test and compaction factor test.

3.1.1 Slump Test

The results of the slump test are shown in the table 4.

Table -4: Slump test results

Vol. Fraction	Steel (mm)	Polypropylene (mm)	Coir (mm)
0%	27	27	27
0.25%	23	22	24
0.5 %	21	20	23
0.75%	20	17	21
1%	18	15	19
1.25%	16	13	18

Comparison of result with other fibres is shown in chart 2.

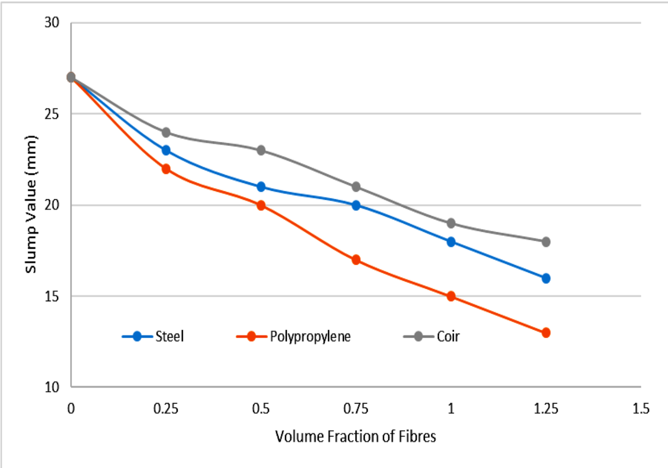

Chart – 2: Comparison of test results for slump test

3.1.2 Compaction Factor Test: The compaction factor test results are shown in table 5 and the comparison of test results between three fibres are shown in chart 3.

Table – 5: Compaction factor test result

Vol. Fraction	Steel	Polypropylene	Coir
0%	0.84	0.84	0.84
0.25 %	0.81	0.80	0.82
0.5%	0.79	0.78	0.79
0.75%	0.76	0.74	0.77
1%	0.74	0.72	0.76
1.25%	0.73	0.70	0.74

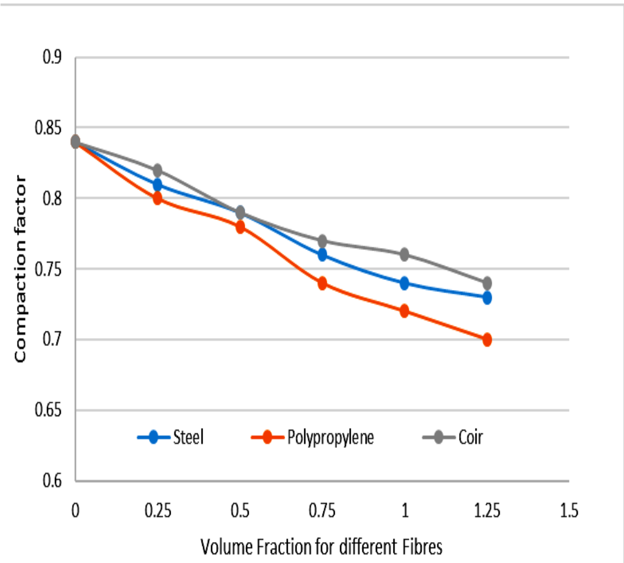

Chart – 3: Comparison of compaction factor test results.

Based on the results of slump test and compaction factor test, it could be concluded that the addition of fibres in plastic concrete changes its mobility. The loss of mobility occurs primarily by the fibres blocking the relative movement of the aggregates. Thus, the use of an appropriate mix design method, considering the effect of the fibres, is needed to guarantee adequate workability conditions for FRC.

3.2 Tests on Hardened Concrete

Specimens casted were cured and tested after 7 and 28 days respectively. The tests done include compressive, tensile, flexural and modulus of elasticity test. The specimens prepared with different volume fraction of fibres was tested. Three specimens of each fraction of one fibre was used for the test and the average value was calculated from the test results.

3.2.1 Compressive Strength Test

The compressive test results are as shown in the table 6. Specimens subjected to the compressive test are shown in figure 4 and figure 5. The comparison of results of various fibres are shown in chart 4.

Table - 6: Compressive strength test results

Volume Fraction of Fibre (%)	Compressive Strength at 7 days (N/mm^2)			Compressive Strength at 28 days (N/mm^2)		
	Steel	Polypropylene	Coir	Steel	Polypropylene	Coir
0%	23.1	23.1	23.1	32	32	32
0.25%	24.5	25.3	25.1	33.1	34.8	33.8
0.5%	26.3	26.7	28.9	34.8	36.1	36.9
0.75%	28.1	28.4	27.4	38.3	38.1	33.2
1%	30.8	27.1	25.8	43.1	37.1	28.1
1.25%	27.1	24.8	22.1	39.1	35.2	27.2

Fig -4: Specimen with fibre

Fig -5: Specimen without fibre.

