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Experimental Investigation on Steel Fibers in the 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 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 work effect of fibers on the strength of concrete for M 20 grade have been studied by varying the percentage of fibers in concrete. Fiber content were varied by 0.50%, 1%, and 2% by volume of cement. The optimum fiber content while studying the compressive strength of cube is found to be 1% and also 1% for flexural strength of the beam. Also, it has been observed that with the increase in fiber content up to the optimum value increases the strength of concrete. Slump cone test was adopted to measure the workability of concrete. The Slump cone test results revealed that workability gets reduced with the increase in fiber content.

Keywords**—**steel fibers, compressive strength, slump test, cost comparison and flexural strength

I.INTRODUCTION

a. General

Fibers are usually used in concrete to control cracking due to plastic shrinkage. They also reduce permeability of concrete and thus reduce the bleeding of water. Fibers produce greater impact, abrasion and shatter-resistance in concrete. They reduce steel reinforcement requirements and crack width & control the crack width tightly and thus improving durability. Fibers improve freeze-thaw resistance and structural strength. Mostly Tunneling projects using precast lining segments reinforced only with steel fibers.

The aim is to provide recommendations with respect to durability and input to service life models for fiber reinforced concrete structures like tunnels & bridges. If the fibers modulus of elasticity is higher than matrix concrete or mortar binder. They help to carry the load of increasing the tensile strength of the material. Fibers which are used in concrete has the ability to absorbs more energy as recommended by 'ACI committee 544' steel fiber reinforced concrete is used as supplementary material to prevent cracking and improve resistance to impact or dynamic loading & to prevent material disintegration.

The real contribution of the fibers is to increase the toughness of the concrete under any type of loading. That is the fibers tends to increase the strain at peak load and provide a great deal of energy absorption.

b. Types of Fibers

i. Steel Fiber Reinforced Concrete
ii. Polypropylene Fiber Reinforced concrete (PFR)
iii. GFRC Glass Fiber Reinforced Concrete
iv. Asbestos Fibers
v. Carbon fiber
vi. Organic fibers

The results indicates that the addition fibers to concrete enhances its toughness and strength and peak stress, but can slightly reduced young's modulus. 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.

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Steel Fiber reinforced concrete (SFRC) is defined as concrete made with hydraulic cement containing Fine and coarse aggregate and discontinuous discrete fiber. In SFRC, thousands of small fibers are dispersed and distributed randomly in the concrete during mixing, and thus improve concrete properties. SFRC is being increasingly used to improve static and dynamic tensile strength, energy absorbing capacity and better fatigue strength. **.**This report explain effect of steel fiber on the strength and behavior of reinforced concrete is two-way action. They concluded that the addition of steel fiber increases the ultimate strength and ductility. The plain structure cracks into two pieces when the structure is subjected to the peak tensile load and cannot withstand further load or deformation. Steel fibers are generally used to enhance the tensile strength and ductility of concrete. As stated in ACI 544, 3R-08 , fiber volume fraction used in producing steel fiber reinforced concrete should be within 0.5% to 2% as the addition of fiber may reduce the workability of the mix and will cause balling or mat which will be extremely difficult to separate by vibration. However higher percentage of fiber can be used with special fiber adding techniques and also placement procedures. According to ACI 544, 3R-08 **,**aspect ratio is referred to the ratio of fiber length over the diameter. The normal range of aspect ratio for steel fiber is from 20 to 100. Aspect ratio of steel fiber greater than 100 is not recommended, as it will cause inadequate workability, formation of mat in the mix and also non uniform distribution of fiber in the mix. To avoid any honeycombing, bleeding, segregation and heterogeneous features by improving the workability, use less water and paste.

In applications where the presence of continuous reinforcement is not essential to the safety and integrity of the structure, e.g., floors on grade, pavements, overlays, and shotcrete linings, the improvements in flexural strength, impact resistance, and fatigue performance associated with the fibers can be used to reduce section thickness, improve performance, or both. The general behavior of steel fiber reinforced concrete (SFRC) under loads produces much higher post cracking residual strength has plain concrete due to the fibers bridging the cracks.

