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Innovative Use of Waste Steel Scrap in Rigid Pavements

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ABSTRACT

This paper work assessment on the study of the workability and mechanical strength properties of the high strength concrete reinforced with industrial waste fibers. This waste steel scrap material which is available from the lathe is used as a steel fiber for innovative construction industry and also in pavement construction. Lathe waste is generated by each lathe industries and dumping of these wastes in the barren soil contaminating the soil and ground water, which creates an unhealthy environment. In addition to get sustainable development and environmental benefits, lathe scrap as recycled fibers with concrete are likely to be used. Experimental studies are done to know about fresh and hardened concrete properties of SFRC and their mechanical properties such as compressive strength, flexural strength and split tensile strength are found to be increased due to the addition of steel scrap fiber in the concrete. When compared with conventional concrete to SFRC, steel fiber increases flexural strength by 40% and considerable increase in compressive and tensile strength. These fibers may also contribute to improve properties such as shrinkage reduction, modulus of elasticity, toughness, resistance to cracking and preventing crack propagation. The workability of fresh concrete containing lathe scraps are carried out by using slump test. This paper focuses on structural strength enhancement and improvement in fatigue life of rigid pavement by locally available scrap steel. These rigid pavements using steel scrap promises an appreciably higher design life, offer better serviceability and minimize crack growth and corrosion. The innovative idea of this paper is the use of waste lathe scrap as recycled steel fibers, which provides more economical and environmental sustainable SFRC PAVEMENTS.

Key words: lathe scarps steel fibers, Fatigue endurance, Flexural strength, workability, Tensile strength.

1. INRODUCTION

Concrete pavement is a key structure of highway pavement in India due to its increase in ride superiority, minimum maintenance, and extended design life. These rigid pavements may sometimes experience pavement distress that results in premature failure. This research studies the application of fibers in concrete due to its enhancement resistance to cracking. Now–a-days steel fibers in concrete increase intensively as an engineering demand. From the present scenario it is not only essential to provide safe, efficient and economical design, but it also provide as balanced base for future application. The energy consumption and cost associated with concrete pavements can be reduced through the use of recycled materials with more effective construction techniques. In many developed countries like India, anxiety over resource conservation, reduced material cost and waste production have paying attention on recycling of materials. This recycling of materials from industrial wastes either helps to conserve natural resources or propose environmental profits (ISSN: 2319-6009).

Conventional plain concrete pavements have low strain capacity, tensile and flexural strength when subjected to repeated loads due to brittleness of concrete; however their structural characteristics and efficiency are improved with fibers addition. The intention of improving the ductility of concrete led to the development of fiber reinforced concrete (FRC) reinforced with the discrete fibers within the concrete mass. These fibers are usually randomly distributed in the concrete and give primary reason to reinforce with concrete is to redistribute the stresses and to delay and control the post cracking of the composite materials. Due to this benefit, the use of FRC has tremendously increases now-a-days. In present different type of fibers are commercially use for Civil engineering applications includes steel or metallic fibers, glass, carbon, aramid, polymeric and cellulose. Among them steel fibers significantly improve the tensile strength, toughness and impact resistance of concrete under subjected to repeat or impact loads. Recent applications of SFRC are found in airport and highway pavements, tunnel linings, shotcreting, earthquake-resistant structures, overlays, bridges deck, industrial floors and marine and hydraulic structures which endure cyclic loading during their design life(ACI 1R-1996). An industrial steel fiber available in market makes steel fiber reinforced concrete uneconomical. Investigations to overcome uneconomical, lathe scraps used as recycled steel fiber which exhibits the property of steel fiber in fiber reinforced concrete.

