Comparison of Properties of Fiber Reinforced Concrete with Conventional Concrete

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Abstract - Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking, so there is a necessity to overcome these problems. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibres to concrete would act as crack arrester and would substantially improve its mechanical and durability properties. This type of concrete is known as Fibre Reinforced Concrete. In the present study, investigations on fiber reinforced concrete is carried out and mainly crimped steel fiber and polypropelyne fibers are used. Pavement quality concrete of grade M-40 is designed as per IRC: 44-2008 and a water cement ratio of 0.38 is adopted. Specimens such as cubes (of size 150 x150 x150mm), cylinders (300mm height and 150mm dia.) and beams (100 x100 x 500mm) are cast by adding different fiber dosages such as 0.5%, 1%, 1.5%, 2% by volume for steel fibers and 0.1%, 0.2%, 0.3%, 0.4% for polypropelyne fibers. The specimens are kept for curing over a period of 7 days and 28 days. The structural behavior of the specimen is determined by conducting destructive(compressive strength, tensile strength and flexural strength), non-destructive(UPV test) and durability tests(water absorption and sorptivity). From the test results it can be concluded that the performance of conventional concrete can be improved by the addition of small amount of fibers. Finally, the optimum dosages of steel and polypropelyne fibers are found to be 1.5% and 0.3% respectively.

Key words: Fibers, Cracking, Crimped steel fiber, Polypropelyne, Dosage, Water absorption, Sorptivity.

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1. INTRODUCTION

A pavement is the layered structure on which the vehicle travels which serves two purposes, namely, to provide a comfortable and durable surface for vehicles and to reduce stresses on underlying soils. Two types of pavements are popularly used in India-rigid pavement and flexible pavement. A flexible pavement is a layered structure which has a low flexural strength. Thus, external load is largely transmitted to the subgrade. If the pavement itself is very strong, but it is constructed on loose and poor subgrade, it can fail and also the maintenance cost is also very high, this necessitates the development of concrete pavements.

Rigid pavements possess high flexural strength and transmits the wheel loads mainly by slab action. Minor imperfections or localized weak spots in the material below the slab can be taken care by the slab itself and this type of pavement can be constructed on weak soils also. Rigid pavement is more precise to structural analysis than the flexible pavement. This is because flexural strength is the main basis for design. On the other hand, flexible pavement design based on empirical method. The initial cost of concrete pavement is high but they require little maintenance and lasts for a longer period. As petroleum products are exhausting day by day it is necessary to adopt concrete pavements than the flexible pavements.

Concrete pavement design has over the years become a more important part of concrete roads. A high investing cost has to be motivated, and the benefits of a pavement with less maintenance over a longer design life have to be proved already before construction. Efforts to avoid premature performance failing of concrete roads are, at a larger degree, considered than for other pavement alternatives since rehabilitation techniques are expensive. A modern design methodology has to take into account all sorts of environmental conditions as well as future estimations on,

for example traffic growth or environmental changes. The optimization of materials in the pavement system, demands for long-term fatigue resistance at the lowest cost and ecologically sound choices must be considered. The understanding of the behaviour of a concrete road is vital for the design and the performance prediction.

1.1 Special concrete

Special types of concrete are those which have improved properties or those produced by unusual techniques. Concrete is by definition a composite material consisting essentially cement as binding medium and aggregate particles, and it can take many forms. These concretes have many advantages and disadvantages. Some special types of concrete are as follows,

1. High Volume Fly Ash Concrete
2. Silica-Fume Concrete
3. GGBS-Slag Based Concrete
4. Light-Weight Concrete
5. Polymer Concrete
6. Self-Compacting Concrete
7. Fiber-Reinforced Concrete
8. Temperature Controlled Concrete etc.,

1.2 Fiber reinforced concrete

In the past, attempts had been made to improve the tensile properties of concrete members by using conventional reinforced steel bars and also by applying restraining techniques. Although both of these methods provide tensile strength to the concrete members, they however, do not increase the inherent tensile strength of concrete itself. In plain concrete and similar brittle materials, structural micro cracks will develop even before the loading, particularly due to drying shrinkage effect or other causes which will change volume of concrete. The development of such microcracks is the main cause of inelastic deformations in concrete. It has been recognized that the addition of small amount of closely spaced, uniformly dispersed fibers to concrete would prevent crack propagation and would substantially improve its static and dynamic properties. This type of concrete is known as Fiber Reinforced Concrete. Fiber reinforced concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibers.