This behavior depends on the geometric characteristics and material properties of the fiber; and the properties of the concrete. The bridging efficiency of individual fiber largely depends on the fiber-matrix bond characteristics which contributes to the improvement in the mechanical properties of SFRC.

Concrete is characterized by brittle failure, the nearly complete loss of loading capacity, once failure is initiated. This characteristic, which limits the application of the material, can be overcome by the inclusion of a small amount of short randomly distributed fibers (steel, glass, synthetic and natural) and can be practiced among others that remedy weaknesses of concrete, such as low growth resistance, high shrinkage cracking, low durability, etc. Steel fiber reinforced concrete (SFRC) has the ability of excellent tensile strength, flexural strength, shock resistance, fatigue resistance, ductility and crack arrest. In the hardened state, when fibers are properly bonded, they interact with the matrix at the level of micro-cracks and effectively bridge these cracks thereby providing stress transfer media that delays their coalescence and unstable growth. If the fiber volume fraction is sufficiently high, this may result in an increase in the tensile strength of the matrix [1]. Indeed, for some high volume fraction fiber composite, a notable increase in the tensile/flexural strength over and above the plain matrix has been reported. Once the tensile capacity of the composite is reached, and coalescence and conversion of micro-cracks to macro-cracks has occurred, fibers, depending on their length and bonding characteristics continue to restrain crack opening and crack growth by effectively bridging across macro-cracks. This post peak macro-crack bridging is the primary reinforcement mechanisms in majority of commercial fiber reinforced concrete composites. Fracture behavior is a multi-scale process, where each type of fiber can facilitate crack arresting at one strain level or within a limited range of strain. Therefore, to enhance the overall performance of FRC, optimization of fiber dosage is essential for various fiber types and their combinations. SFRC has been found to show better performance within small crack mouth opening displacement.

A fiber-reinforced composite is a material system made primarily of varying amount of particular fiber reinforcement embedded in a protective material called a matrix. The degree of performance of a fiber reinforced composite depends on the fiber, its orientation, loading and the matrix. Fiber reinforced concrete has found interesting new applications in the past two decades due to its inherent superiority over normal plain and reinforced concrete in the following properties: higher flexural strength, better tensile strength and modulus of rupture, higher shear strength, higher shock resistance, better ductility and fatigue resistance, crack resistance and failure toughness [2]. FRC is now increasingly used in structures such as airport pavement, bridged decks, machine foundations, blast resistant structures, piles, pipes, sea protective structure, hip-hulls and storage tanks. Fiber reinforced concrete is a relatively new construction material developed through extensive research and development work during the last two decades. It has been proved as a reliable construction material having superior performance characteristics compared to the conventional concrete.

The structural behavior of reinforced concrete has become more brittle. In order to reduce this side effect, steel fiber-reinforced concrete (SFRC) has arisen as a viable method to attain ductility not only during post-cracking behavior under

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tension, but also during post-peak softening behavior under compression. For the last several decades, use of steel fibers has been limited to tunnel lining or crack control in concrete slabs as a non-structural material. Development of a rational compressive model for SFRC has been of importance since many researchers [1–10] have continuously conducted experimental and analytical research to exploit SFRC as a structural material. Construction of high-rise buildings, long span bridges, and off shore structures has made steel fibers important in improving the properties of concrete such as strength, toughness, energy absorption capacity, and durability. The addition of steel fibers in high performance concrete (HPC) can improve the brittle behavior rand the energy absorption capacity.

From the literature studied it is observed that the fibers can be added in the concrete in different proportion and accordingly the compressive strength, flexural strength can be checked. In the present work steel fibers are added in the concrete and experiments are to be carried out.

