Influence of Steel Fiber on Mechanical Properties of Concrete

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Abstract: Concrete is a versatile material due to casting in any shape and provides good workability. Our infrastructure like rigid pavements of highways, bridges, harbors etc. develops rapidly. it requires improved mechanical properties of concrete. This research work is carried out to study the effects of steel fibre inclusion on mechanical properties of concrete. The present work deals with the compressive strength and water absorption studies on steel fibre reinforced concrete (SFRC) of grade M40 with steel fibre. The mix proportions for SFRC were arrived at by performing mix design. In SFRC the steel fibre total is 1%, 1.5%, 2% by volume of concrete has been taken. In this experiment two types of fibres has been used hooked end fibres and flat crimped fibres. All mixes were designed at single water cement ratio (w/c ratio) is 0.4. The results of compressive strength test and water absorption test has been compared and also equate with conventional concrete. Addition of fibres to concrete increased the 28 days Compressive strength and decreased water absorption.

***Index Terms* - Steel Fiber, Compressive Strength, Concrete, Hooked end, Flat Crimped, Water Absorption**

1. INTRODUCTION

Civil engineering means construction, maintenance, planning, and rehabilitation for humanity. It represents the redesign of our daily life in unique ways. It is one of the world's largest consumers of raw materials and resources. For several decades, concrete is a versatile material due to casting in any shape and provides good workability. The concept of using fibers in concrete to improve resistance to cracking and fragmentation is old and intuitive. During the last 3 decades different types of fibers were introduced and are being continuously introduced in the market as new applications. These fibers can be made of metals, natural, glass or organic materials. Some types of fibers can be added to concrete to improve its durability and physical properties such as cracking induced by plastic shrinkage, drying shrinkage and thermal gradient on the surface of fresh and mature concrete due to the environmental conditions. This research is intended to utilize steel fibres in concrete. It is now well established that one of the important properties of steel fibre reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particularly under flexural loading i.e. highway pavements. Steel fibres increase ductile properties of concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the Concrete and its ability to resist fatigue stress or cyclic loading.

2. Experimental Materials

The materials utilized during the present research are as follows

2.1. Steel Fibre

Steel fibers are produced by cutting or chopping the wire and thin flat sheet. A number of steel fiber types Indented round, Crimped round, Machined round, Hook-ended round, Flat sheet and crimped flat are available as reinforcement to concrete conforming IS: 280-1976 with an aspect ratio 30-250. Table 1 shows physical and properties of Steel fiber which procured from Anand, Gujarat.

Table 1 Physical properties of Steel fibre

Hooked End Steel Fibres		Flat Crimped Steel Fibres	
Physical Properties	**Values**	**Physical Properties**	**Values**
Average length (mm)	30	Average length (mm)	30
Diameter (mm)	0.6	Thickness (mm)	0.7
Aspect ratio (L/d)	50	Aspect ratio (L/d)	43
Density (g/cm^3)	7.8	Density (g/cm^3)	7.8
Tensile Strength (GPa)	1.1	Tensile Strength (GPa)	1.1
Young’s Modulus (GPa)	200	Young’s Modulus (GPa)	200

(Source: Acrysil solution, Anand)

2.2. Cement

The broadly and most generally utilized cement in all types of construction works is Ordinary Portland Cement (OPC). The OPC 53 Grade cement conforming to IS: 12269-2013 was utilized for all concrete mixes. Whereas the water is included in the Portland cement, chemical reactions happen between the cement and water and thus coming about within the energy release and the cement paste event which is mindful for making hardened substance. This process of response happens between cement and water is named as the hydration process and the help of the energy during this process is named as the heat of hydration. For the research work, the Ordinary Portland Cement of 53-grade use. Table 2 shows properties of cement which procured from local market, Anand, Gujarat. Figure 1 shows the hooked end steel fibres and flat crimped steel fibres used in experiments.

