EXPERIMENTAL WORK ON STEEL FIBRE REINFORCED CONCRETE

Avinash Joshi , Pradeep reddy ,Punith kumar and Pramod hatker

Abstract: The various aspects covered are the materials, mix proportioning for M20, M25, M30, M40 grades of concrete. As the concrete is weak in tension, a work has been carried out to investigate the improvement in tensile, shear, flexure, and even compressive strength of concrete and also to investigate the cracking strength and reserve strength of concrete & FRC.M20, M25, M30, M40 grades of concrete have been added to investigate the compressive strength, tensile strength & shear strength of concrete. Steel fibers acts as a bridge to retard their cracks propagation, and improve several characteristics and properties of the concrete. Fibers are known to significantly affect the workability of concrete. The aspect ratio (50) and variable in this study were percentage of volume fraction (0, 0.5, 1.0 and 1.5) of steel fibers. Compressive strength, splitting tensile strength and flexural strength of the concrete were determined for the hardened properties. Their main purpose is to increase the energy absorption capacity and toughness of the material. But also the increase in tensile and flexural strength is often the primary objective. A marginal improvement in the ultimate strength was observed. The addition of fiber enhanced the ductility significantly.

Index Terms: Aspect ratio, Compressive strength, Concrete mix proportioning, Ductility, Shear strength, Steel fibers Tensile strength.

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1 INTRODUCTION

1.1 CONCRETE MIX AS A SYSTEM

Concrete is by far the most widely-used man-made construction material and studies indicating that it will continue to be so in the years and decades to come. Such versatility of concrete is due to the fact that from the common ingredients, namely, cement, aggregate and water (and sometimes admixtures), it is possible to tailor the properties of concrete so as to meet the demands of any particular situation. In the true sense, concrete is thus the real building material rather than the ingredients like cement and aggregates, which are only intermediate products. This concept of treating concrete as an entity is symbolized with the progress of ready-mixed concrete industry, where the consumer can specify the concrete of his needs without bothering about the ingredients; and further in pre-cast concrete industry where the consumer obtains the finished structural components satisfying the performance requirements. Therefore, treating concrete in its entity as a building material. In this context a concrete mix forms a 'system'. Concrete mixes are also characterised by the fact that, unlike the other common structural materials like steel, these are mostly manufactured at site; the inherent variability of their properties and need for proper quality control, therefore, become important considerations.

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1.2 CLASSIFICATION OF CONCRETE MIXES

Concrete mixes are classified in a number of ways, often depending upon the type of specifications, which are broadly of two types; the '**prescriptive**' specifications where the proportions of the ingredients and their characteristics (namely, type of cement, maximum size of aggregate, etc.) are specified, with the hope that adherence to such prescriptive specification will result in satisfactory performance. Alternately, a '**performance**' oriented specification can be used wherein. The requirements of the desirable properties of concrete are specified (example - strength, workability or any other property).
Based on the above considerations, concrete can be classified either as 'nominal mix' concrete or 'designed mix' concrete as has been specified in IS : 456-2000*.

1.3 GRADES OF CONCRETE

Among the many properties of concrete, its compressive strength is considered to be the most important and has been held as an index of its overall quality. Many other engineering properties of concrete appear to be generally related to its compressive strength. Concrete is, therefore, mostly graded according to its compressive strength. The various grades of concrete as stipulated in IS : 456-2000 and IS : 1343-1980. Grades of concrete lower than M 15 are not to be used in reinforced concrete works and grades of concrete lower than M 30 are not to be used for pre-stressed concrete works. Similar grading of concrete on the basis of 28 days characteristic strength has also been adopted by ISO and most of the other codes of practices.

1.4 CONSTITUENTS OF CONCRETE

Concrete is a composite material aggregate composed of hydrated cement (binder), gravels or crushed stones (coarse aggregate), and sand (fine aggregate).A fourth ingredient called 'admixtures' is used to modify certain specific properties of the concrete mix in fresh and hardened states. By judicious use of available materials for concrete making and their proportioning, concrete mixes are produced to have the desired properties in the fresh and hardened states, as the situation demands. The following figure shows a petrographic section of concrete. Note the scattered coarse aggregates and the matrix surrounding them. The matrix consists of sand, hydrated cement and tiny voids.