II.EXPERIMENTS AND TESTS

a. Cement

Ordinary Portland 53 grade cement was used for making the concrete specimens. The specific gravity of the cement was found to be 3.15. The initial setting time and the final setting time of the cement were found to be 140 min and 245 min respectively.

b. Aggregate

Aggregates of size ranging from 20 mm to 12 mm were used in this work. The specific gravity of the coarse aggregates was found to be 2.78, and the water absorption of the coarse aggregates 0.5%. The specific gravity of the fine aggregates was 2.60 and its water absorption was 1.02%

c. Fiber reinforcement

Discrete steel fibers conforming to ASTM A 820/A 820M – 04 were used. They were Type 1 cold drawn wire grooved. The steel fibers had a length of 50 mm and a diameter of 1 mm. Hence, their aspect ratio was 50. The tensile strength of the fiber was found to be 1098 MPa using tens meter. Fiber content was varied as 0%, 0.5%, 1% and 2% by volume of concrete.

d. Sand

Cement isn't typically used without sand and gravel. The addition of sand makes cement more binding. Cement mixed with water and sand becomes mortar.

e. Water cement ratio

Water–cement ratios of **0.45 to 0.60** are more typically used. For higher-strength concrete, lower ratios are used, along with a plasticizer to increase flow ability. Too much water will result in segregation of the sand and aggregate components from the cement paste.

f. Physical property of concrete

- Density - ρ : 2240 - 2400 kg/m^3 (140 - 150 lb/ft^3)
- Compressive strength : 20 - 40 MPa (3000 - 6000 psi)
- Flexural strength : 3 - 5 MPa (400 - 700 psi)
- Tensile strength - σ : 2 - 5 MPa (300 - 700 psi)
- Modulus of elasticity - E : 14 - 41 GPa (2 - 6 x 10^6 psi)
- Permeability : 1 x 10^{-10} cm/sec
- Coefficient of thermal expansion - β : 10^{-5} ^{o}C^{-1} (5.5 x 10^{-6} ^{o}F^{-1})
- Drying shrinkage : 4 - 8 x 10^{-4}
- Drying shrinkage of reinforced concrete : 2 - 3 x 10^{-4}
- Poisson's ratio : 0.20 - 0.21
- Shear strength - τ : 6 - 17 MPa
- Specific heat - c : 0.75 kJ/kg K (0.18 Btu/lb$_m$ ^{o}F (kcal/kg ^{o}C))

g. Chemical property of cement

Table No.1 – Chemical and physical property of cement

Constituent	Value(%)
CaO	62.12
SiO_2	19.62
Al_2O_3	5.16
Fe_2O_3	2.88
MgO	1.17
SO_3	2.63
K_2O	0.88
NA_2O	0.17
Loss of ignition	2.99
specific gravity	3.15
Blaine fineness (m^2/kg)	394

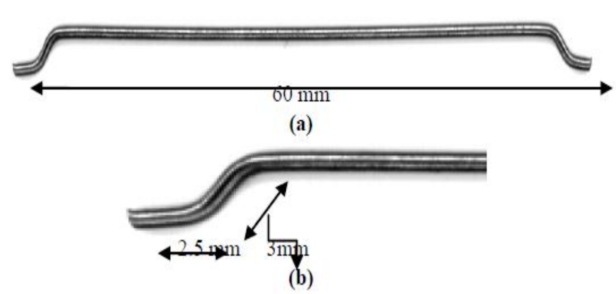

Figure No.1 – Hooked steel fiber

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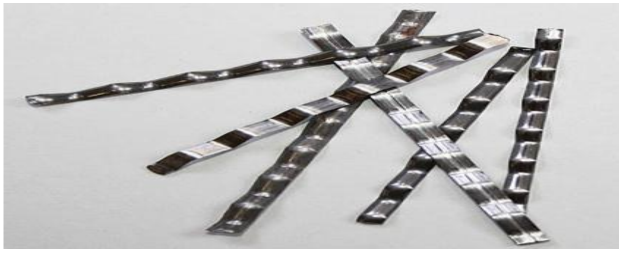

Figure No.2 – Flat crimped steel fiber

Figure No.3 – Rubberized steel fiber

III.EXPERIMENTAL STUDIES

There is an experimental analysis take place in this project , first of all there is research on compression test and then flexural strength by using different types fibers mix in concrete with different types of percentage and mix design proportion.