1.3 Effect of fibers in concrete

Fibers are normally used in concrete to control cracks caused due to plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and also bleeding of water. Some types of fibers produce greater impact, abrasion and shatter resistance in concrete. Generally, fibers do not increase the flexural strength of concrete, so it cannot replace moment resisting or structural steel reinforcement.

The amount of fibers used in a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed volume fraction (V_F). V_F typically ranges from 0.1 to 3%. Aspect ratio (l/d) is calculated by dividing fiber length (l) to its diameter (d). If the Youngs modulus of the fiber is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increase in the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers which are too long tend to "ball" in the mix and will cause workability problems. Some recent research indicated that using fibers in concrete has limited effect on the impact resistance of concrete materials. The results also pointed out that the micro fibers would improve the impact resistance as compared to the long fibers.

1.4 Factors affecting properties of fiber reinforced concrete

- Relative Fiber Matrix Stiffness
- Volume of Fibers used
- Aspect Ratio of the Fiber
- Orientation of the Fibers
- Workability
- Compaction of Concrete
- Size of Coarse Aggregate used
- Mixing procedure adopted

2. OBJECTIVES OF THE STUDY

- To compare the non-destructive and durability test results of fiber reinforced concrete with conventional concrete specimens.
- To study the mechanical properties of concrete reinforced with steel and polypropylene fibers.
- To find the optimum dosage of fiber content.

3. LITERATURE REVIEW

Faisal Fouad Wafa (1990) "Properties and Applications of Fiber Reinforced Concrete" This paper describes the different types of fibers and their application in different areas. The mechanical properties of FRC are much improved by the use of hooked fibers than straight fibers, the optimum volume content being 1.5 percent. While fibers addition does not increase the compressive strength, the use of 1.5 percent fiber increase the flexure strength by 67 percent, the splitting tensile strength by 57 percent, and the impact strength 25 times.

Gopala Krishnan M (2014) "Experimental Study on Slurry Infiltrated Fibrous Concrete with Sand Replaced By M-sand" The main objective of this project is to determine the effect of M-sand on compressive strength, split tensile strength behaviour on slurry infiltrated fibrous concrete. It is observed that utilization of M-sand in SIFCON is well accepted because of its strength properties. Thus M-sand can be a better replacement to river sand in Slurry infiltrated fibrous concrete.

Bazgir et al (2016) "The behaviour of steel fibre reinforced concrete material and its effect on impact resistance of slabs" The results of this study showed that the use of fibers in concrete enhanced all aspects of material capacity namely compression strength, tensile strength and flexural strength. Amongst all tests the performance of the specimens under split tensile test and flexural test, which the tensile properties of the concrete are of importance, showed better results. This was due to the effect of fibers and arresting the cracks when concrete starts to crack at its capacity. The presence of fibers increases the load capacity of the samples and makes the concrete a more ductile material than conventional concrete.

Vamshi Krishna K et al (2014) "Experimental study on behaviour of fiber reinforced concrete for rigid pavements" this paper deals with experimental investigation on mechanical properties of concrete by adding polypropylene fibers into the mix. IS: 10262-2009 recommendations are adopted for the design of mix. For compressive strength test, cube specimens of dimensions 150 x 150 x 150 mm were casted. The moulds were prepared with 0.1%, 0.2%, 0.3% and 0.4% polypropylene fibers. It is observed that at 0.3% of fiber in the weight of cement, maximum strength was attained and later with increase in fiber content reduction in strength is observed. And pavement slab was designed as per IRC 58. The thickness of the pavement is calculated by taking flexural strength of conventional concrete and polypropylene fiber reinforced concrete at 0.3% fiber content.