1.5. FIBRE REINFORCED CONCRETE

Fibre reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres. Within these different fibres that character of fibre reinforced concrete changes with varying concretes, fibre materials, geometries, distribution, orientation and densities and also be defined as a composite materials made with Portland cement, aggregate, and incorporating discrete discontinuous fibres. Now, why would we wish to add such fibres to concrete? Plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capacity. The role of randomly distributes discontinuous fibres is to bridge across the cracks that develop provides some post- cracking "ductility". If the fibres are sufficiently strong, sufficiently bonded to material, and permit the FRC to carry significant stresses over a relatively large strain capacity in the post-cracking stage. The real contribution of the fibres is to increase the toughness of the concrete (defined as some function of the area under the load vs. deflection curve), under any type of loading. That is, the fibres tend to increase the strain at peak load, and provide a great deal of energy absorption in post-peak portion of the load vs. deflection curve.

1.5.1 HISTORY OF FRC.

Historically fibres have been used to reinforce brittle materials since ancient times. Straws were used to reinforce sun baked bricks; horsehair was used to reinforce plaster. In the early 1900s, asbestos fibres were used to reinforce Portland cement. Even though reinforcing a brittle matrix with discrete fibres is an age old concept, modern day use of fibres in concrete started in the early 1960s. In the beginning, only straight steel fibres were used. The major improvement occurred in the areas of ductility and fracture toughness, even though flexural strength increases were also reported. The law of mixture was applied to analyze the fibre contributions. It was understood that fibre reinforced concrete can be designed to obtain a specific ductility or energy absorption. Research by Romualdi, Batson, and Mandel in the late 1950's and early 1960's represented the first significant steps towards development of steel fibre reinforced concrete (SFRC).

1.5.2 FIBRE MECHANISMS

Fibres work with concrete utilizing two mechanisms: the spacing mechanism and the crack bridging mechanism. The spacing mechanism requires a large number of fibres well distributed within the concrete matrix to arrest any existing micro-crack that could potentially expand and create a sound crack. For typical volume fractions of fibres, utilizing small diameter fibres or micro fibres can ensure the required number of fibres for micro crack arrest. The second mechanism, termed crack bridging, requires larger straight fibres with adequate bond to concrete. Steel fibres are considered a prime example of this fibre type, that is, commonly referred to as large diameter fibres or macro fibres. Benefits of using larger steel fibres include impact resistance, flexural and tensile strengths, ductility, and fracture toughness.

Fibres used…Although every type of fibre has been tried out in cement and concrete, not all of them can be effectively and economically used. Each fibre has some characteristic properties and limitations. Fibres used are Steel fibres, Polypropylene, nylons, Asbestos, Coir, Glass, Carbon. The designer may best view fiber reinforced concrete as a concrete with increased strain capacity, impact resistance, energy absorption, and tensile strength. However, the increase in these properties will vary from substantial to nil depending on the quantity and type of fibers used; in addition, the properties will not increase at the same rate as fibers are added. While **steel fibres** are probably the most widely used fibres for many applications, other types of fibres are more appropriate for

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special applications. Fibre addition in the concrete brings a better control of its cracking and improves its mechanical properties. Particularly, it imparts to the material a post cracking load carrying capacity inducing pseudo ductility, which decreases its fragile character

1.6 STEEL FIBRE REINFORCED CONCRETE.

Steel fibres are short, discrete lengths of steel with an aspect ratio from about 30 to 150, and with any of several cross sections. Some steel fibres have hooked ends to improve resistance to pullout from a cement-based matrix. These are Most commonly used fibre. Their shape will be Round of diameter 0.25 to 0.75mm. they Enhances flexural, impact and fatigue strength of concrete and Used for-overlays of roads, airfield pavements, bridge decks.