Table 2 Chemical and Physical Properties of Ordinary Portland cement

Sr. No.	Particular	Test Results	Requirement of IS 12269-2013
Chemical Properties			
1	Al_2O_3/Fe_2O_3	1.27	0.66
2	Insoluble residue	1.75	3.00
3	Magnesia(% by mass)	1.01	6.00
4	Total loss of Ignition (% by mass)	2.80	4.00
5	Total chloride (% by mass)	0.065	0.10
Physical Properties			
1	Fineness (m^2/kg)	320	225
2	Standard consistency (%)	28	30-35
3	Setting time (min.) a) Initial b) Final	 155 235	 30 600
4	Soundness a) Le chat expansion (mm) b) Autoclave expansion (%)	 0.7 0.062	 10.0 0.8
5	Compressive Strength (Mpa) a) 72+/-1hr. b) 168+/-2hr. c) 672+/-4hr.	 41.0 51.0 65.6	 27 37 53


Figure 1 Flat crimped Steel fibres and Hooked end steel fibres

2.3. Coarse aggregate 10mm (Grit)

As per IS 383:2016, an aggregate which is retained on IS 10mm sieve is called coarse aggregate. A material that has utilized in a drain, retaining wall, prevents differential setting, works as a low-cost binder in the road and giving base material in rail/road base. Concurring to expectations, size of 10mm has more strength as compared to 20mm aggregates. Just because of the measure of 10mm easier to fill little spaces and simple to compact. Table 3 shows properties of 10mm graded coarse aggregate (grit) which procured from local market, Anand, Gujarat.

Table 3 Physical properties of coarse aggregate (Grit)

Property	Values
Source	Sevaliya, Gujarat
Fineness modulus	6.08
Specific gravity	2.81

(Source: Concrete Technology Lab, BVM Engineering college, V.V.Nagar, Anand)

2.4. Coarse aggregate 20mm

As per IS 383:2016 an aggregate which is retain on IS 20mm sieve is called coarse aggregate. Coarse aggregates are responsible for providing 70-75% bulk within the constituents of concrete.it is the prime ingredient within the concrete. When it blended with cement and water it gets to be glued and therefore the entire strong matrix is bound during a strong mass which called concrete. Coarse aggregates are larger size filler materials in construction. As the name indicates, they are classified depending on the sizes of aggregate particles. The surface area of the coarse aggregate is less than fine aggregates. Coarse aggregates are utilized in concrete, railroad track ballast, etc. Coarse aggregate size 20 mm graded as per IS 383:2016 locally available is utilized for HSC. Table 4 shows properties of 20mm graded coarse aggregate which procured from local market, Anand, Gujarat.

Table 4 Physical properties of coarse aggregate

Property	Values
Source	Sevaliya, Gujarat
Fineness modulus	6.94
Specific gravity	2.81

(Source: Concrete Technology Lab, BVM Engineering college, V.V.Nagar, Anand)

2.5. Fine aggregate

As per IS 383:2016 an aggregate which is retain on IS 4.75mm sieve is called fine aggregate. Sand is shining yellow, off white, and rounded. The cost of Construction Sand is nil due to its normal availability but its transportation cost is more. Processing is easy by normal machines without using and Blast materials or any Crushing machines. Sand is free of any Organic Materials or any radiation or big blocks or concrete stones. Sand is utilized for backfilling, mortar, concrete and manufacturing masonry blocks. Table 5 shows the properties of fine aggregate which procured from the local market, Anand, Gujarat.

Table 5 Physical properties of fine aggregate

Property	Values
Source	Bodeli, Gujarat
Fineness modulus	3.16
Specific gravity	2.67

(Source: Concrete Technology Lab, BVM Engineering college, V.V.Nagar, Anand)

2.6. Water

Water is a universally adopted key ingredient liquid for all types of work.in this research potable water is utilized for casting and curing purposes respectively. When water is mixed with cement it forms a paste that binds all aggregate together. The role of water within the concrete is most critical because of the water-cement ratio. In this research w/c ratio is 0.4 taken out.

3. Design Mix

In this paper, the main objective of this study is to find out the strength characteristics of steel fibre reinforced concrete with varying percentages of fibres and hence to arrive at optimum percentage of steel fibres. In the experimentation 53 grade OPC was used in the experimentation. Coarse aggregates of 20mm and 10mm size having a specific gravity of 2.81 and locally available sand with a specific gravity of 2.67 and falling in Zone-II were used. Steel fibers of 30 mm length and 0.6 diameter with hooked end shape and flat crimped type which gave an aspect ratio of 50 were used. The mix design was carried out for M40 grade concrete as per IS: 10262-2009(4) which yielded a proportion of 1:1.64: 2.68 with a w/c ratio of 0.40. The steel fibres were added at the rate of 1.0%, 1.50%, and 2.0% by volume fraction. The required amount of water was added to this dry mix and intimately mixed. The Design mix nomenclature are shown in Table 6 and Design mix properties for 1m^3 concrete mix shown in Table 7.

