Effects of Crimped Steel Fiber on Fresh and Hardened Properties of Medium Strength Concrete

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Abstract - *Concrete is characterized by brittle failure thus nearly complete loss of loading capacity, once the failure is initiated. This characteristic, which limits the application of the material, can be overcome by the incorporation of steel fibre. Steel fibers in concrete are mostly used for resisting cracks and increase the strength of concrete moreover steel fibre also helps in enhancing toughness, ductility and damage tolerance. This performance enhancement makes steel fibre-reinforced concrete (SFRC) an ideal material as a sustainable building construction material. This paper gives a representation of the positive and negative change in the properties of normal traditional concrete mix to steel fibre reinforced concrete (SFRC). In this project, the effect of crimped steel fibre on medium strength concrete has been observed. Fresh and hardened property of the concrete and been observed with partial incorporation of steel fibre as a percentage of the total volume of concrete. In the experimental program, slump test and compaction factor test has been conducted on fresh concrete and compression, flexure and tensile test has been conducted on hardened concrete. Strength tests are done on standard-sized specimen of cubes, cylinders and beams. Three age level, 7day, 28 day and 90 day tests are being done for compressive strength test and one age level, 28day test is being done for split tensile strength test and flexural strength test. The test parameter includes preparing mix of M25, M30, M35 grade of control mix as well as steel fibre reinforced concrete (SFRC) with steel fibre content of 0.2%, 0.4%, 0.6% (by volume of concrete) for each grade. The result showed a significant increase in compressive, split tensile and flexural strength of concrete whereas it also shows a significant loss of slump value. Best fit relationship curve has been plotted for each properties of fresh and hardened concrete.*

***Key Words*: Fiber Reinforced Concrete (FRC), Steel Fiber Reinforced Concrete (SFRC), Mechanical properties, Compressive Strength, Split Tensile Strength, Flexural Strength**

1. INTRODUCTION

Concrete has a characteristic of having a brittle failure, there is a significant loss of loading capacity when failure is initiated. This characteristic, which limits the application of concrete can be get over by the inclusion of a small amount of short randomly distributed fibers which can be steel, glass, synthetic or even natural fibres. Steel fiber reinforced concrete (SFRC) has the benefits of being excellent in tensile strength, flexural strength, shock resistance, fatigue resistance, ductility and crack arrest. Therefore, it has found its application in various fields of construction, irrigation works and even architecture. Till now presently 300,000 metric tons of fibers have been used for reinforcing concrete. Steel fiber by far the most used fiber among all (50% of total tonnage used) followed by polypropylene fibre (20%), glass fibre (5%) and other fibers (25%) (Banthia, 2012). More than 400 tons of Steel Fibers have been used recently in the construction of a road overlay for a project at Mathura (UP). A 3.9 km long district heating tunnel, carrying heating pipelines from a power plant on the island Amager into the center of Copenhagen, is lined with SFC segments without any conventional steel bar reinforcement. Literature is affluent in the field of concrete incorporating steel fibres. Steel fiber reinforced concrete under compression and Stress-strain curve for steel fiber reinforced concrete in compression was done by Nataraja, Dhang and Gupta. They have proposed an equation to quantify the effect of fiber on compressive strength of concrete in terms of fiber reinforcing parameter. Mechanical properties of high-strength steel fiber reinforced concrete were done by Song and Hwang. They have marked brittleness with low tensile strength and strain capacities of high strength concrete can be overcome by addition of steel fibers. Based on review of existing works, it was observed that fiber reinforced concrete results in a greater negative effect on workability and the necessity for mix design changes. The slump changed due to the different type of fiber content and form. The reason behind lower slump is that adding steel fibers forms a network structure in concrete, which resists the mixture from segregation and flow. 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 composite and unstable growth. If the fiber volume fraction is sufficiently high, this may result in an increase in the tensile strength of the matrix. The post peak macro-crack bridging is the primary reinforcement mechanisms in majority of commercial fiber reinforced concrete matrix. In the present investigation, an effort has been made to study the effect of inclusion of moderate dosage of steel fibers (dosage ranging from 0.2% to 0.6%) on fresh concrete properties viz. slump and compacting factor and the hardened concrete properties namely compressive strength, split tensile and flexural tensile strength at 3 age level varying from 7 to 56 days. Design strength of concrete will vary from 25 MPa to 35 MPa with target slump of 125 mm. Very commonly used steel fibers (crimped round) with aspect ratio of 50 and diameter of 0.5 mm has been chosen for investigation. A good quality plasticizer will be employed in making all the concrete mixes.