Thin shells and plates have also been constructed using steel fibres. These methods generally modify the internal forces in the member to account for the additional tension from the fibers. When supported by full-scale test data, these approaches can provide satisfactory designs. The major differences in the proposed methods are in the determination of the magnitude of the tensile stress increase due to the fibers and in the manner in which the total force is calculated. Other approaches that have been used are often empirical, and they may apply only in certain cases where limited supporting test data have been obtained. They should be used with caution in new applications, only after adequate investigation. Generally, for structural applications, steel fibers should be used in a role supplementary to reinforcing bars. Steel fibers can reliably inhibit cracking and improve resistance to material deterioration as a result of fatigue, impact, and shrinkage, or thermal stresses. A conservative but justifiable approach in structural members where flexural or tensile loads occur, such as in beams, columns, or elevated slabs (i.e., roofs, floors, or slabs not on grade), is that reinforcing bars must be used to support the total tensile load. This is because the variability of fiber distribution may be such that low fiber content in critical areas could lead to unacceptable reduction in strength.

1.6.1 SHAPES OF STEEL FIBRE

ASTM A 820 classifies four different types of fibres based on their manufacture :

1- Cold-drawn wire fibres are the most commercially available, manufactured from drawn steel wire.

2- Cut sheet fibres are manufactured as the name implies by laterally shearing off steel sheets.

3- Melt-extracted fibres are manufactured with a relatively complicated technique where a rotating wheel is used to lift liquid metal from a molten metal surface by capillary action.

The extracted molten metal is then rapidly frozen into fibres and thrown off the wheel by centrifugal force. The resulting fibers have a crescent-shaped cross section.

4- Other fibres are manufactured for tolerances in length, diameter, and aspect ratio, as well as minimum tensile strength, and bending requirement. The amount of fibres added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibres) termed Vf . Vf typically ranges from 0.1 to 3%. Aspect ratio (l/d) is calculated by dividing fibre length (l) by its diameter (d). Fibres with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. The present study focuses on steel fibres.

1.6.2 MECHANICAL PROPERTIES OF STEEL FIBRE REINFORCED CONCRETE

The mechanical properties of steel fiber reinforced concrete are influenced by the type of fiber; length-to diameter ratio (aspect ratio); the amount of fiber; the strength of the matrix; the size, shape, and method of preparation of the specimen; and the size of the aggregate. For this reason, mixtures proposed for use in design should be tested, preferably in specimens representing the end use, to verify the property values assumed for design. Most properties are for the lower fiber percentage range. Some properties, however, are given for the higher fiber percentage mixtures for information in applications where the additional strength or toughness may justify the special techniques required.

2 EXPERIMENTAL INVESTIGATIONS

2.1 PRELIMINARY INVESTIGATION

The constituent materials used in the present experimental work as follows

1. **CEMENT**

Cement used is Ordinary Portland Cement (OPC 53 grade) as a binding material as per IS 12269-1970. The preliminary tests like normal consistency(33%), specific gravity, intial(50 min) and final(300 min) setting times and compressive strength (59.3 N/ mm^2)are conducted. Sieve analysis for the grading curve and fineness test were conducted as well as the determination of its moisture and with specific gravity (2.89).

2. **AGGREGATES**

The river sand with zone II, passing through 4.75mm sieve(fine aggregate), the crushed granite, passing through 20 mm and retained on 4.75mm sieve(coarse aggregate), some preliminary tests are conducted as per IS 383-1978.

3. **WATER :** Portable water as per IS 456-2000.

4. **SUPER PLASTICIZER :** CONPLAST SP 430 as per IS 9103-1999.

PROPERTY	FINE AGGREGATE (zone-II)	COARSE AGGREGATE
SPECIFIC GRAVITY	**2.63**	**2.65**
WATER ABSORPTION	1%.	0.5%.
FINENESS MODULUS	2.5.	4.5.

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Table-1: Basic properties of fine aggregate and coarse aggregate

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2.2 MIX PROPORTIONING-EXPERIMENTAL INVESTIGATION (10262:2009)

GRADE	WATER – CEMENT RATIO	MIX PROPORTION
M_{20}	0.55	1:2.21:3.49
M_{25}	0.5	1:1.931:3.174
M_{30}	0.45	1:1.658:2.845
M_{40}	0.4	1:1.761:3.154

Table-2: water cement ratio and mix proportion for different grades

"CONCRETE SHOULD FLOW LIKE HONEY" As increasing the grade from M30 to M40, it is difficult to work with the materials because the amount of binding material(cement) increases at the same time w-c ratio decreases. So there is a reduction in water amount. Therefore it is very difficult to get good workability, to improve the workability we used the chemical admixture i.e Naphthalene based Super plasticizer –Conplast SP 430 A2-from fosroc chemicals, Bangalore was used to obtain the required workability. The super plasticizer- Conplast SP 430 A2, 1% of total volume of concrete was used for M40 by trial and error method by reducing 15% of water amount.