Table 6 Shows Nomenclature for design mix properties

Meaning	Description
A0	Control Mix for M40 grade of concrete
H1.0	Concrete with inclusion of 1.0% Hooked end Steel Fibres
H1.5	Concrete with inclusion of 1.5% Hooked end Steel Fibres
H2.0	Concrete with inclusion of 2.0% Hooked end Steel Fibres
C1.0	Concrete with inclusion of 1.0% Flat Crimped Steel Fibres
C1.5	Concrete with inclusion of 1.5% Flat Crimped Steel Fibres
C2.0	Concrete with inclusion of 2.0% Flat Crimped Steel Fibres

Table 7 Design Mix Properties in 1 m^3 concrete (kg)

Concrete mixes	Design mix for concrete (Kg)						
	Cement	Fine Agg.	Coarse Agg.10 mm	Coarse Agg.20 mm	Water	Steel Fibres	Type of steel fibre
A0	479	661.00	462.31	693.47	191.6	0	-
H1.0	479	661.00	462.31	693.47	191.6	78	Hooked end
H1.5	479	661.00	462.31	693.47	191.6	117	Hooked end
H2.0	479	661.00	462.31	693.47	191.6	156	Hooked end
C1.0	479	661.00	462.31	693.47	191.6	78	Flat Crimped
C1.5	479	661.00	462.31	693.47	191.6	117	Flat Crimped
C2.0	479	661.00	462.31	693.47	191.6	156	Flat Crimped

4. Experimental Methodology

The test examination carried out on SFRC with inclusion of hooked end steel fibres and flat crimped steel fibres at different extents by volume of concrete. For all mixes, w/c ratio is 0.4. SFRC contains cement, fine aggregate, coarse aggregate 10mm and 20mm and steel fibres. Determination of compression test and Water absorption test both three cube tests were cast on mould size 150X150X150 mm for each concrete mix with inclusion of steel fibres for compression test and Water absorption test.

4.1 Compressive strength test [IS: 516 - 1959]

When a specimen of material is stacked in such a way that within the event that the material compresses and shortens it is said to be in compression. Compressive strength is frequently measured on a universal testing machine. Compressive strengths are usually reported concerning a particular specialized standard. Compressive strength is one of the foremost critical engineering properties of concrete. It is a standard mechanical practice that the concrete is classified based on grades. Fig. 2 shows the universal testing machine which is conducted compressive strength test at BVM Engineering College, V.V. Nagar, Gujarat. For the compression test, a specimen of the size of 150mm X 150mm X 150 mm was cast and tested in a compression testing machine concerning the test procedure given in IS: 516-1959. The equation for finding out compression test is given underneath,

Compressive Strength (N/mm^2) = P / Δ ……… (1)

Where, P =Failure load of specimen (N)

Δ = Area of specimen (mm^2)

Figure 2 Compressive strength testing machine

4.2 Water absorption test [IS: 2185 (Part I) – 1979]

Standard measure concrete blocks ought to be completely submerged in clean water at room temperature for 24 hours. All concrete blocks should be dried in a ventilated oven at 100 to 115°C for not less than 24 hours, and measuring the saturated weight. After that the tests were kept in oven by keeping up 100 ± 5° C for one day. Oven dry weight of the samples is recorded and the water absorption is assessed.

Water absorption = $(W_1-W_2) / W_2 \times 100$…… (2)

Where, W_1=Wet mass unit (kg)

W_2=Dry mass of unit in (kg)

5. Experimental Results and Discussion

5.1 Compressive strength test

Following table 8 gives the overall results of compressive strength of concrete with different percentage of steel fibres. Table 8 appears Compressive strength at 7, 28, and 56 days for different SFRC mixes. A0 represent 43.7 N/mm^2 at 56 days. H1.5 is made with 1.5% hooked end steel fibres shows 52.3 N/mm^2 at 56 days. C1.5 is made with 1.5% flat crimped steel fibres shows 51.26 N/mm^2 at 56 days. Also it gives the percentage increase or decrease of compressive strength w.r.t. reference mix. The variation of the compressive strength is depicted in the form of graph as shown in fig. 3.