2. MATERIALS AND METHODS

2.1 Materials

The material used for this experimental work are cement, aggregate, water, admixture and steel fibers.

i) Cement: Portland slag cement was used in this experimentation conforming to I.S. – 455 – 1989.

ii) Fine Aggregate: Natural clean river sand was used of zone II with specific gravity and water absorption were obtained as 2.60 and 0.4% respectively. The Fineness Modulus was about 2.67, conforming to I.S. – 383-1970.

iii) Coarse Aggregate: Crushed granite stones of 20 mm nominal maximum size as per IS: 383 for investigation. 20 mm graded coarse aggregates are rarely available in market. The specific gravity and water absorption values obtained as 2.69 and 1.1%, conforming to IS 383-1970

iv) Water: Potable tap water was used for the experimentation.

v) Admixture: To impart additional water proofing, workability, corrosion resistance, compatibility, shrinkage, durability and strength an admixture (Dr. Fixit PIDIPROOF 101 LW+) 1% by weight of cement was used. It is composed of surface-active plasticizing agents, polymers & additives with properties as per IS: 2645: 2003

vi) Fibers: Steel Fibers: - In this experimentation round crimped Steel fibers were used. Round crimped mild steel fiber was used (manufacturer name - Stewols India (P) Ltd. with the brand name "SHAKTIMAN") with aspect ratio of 50 and diameter of 0.5mm.

2.2 Mix Proportioning

After a detailed literature review over last ten years, mix proportions for steel fibre reinforced concrete have been finalized. Indian Standard Guidelines for mix proportioning of concrete mixes (IS 10262: 2009) have been invariably followed in determining mix composition for all the concrete mixes investigated. It was decided that concrete strength will vary from 25 MPa to 35 MPa with target slump of 100-150 mm. Majority of construction activities across different parts of our country deal with medium to standard strength concrete (i.e., between 20 to 40 MPa). Demand of pumpable concrete is increasing by leaps and bounds. Keeping all these in view, mix proportions have been framed. A good quality plasticizer was chosen to enhance the workability and to obtain good quality uniform, homogeneous, concrete mixes. While determining the mix composition for steel fibre reinforced concrete, fibres were added @ 0.2%, 0.4% and 0.6% by volume of concrete keeping all other proportions constant. The goal was to investigate the effect of mild dosage of fibres on fresh and hardened concrete properties. Based on a large number of trials, dosage of plasticizer was selected as 1% by weight of cement.

Table -1: Mix Compositions

Grade with percentage of steel fibre	Material Mix Proportion (Weighted Batching) (kg/m^3)				
	Cement	Water	Fine Aggregate	Coarse Aggregate	Plasticizer
M25 (PCC) (Reference)	428.5	193	743.55	988.35	4
M25 SFRC (0.2%)	428.5	193	741.25	985.5	4
M25 SRFC (0.4%)	428.5	193	738.95	982.24	4
M25 SRFC (0.6%)	428.5	193	736.66	979.2	4
M30 (PCC) (Reference)	448.4	192.85	718.99	991.49	4.1
M30 SRFC (0.2%)	448.4	192.85	716.85	988.54	4.1
M30 SRFC (0.4%)	448.4	192.85	714.61	985.44	4.1
M30 SRFC (0.6%)	448.4	192.85	712.36	982.34	4.1
M35 (PCC) (Reference)	482.1	192.85	705.171	972.43	4.4
M35 SRFC (0.2%)	482.1	192.85	703.37	969.94	4.4
M35 SRFC (0.4%)	482.1	192.85	701.13	966.85	4.4
M35 SRFC (0.6%)	482.1	192.85	698.88	963.75	4.4