2. STEEL FIBER REINFORCED CONCRETE (SFRC)

Steel fiber reinforced concrete (SFRC) is composite material made of hydraulic cements containing fine and coarse aggregate and using discontinuous discrete steel fibers as raw material (ACI1R-1996). Plain concrete or conventional concrete mostly suffer from cracking due to intrinsic weakness of material to resist tensile forces (Dr.M.C.Nataraja).Concrete have poor tensile strength propagate micro-cracks and leading concrete to the brittle fracture. At cracked section traditional reinforcement successfully work either in the form of bars or mess to offer load carrying capacity in ultimate limit state and also effort in serviceability limit state to control cracking, rotations and deflections. When load is further increased, due to the effect of stress concentration structural crack proceed and causes inelastic deformation in concrete matrix. Concrete will again crack when it shrink or restrained(Shirule Pravin, Ashok,Swami Suman and nilesh2012) Thus necessitate for intimately spaced multi directional reinforcement arises which provide tensile capacity to the cracked section. Addition of short, discrete steel fibers to plain or reinforced concrete provide discontinuous three-dimensional reinforcement that sustain load and distribute stresses at the micro-cracks level. Steel fibers impart improvements to strength, stiffness, and recital to the concrete which offer increased toughness, abrasion and impact resistance. According to JSCE nominal parameters for steel fibers:

Table 1
Parameters for steel fiber

Fiber length mm	25-40
Fiber diameter mm	0.3-0.6
Aspect ratio	50-100
Fiber content %(by volume)	0.5-2.0(40-180 kg/m³)

Owing to ductile property of SFRC, it is well suited for structures which are required to exhibit;

- Resistance to seismic exposures.
- Splitting , erosion and abrasion resistance.
- Resistance to susceptible shrinkage cracking or reflex cracking.
- Resistance to blast and shocks.
- Resistance to high thermal and temperature expansion.
- High flexural strength, tensile and shear.
- Reduce the permeability and water migration in concrete.

Steel Fibers mechanism in Concrete:

Properties of SFRC are more significant in both fresh mixed and hardened state. The mechanics of fibers in SFRC is consider to be a composite material, whose properties can be related to the properties of concrete, fiber and matrix bond between fiber and concrete i.e. strength, volume percentage, elastic modulus, aspect ratio of fiber(ACI -1R 96). Fiber reinforcing in concrete believes a crack arrest mechanism and bonded with concrete in critical cracked section. For attaining superior properties of SFRC requires proper quality control, dosing of fibers, mixing, placing and finishing. SFRC property depends on quantity of fibers added in concrete matrix defined as volume fraction i.e. percentage of total volume of mix (concrete and fibers) and ranges from 0.1-2.0%. Fibers are micro or macro fibers added according to the size of aggregate. Aspect ratio (l/d) expressed as ratio length of fibers to the diameter of fibers. Higher aspect ratio should be avoid due to workability problem, it tend to produced balling of fibers. From the workability point of view, micro fibers are more preferable and recommend better impact resistance as compare to macro fibers or longer fibers. If modulus of elasticity of fiber is higher than concrete composite, it tends to sustain load by increasing tensile strength of SFRC (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 1, January 2013). This is finding that steel fibers in SFRC increase ductility of concrete composite.