Table 8 Average Compressive Strength at 7 days, 28 days and 56 days.

Concrete Mixes	7 Days		28 Days		56 days	
	Average compressive strength (MPa)	Percentage change of compressive strength w.r.t. ref. mix	Average compressive strength (MPa)	Percentage change of compressive strength w.r.t. ref. mix	Average compressive strength (MPa)	Percentage change of compressive strength w.r.t. ref. mix
A0	28.59	-	41.19	-	43.7	-
H1.0	30.67	(+) 7.3	44.15	(+) 7.2	46.37	(+) 6.1
H1.5	33.48	(+) 17.1	48.00	(+) 16.5	52.3	(+) 19.6
H2.0	31.56	(+) 10.4	45.33	(+) 10	48.89	(+) 11.8
C1.0	30.37	(+) 6.2	43.85	(+) 6.4	46.67	(+) 6.8
C1.5	33.04	(+) 15.6	47.70	(+) 15.8	51.26	(+) 17.2
C2.0	31.26	(+) 9.3	45.19	(+) 9.7	48.74	(+) 11.5

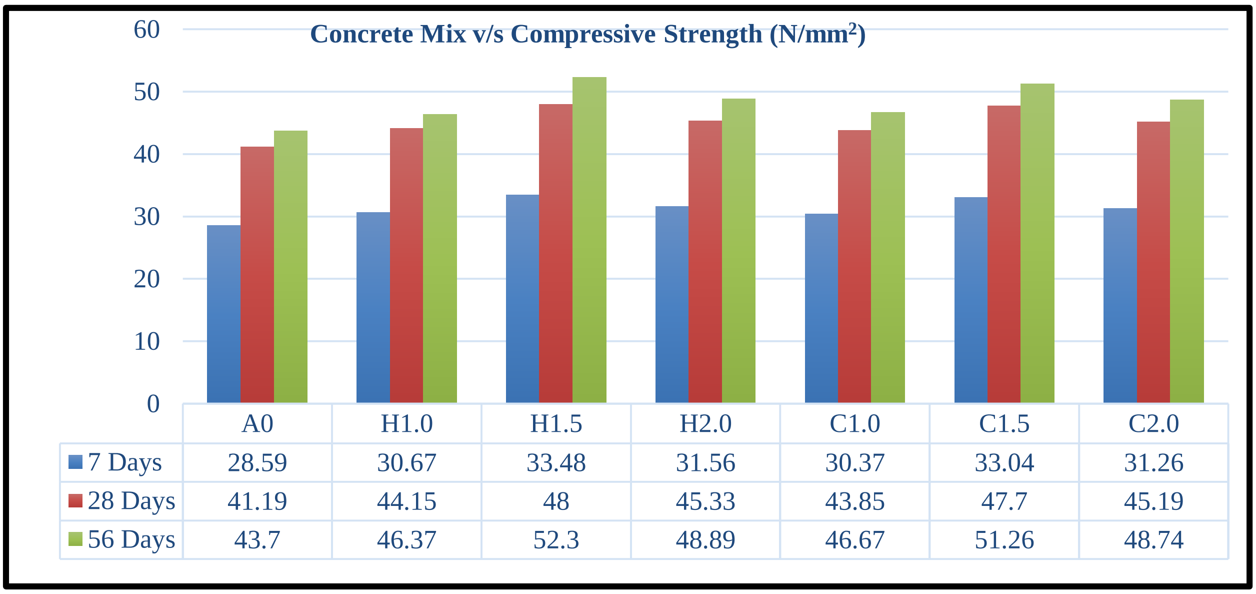

Figure 3 Compressive strength results for all Concrete mixes at 7 days, 28 days and 56 days.

5.2 Water absorption test results

Following table 9 appears the results of percentage water content submerged in cubes for the water absorption test done on concrete cubes at 28 days for M40 grade concrete control mix concrete and concrete with steel fibres in several proportions.