2.3 Analytical Method

For the determination of fresh properties of concrete slump test and compaction factor test has been performed. For determination of compressive strength —150 x 150 x 150 mm cube specimens have been used, split tensile strength will be measured on 150 x 300 mm cylinders. For flexural tensile strength, 100x100x500 mm prism specimens have been prepared. Correlation has been done with split tensile strength and compressive strength and also between flexural strength and compressive strength. New relations have been developed for SFRC apart from those already exist for normal concrete.

2.4 Experimental Studies

Fresh Property Test

Slump Test:

For the test of workability or consistency of freshly mixed concrete slump cone test was conducted as per IS: 1199 – 1959. In this test freshly mixed concrete is poured in a 300mm height truncated cone in approximately 4 equal layers which is being tamped with a rod of specific dimension 25 times in each layer. Then the slump cone arrangement is lifted with both hands and the subsidence height is noted i.e. the required slump value.

Compaction Factor Test:

For the test of workability of freshly mixed concrete compaction factor test was conducted as per IS: 1199 – 1959. In this test the freshly prepared concrete matrix is made to free fall from a series of two hopper namely upper and lower hopper consecutively to a cylinder which has an empty weight (W). The weight of the cylinder is taken with the free fall concrete i.e. partially compacted concrete nearest to 10gm (W1) then the cylinder is emptied and it is again filled in layers of approximately 50mm and heavily rammed to full compaction and weight is taken of the cylinder (W2). Compaction factor is given as follows:

Compaction Factor: [(W1-W) / (W2-W)]

Hardened Property Test

Compressive strength test:

For compressive strength test, cube specimens of dimensions 150 x 150 x 150 mm were cast for M 25, M30, M35 grade of concrete. Admixture (1% by weight of cement) was added to this. The molds were filled with 0%, 0.2% 0.4% and 0.6% fibres. Vibration was given to the molds using table vibrator. The top surface of the specimen was levelled and finished. After 24 hours the specimens were demolded and were transferred to curing tank wherein, they were allowed to cure for 7, 28 and 90 days. After 7, 28, 90 days of curing, these cubes were tested on digital compression testing machine as per I.S. 516-1959. The failure load was noted. In each category three cubes were tested and their average value is reported. The compressive strength was calculated as follows:

Compressive strength (MPa) = Failure load / cross sectional area.

Flexural strength test:

For flexural strength test beam specimens of dimension 100x100x500 mm were casted. The specimens were demolded after 24 hours of casting and were transferred to curing tank wherein they were allowed to cure for 28 days. These flexural strength specimens were tested under two point loading as per I.S. 516-1959, over an effective span of 400 mm on Flexural testing machine. Load and corresponding deflections were noted up to failure. In each category three beams were tested and their average value is reported. The flexural strength was calculated as follows:

Flexural strength (MPa) = (P x L) / (b x d2),

Where, P = Failure load, L = Centre to center distance between the support = 400 mm, b = width of specimen=100 mm, d = depth of specimen= 100 mm.

Split Tensile strength test:

For Split tensile strength test, cylinder specimens of dimension 150 mm diameter and 300 mm length were cast. The specimens were demolded after 24 hours of casting and were transferred to curing tank wherein they were allowed to cure for 28 days. These specimens were tested under compression testing machine. In each category three cylinders were tested and their average value is reported. Split Tensile strength was calculated as follows:

Split Tensile strength (MPa) = 2P / π DL,

Where, P = failure load, D = diameter of cylinder, L = length of cylinder

3. RESULTS AND DISCUSSION

3.1 Fresh Concrete Results:

Table -2: Slump and Compaction Factor

Mix	Slump value(mm)	Compacting Factor (C.F.)
M25 (PCC) (Reference)	130	0.98
M25 SFRC (0.2%)	125	0.96
M25 SRFC (0.4%)	105	0.95
M25 SRFC (0.6%)	90	0.90
M30 (PCC) (Reference)	145	0.98
M30 SRFC (0.2%)	130	0.97
M30 SRFC (0.4%)	110	0.96
M30 SRFC (0.6%)	100	0.96
M35 (PCC) (Reference)	160	0.98
M35 SRFC (0.2%)	145	0.98