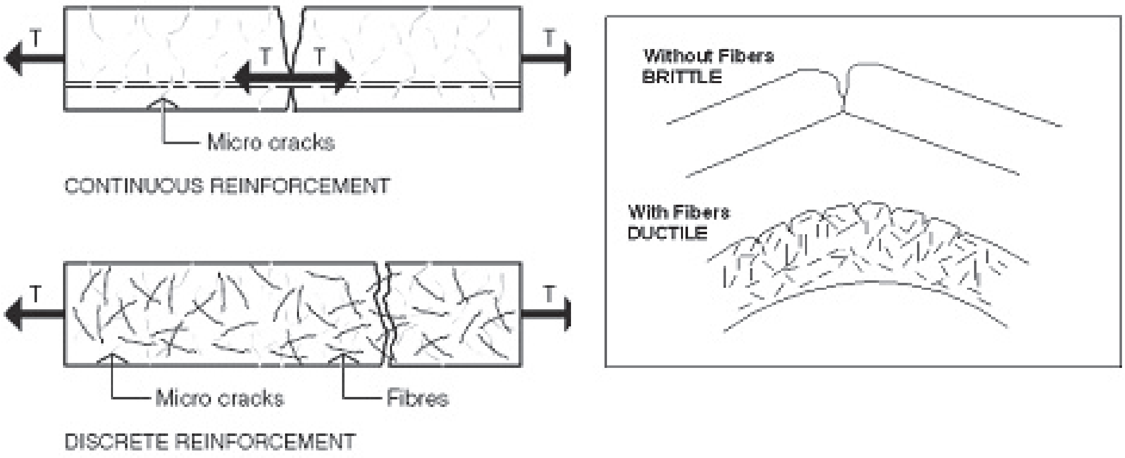

Figure.2.1Steel Fibers mechanism in Concrete

2.1 FIBER CHARACTERISTICS CONTROLLING SFRC

2.1.1 Fiber Types

Fibers types on the basis of manufacture process, shape, size, length and diameter strictly influence the properties of SFRC**.** The Japanese Society of Civil Engineers (JSCE) has specified the nominal standard of steel fibers according to their section; they are

Table 2
JSCE Classification of steel fibers

Types of fibers		Symbol
TYPE 1	With square section	SFR 1
TYPE 2	With circle section	SFR2
TYPE 3	With crescent section	SFR3

And according to ACI 544-1R steel fibers classified as shown in figure.

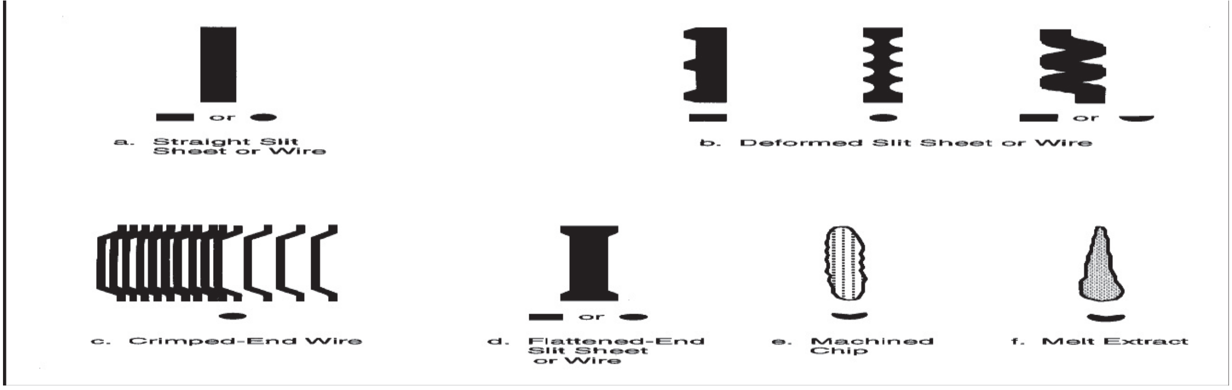

Figure.2.1.1 ACI 544-1R classification of steel fibers

Table 3
Fibers classification on basis of manufacture process

S.No.	Types of steel fibers	Manufacture process
1.	Round , straight fibers	Cutting or Chopping of wire
2.	Flat, straight steel fibers (Fig .a)	Shearing sheet or flattening wire
3.	Crimped steel wire(Fig. b)	Full length crimping or tucking of sheets
4.	Deformed steel wire (Fig. c, d).	Bend or enlarge at end or By bending or flattening of sheets to increase mechanical bonding
5.	Elongated chips or steel scrap (Fig. e).	Machining process or produced by lathe machines
6.	Steel fiber from melt extraction process (Fig. f).	Molten metal surface, lifts off liquid surface, ad rapidly solidifies it into fibers

Fiber materials such as steel, asbestos and carbon have high modulus of strength contribute to produce strong concrete composite, while low modulus, high elongation fibers are nylon, polypropylene and polyethylene are skilled of large energy absorption under repetition of loads, they do not lead significant improvement to the strength (Swamy et al. 1974).

2.1.2 Fiber-matrix bond

Fiber-matrix bond describes the interface between the fiber and concrete matrix. This interface depend on the concrete matrix strength and again fibers content i.e. fiber types and volume fraction (Bentur and Mindess 1990). Indirectly interfacial bond strength defines the restraining of fibers with the matrix before fiber slip take place. At the fiber- matrix interface when fiber prepare to slip due to fiber mobilization some energy inclusion takes place. Antoine (1991) investigated that the slip occurs earlier at maximum load for smooth fibers than that of hooked or deformed fibers. The suitability of the fiber-matrix bond is calculated by the interfacial bond strength. The Value range of 0.8 t0 13 MPa for bond strength.

