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Effect of Steel Fibers on Compressive and Flexural Strength of Concrete

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Abstract: Cement concrete is the most extensively used construction material in the world. The reason for its extensive use is that it provides good workability and can be moulded to any shape. Ordinary cement concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal micro cracks, leading to brittle failure of concrete. In this modern age, civil engineering constructions have their own structural and durability requirements, every structure has its own intended purpose and hence to meet this purpose, modification in traditional cement concrete has become mandatory. It has been found that different type of fibers added in specific percentage to concrete improves the mechanical properties, durability and serviceability of the structure. It is now established that one of the important properties of Steel Fiber Reinforced Concrete (SFRC) is its superior resistance to cracking and crack propagation. In this paper effect of steel fibers on the strength of concrete for M 40 grade have been studied by varying the percentage of fibers in concrete.

Keywords: *Concrete, Fibers, Beam, Strength*

1. Introduction:

Plain concrete has two major deficiencies, Aghuy y low tensile strength and a low strain at fracture. The tensile strength of concrete is very low because plain concrete normally contains numerous micro cracks. It is the rapid propagation of these micro cracks under applied stress that is responsible for the low tensile strength of the material, eventually leading to brittle fracture of concrete. In past attempts have been made to impart improvements in tensile properties of concrete members by way of using conventional reinforced steel bars and also by applying restraining techniques. Although both methods provide tensile strength to concrete members, they how ever do not increase inherent tensile strength to concrete itself. It has been found that the addition of small closely spaced and uniformly dispersed fibers to concrete would act as crack arresters and would substantially improve it's static and dynamic properties. This type of concrete is known as "Fiber Reinforced Concrete" (F.R.C.)

F.R.C. can be defined as "A composite material consisting of a mixture of cement, mortar or concrete and discontinuous, discrete uniformly dispersed suitable fibers ".The new generation technology utilizes discrete fiber from 19mm to 64mm in length. The fibers are randomly throughout the concrete matrix providing for better distribution of both internal and external stresses by using a three dimensional network. The Primary role of fibers in hardened concrete is to modify the cracking mechanism. The cracks are smaller in width thus reducing the permeability of concrete and the ultimate cracking strain of concrete is enhanced. Un-reinforced concrete will separate at a crack, reducing the load carrying ability to zero across the crack. The fibers are capable of Carrying a load across the crack.

2. What is F. R. C?

The presence of micro-cracks at the mortar aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by in inclusion of fibers in the mix. The fiber helps to transfer the loads at the internal micro-cracks. Such a concrete is called as Fiber Reinforced Concrete. Thus the fiber reinforced concrete is a composite material essentially consisting of conventional concrete or mortar reinforced by random dispersal of short, discontinuous and discrete fine fibers of specific geometry. The fibers can be imagined as an aggregate with an extreme deviation in shape from the rounded smooth aggregate. The fibers interlock and entangle around aggregate particles and considerably reduce the workability while the mix becomes more cohesive and less prone to segregation. [1]

In contract to reinforcing bars in reinforced concrete which are continuous and carefully placed in the structure to optimize their performance, the fibers are discontinuous and are generally randomly distributed throughout the concrete matrix. As the result, the reinforcing performance of steel fibers, for example, is inferior to that of reinforcing bar. In addition, the fibers are likely to be considerably more expensive than the convectional steel rods. Thus fibers reinforced concrete is not likely to replace conventional reinforced concrete. [2]

However the addition of fibers to the brittle cement and concrete materials can offers a convenient, particle and economical method of overcoming their inherent deficiencies of poor tensile and impact strengths and enhances many of the structural properties of the basic materials such as fracture toughness, flexural strength and resistance to fatigue impact, thermal shock or spalling.

Essentially, fiber act as crack arrestor restricting the development of cracks and thus transforming an inherently brittle matrix i.e. Portland cement with its low tensile and impact resistance, into a strong composite with superior crack resistance, improved ductility and distinctive post-cracking behavior prior to failure.[3] Due to such superior properties, fiber reinforced concrete (F.R.C) has found special application in hydraulic structure, airfield and highways pavement bridges decks heavy duty floor and tunnel things.