There are three types of fiber
i. Hooked steel fiber
ii. Flat crimped steel fiber
iii. Rubberized steel fiber
Percentage of adding fiber in concrete with respect to volume of concrete i.e 0.5% ,1% and 2%

a. Compression test

- Volume of mould = 150mm x 150mm x 150mm
- Grade M20 = 1:1.5:3
- Quantity of cement (for 1 mould) = 1.33kg
- Quantity of sand (for 1 mould) = 1.95kg
- Quantity of aggregate(for 1 mould) = 3.90kg
- Water cement ratio (w/c=0.5) = 650ml
- Mix design proportioned (for 1 mould) = 1.33:1.95:3.90
- Compression strength = Failure load / c/s area of specimen

b. Flexural strength

- Volume of mould = 150mm x 150mm x 750mm
- Grade M20 = 1:1.5:3
- Quantity of cement (for 1 mould) = 6.63 kg
- Quantity of sand (for 1 mould) = 9.94 kg
- Quantity of aggregate(for 1 mould) = 19.89 kg
- Water cement ratio (w/c=0.5) = 5850 ml
- Mix design proportioned (for 1 mould) = 6.63 : 9.94 : 19.89
- Flexural strength = $P\, l/ bd^2$
  Where,
  P – failure load.
  l – length of specimen.
  b – width of specimen.
  d – depth of specimen.

c. Slump Cone Test

The concrete slump test measures consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete flows .The test is popular due to its simplicity of apparatus test is used to ensure uniformity for different loads of concrete under field conditions.

IV. RESULT AND CONCLUSION

a. Hooked steel fiber

Effect of steel fiber reinforcement for studying the parameters of SFRC, like cube compressive strength and flexural strength, cubes and beams were casted and tested. The effect of increase in steel fiber percentage by volume of cement were studied.

As the peak value of graph at 1% i.e for 7,14 and 28 days are 26.94 N/mm^2 , 31.09 N/mm^2 and 36.10 N/mm^2 .

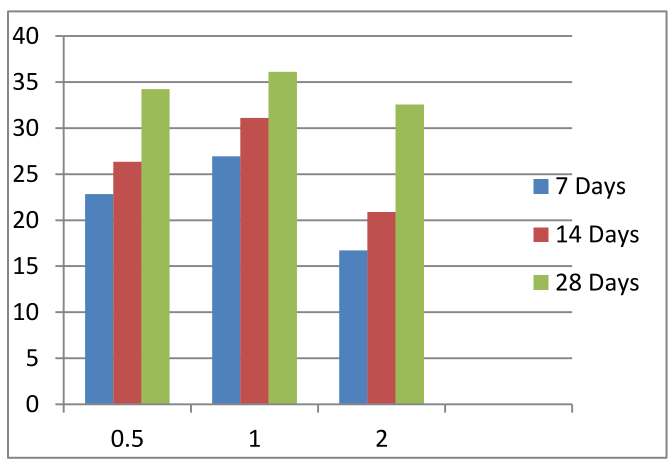

Figure No.2- This graphs shows the percentage variations in the fiber (hooked steel fiber) with respective compression strength.

As we test the flexural strength for an 14 and 28 days and peak percentage is 1% i.e the value are 4.97 N/mm^2 and 5.77 N/mm^2 .

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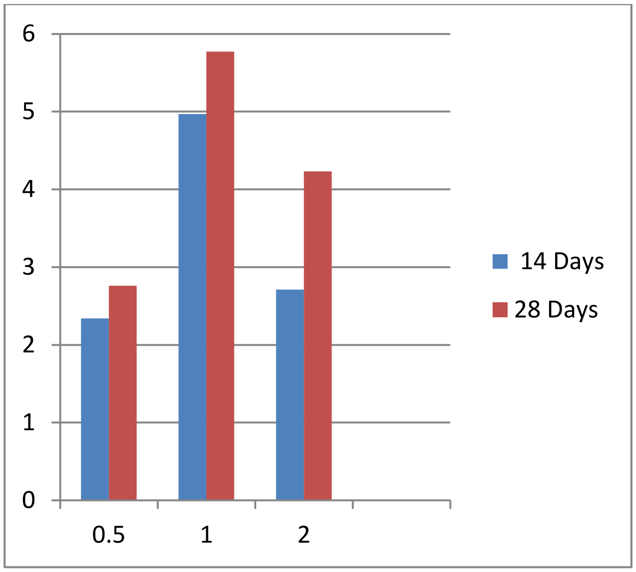

Figure No.3- This graphs shows the percentage variations in the fiber (hooked steel fiber) with respective flexural strength.

b. Flat crimped steel fiber

Workability of steel fiber reinforced concrete mix was observed by the slump cone test. The observation for 3, 7 and 28 days curing period were recorded and presented in the form of tables and graphs.