2.3 ADDITION OF STEEL FIBERS

In the present work we used a steel fibres with a density of 7850 kg per m^3. we added a steel fibres of 0.5%, 1% and 1.5% of volume of concrete.

2.4 COMPRESSIVE STRENGTH

In the present investigation the cubes were casted with steel fibre reinforcement, and tested. The dimensions of the cube are 150X150X150 mm in accordance to IS 456-2000. The casted cubes kept for curing and tested after 3days, 7days , and 28days and the capacity of concrete cube noted in KN .i.e force(P) by placing on any one side of the cube. The cross sectional area(A) of cube is $225cm^2$. Finally the division compressive force by cross sectional area of cube gives the compressive strength of that particular cube. This work is carried out for all grades M20,M25,M30&M40 after 3days, 7days and 28 days. The compressive strength is represented in N/mm^2. The Mathematical representation of compressive strength , $\sigma_c = P/A$.

2.5 TENSILE STRENGTH

Generally the split tensile strength will be predicted by using cylinders of diameter 150mm and depth or height of 300m placing longitudinally and applying force by machine. The Mathematical representation of split tensile strength is, $\sigma_T = 2P/\Pi hd$. In the present investigation the cubes were casted with steel fibre reinforcement, and tested. The dimensions of the cube are 150X150X150 mm in accordance to IS 456-2000. The casted cubes kept for curing and tested after 3days, 7days , and 28days and the capacity of concrete cube noted in KN .i.e force(P) by placing diagonally in the testing machine. The cross sectional area(A) of cube is $225cm^2$. Finally the division tensile force by cross sectional area of cube gives the tensile strength of that particular cube. This work is carried out for all grades M20,M25,M30&M40 after 3days, 7days and 28 days. The tensile strength is represented in N/mm^2.


Fig.1 Diagonally placed tesile failure
Fig.2 shear failure

2.6 SHEAR STRENGTH

Shear strength can be predicted using prism in the laboratory of dimensions 100X100X500. Plain cement concrete prism fails in flexure first but, if it is suitably reinforced to care of that bending moment and flexure tension by providing steel (say 1% of cross section) in the tension zone, than flexural strength is increases and hence the prism fails in shear.If stirrups or shear steel is not provided then the reinforcing bars are insignificant in taking dowel force(i.e shear force). Hence shear strength of concrete can be predicted.

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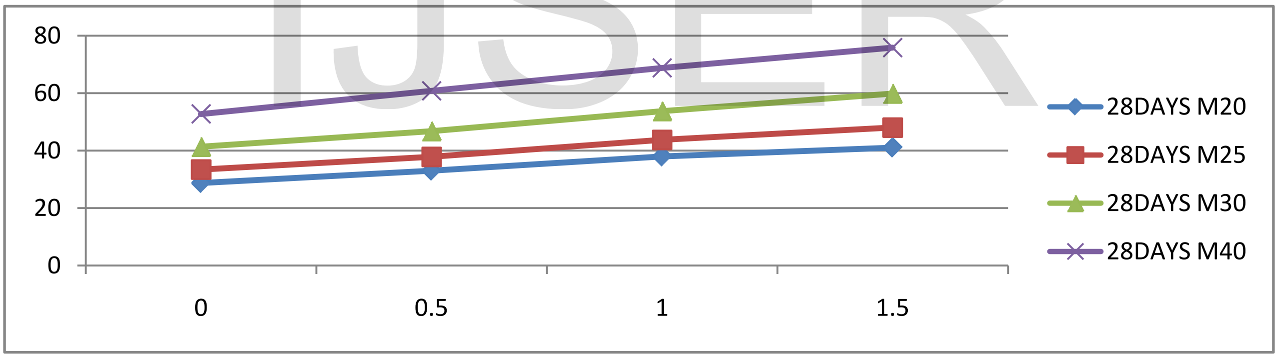
3. RESULTS AND DISCUSSION