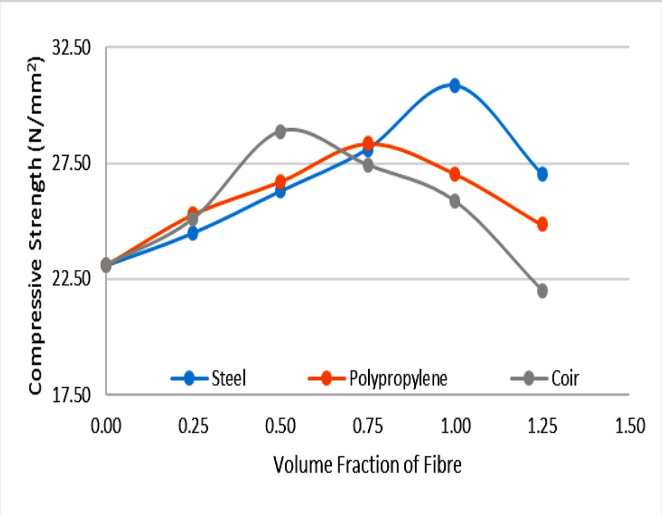

Chart -4: Comparison of 7th day strength

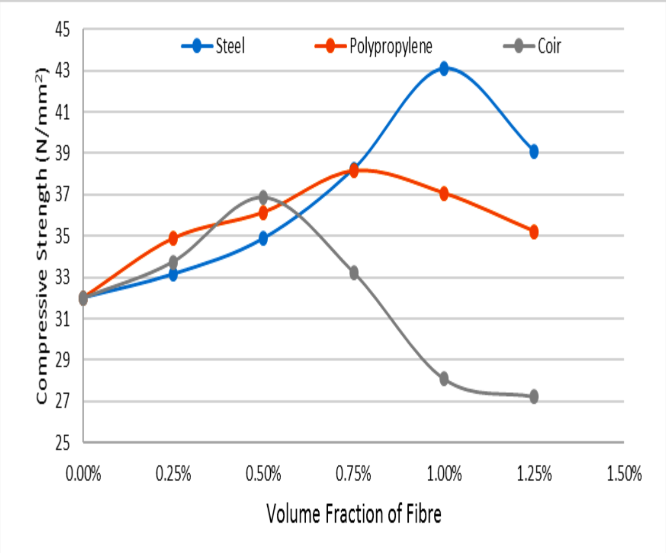

Chart -5: Comparison of 28th day strength

Chart 4 and 5 show the comparison between 7th and 28th day compressive strength for the different FRC mixes. Table 6 show that all specimens are satisfying the nominal criteria that the 7th day strength shall be 65% of the concrete grade. After 28 days of proper curing the gain in strength was observed to satisfy the target strength.

The compressive strength of steel fibre concrete ranged between 23 and 30 Mpa at 7 day curing and 28 day strength ranged between 32 and 43 MPa, for different fibre volume fractions. 7th day test results shows a 33% increase in strength and 28th day test results for shows an increase in strength of about 34% when compared with the conventional concrete. The optimum dosage was found to be 1% fibre volume.

For polypropylene fibre concrete cube specimens, the test results vary from 23.1 MPa to 28.35 MPa for 7 days of curing and 32 MPa to 38.15 MPa for 28 day cured specimens. For 7th day test there was an increase of 22% and for 28th day test the increment was about 19% in strength. The optimum dosage of polypropylene dosage was found to be 0.75% fibre volume.
Addition of coir fibre also showed an increase in the compressive strength of the concrete after 7days and 28 days of curing. The test results show that the compressive strength of the coir reinforced concrete specimens vary between 23.1 MPa and 28.89 MPa for 7 days of cured specimens and for 28 days cured specimens the values ranges between 32 MPa and 36.85 MPa. There was an increase of 25% for 7th day strength and 15% increase for the 28th day strength. 0.5% volume fraction was found to be the optimum dosage.

From the comparison of the results, it is observed that the increase in the volume fraction after the optimum dosage reduces the increment of compressive strength of the specimens irrespective of fibre type used. This may be due to the balling effect during the concrete mixing.

3.2.2 Flexural Strength Test

The results for flexural test for various fibres are as shown in table 7 and the comparison of results for various fibre types are shown in chart 6. The specimens after testing are shown in figure 6 and 7.