From Figure 4, it is observed that for SFRC mix percentage water absorbed was decreases with an increase in steel fibres in concrete. The most elevated water absorption ratio is observed at A0 which is 2.35% and the least water absorption ratio is observed at H1.5 which is 1.99%. Which states that increment of steel fibres content reduces the water absorption ratio without changing its property.

Table 9 Average Water Absorption rate after 28 days.

Concrete Mixes	Average Weight after 24 hr. saturation (W1) in kg	Average Oven dry Weight (W2) in kg	Average Water Absorption (%)	Percentage change of water absorption w.r.t. ref. mix
A0	8.71	8.51	2.35	-
H1.0	9.01	8.81	2.23	(-) 5.11
H1.5	9.21	9.03	1.99	(-) 15.32
H2.0	9.23	9.04	2.10	(-) 10.63
C1.0	8.98	8.78	2.32	(-) 1.27
C1.5	9.17	8.99	2.08	(-) 11.48
C2.0	9.23	9.03	2.18	(-) 7.23

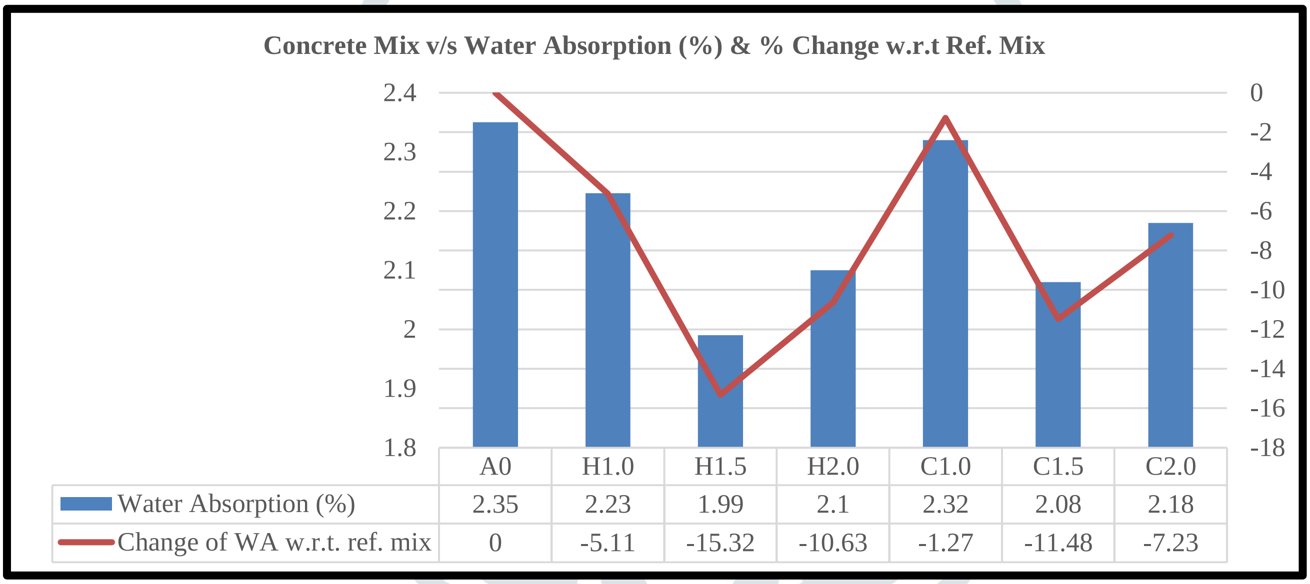

Figure 4 Concrete Mix v/s Water Absorption (%) & % Change with respect to Reference Mix

6. Cost Comparison

Following table 10 shows the cost as per current market rates for different concrete materials. Table 11 shows total Cost of Concrete Mixes for 1 m^3 with inclusion of steel fibres in Different Proportions.