Ankit Pansuriya1 N et al (2016) "Use of polypropylene fiber in rigid pavement" this paper makes exploratory examination on mechanical properties of M30grade concrete by adding polypropylene fibers in the blend at measurements of 0.5%, 1%, 1.5%, 2%, 2.5% by weight of cement added to the mix. The compressive strength, split tensile strength, flexural strength and modulus of elasticity would increased with the addition of fiber content as compared with conventional concrete. By replacing cement with polypropylene fiber dosage helped in saving the cement content in concrete.

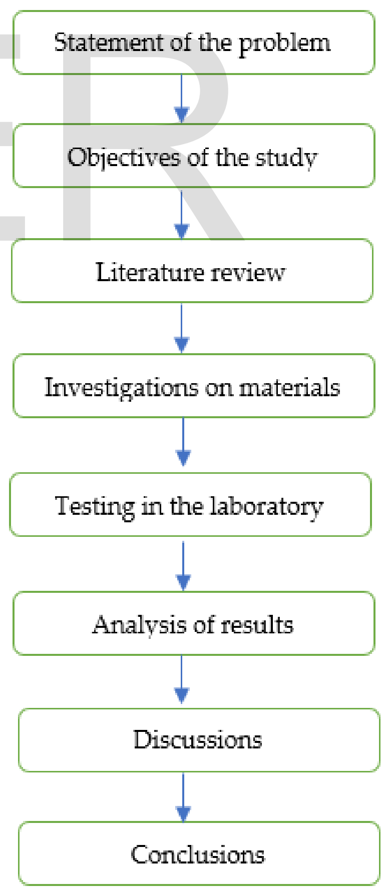
Athira das et al (2016) "Experimental investigation on properties of synthetic fiber reinforced concrete pavements" this work presents a preliminary study on the fundamental material properties of synthetic fibre reinforced concrete used in pavements for M-25 grade concrete mix and the fibers used were polyester, polypropylene and nylon. As per IRC 44-2008, a mix design was suitably designed for M-25 grade concrete based on the material properties. In all mixes slump value and compacting factor value were found to be less than that of control mix. Compressive strength, flexural strength, split tensile strength, gets improved due to the addition of small amount of fibres, on comparing with the normal mix. Optimum dosage of each fibre was determined at highest compressive strength. It was seen that the addition of nylon fibre imparts better flexural strength compared to other fibres and maximum increment was observed by 44.75%.

Aditya Tom et al (2014) "Coconut Fiber Reinforced Concrete" this study aimed at analyzing the variation in strength of coconut fiber reinforced concrete at varying fibre contents and to compare it with that of conventional concrete. The dosages used for the flexural, compressive and tensile strength tests were 4%, 5%, 6% by the weight of cement. At 5% addition of coconut fibre with a water cement ratio of 0.5, tests yielded best results. The optimum fiber content was found to be 5%. So that from the results it can be concluded that coconut fiber can be used as reinforcing material.

Rudresh A.N et al (2018) "Experimental Study on Strength of Fiber Reinforced Concrete for Rigid pavements" the aim of study was to check the various characteristic of M- 40 concrete mix design by using steel fibers and polypropylene fibers individually as well as in hybrid form with normal mix design by varying the fiber percentages, to check the effects of hybrid fibers on behaviour of pavement quality concrete. The steel fibers used in this study were of two types hooked and straight type. The dosages steel fibers adopted here was 2%, 2.5% and 3%, and that of polypropylene was 0.5%, 0.75% and 1% respectively. Pavement slab thickness was designed as per IRC 58. It is observed that slump values for FRC mix with steel fibers as well as polypropylene is found slight decreasing with respect to normal concrete mix of PQC M-40 grade. It is observed that compressive strength and flexural strength are on higher side for 3% Steel and 1% polypropylene fibres content as compared to that produced from 2% steel and 0.5% polypropylene fibres. From this study it can be concluded that, hybridization may allow us to reduce the thickness of the rigid Pavements upto 30% on achieving the remarkable compression and flexural strengths.

4. METHODOLOGY

In the present study, I have selected crimped steel and polypropylene fibers. Experimental investigations are carried out and a comparison is made between them.



5. EXPERIMENTAL INVESTIGATIONS ON MATERIALS

In the present study materials such as cement, fine aggregate, coarse aggregate, superplasticizers(Sika fluid) and water are used.