2.1.3 Fiber length Critical length

Nominal fiber length is the critical or minimum length required to attain its full tensile capacity in concrete, outside this fiber will fail. A relationship is given by Maidl 1995 for critical fiber length i.e. Fibers length less than this value will not be achieved its full tensile capacity. However, practically length of fiber consider less than it, the reason is that longer fibers contribute greater strength to the concrete but would be prone to the balling problem in steel fibers. Therefore to improve concrete matrix strength, it is necessary to increase the interfacial bond strength by improving length and shape of fiber.

2.1.4 Fiber orientation

Researchers have introduced an important factor to define alignment of fibers in matrix, i.e. orientation factor $n_{ø}$ (Paine 1998). Orientation in the direction of stresses will be preferable to increase the post-cracking strength of concrete matrix. It works significantly to resist or redistribute the tensile stresses. Another one more term Snubbing is define i.e. relates to the additional energy required to overcome the local frictional forces and the matrix resists fiber pull out.

For different cases of alignment, values of orientation factor;

Table 4
Orientation factor

S.NO.	Alignment direction	Orientation factor
1.	In direction of stresses(Paine 1998)	1.0
2.	Randomly 3-dimension	0.41
3.	Randomly 2-dimension	0.33-0.67
4.	In worst case(Lanu 1996)	< 0.2

2.1.5 Fiber volume fraction V_F

Fiber volume fraction is defined as the quantity of fibers used in matrix in percentage of the total volume of the mix (fiber and concrete). Volume fraction also defines as ratio of the volume of fiber to the volume of compacted concrete. IRC SP: 46-2013 gives the nominal fiber dosage in kg/m³ for different volume fraction in %.

Table 5
Fiber dosage by volume fraction (%)

S.NO.	Fiber Volume (%)	Steel Fiber (kg/m³)
1.	0.1	8
2.	0.2	16
3.	0.3	24
4.	0.4	32
5.	0.5	40
6.	0.75	60
7.	1.0	80
8.	1.5	120
9.	2.0	160

Specific gravity of steel fibers =7.85

With increase of fiber volume fraction, post-crack ductility of SFRC is improved (ACI 544 1996). The first crack would be expected in matrix and volume fraction at this stage is known as critical fiber volume ($\mathbf{V_{f\,crit}}$)

2.1.6 Aspect ratio, l/d

The aspect ratio of a fiber is the ratio of the length of the fiber to its equivalent diameter. Equivalent diameter is the diameter of a circle with an area equal to the cross-section of fiber. High aspect ratio of steel fibers tends to improve post–cracking load carrying capacity, toughness, ultimate strength, first crack strength of SFRC as compared to lower aspect ratio (Swamy 1974). It is increases due to the increase in fiber count i.e. number of fibers in a unit volume of concrete matrix (ACI 544-1R). Aspect ratios are normally ranges 40-100.

The aspect ratio influences the workability of fresh concrete and long fibers become entangled into large clumps or balls during mixing, this phenomenon of fibers known as ‘balling of fibers’. To overcome the problem of balling operation mixing should be done properly and some super plasticizers added to the concrete mix to improve workability. Some fiber manufacturers supply steel fiber with coating of soluble glue. Steel scraps fibers provided here normally aspect ratio will vary from 50-70.

2.1.7 Fiber reinforcing index, RI

The fiber reinforcing index of fibers defined as the product of the aspect ratio to the fiber volume fraction (Gambhir).

$$\mathbf{RI = l/d \times V_F}$$

This fiber reinforcing indices (FRIs) was used in regression analysis to derive relations between different parameters (MSivaraja 2009).

$$\mathbf{F_f = A\,(FRI) + F}$$

Where, F_F= strength of fibrous concrete
F=strength of plain concrete (FRI = 0)
A= coefficient

3. MATERIALS

3.1 CEMENT: Ordinary Portland cement (OPC- 53 grade) was used and tested as per IS 12269-1987.The properties of cement are as follows:

Table 6
Properties of cement

S.NO.	PROPERTIES	VALUES
1.	Standard consistency (%)	33
2.	Initial setting time(min.)	30
3.	Final setting time (min.)	600
4.	Specific gravity	3.15
5.	Compressive strength at 28 days N/mm²	53
6.	Fineness (%)	2.25

3.2AGGREGATES

3.2.1 FINE AGGREGATE: IS 383-1970 has divided the fine aggregates into four zones depend on the particle size distribution, grading zones become gradually finer from grading zone I to grading zone IV(Gambhir).fine aggregate should be passed through 4.75 mm IS sieve and coarse aggregate permitted as per specifications. Fine sand used from zone I consider for the experiment. The properties of fine aggregates are given below in table 7.

Table 7
Properties of fine aggregate

S.NO.	PROPERTIES	VALUES
1.	Water absorption (%)	0.05
2.	Specific gravity	2.65
3.	Fineness modulus	2.46

3.2.2 COARSE AGGREGATE: Crushed gravel stones obtained from hard stone retain on 4.75 mm used as coarser material and properties were tested as per IS 383:1970 .Flaky particles should not be permitted more than 10% and practically it should be avoided .for bearing heavy traffic load, hard aggregates are preferred to resist abrasion and crushing effects and weather conditions. The properties of the coarse aggregate are given table 8.

Table 8
Properties of Coarse Aggregate

S.NO.	PROPERTIES	VALUES
1.	Water absorption (%)	1
2.	Specific gravity	2.70
3.	Fineness modulus	7.133
4.	Impact value (%)	7.5
5.	Abrasion value (%)	18.9
6.	Crushing value (%)	20

3.3.3 Water: Water is an important ingredient of concrete to form strength giving cement paste. Its pH value should be lies between 6 and 8. It actively participates in chemical reaction with cement; therefore for quality and quantity should be careful. It also free from organic matter, alkalis, oils, dust and other foreign materials, these impurities seriously affect the strength of concrete.

3.3.3 SCRAP STEEL FIBERS

As describe earlier, one of the steel fibers are obtained from machining process of lathe machines. These steel fibers are called steel scrap or elongated chips. They are available in form of waste product and used as steel fibers in concrete. Composite material of hydraulic cement, water fine and coarse aggregates and waste steel scrap (fibers) are defined as Scrap Steel Fiber Reinforced Concrete (SSFRC) (Shirule Pravin Ashok, Swami Suman, and Nilesh Chincholkar 2012). Gambhir 1986 also illustrated the significance of steel scrap in concrete. These industrial wastes effectively used as raw material in concrete to produce low cost FRC.

Along with production of low cost concrete SSFRC also give healthier recycling of industrial waste. After exploring the appropriateness of SSFRC boost its applications in wide field.

Table 9
Properties of Scrap Steel Fiber

S.NO.	Properties	Values
1.	Cross –section	Straight and deformed
2.	Diameter(mm)	0.3-0.75
3.	Length (mm)	25-40
4.	Density kg/m^3	7850
5.	Young modulus(N/mm²)	2 x 10^5
6.	Tensile strength (N/mm²)	500-3000
7.	Specific gravity	7.85
8.	Aspect ratio	45-100
9.	Elongation (%)	5-35

4. Experimental work

Experiments were conducted by adding lathe scrap steel fibers in M- 20 concrete varying in percentage from 0 to 2% by volume with 10 to 20 mm aggregates. The workability and strength of SFRC for pavements construction are studied by the workability, compressive strength test, split tensile test and flexural strength test.

4.1 Workability

Workability for conventional concrete defines in IS: 6461 (Part- VII)-1973, as its ability to be mixed, handled, transported, placed and finished (ACI 2R-R). The slump test was used to determine the workability of scarp SFRC. In ACI.3R-4R recommends the standard slump per ASTM C 143 should not be greater than 4 in. (25 mm to 100mm). The following slump was obtained from experiment for each fiber contents.

Table 10
Slump for SFRC

S.NO.	Steel fibers (%)	Slump (mm)
1.	0	80
2.	0.5	75
3.	1	70
4.	1.5	70
5.	2	70

4.2 Compressive Strength

The compressive strength test is significantly increases as compared to conventional concrete addition of fibers in lower strength of concrete. The numbers of specimens15 Cubes were casted size of 150 x 150 x 150 mm for different fiber contents from 0 to 2 % and 3cubes were used for each percentage.