M35 SRFC (0.4%)	120	0.97
M35 SRFC (0.6%)	110	0.97

Discussion:

i) From the value obtained from slump test and compacting factor test and from the visual observation it could be said that the addition of fibers had made the matrix stiffer and higher the concentration of steel fiber used lower is the mobility of concrete, consequently decrease in the slump value.

ii) The reason of lower slump was that adding steel fibers can form a network structure in concrete, which restrain mixture from segregation and flow. Due to the high content and large surface area of fibers, fibers are sure to absorb more cement paste to wrap around.

iii) From Table 2 it is clearly visible that, slump value is higher for higher grade of concrete.

iv) Slump value reduces with increment of steel fibre content

v) Compaction Factor has less effect of change with changing of steel fibre percentage in concrete.

Essentially, each individual fiber needs to be coated with cement paste to provide any benefit in the concrete. To avoid such difficulty of stiffness and to improve workability of concrete we have adopted the strategy of using plasticizer "Dr. Fixit PIDIPROOF 101 LW+". From the results of the present investigation, the following conclusions may be drawn –

Incorporation of steel fiber in concrete —

i) Reduces the density of fresh concrete.

ii) Increases the cohesiveness of the mix.

iii) Reduces bleeding.

iv) Prevents segregation and makes the concrete easier to compact.

3.2 Hardened Concrete Results:

Compressive Strength test results

Table -3: Compressive Strength Values

Mixes	Compressive Strengths (MPa)		
	7 days	28 days	90 days
M25 (PCC) (Reference)	17	27	31
M25 SFRC (0.2%)	18	29	33
M25 SRFC (0.4%)	18.5	30	35
M25 SRFC (0.6%)	20	30.5	36
M30 (PCC) (Reference)	20	31	33
M30 SRFC (0.2%)	21	31.8	35
M30 SRFC (0.4%)	22.7	32.5	36
M30 SRFC (0.6%)	24	34	38
M35 (PCC) (Reference)	25	36	39
M35 SRFC (0.2%)	25.7	36.8	40
M35 SRFC (0.4%)	26.6	38	42.5
M35 SRFC (0.6%)	28	40	44

Table -4: Percentage increment of compressive strength

Mixes	Percentage Increment Of Compressive Strength With Reference Concrete		
	7 days	28 days	90 days
M25 SFRC (0.2%)	5.88	7.41	6.45
M25 SFRC (0.4%)	8.82	11.11	12.9
M25 SFRC (0.6%)	17.6	12.96	16.13
M30 SFRC (0.2%)	5.00	2.30	6.06
M30 SFRC (0.4%)	13.5	4.84	9.09
M30 SFRC (0.6%)	20	9.68	15.15
M35 SFRC (0.2%)	2.8	2.22	2.56
M35 SFRC (0.4%)	6.4	5.55	8.97
M35 SFRC (0.6%)	12	11.11	12.82

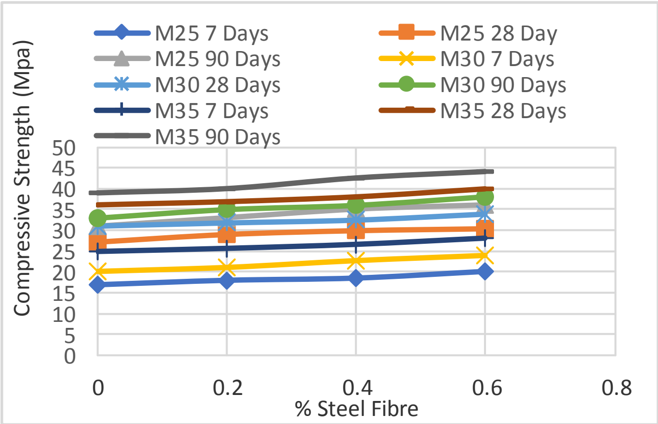

Chart - 1: **7, 28, 90 Days Compressive strength with change in % steel fibre for M25, M30, M35 concrete**