3. Types of fibers

There are mainly two types of fibers which are used in concrete.

3.1 Low Modulus High Elongation Fibers:

These types of fibers have capacity to absorb large amount of energy, but do not lead to strength improvement; however they impart toughness, and resistance to impact and explosive loading For e.g. Nylon, Polyethylene etc.

3.2 High Modulus High Elongation Fibers:

These fibers produces strong composite primarily they impart characteristics of strength and stiffness to the composites, and also dynamic properties to varying degrees. For e.g. steel, asbestos and carbon

4. Introduction to steel fibers

A number of steel fiber types are available as reinforcement. But generally round steel fibers are commonly used. These fibers found extensive engineering application. Most of the steel fibers are obtained by cutting drawn wires and fibers with different types of crimps, indentations and shapes to increase mechanical bond are also being produced steel fibers with low tensile strength (7141kg/cm2) are also produced from low carbon flat rolled steel coils. Generally the steel fibers used in concrete as reinforcement of diameter lying inbetween5-500mm specific gravity 7.8, modulus of elasticity 200 GPA, Failure3-4% and Tensile strength 1 to 3 GPA.

However tests show that the tensile strength has little influence on the first crack flexural strength although it may have significant effect on the ultimate flexural strength, if the composite failure occurs by fiber failure rather than fiber pull out. The method of fiber production may however influence the cost of the fiber and significant improvement in the first crack. Flexural strength and ultimate flexural strength have been obtained through the use of short (6.4to63.5 mm) and small diameter (0.15 to 0.91mm) steel fibers. However the property improvement can only be obtained by ensuring uniform distribution of fibers and consolidation of the matrix around the fibers.

In the present state of fiber development, composite failure occurs by fiber pull out rather than fiber yielding so fiber matrix bond is the significant phase of composite.

A number of practical applications of steel fiber reinforced concrete have achieved to date. The superior structural properties of steel fiber reinforced concrete have found it an material for over lays and over slab for roads pavements, airfields and bridge decks and industrials well as other flooring, particular subjected to were and tear and chemical attack. Gunniting have also been successfully applied by using steel fibers of all the fibers, steel fibers are probably the best suited for structural applications.

5. Experimental procedure

The main aim is to study the effect of steel fibers on flexural & compressive strength of concrete. An experimental program includes two phases. The first consists of high strength concrete mix design for grade of M40 by using IS 10206-1982,[5] whereas the second phase consists of casting and testing of 15 concrete beam specimens with different percentage of steel fibers (0%, 0.5%, 0.75% & 1% by volume of concrete) for flexural strength of concrete and it also consists of casting and testing of 15 concrete cubes with different percentage of steel fibers (0%, 0.5%, 0.75% & 1% by volume of concrete) for compressive strength of concrete. For each percentage of steel fiber three beams and three cubes were casted.

The properties of materials used for casting the concrete beam & cube specimens were observed by performing the necessary tests. The materials were categorized in two groups i.e concrete and steel

Cement- 43 grade Ordinary Portland cement was used for casting the beams. It was tested in the laboratory and results are as follows.

1. Initial setting time = 190 min.
2. Final setting time = 240 min.
3. Compressive strength-
    - 3 days = 24.11 Mpa.
    - 7 days = 33.26 Mpa.
    - 28 days = 43.60 Mpa.

Sand- The sand used for concrete was from Krishna river. The properties are as follows.

1. Specific gravity = 2.65
2. Fineness modulus = 2.28

Aggregate- Locally available crushed stones aggregate with maximum size 20 mm were used The properties are as follows.

1. Specific gravity = 2.45

Fineness modulus = 2.60

Steel fibers having 0.75mm dia. And lengths 60 mm (i.e. aspect ratio) were randomly distributed into the concrete mixes to obtain the fiber reinforced concrete. The fiber taken by volume of concrete and grade of concrete is kept constant.