Table 7: Flexural strength test results for various fibres

Volume Fraction	Steel (N/mm²)	Polypropylene (N/mm²)	Coir (N/mm²)
0	4.09	4.09	4..09
0.25	4.86	5.13	5.069
0.5	5.35	5.79	6.045
0.75	6.71	6.25	5.46
1	8.1	6.01	4.29
1.25	7.09	5.22	3.9

Fig 6: Flexural test specimen without fibre

Fig 7: Flexural test specimen with fibre

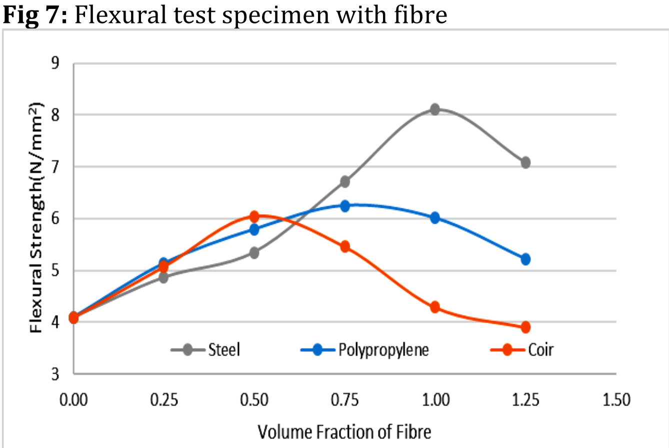

Chart -6: Comparison of flexural strength

Chart -6, shows continuous drop of strength for specimen with polypropylene fibre after 0.75% fibre content. Strength of specimens with steel fibre dropped after 1% fibre content and for coir fibre samples, the drop in strength occurred after 0.5% fibre content. Hence, we may conclude that the optimum value of fibre content is 0.5% for flexural strength for coir fibre samples, 0.75% for samples with polypropylene and for steel fibre, the optimum fibre dosage is 1%.

3.2.3 Split Tensile Strength Test

The test results are presented in Table 8. The specimens subjected to split tensile strength test are shown in the figure. 8 and 9. Comparison of test results between all three fibres are shown in chart 7.

Table 8: Split tensile strength for different mixes

Volume Fraction of Fibre (%)	Strength at 28days (N/mm²)		
	Steel	Polypropylene	Coir
0%	3.15	3.15	3.15
0.25%	4.72	3.55	3.9
0.5%	5.29	4.33	4.35
0.75%	5.80	5.65	4.22
1%	6.30	4.89	3.75
1.25%	5.15	4.02	3.45

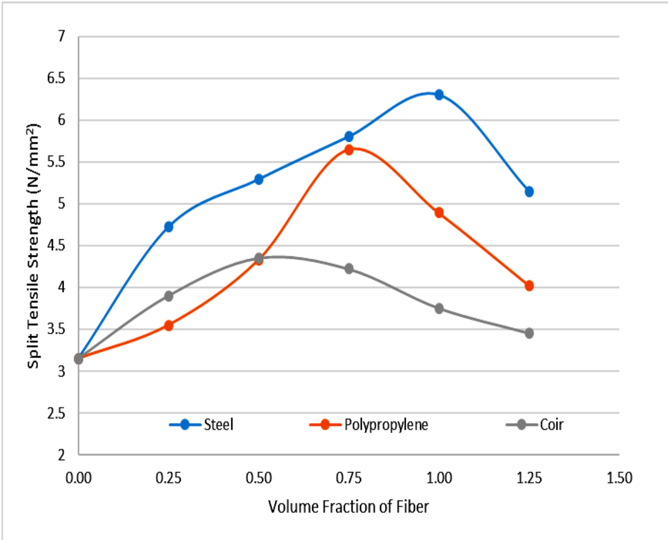

Chart -7: Split Tensile Strength at 28 days

Fig 8: Splitting tensile strength test of specimen with fibre.

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Fig 9: Splitting tensile strength test of specimen without fibre.

It was observed that, the 28 days spilt tensile strength increased continuously with increase in fibre content. Hence, the Fibres are best suitable for improving the spilt tensile strength of structural concrete.

3.2.4 Modulus of Elasticity of Concrete

Results for modulus of elasticity based on the average values of three test data for all fibre contents are presented in table 9. Result comparison graph for various fibre types is shown in chart 8.

Table 9: Modulus of elasticity for different mixes

Volume Fraction of Fibre (%)	Strength at 28 days (GPa)		
	Steel	Polypropylene	Coir
0%	28.1	28.1	28.1
0.25%	27.23	27.34	27.51
0.5%	26.43	23.42	26.35
0.75%	25.51	26.01	24.22
1%	23.83	24.48	23.75
1.25%	21.76	22.79	22.45

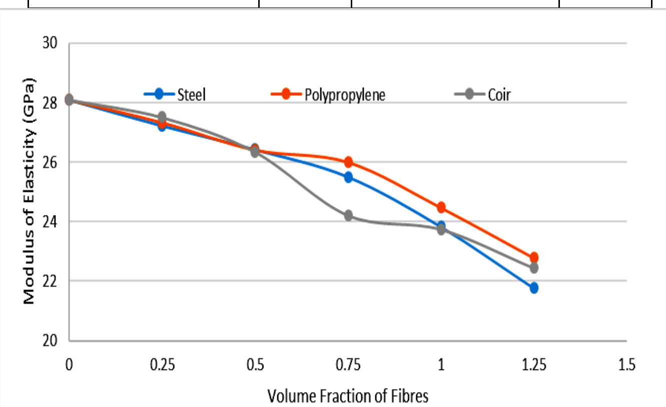

Chart -8: Modulus of elasticity test result comparison

Results shows a reduction in modulus if elasticity values as fiber content increases. Hence, fiber addition reduces the elasticity property of the concrete.