As the peak value of graph at 1% i.e for 7,14 and 28 days are 19.29 N/mm^2 , 27.42 N/mm^2 and 36.02 N/mm^2 .

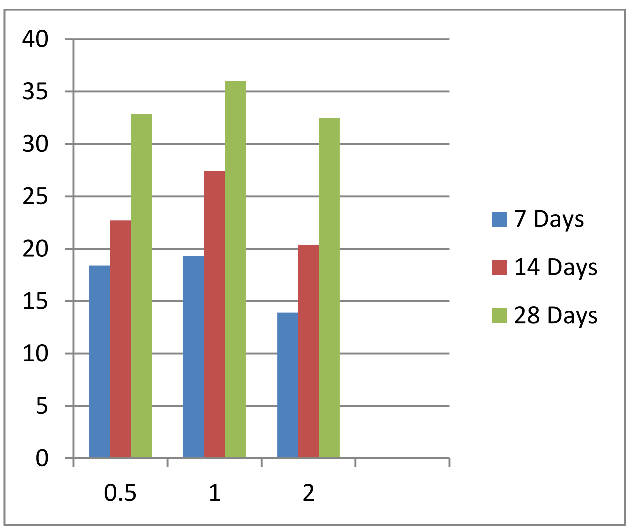

Figure No.4- This graphs shows the percentage variations in the fiber (Flat crimped steel fiber) with respective compression strength.

As we test the flexural strength for an 14 and 28 days and peak percentage is 1% i.e the value are 3.56 N/mm^2 and 4.68 N/mm^2 .

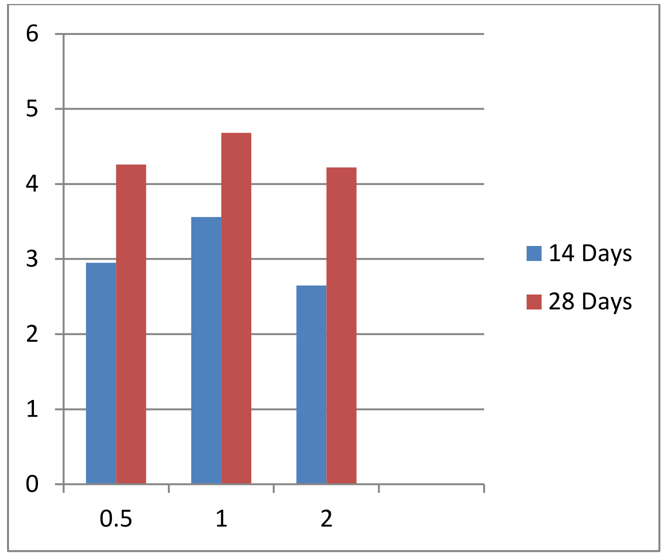

Figure No.5- This graphs shows the percentage variations in the fiber (Flat crimped steel fiber) with respective flexural strength.

c. Rubberized steel fiber

The performance of the Steel Fiber Reinforced Concrete (SFRC) has shown a significant improvement in flexural strength and overall toughness compared against Conventional Reinforced Concrete.

As the peak value of graph at 1% i.e for 7,14 and 28 days are 22.708 N/mm^2 , 25.97 N/mm^2 and 35.3 N/mm^2 .