3.1 COMPRESSIVE STRENGTH RESULTS

Table-3: Compressive strength of steel fibre reinforced concrete

GRADE	DAYS OF CURING	COMPRESSIVE STRENGTH(N/mm²)			
VOLUME OF STEEL FIBRES		0%	0.5%	1%	1.5%
M20	3days	13.2	15.2	17.11	18.69
	7days	18.9	21.11	24.38	27.73
	28days	**28.7**	**32.98**	**37.93**	**41.02**
M25	3days	15.69	18.34	20.63	22.12
	7days	24.6	28.78	33.1	35.71
	28days	**33.4**	**37.83**	**43.74**	**48.03**
M30	3days	19.41	22.87	25.6	27.89
	7days	32.21	37.37	42.81	46.03
	28days	**41.37**	**46.79**	**53.76**	**59.86**
M40	3days	27.17	32.91	36.4	39.39
	7days	41.45	47.67	54.37	59.93
	28days	**52.76**	**60.8**	**68.79**	**75.84**



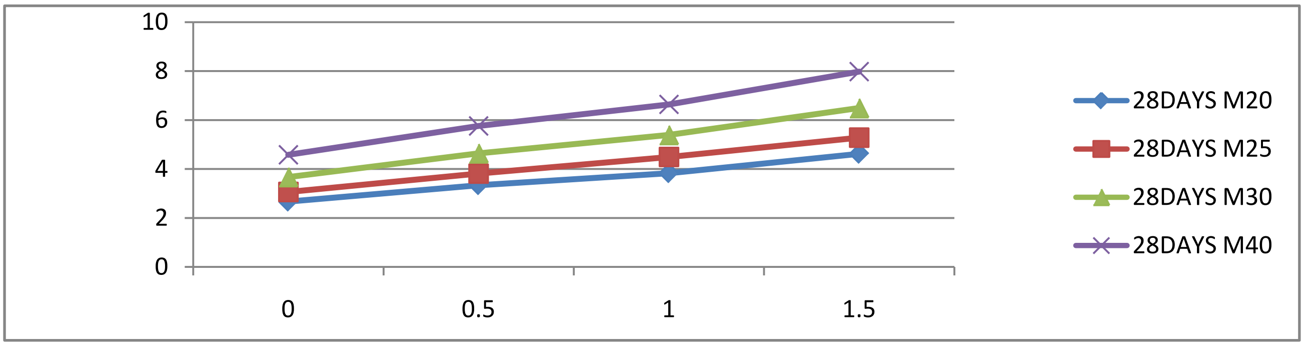
GRAPH-1 : As increase in % of steel fibres the compressive strength increases

3.2 TENSILE STRENGTH RESULTS

TABLE-4: Tensile strength of steel fibre reinforced concrete

GRADE	DAYS OF CURING	TENSILE STRENGTH(N/mm²)			
VOLUME OF STEEL FIBRES		0%	0.5%	1%	1.5%
M20	3days	1.11	1.38	1.63	1.89
	7days	2.16	2.57	3.04	3.64
	28days	**2.67**	**3.34**	**3.83**	**4.62**
M25	3days	1.39	1.76	2.03	2.39
	7days	2.62	3.29	3.86	4.47
	28days	**3.06**	**3.81**	**4.49**	**5.28**
M30	3days	1.71	2.13	2.46	2.9

	7days	2.93	3.69	4.21	4.98
	28days	**3.67**	**4.64**	**5.39**	**6.49**
M40	3days	2.3	2.87	3.33	4.01
	7days	3.7	4.73	5.36	6.47
	28days	**4.58**	**5.76**	**6.64**	**7.98**