Table 11
Compressive strength of SFRC

Steel fibers (%)	S.NO	Load at failure (KN)	Strength at 28 days (N/mm²)	Average strength at 28 days (N/mm²)
0%	1	520	23.67	24.41
	2	530	24.11	
	3	560	25.44	
0.5%	1	510	23.22	24.55
	2	540	24.55	
	3	570	25.89	
1%	1	530	24.41	24.95
	2	560	25.44	
	3	550	25	
1.5%	1	550	25	25.00
	2	570	25.89	
	3	530	24.11	
2%	1	540	24.55	23.92
	2	520	23.67	
	3	540	23.55	

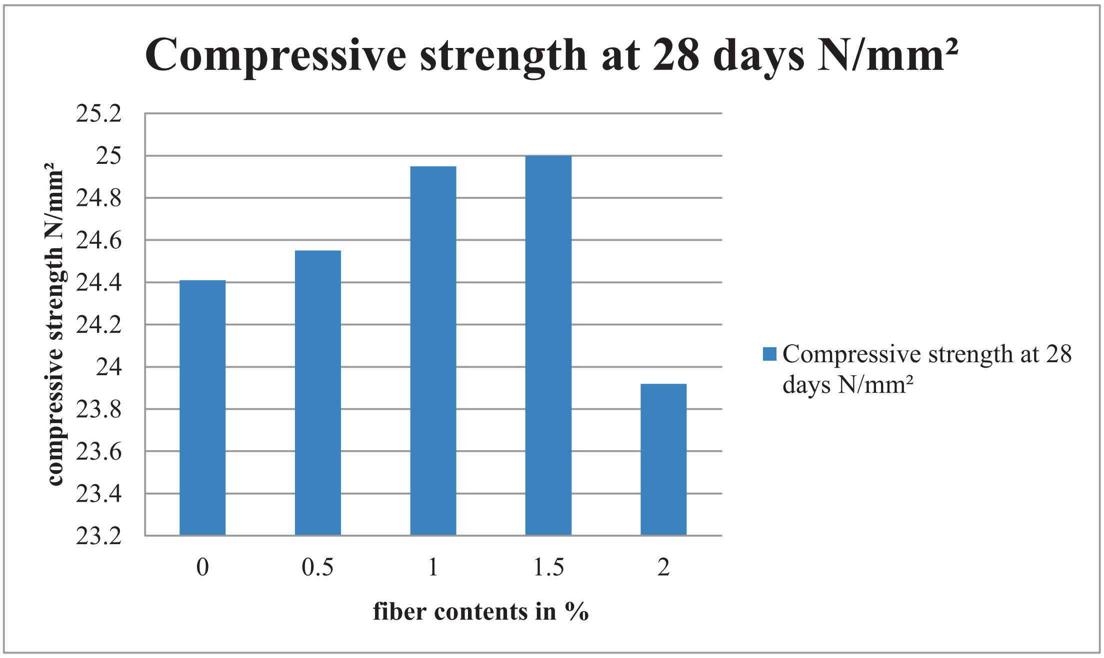

Figure.4.1.1 Compressive strength of SFRC after 28 days

4.3 Flexural strength test

ACI 544.2R-89 used third point loading for flexural testing, calculated at section of maximum bending moment in specimen where stress is in tension. For finding toughness, ASTM C 1018 may be used and 3 specimens were made for each fiber percentage as like compressive strength test. Size of flexural beam 700 x 150 x 150 mm was used in testing of flexural strength. Standard specimen dimension consider according to the fiber length and maximum size of aggregate i.e. depth and width are equal or three times of fiber length (ACI 544.2R-89). Following flexural strength of SFRC increases with increases in fiber contents of steel.