The test beam specimens were of dimensions 150x150x700 mm. The beams were reinforced with steel fibers of size 60 mm long and 0.75 mm diameter. Typical section of beam is as shown in figure:

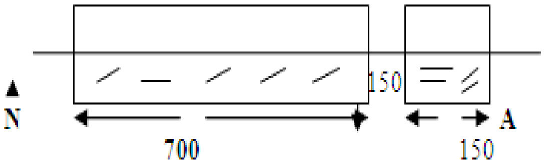

Figure 1: *Details of beam Specimen*

The test cube specimens were of dimensions 150x150x150 mm. These were also reinforced with steel fibers of size 60 mm long and 0.75mm diameter

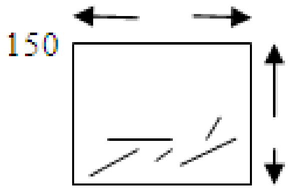

Figure 2: *Details of beam Specimen*

The second phase of experimental program consists of casting & testing of 15 concrete beams for flexural test and 15 cubes for compression test with varying percentage of steel fibers (0%, 0.5%, 0.75% & 1% by volume of concrete).

The ingredients of concrete viz. cement, sand and coarse aggregate, were weighted according to the mix proportion 1:0.81:2.52 by weight (say 515kg, 422kg and 1296kg respectively for 1 m3). The ingredients are thoroughly mixed in the dry state with respective fiber percentage (0%.0.25%, 0.50%, 0.75% & 1% by volume of concrete). To this, the calculated quantity of water with water cement ratio 0.35 (180 liters for $1m^3$) was added & thoroughly mixed. For beams 15cm x 15cm x 70cm beam moulds with inner faces oiled are taken &filled them in layers approximately 5cm deep. At the same time for cubes 15cm x 15cm x 15cm cubical moulds with inner faces oiled are taken &filled them in layers approximately 5cm deep. Each layer is compacted by a standard tamping rod (16mm diameter and 60cm long with bulleted end) &25 uniformly distributed strokes were given. Finally the surface is leveled with the help of a trowel. Three beams and three cubes for each percentage of steel fibers were casted. After 24 hours the beams and cubes were removed from the moulds and kept them for curing. The water in which the specimens are submerged was renewed after every seven days.

After 28 days of curing, the beams with different percentage of steel fibers (0.25%, 0.50%, 0.75% & 1% by volume of concrete) are tested under UTM(Universal Testing Machine) using three-point loading for flexural strength. Similarly, the cubes with different percentage of steel fibers (0.25%, 0.50%, 0.75% & 1% by volume of concrete) are tested under CTM (Compression Testing Machine) for compressive strength.

Flexural strength is calculated by equation (f) = PL/bd2

Where,

P = Failure load in Newton
L = Effective span in mm.
b = Breadth of beam
d = Depth of the beam

Similarly, Compressive strength is calculated by the equation

$$\delta c = \text{Load/cross sectional area of cube}$$

Where,

δc = Compressive strength of concrete

6. Test results:

6.1 Flexural Test Result:

The following table number 1 gives the test results of flexural test for beams with different percentage of steel fibers (0%, 0.25%, 0.5%, 0.75% and 1% by volume of concrete).

6.2. Compression test result:

The following table number 2 gives the test results of compressive test for cubes with different percentage of steel fibers (0%, 0.25%, 0.5%, 0.75% and 1% by volume of concrete).

Table 1: *Test result for flexural strength*

Details of beams	Size of beam in (B x D x L)mm	Weight of beam in Kg.	Average Failure Load in kN	Average Flexural strength in N/mm2	% increase / decrease in flexural strength
0% steel fiber	150x150x700	39.800	25.94	4.62	---
0.25% steel fiber	150x150x700	39.850	33.26	5.91	27.92%
0.50% steel fiber	150x150x700	40.050	36.14	6.42	38.96%
0.75% steel fiber	150x150x700	40.250	37.22	6.62	43.29%
1% steel fiber	150x150x700	40.600	34.90	6.20	34.19%