5.1 Cement

In the present study OPC 53 grade cement conforming to IS: 12269-1987 is used. The quantity of cement required for the experiments is collected from single source and stored in a nearly airtight container. The tests are conducted on cement to obtain Specific gravity, Normal consistency, Initial setting time and Compressive strength.

Table 1. Physical properties of cement

Physical properties of cement			
Sl. No.	**Details of test**	**Test Results**	**Requirements as per IS: 12269-1987**
1	Specific Gravity	3.10	2.9-3.15
2	Soundness	1.25	10 mm
3	Fineness of cement	4.0%	Less than 10%
4	Standard Consistency	30%	Not Specified
5	Setting time (in minutes)		
	Initial Setting time	130	Shall not be less than 30 minutes
	Final Setting Time	240	Shall not be more than 600 minutes

5.2 Fine aggregate

Locally available M-Sand obtained from nearby Quarry in Bangalore is used. The Physical properties of M-Sand are determined by conducting tests as per IS: 2386-part3 and IS: 383-2016. The test results are shown in the Table 2. The Fine aggregate satisfies the requirement of grading Zone II as per IS: 383-2016.

Table 2. Properties of M Sand

SI. NO.	Property	Test results	Requirement as per MORT&H (V revision) 2013
1	Aggregate impact value, %	23.50	30% max
2	Water absorption, %	0.50	2.0% max
3	Abrasion value, %	26.64	30% max
4	Aggregate crushing value, %	23.44	30% max
5	Specific gravity	2.70	---
6	Combined Flakiness and Elongation Index (%)	25.23	35% max

5.3 Coarse aggregate

Locally available crushed granite coarse aggregates are used in this study. The tests for physical properties on coarse aggregates are conducted as per IS: 383-2016 and the test results are shown in Table 3.

Table 3. Test results of Coarse Aggregates

Sieve Size	Percentage passing	As per IS: 383 – 2016 (% passing)			
		Zone I	Zone II	Zone III	Zone IV
10 mm	100	100	100	100	100
4.75 mm	97.30	90-100	90-100	90-100	95-100
2.36 mm	89.40	60-95	75-100	85-100	95-100
1.18 mm	81.00	30-75	55-90	75-100	90-100
600μm	46.80	15-34	35-59	60-79	80-100
300μm	23.92	5-20	8-30	12-40	15-50
150μm	8.76	0-10	0-10	0-10	0-20

5.4 Water

Water is an important costituent of concrete, as it actively participates in the chemical reaction with cement. In the present investigation potable water free from salts and other impurities is used for mixing and curing of concrete as per IS: 456-2000.

5.5 Chemical admixture

Admixture is defined as a material, other than cement, water and aggregates that is used as an ingredient of concrete and is added to the batch immediately before or during mixing. Additive is a material which is added at the time of grinding cement clinker at the cement factory.

Superplasticizers (High Range Water Reducers):

Superplasticizers constitute relatively new category and improved version of plasticizer. The use of which was developed in Japan and Germany countries in the year 1960 and 1970 respectively. They are chemically different from normal plasticizers. Use of superplasticizers permit the reduction of water to the extent upto 30 per cent without reducing workability. In the present investigation Sika is used as superplasticizer. The superplasticizer used in the present study is collected from "Durgamba Build Solutions" near RR Nagara in Bengaluru and the properties are as shown in Table 4.

Table 4. Properties of superplasticizer (Sika fluid)

Property	Description
Form	Liquid
Color	Yellow
Relative density	1.080
pH value	4.3
Chloride content	<0.1
Alkali content	0.6
Dosage	0.6

5.6 Fibers

Fiber is a small piece of reinforcing material possessing certain characteristic properties. The fiber is often described by a convenient parameter called "aspect ratio". The aspect ratio of the fiber is the ratio of its length to its diameter (l/d). Generally fibers with aspect ratio varying from 30 to 150 are used. In the present studies crimped steel and polypropylene fibers are used. Polypropylene fibers and steel fibers used in this study are collected from Ana Enterprises near Sudhama Nagara, Bengaluru and Sanjay implex near Bilekahalli, Bengaluru respectively.

*The properties are tabulated as provided by the manufacturer.