Table 12
Flexural strength of SFRC

Steel fibers (%)	S.NO	Load at failure (Kg)	Strength at 28 days (N/mm²)	Average strength at 28 days (N/mm²)
0%	1	2170	4.432	4.110
	2	2330	4.752	
	3	1530	3.148	
0.5%	1	1850	3.790	4.164
	2	2090	4.272	
	3	2170	4.432	
1%	1	2330	4.753	4.59
	2	2250	4.593	
	3	2170	4.432	
1.5%	1	2570	5.234	5.79

	2	2490	6.074	
	3	2490	6.074	
2%	1	2650	5.395	5.02
	2	2410	4.913	
	3	2330	4.753	

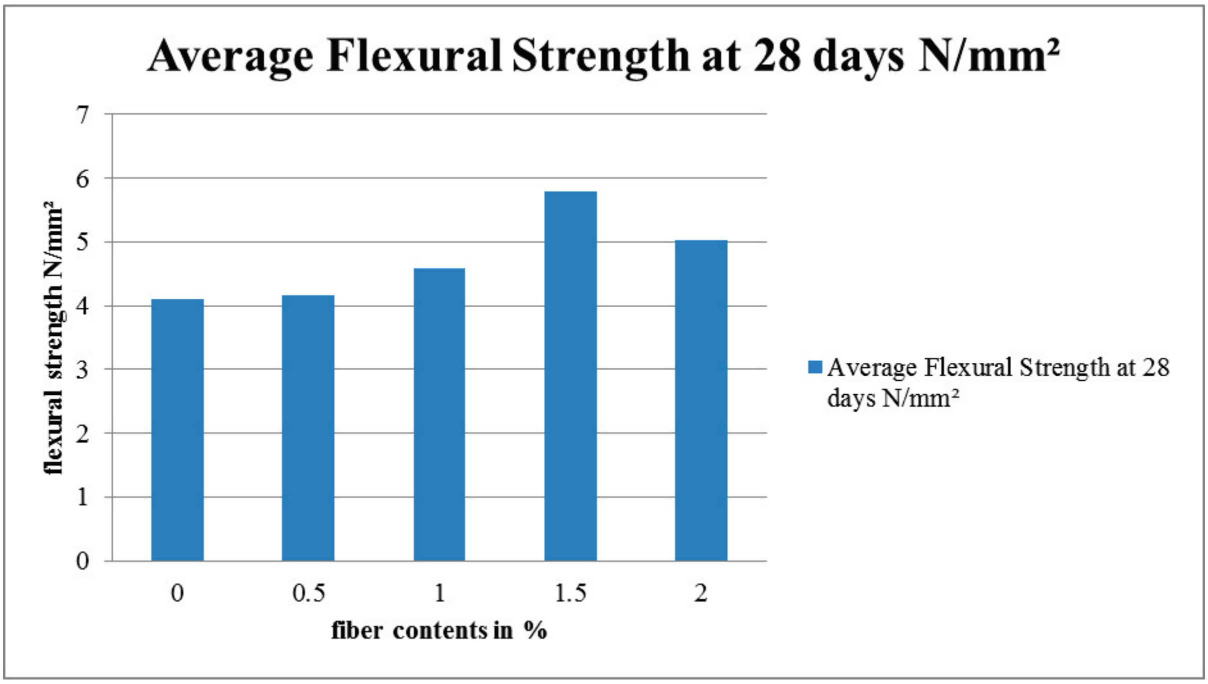

Figure.4.2.1 Flexural strength of SFRC after 28 days

4.4 Split Tensile strength test

When load applied on specimen, stress-strain curve for SFRC occurred in 3 stages (Gambhir);

a) First stage :Stage of bridging the cracked surface
b) Second stage: Multiple cracking stage where maximum post cracking stress is recognized.
c) Third stage: Pull out of fibers or critical failure.

15 cylinder specimens of size 150 mm dia. by 300 mm height were prepared for each fiber contents. Result from the tensile test, following tensile strength of SFRC after 28 days .ACI 544, 2R-89 consider splitting tensile test for fiber content concrete.