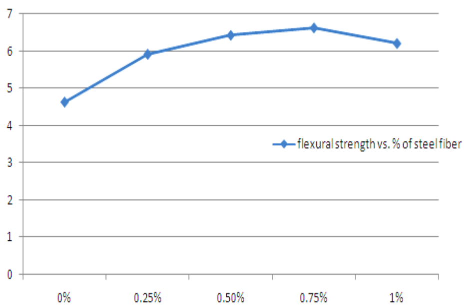

Figure 1 *Flexural strength vs. Percentage steel fiber content*

Figure shows. The variation of flexural strength for different percentage of steel fibers(0%,0.25%,0.50%,0.75%,1%)

Table 2: *Test result for compressive strength*

Details of beam	**Size of beam in (B x D x L)mm**	**Average Failure Load in kN**	**Average Compressive strength in N/mm2**	**% increase / decrease in compressive strength**
0% (Plain beam)	150x150x150	931.95	41.42	-
0.25% steel fiber	150x150x150	1039.86	46.21	11.56
0.50% steel fiber	150x150x150	1128.15	50.14	21.05
0.75% steel fiber	150x150x150	1128.15	51.45	24.15
1% steel fiber	150x150x150	1030.05	45.78	10.52

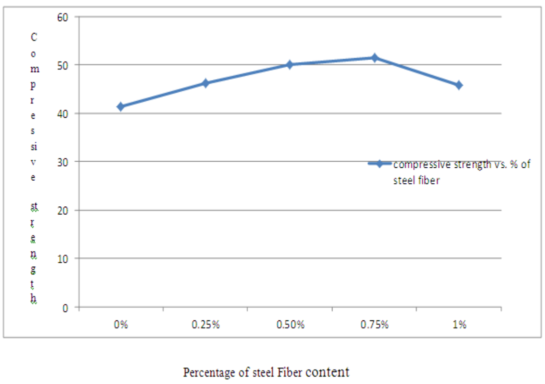

Figure.2*- Compressive strength vs. Percentage steel fiber content*

Figure shows. The variation of compressive strength for different percentage of steel fibers (0%, 0.25%, 0.50%, 0.75%, 1%)

7. Observation and conclusion:

To study the effect of steel fibers on flexural and compressive strength of concrete, the experimentation is conducted in the laboratory. Based on the experimentation conducted, on the beams and cubes with different percentage of steel fibers the following observations were made and hence some conclusions.

7.1 Flexural strength-

It has been observed that the flexural strength of concrete for the beams with steel fibers 0.25%, 0.50%, 0.75% and 1% is more than that of beam without steel fibers. This may be due to the fact that the steel fibers will effectively hold the micro cracks in concrete mass.

The percentage increase in the flexural strength for the beams with steel fibers 0.25%, 0.50%, 0.75% and 1% compared to the beams without steel fibers are +27.92%, +38.33%, +43.29%, and +34.19% respectively.

It can be seen from the observations that the maximum percentage increase in flexural strength can be obtained for the beams with steel fibers 0.75% by volume of concrete (+30.21%). Thus it is recommended to use steel fibers 0.75% by volume of concrete to get the maximum benefit in improving flexural strength.

7.2 Compressive strength:

It has been observed that the compressive strength of concrete for the cubes with steel fibers 0.25%, 0.50%, 0.75% and 1% is more than that of cubes without steel fibers. This may be due to the fact that the steel fibers will effectively holds the micro cracks in concrete mass.

The percentage increase in the compressive strength for the cubes with steel fibers 0.25%, 0.50%, 0.75% and 1% compared to the cubes without steel fibers are 11.56%, 21.05%, 24.15% and 10.52% respectively.
It can be seen from the observations that the maximum percentage increase in compressive strength can be obtained for the cubes with steel fibers 0.75% by volume of concrete (+19.50%). Thus it is recommended to use steel fibers 0.75% by volume of concrete to get the maximum benefit in improving compressive strength.

In a nutshell it can be concluded that the use of steel fibers is an effective method to improve the flexural & compressive strength of concrete. To get the maximum benefit it is recommended to use steel fibers 0.75% by volume of concrete. More percentage of steel fibers will have the workability problem & also air cavities are left in the system.

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