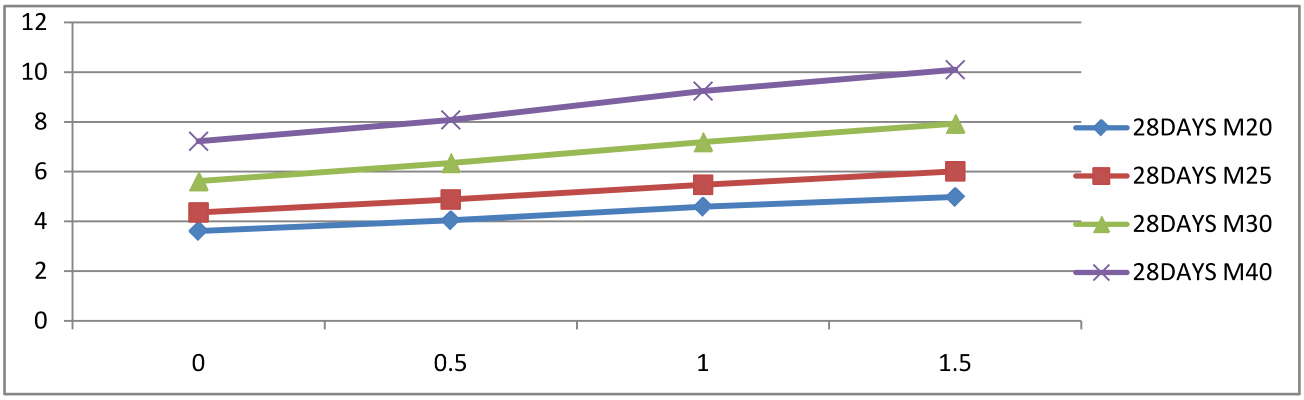


GRAPH-2 : As increase in % of steel fibres the tensile strength increases

3.3 SHEAR STRENGTH RESULTS

TABLE-5: Shear strength of steel fibre reinforced concrete

GRADE	DAYS OF CURING	SHEAR STRENGTH(N/mm²)			
VOLUME OF STEEL FIBRES		0%	0.5%	1%	1.5%
M20	3days	1.66	1.85	2.09	2.29
	7days	2.41	2.69	3.03	3.32
	28days	**3.61**	**4.04**	**4.59**	**4.98**
M25	3days	1.99	2.24	2.54	2.78
	7days	3.39	3.83	4.33	4.74
	28days	**4.36**	**4.88**	**5.47**	**6.01**
M30	3days	2.49	2.78	3.18	3.53
	7days	4.38	4.94	5.6	6.13
	28days	**5.62**	**6.35**	**7.19**	**7.93**
M40	3days	3.42	3.83	4.37	4.78
	7days	5.76	6.5	7.25	8.06
	28days	**7.22**	**8.08**	**9.24**	**10.1**



GRAPH-3 : As increase in % of steel fibres the tensile strength increases.

3.4 INCREMENT IN THE STRENGTHS (IN %)

1. FOR M20 GRADE

TABLE-6: Increase in compressive strength, tesile strength and shear strength for M20 grade

		0.50%	1%	1.50%
M20	C/S	15	29	40
	T/S	24	43	69
	S/S	12	26	38

By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in compressive strength are 15%, 29% and 40% respectively, for M20 grade.
By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in tensile strength are 24%, 43% and 69% respectively, for M20 grade
By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in shear strength are 12%, 26% and 38% respectively, for M20 grade.

2. FOR M25 GRADE

TABLE-7: Increase in compressive strength, tesile strength and shear strength for M25 grade

		0.50%	1%	1.50%
M25	C/S	17	31	41
	T/S	25	43	70
	S/S	13	28	39

By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in compressive strength are 17%, 31% and 41% respectively, for M25 grade.
By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in tensile strength are 25%, 43% and 70% respectively, for M25 grade
By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in shear strength are 13%, 28% and 39% respectively, for M25 grade

3. FOR M30 GRADE

TABLE-8: Increase in compressive strength, tesile strength and shear strength for M30 grade
By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in compressive strength are 19%, 33% and 43% respectively, for M30 grade.
By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in tensile strength are 25%, 44% and 70% respectively, for M30 grade

		0.50%	1%	1.50%
M30	C/S	19	33	43
	T/S	25	44	71
	S/S	13	28	42

By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in shear strength are 13%, 28% and 42% respectively, for M30 grade