Table 5. Properties of crimped steel fiber

Property	Specifications
Density	7860kg/m^3
Ultimate strength	1500Mpa
Modulus of elasticity	2×10^5Mpa
Poisson's ratio	0.28
Length	35mm
Diameter	0.35mm
Aspect ratio	100

*The properties are tabulated as provided by the manufacturer.

Table 6. Properties of polypropylene fiber

Fiber type	Polypropylene
Tensile strength	700Mpa
Modulus of elasticity	3.5Mpa
Elongation	25%
Specific gravity	0.9
Filament diameter	0.01mm

*The properties are tabulated as provided by the manufacturer.

6. BATCHING AND CASTING OF SPECIMENS

All ingredients were batched as per mix proportions. Standard steel moulds of size (150x150x150) mm, cylinders of size 150mm diameter 300mm height and beams of size (100x100x500) mm were used for casting purpose and size specifications are as per IS: 516-1959. The fibers are added at the time of dry mix of ingredients. The moulds were properly oiled before placing the concrete. The specimens were compacted by using needle vibrator. The specimens were demoulded after the final setting of concrete i.e., 24 hours. The specimens were cast and cured for 7 days and 28 days. These specimens were subjected to (i) Destructive tests such as compressive strength, split tensile, flexural strength and (ii) Non- destructive tests such as ultra-pulse velocity, rebound hammer test and (iii) durability tests are carried out and the results are tabulated.

Fig 1. Casting of specimens

7.TESTS RESULTS OF HARDENED CONCRETE

Testing of hardened concrete specimen plays an important role in controlling and confirming the quality of cement concrete works. Systematic testing of raw materials, fresh concrete and hardened concrete are inseparable part of any quality control programme for concrete, which helps to achieve higher efficiency of the material used and greater assurance of the performance of the concrete with regard to both strength and durability. One of the purposes of testing hardened concrete is to confirm that the concrete used at site has developed the required strength. As the strength of concrete takes more time, one will not come to know, the actual strength of concrete for some time. This is one of the disadvantage in conventional test. But, if strength of concrete is to be known at an early period, accelerated strength test can be adopted to predict 28 days strength.

The strength of concrete is one of the most important and useful properties of concrete. In the hardened concrete there are three types of tests, they are as follows,

- Destructive tests
  1) Compressive strength
  2) Split tensile strength
  3) Flexural strength
- Non-destructive tests
  1) Rebound hammer test
  2) Ultra-pulse velocity test
- Durability tests
  1) Water absorption test
  2) Sorptivity test

Table 7. Compressive strength of tested specimens

Type of fiber	Fiber dosage, (%)	Compressive strength, (N/mm2)	
		7 days	28 days
Plain concrete	0.0	26.14	42.26
SFRC	0.5	29.77	45.34
SFRC	1.0	30.66	48.55
SFRC	1.5	31.55	54.44
SFRC	2.0	30.22	51.22
PFRC	0.1	25.77	44.65
PFRC	0.2	27.11	46.78
PFRC	0.3	32.00	51.25
PFRC	0.4	29.44	49.21

Figure 2. Compressive strength test

Table 8. Split tensile strength of tested specimens

Type of concrete	Fiber dosage, (%)	Split tensile strength, (N/mm2)	
		7 days	28 days
Plain concrete	0.0	2.90	4.58
SFRC	0.5	3.31	4.70
SFRC	1.0	3.41	5.06
SFRC	1.5	3.51	5.66
SFRC	2.0	3.36	5.10
PFRC	0.1	2.86	4.76
PFRC	0.2	3.01	5.15
PFRC	0.3	3.56	5.35
PFRC	0.4	3.27	4.94

Figure 3. Split tensile strength test

Table 9. Flexural strength of tested specimens

Type of concrete	Fiber dosage, (%)	Flexural strength, (N/mm2)	
		7 days	28 days
Plain concrete	0.0	3.58	4.64
SFRC	0.5	3.82	4.95
SFRC	1.0	3.88	5.42
SFRC	1.5	3.93	6.22
SFRC	2.0	3.85	5.82
PFRC	0.1	3.55	4.78
PFRC	0.2	3.64	5.26
PFRC	0.3	3.96	5.81
PFRC	0.4	3.80	5.56