3.3 Test on Joined Concrete Slabs

The test was done on a hydraulic loading apparatus.. Load vs deflection graph was obtained from the test. The slabs were placed on the simulated subgrade model and joined together such that the dowel bar had a perfect fit in the adjoining slab and no change in the alignment of slabs occurred. Point load was applied on the edge of the slab having the dowel bar embedded in the hardened concrete. Deflection was measured from the bottom surface of the slab using two LVDTs and average value was taken. The ultimate load and corresponding deflection for each type of fiber specimen is presented in table 10 and load vs deflection graph is shown in the chart 9. The testing set up is shown in the figure 10 and 11.

Table -10: Slab specimen test result

Specimen	Ultimate Load (kN)	Deflection 1(mm)	Deflection 2 (mm)	Avg. Deflection (mm)
Control	61.3	28.19	24.49	26.34
Steel	169.2	29.5	21.5	25.5
Polypropylene	128.1	25.1	22.5	23.8
Coir	156.8	16.3	14.58	15.44

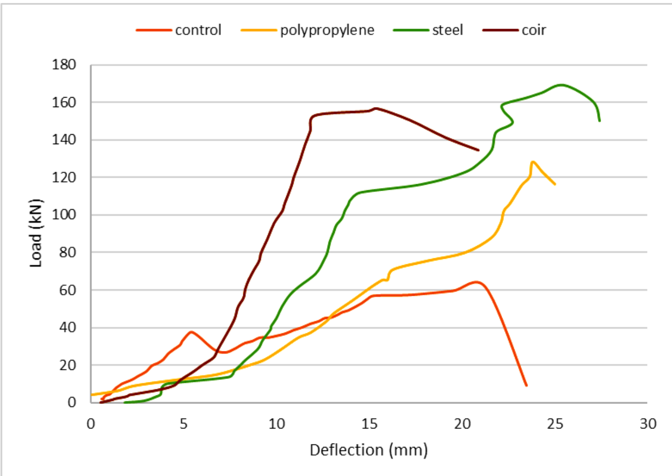

Chart-9: Load – deflection curve for slab specimen

From the results, it is clear that the steel fibre reinforced slab can withstand much more load than the other type of fibre reinforced slabs and the control specimen itself. As expected

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there is an increase in the load carrying capacity of the specimens due to the addition of the fibres. For the steel fibre reinforced slab specimen there is an increase of 68% in load carrying capacity. For coir reinforced slab specimen the increase in the strength was about 60% and finally for polypropylene fibre reinforced specimen there is an increase of 42% in load carrying capacity.

Fig 10: Testing of slab specimens

Fig 11: Testing of slab specimens

During the test, load at which first crack occurred on the specimen was also noted. The first crack load is presented in table 11.

Table -11: First crack load

Specimen	Control	Steel	Polypropylene	Coir
First crack load (kN)	23.3	60.71	33.6	56.7

The first cracking load of FRC pavements are much higher than that of the ordinary portland cement concrete pavement slab. Thus, FRC pavements can withstand more load without causing any cracks, which in turn increase the life of the concrete pavements as most of the failure occurs due to the early cracking of the pavements.

4. CONCLUSIONS

From the experimental study, it is clear that the addition of steel, polypropylene and coir fibres in their optimum dosage improves the mechanical properties and there by increases in the overall load bearing ability of pavement slabs. The fibres hold together the concrete matrix, which prevents the edge & corner stress from damaging the pavement. As the fiber reinforced concrete has more strength than that of the design strength, normal traffic load will not damage the pavement and crack formation is prevented. This will increase the life of the pavement and reduces the yearly maintenance and repair cost.

Faulty pavement leads to accidents, vehicle damages, reduction in travel speed, time loss etc. Thus, addition of fibres will also reduce these defects to some extent.

However, there are some problems associated with the incorporation of these fibres. Steel fiber can deteriorate due to corrosion and coir fibers can undergo natural deterioration as pavement ages. These problems can be avoided by the use of a non-corrosive and non-degrading synthetic fibre like polypropylene, nylon etc. Use of non-corrosive steel fibres are an alternative but due to the high cost of such fibers, they are not used in pavement construction at present. At present many researches are in progress on developing cheaper and non corrosive steel fiber.

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