4. FOR M40 GRADE

TABLE-9: Increase in compressive strength, tesile strength and shear strength for M40 grade

		0.5%	1%	1.5%
M40	C/S	19	34	44
	T/S	25	46	74
	S/S	14	28	43

By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in compressive strength are 19%, 34% and 44% respectively, for M40 grade(1%super plasticizer).
By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in tensile strength are 25%, 46% and 74% respectively, for M40 grade(1%super plasticizer).
By increasing the % of steel fibres from 0 to 0.5%,1% and 1.5%. the increment in shear strength are 14%,

28% and 43% respectively, for M40 grade(1%super plasticizer).

4 CONCLUSION

Based on the experimental investigations the following conclusions are arrived.

1. Steel fibers decrease the workability so, use of superplasticer improve the workability.
   As the volume of steel fibers increases from 0.5% to 1.5% the workability decreases that is slump loss.
2. The compressive strength of concrete increases considerably as the volume of steel fibers is increased from 0.5% to 1% and the increase is almost similar to all the grade of normal concrete that is M20, M25, M30, M40.
3. The tensile strength increases significantly as the volume of steel fibers is increase is similar to the grade of concrete.
4. The shear strength of concrete improves as the volume of fibers is increased.
5. The reserve strength and the ultimate strength of FRC is significant than conventional concrete and it is very significant tensile strength of concrete.
6. The toughness of concrete is also increased very significant the crack patterns changes as the failure is more ductile in FRC, as compared to compression shear crack pattern failure of conventional concrete under compression.
7. The tensile strength will be around 8% of compressive strength.
8. The shear strength will be around 12% of compressive strength.

From the experimental work we conclude that as we increasing the amount of steel fibres, ther is a increase in compressive strength by 44%, tensile strength by 74% and shear strength by 43% for optimum dosage of steel fibres(1.5% of cement) for M40 grade. It is difficult to work with M40, to improve workability of fresh concrete mix, it is better to use super plasticizer i.e conplast SP 430 with a dosage of 1% of total volume of concrete.Without any difficulty in workability and balling effect of fibres, we can use the optimum dosage of steel fibre is 1.5%. more than that there may be a choice of reduction in compressive strength.

4.1 SCOPE IN FUTURE

As recommended by ACI Committee 544, 'when used in structural applications, steel fibre reinforced concrete should only be used in a supplementary role to inhibit cracking, to improve resistance to impact or dynamic loading, and to resist material disintegration. In structural members where flexural or tensile loads will occur. The reinforcing steel must be capable of supporting the total tensile load'. Thus, while there are a number of techniques for predicting the strength of beams reinforced only with steel fibres, there are no predictive equations for large SFRC beams, since these would be expected to contain conventional reinforcing bars as well. An extensive guide to design considerations for SFRC has recently been published by the American Concrete Institute. For beams containing both fibres and continuous reinforcing bars, the situation is complex, since the fibres act in two ways:

(1) They permit the tensile strength of the SFRC to be used in design, because the matrix will no longer lose its load-carrying capacity at first crack; and
(2) They improve the bond between the matrix and the reinforcing bars by inhibiting the growth of cracks emanating form the deformations (lugs) on the bars.

However, it is the improved tensile strength of SFRC that is mostly considered in the beam analysis, since the improvements in bond strength are much more difficult to quantify. Steel fibres have been shown to increase the ultimate moment and ultimate deflection of conventionally reinforced beams; the higher the tensile stress due to the fibres, the higher the ultimate moment.

The uses of SFRC over the past thirty years have been so varied and so widespread, that it is difficult to categorize them.The most common applications are pavements, tunnel linings, pavements and slabs, shotcrete and now shotcrete also containing silica fume, airport pavements, bridge deck slab repairs, and so on. There has also been some recent experimental work on roller-compacted concrete (RCC) reinforced with steel fibres. The list is endless, apparently limited only by the ingenuity of the engineers involved. The fibres themselves are, unfortunately, relatively expensive; a 1% steel fibre addition will approximately double the material costs of the concrete, and this has tended to limit the use of SFRC to special applications.

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