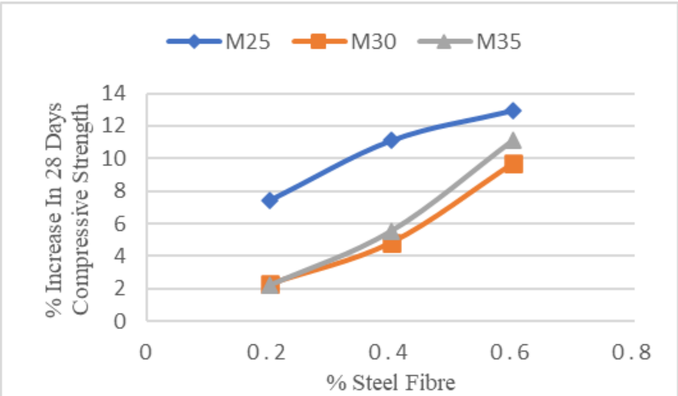

Chart - 2: % increase in 28-day Compressive Strength with % increase in Steel Fibre

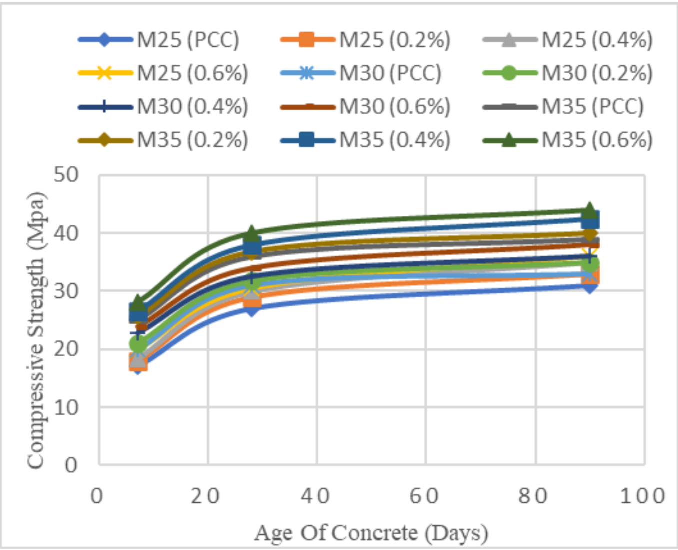

Chart - 3: Variation compressive strength of concrete w.r.t age of concrete

Discussion:

i) It was observed that the compressive strength of concrete for the cubes with steel fibers 0.20%, 0.40% and 0.60% is more than that of cubes without steel fibers. This may be due to the fact that the steel fibers would have effectively hold on to the micro cracks in concrete mass.

ii) The percentage increase in the compressive strength for the cubes with steel fibers 0.20%, 0.40%, and 0.60% compared to the cubes without steel fibers are significantly higher.

iii) From **Chart – 1** it can be concluded that the variation of compressive strength for each grade is almost linear. It has been observed that the trend is concrete with 0.8-1.0% steel fibre has optimum value for enhancing compressive strength.

iv) It can be observed that the slope of gaining compressive strength is much greater for 7-90 days; after that increment of strength becomes slower (almost linear).

v) So, in a nutshell it can be concluded that the use of steel fibers is an effective method to improve the compressive strength of concrete. To get the maximum benefit it is recommended to use steel fibers in proper proportion. More percentage of steel fibers will have the workability problem & also air cavities are left in the system.