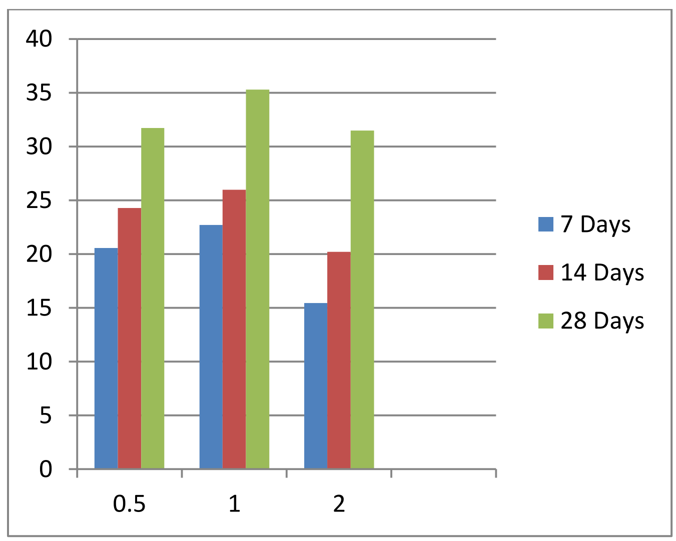

Figure No.6- This graphs shows the percentage variations in the fiber (Rubberized steel fiber) with respective compression strength.

As we test the flexural strength for an 14 and 28 days and peak percentage is 1% i.e the value are 3.77 N/mm^2 and 4.589 N/mm^2 .

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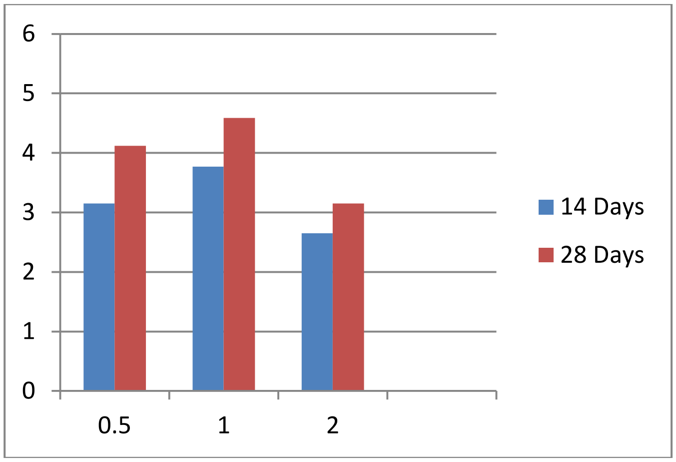

Figure No.7- This graphs shows the percentage variations in the fiber (Rubberized steel fiber) with respective flexural strength.

Comparison between Hook's Steel Fiber, Flat crimped steel fiber and Rubberized steel fiber for 28 Days.

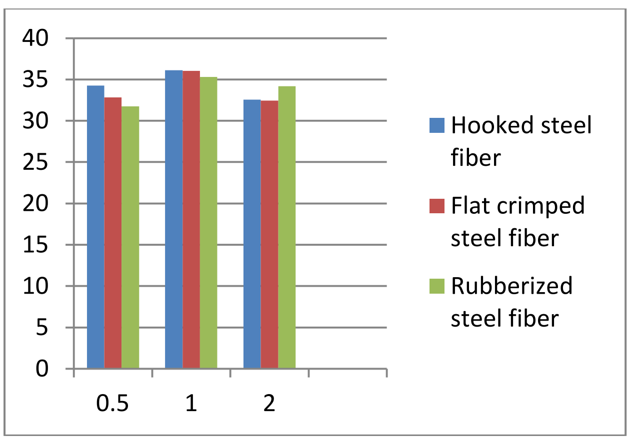

Figure No.8- This graphs shows the percentage variations in the Fibers with respective Compression strength.

Comparison between Hook's Steel Fiber, Flat crimped steel fiber and Rubberized steel fiber for 28 Days.