Table 10 Material cost per kg

Materials	Rupees (₹) per kg
Cement	₹ 6.00
Fine Aggregate	₹ 0.45
Coarse Aggregate - 10mm	₹ 0.65
Coarse Aggregate - 20mm	₹ 0.65
Hooked end steel fiber	₹ 60.00
Flat crimped steel fibre	₹ 55.00

Table 11 Total Cost of Concrete Mixes for 1 m^3 with steel fibres in Different Proportions

Concrete Mixes	Cost of Material of Concrete/ m^3
A0	₹ 4,114
H1.0	₹ 8,794
H1.5	₹ 11,134
H2.0	₹ 13,474
C1.0	₹ 8,404
C1.5	₹ 10,549
C2.0	₹ 12,694

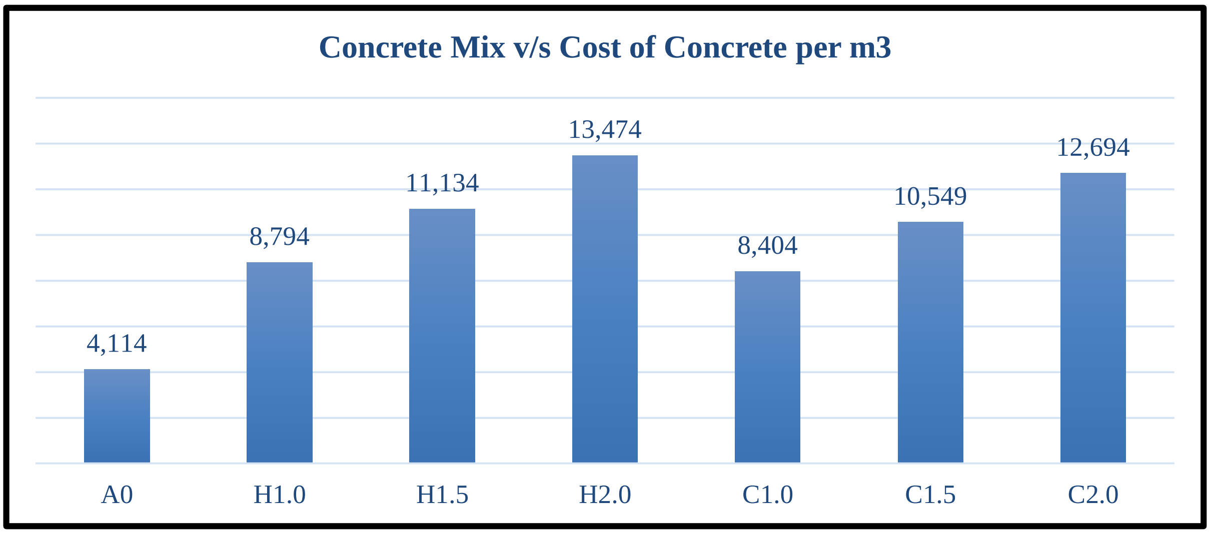

Figure 5 Total Cost of Concrete for 1 m^3 M40 Concrete Mixes

From above Figure 5, it is observed that concrete mix with Inclusion of steel fibres with different proportions have higher rates for 1 m^3 concrete compared to Conventional Mix Concrete A0. Rates of concrete increase with an increment in steel fibres proportion. This is drawback of SFRC because steel is expansive material.

7. Conclusion

The conclusions based on experimental work are as follows

1. The compressive strength increments with the inclusion of steel fibres. It is observed that the percentage of fibre is less, the strength to begin with increases, and with increasing the content of fibre at that point encompasses a downward trend implies the strength is decreasing.
2. The strength has been appearing the most extreme in concrete mix with 1.5% steel fibres by volume. Concrete mix with hooked end fibres is give better performance as compare to concrete mix with flat crimped fibres.
3. The inclusion of steel fibres increases the compressive strength of concrete up to certain proportion. The results indicate that the H1.5 concrete mixes exhibit the increment in compressive strength of 19.6% at 56 days.
4. The inclusion of steel fibres significantly influences the water absorption properties of concrete. Percentage change of water absorption with respect to reference mix A0 is 15.32% in the H1.5 concrete mix.
5. SFRC is expansive due to high price of steel fibres, but this drawback is overcome by advantages of SFRC like crack resistance and highly improved mechanical property of concrete.
6. Optimum fibre content in SFRC is 1.5% by volume of concrete in both type of fibres. Cost of optimum concrete mix is almost 170% higher than conventional concrete mix.
7. Steel fibres have no poisonous impact on air & water even water absorption without changing its property is observed which is satisfying special needs of special application for a specific site condition.
8. As a result of its characteristics, Hooked end steel fibres is better than flat crimped steel fibres.

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