Figure 4. Flexural strength test

Table 10. E-value of tested specimens

Type of fiber	Fiber dosage (%)	Pulse velocity (km/sec)	
Plain concrete	0.0	4.090	38022
	0.0	4.100	38208
SFRC	0.5	4.559	47242
SFRC	1.0	4.717	50573
SFRC	1.5	4.808	52543
SFRC	2.0	4.747	51218
PFRC	0.1	4.573	47532
PFRC	0.2	4.601	48116
PFRC	0.3	4.662	48557
PFRC	0.4	4.557	47200

Figure 5. Ultra pulse velocity test

Table 11. Water absorption values of tested specimens

Specimen	Fiber dosage (%)	Water absorption (%)
PFRC	0.1	0.54
PFRC	0.2	0.40
PFRC	0.3	0.37
PFRC	0.4	0.59
SFRC	0.5	0.59
SFRC	1.0	0.56
SFRC	1.5	0.47
SFRC	2.0	0.45
PCC	0.0	1.08

Table 12 Sorptivity values of tested specimens

Specimen	Fiber dosage (%)	Sorptivity ($mm/min^{0.5}$)
PFRC	0.1	0.122
PFRC	0.2	0.081
PFRC	0.3	0.041
PFRC	0.4	0.081
SFRC	0.5	0.122
SFRC	1.0	0.092
SFRC	1.5	0.081
SFRC	2.0	0.090
PCC	0.0	0.162

Figure 5. Sorptivity test

8. DISCUSSIONS

Mechanical properties:

- The 28 days compressive strength of concrete cubes reinforced with steel fibers at optimum dosage is found to be 54.44 N/mm^2. As compared to the conventional concrete compressive strength increases by 28.82%.
  The 28 days compressive strength of concrete cubes reinforced with polypropylene fibers at optimum dosage is found to be 51.25 N/mm^2. As compared to the conventional concrete compressive strength increases by 21.20%.
- The 28 days split tensile strength of cylindrical specimens reinforced with steel fibers at optimum dosage is found to be 5.66 N/mm^2. As compared to the conventional concrete split tensile strength increases by 23.50%.
  The 28 days split tensile strength of cylindrical specimens reinforced with polypropylene fibers at optimum dosage is found to be 5.35 N/mm^2. As compared to the conventional concrete split tensile strength increases by 16.81%.
- The 28 days flexural strength of beams reinforced with steel fibers at optimum dosage is found to be 6.22 N/mm^2 respectively. As compared to the conventional concrete flexural strength increases by 34.05%.
  The 28 days flexural strength of beams reinforced with polypropylene fibers at optimum dosage is found to be 5.81 N/mm^2 respectively. As compared to the conventional concrete flexural strength increases by 25.21%.

UPV test results:

- The E-value of steel fiber reinforced concrete at optimum dosage is found to be 52543Mpa. As compared to the conventional concrete E-value increases by 37.80%.
  The E-value of polypropylene fiber reinforced concrete at optimum dosage is found to be 48557Mpa. As compared to the conventional concrete E-value increases by 27.39%.

Durability test results:

- The water absorption value of steel fiber reinforced concrete is found to be 0.47%. As compared to the conventional concrete water absorption capacity is reduced by 53%.
  The water absorption value of polypropylene fiber reinforced concrete is found to be 0.37%. As compared to the conventional concrete water absorption capacity is reduced by 65.74%.
- The sorptivity value of steel fiber reinforced concrete is found to be 0.081 $mm/min^{0.5}$. As compared to the conventional concrete sorptivity capacity is reduced by 50.00%.

- The sorptivity value of polypropylene fiber reinforced concrete is found to be 0.041mm/min$^{0.5}$. As compared to the conventional concrete sorptivity capacity is reduced by 74.69%.

9. CONCLUSIONS

- Mechanical properties of the conventional concrete can be improved by the addition of steel fibers and polypropylene fibers.
- It can be concluded that the durability properties of conventional concrete can be improved by the addition of steel fibers and polypropylene fibers.
- The optimum dosage of crimped steel fibers is found to be 1.5% and that of polypropylene fibers is 0.3%.
- Concrete reinforced with crimped steel fibers shows better results as comppared to the polypropylene fibers.

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