Split Tensile Strength test results

Table -5: Split Tensile strength and percentage increment values

Mixes	Split tensile Strength (MPa) at 28 days	Percentage increase in split tensile strength with addition of steel fiber w.r.t respective Reference Concrete
M25 (PCC) (Reference)	2.1	--
M25 SFRC (0.2%)	2.3	9.52
M25 SRFC (0.4%)	2.63	25.23
M25 SRFC (0.6%)	2.82	34.28
M30 (PCC) (Reference)	2.85	--
M30 SRFC (0.2%)	3.04	6.66
M30 SRFC (0.4%)	3.20	12.28
M30 SRFC (0.6%)	3.51	23.16
M35 (PCC) (Reference)	3.1	--
M35 SRFC (0.2%)	3.39	9.35

M35 SRFC (0.4%)	3.70	19.35
M35 SRFC (0.6%)	3.85	24.19

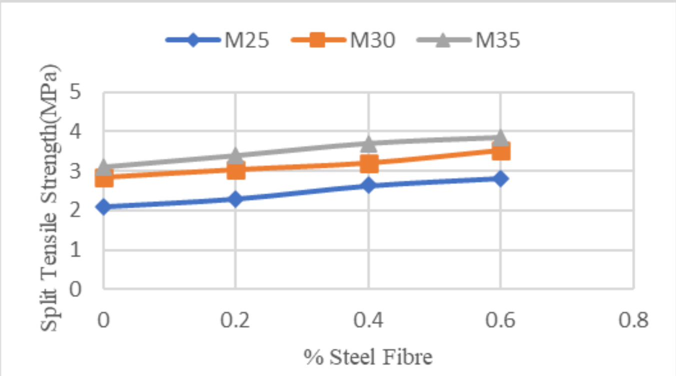

Chart - 4: Variation in 28 Days Split Tensile Strength with Increase in % of Steel fibre

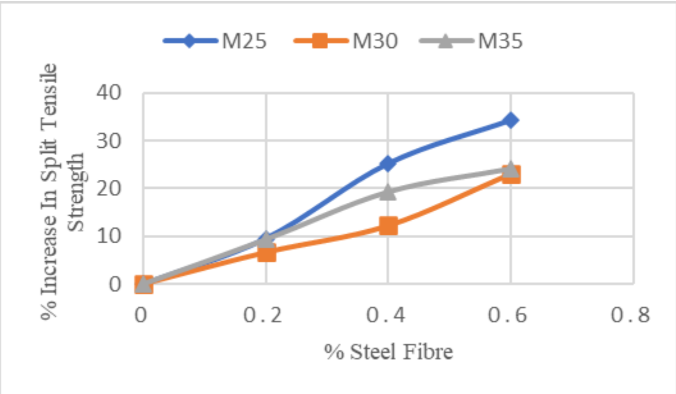

Chart - 5: % increase in 28-day Split Tensile Strength with % increase in Steel Fibre

Discussion:

i) For a particular grade of concrete with increase in % of steel fiber a noticeable increase in split tensile strength was observed.

ii) From the result, it was clearly visible that increment of percentage of steel fibre will surely add up its tensile strength.

iii) From Figure 4 the analysis of the test specimen implies that, it has incremental curve for every grade (M25, M30, M35) of concrete.

iv) The range of split tensile strength value lies between 2.1 - 3.9 MPa for M25, M30, M35

v) 6.13% - 34.29% of increment in split tensile strength of concrete has been achieved by adding steel fiber.

Flexural Strength test results

Table - 6: Flexural Strength and percentage increment values

Mixes	Flexure Strength (MPa) at 28 days	Percentage increase flexural strength with addition of steel fiber w.r.t respective Reference Concrete
M25 (PCC) (Reference)	3.7	--
M25 SFRC (0.2%)	4.1	10.81
M25 SRFC (0.4%)	4.6	24.32
M25 SRFC (0.6%)	5.1	37.83
M30 (PCC) (Reference)	4.0	--
M30 SRFC (0.2%)	4.52	13
M30 SRFC (0.4%)	4.9	22.5
M30 SRFC (0.6%)	5.3	32.5
M35 (PCC) (Reference)	4.6	--
M35 SRFC (0.2%)	5.3	15.21
M35 SRFC (0.4%)	5.78	25.65
M35 SRFC (0.6%)	6.45	40.21