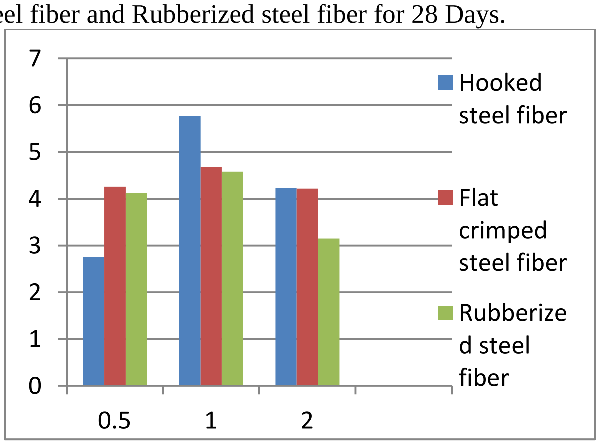

Figure No.9- This graphs shows the percentage variations in the fiber with respective flexural strength.

d. Rate Analysis

Volume of concrete = 1cu.m
Dry volume of concrete = 52/100 * 1+1 = 1.52 cu.m
Volume of cement = 1.52/1+1.5+3 *1 = 0.276 cu.m
No of bag = 0.276/0.035 = 7.88 nos
Volume of sand = 1.52/1+1.5+3 * 1.5 = 0.414 cu.m
Volume of aggregate = 1.52/1+1.5+3 * 3 = 0.829 cu.m
For 0.5% of steel Fibers = 0.5% of vol of concrete
= 0.5/100 * 1 * 7850
= 39.25 kg
For 1% of steel fibers = 1% of vol of concrete
= 1/100 * 1 * 7850
= 78.5 kg
For 2% of steel fibers = 2% of vol of concrete
= 2/100 * 1 * 7850
=157 kg

Table No.2 – Rate analysis of 1 cu.m concrete.

Materials	Quantity	Rate	Unit	Amount (Rs)
Cement	08	300	bag	2400
Sand	0.414	800	Cu.m	331.2
Aggregate	0.829	750	Cu.m	621.75
TOTAL				3353

Table No.3– Rate analysis of 1 cu.m concrete with hooked steel fiber.

% of steel	Quantity	Rate	Unit	Amount (Rs)
0.5%	39.25	75	kg	2943.75+3353 =6296.75
1.0%	78.50	75	kg	5887.50+3353 =9240.50
2.0%	157.0	75	kg	11775.0+3353 =15128

Table No.4 – Rate analysis of 1 cu.m concrete with flat crimped steel fiber.

% of steel	Quantity	Rate	Unit	Amount (Rs)
0.5%	39.25	55	kg	2158.75+3353 =5511.75
1.0%	78.50	55	kg	4317.50+3353 =7670.50
2.0%	157.0	55	kg	8635+3353 =11988

Table No.5 – Rate analysis of 1 cu.m concrete with rubberized steel fiber.

% of steel	Quantity	Rate	Unit	Amount (Rs)
0.5%	39.25	79	kg	3100.75+3353 =6453.75
1.0%	78.50	79	kg	6201.50+3353 =9554.50
2.0%	157.0	79	kg	12403+3353 =15756

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Table No.6 - Comparison of strength with literature paper strength

Sr. No	Author	Percentage of steel	Compression strength (28 days)	Flexural strength (28 days)
1	Milind V. Mohod	0.5	34	8.5
		1	36	8.9
		2	32	8.3
2	Hamid Pesaram Behbahani	0.5	31	-
		1	36	-
		2	-	-
3	B.R Phanikumar	0.5	36.16	6.38
		1	36.13	7.1
		2	36.76	8.29
4	Present work	0.5	34.24	2.76
		1	36.1	5.77
		2	32.55	4.23

V.CONCLUSION

- It is observed that the workability of steel fiber reinforced concrete gets reduced as the percentage of steel fibers increases.
- Compressive strength goes on increasing by increase in steel fiber percentage up to the optimum value. The optimum value of fiber content of steel fiber reinforced concrete was found to be 1%.
- The flexural strength of concrete goes on increasing with the increase in fiber content up to the optimum value. The optimum value for flexural strength of steel fiber reinforced cement concrete was found to be 1%.
- While testing the specimens, the plain cement concrete specimens have shown a typical crack propagation pattern which leaded into splitting of beam in two piece geometry. But due to addition of steel fibers in concrete cracks gets ceased which results into the ductile behavior of SFRC.
- For 28 days strength, flat crimped steel fiber compression strength and flexural strength slightly decreases up to 4% as compare to hooked steel fiber but for economy flat crimped steel fiber have low cost i.e 26% .

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