Table 13
Split tensile strength of SFRC

Steel fiber (%)	S.NO.	Load at failure KN	Strength at 28 days (N/mm²)	Average strength (N/mm²)
0%	1	270	3.64	3.4
	2	220	3.07	
	3	250	3.49	

0.5%	1	280	3.91	3.63
	2	240	3.35	
	3	260	3.64	
1%	1	300	4.20	3.91
	2	280	3.91	
	3	260	3.64	
1.5%	1	300	4.20	4.06
	2	310	4.34	
	3	260	3.64	
2%	1	280	3.91	3.82
	2	280	3.91	
	3	260	3.64	

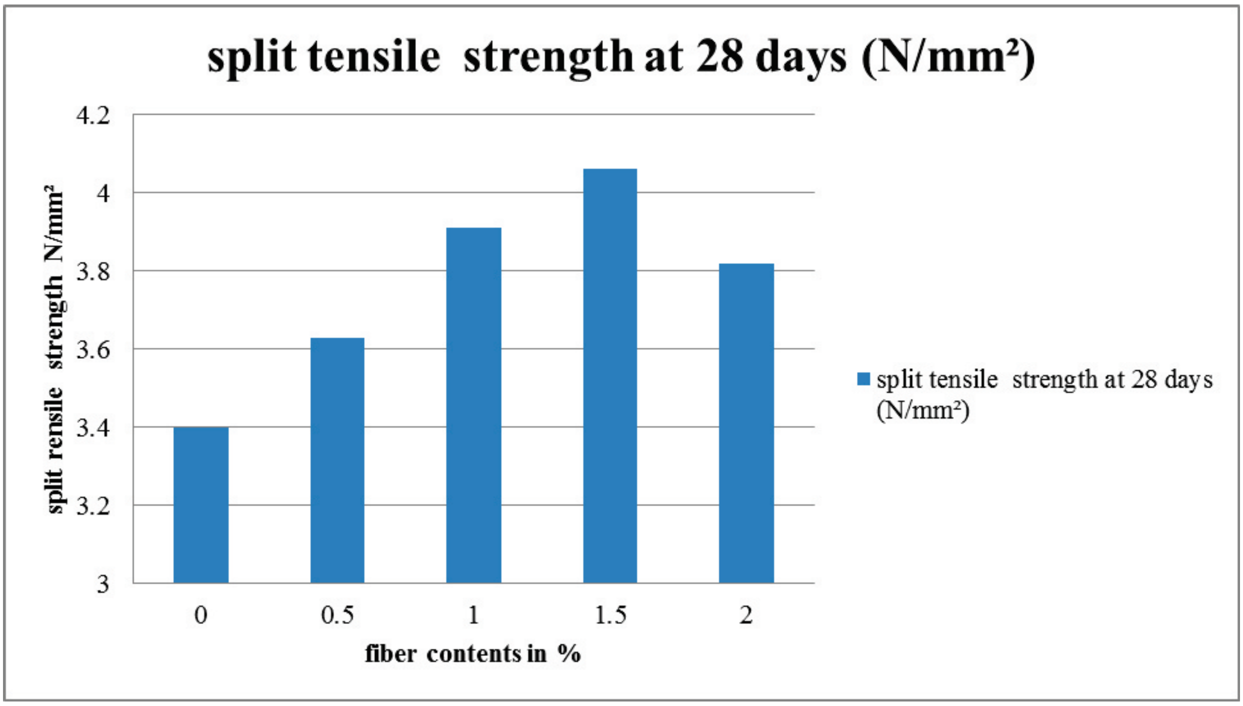

Figure.4.3.1 Split tensile strength of SFRC after 28 days

5. Result and Discussion

Total 15 Cubes. Cylinder and beams were tested containing fiber contents 0 to 2 % in M-20 concrete using mix proportion of 1:2:4, following results were acquired;

1. After 28 days Compressive strength of SFRC slightly increases 3% as compared to plain concrete.
2. Tensile strength OF scrap steel fiber concrete increases up to 20% considerable increases.
3. Flexural strength of SFRC effectively increases nearly 40 % after 28 days.

But all these mechanical properties increases up to 1.5 % fiber contents, on further increasing fiber contents tends to decrease in strength .ACI and JSCE also recommends use of fiber contents up to 2 % more than it needs further investigations. Due to increase in flexural strength of SFRC, fatigue behaviour of SFRC also analysis, stress ratio for flexural fatigue endurance is 0.65 to 0.90(IRC: SP-46-2013).

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