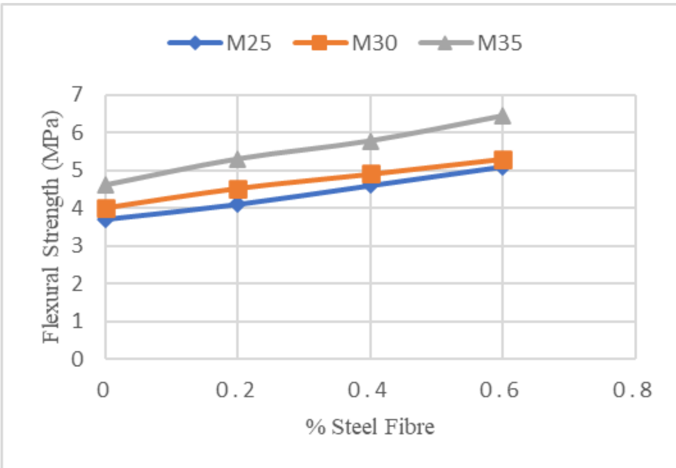

Chart - 6: Variation in Flexural Strength with Increase in % of Steel fibre

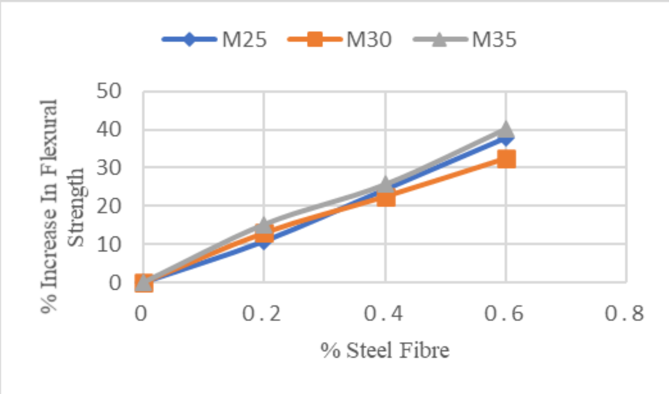

Chart - 7: **% increase in 28-day Flexural Strength with % increase in Steel Fibre**

Discussion:

i) The results of flexural strength tests are tabulated in **Table - 6** It was observed from **Chart - 6** and **Chart - 7** that addition of steel fibers to cement concrete, the flexural strength significantly increased.

ii) It was observed that addition of 0.2% to 0.6% of fibre with aspect ratio 50, the flexural strength was nearly 1.4 times the plain cement concrete strength.

iii) 10.81% - 40.22% of increment in Flexural strength of concrete by adding steel fiber was achieved as inferred from **Chart - 7** and **Table - 6.** So, it can be said that Flexural Strength can very much be improved by adding fiber.

4. CONCLUSION

The study on the introduction of effect of steel fibers showed promising results as steel fiber reinforced concrete is used for sustainable and long-lasting concrete structures. Steel fibers are widely used as a fiber reinforced concrete all over the world. Lot of research work had been done on steel fiber reinforced concrete and lot of researchers work prominently over it. Through this investigative review study an attempt has been made to focus on the most significant effects of addition of steel fibers to the concrete mixes i.e. on fresh and hardened properties of concrete mix. In this project comparative study has been done between plain cement concrete (PCC) with steel fibre reinforced concrete (SFRC) for M25, M30, M35 by introducing 0.2%, 0.4%, 0.6% steel fibre by total volume of concrete. Steel fibre of aspect ratio 50 and diameter of 0.5mm has been used. Compressive strength on (150mm x 150mm x 150mm) cube sample, Split tensile strength on (300mm×ϕ150mm) cylinder, Flexural strength on (100 mm×100 mm×500 mm) beam is performed.

i) Maximum reduction of 31.25% in slump has been noticed with increased steel fiber percent.

ii) Maximum compression strength increment of 15.15% has been achieved.

iii) Maximum Split strength increment of 34.29% has been achieved.

iv) Flexure strength increment of 40.22% has been achieved.

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