Reinforced Concrete (SFRC)

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Abstract

Even though concrete has a high compressive strength, it performs poorly in tensile and flexural stresses, which raises the risk of cracking. These errors are resolved by steel fiber reinforced concrete (SFRC), which improves toughness, ductility, and crack resistance. This study looks into how steel fibers influence the mechanical qualities of concrete and highlights how crucial material testing is to achieving high performance. Cement, coarse aggregate, fine aggregate, steel fibers, and other materials used in SFRC were tested by Indian Standards (IS) and Indian Road Congress (IRC) codes. The findings showed that OPC 43 grade cement satisfied all requirements, that fine aggregates were within permissible bounds for concrete mix design, and that coarse aggregates showed appropriate specific gravity, sieve analysis, and crushing value. The study indicates the use of SFRC in construction for better structural performance durability and by highlighting the crucial role that precise material testing plays in achieving a homogeneous mix and improving the mechanical properties of SFRC.

Keywords

Steel fiber reinforced concrete, Flexural Strength, Crack resistance, Material testing, Durability

1. Introduction

The brittleness of concrete is well-known, and while this is advantageous for compression, it performs poorly in tensile and flexural strength tests. Additionally, it can lead to the formation of cracks, which can be prevented by adding steel fiber to the concrete, which increases the material's toughness and ductility. [1]. fibers possess a very high modulus of elasticity and tensile strength, since the Fiber reinforced concrete is more effective in flexural strength and tensile strength than compressive strength, it can considerably improve the capabilities of structural members [2][17][18][19]. Compressive strength, tensile strength, flexural strength, crack resistance, ductility, and toughness would all increase with the addition of steel fibers [1][3][15][17][18][19]. The number of crack control rebars is frequently huge since crack control rebars are commonly utilized for crack control, even though their effectiveness is not particularly high. For this reason, adding fibers is a better approach [3][20]. Concrete's mechanical properties are significantly influenced by the shape and proportion of steel fibers; corrugated and hooked-end steel fibers demonstrated more compressive strength than straight steel fibers, and adding steel fibers caused an enormous rise in flexural strength [4].

1.1 Applications of SFRC

Steel fiber reinforced concrete (SFRC) is used in various construction activities like tunnel linings, road pavement slabs, pre-constructed elements, concrete sewage tubes, waterproofing, containment and defensive structures, SFRC in slabs, Structural applications, crack reduction, etc [1][2][3][4][5][6][12][13][18]. Comparing the downward limbs of glass fiber and polypropylene fiber reinforced mixes, the limbs of steel fiber reinforced concrete are narrower. This indicates that steel fiber-reinforced mixes have higher flexural toughness and energy absorption capacity than other fiber-reinforced mixes after the peak load [2]. Fibers were first implemented in less essential concrete components to reinforce or prevent cracks. These days, they serve as the structural base, industrial floors, slabs on grade, and the primary structural reinforcement. These can also be utilized in cement-treated sub-bases or pavement sub-bases prone to shrinkage cracking [12]. Concrete flexural resistance and crack widening have both been revealed to be enhanced by steel fibers [8]. Particularly for rigid pavements, which need less reconstruction and maintenance than other pavements. The reduction of fatigue failure brought on by repetitive traffic loading is an important factor in pavements; yet, the integration of steel fibers has strengthened the concrete's strength to fatigue failure furthermore, SFRC maintains its outstanding ductility while greatly decreasing the possibility of cracks forming [7]. Compared to glass and polypropylene fiber, steel fiber has a higher better strength and modulus of elasticity, which takes into account its higher contribution to compressive strength. Likewise, steel fibers with hooks have a stronger bond with the binder matrix. Because of their great tensile strength and crack-arresting properties, fibers prevent concrete from tensile cracking too early [1][2]. In addition to the proportion of steel fibers to concrete weight, other variables that may impact how steel fibers behave in concrete include the kind of steel fibers utilized, their shape, surface roughness, and orientation [9][14]. Although fiber reinforcements are very expensive, their potential benefits cannot be ignored in performing the economic analysis, such as improved mechanical properties and the requirement of lesser design dimensions. Improvement in flexural strength due to fibers leads to smaller design thickness in the case of rigid pavements; therefore, a cost-to-benefit analysis of each mix should be performed considering the reduction in strength of the material costs carried about by improvements in per unit volume. Although fibre reinforcements are costly, their potential advantages—such as improved mechanical characteristics and a reduction for design dimensions cannot be ignored when conducting an economic analysis. In the case of rigid pavements, an increase in flexural strength due mainly to fibers results in a smaller design thickness; so, a cost-benefit analysis of each mix must be carried out, taking into account the savings in material prices brought about by the increases in strength per unit volume of material [2]. Steel fiber blended with Conventional RC elements becomes more ductile, improving their structural unity and dynamic stability [10]. Steel fibers are often used in surface course to avoid corrosion [11]. Fibers are placed close to each other and in disoriented form, so this affects the bridging of the cracks [12][16][17]. Significant increase in Compression strength can be obtained by adding steel fibers up to 1.5% [15]. Steel fiber's pull-out behaviour provides crack bridging due to its bond-slip relation [16]. SF addition can considerably increase flexural strength and delay crack formation, and then it provides for improving compressive and tensile strength [20].

1.2 Importance of tests performed on materials

Concrete fully attains its strength when the materials are used in appropriate amounts and within their permeable limits and ranges. In the case of SFRC, the concrete mix needs to be absolute. The concrete mix should be homogeneous in nature. Mix design is to be prepared to achieve the targeted and desired strength and properties in a fresh as well as hardened state. The design shall be aimed at enhancing the performance efficiency of the fibers in the concrete. For all these criteria to be fulfilled, all materials must possess physical characteristics within the range and limitations of specific IS code preferences. All the materials essential for mix design shall fall under the categorization of preferred IS codes and IRCs, and for that, the physical characteristics tests shall be performed carefully, and the readings and calculations should also be done precisely.

Physical characterization of materials within IS codes and IRCs

1.2.1 Cement

Slag cement (PSC-IS:455), PPC (IS:1489-1), and OPC (IS:8112, IS:12269, IS:8041) cements can be utilized. At 28 days, the cement's strength must be at least 43 MPa.

Properties to be checked for cement:

a) Fineness
b) Soundness
c) Initial ad final setting time

d) Specific gravity
e) Consistency
f) Compressive strength

All these properties shall be tested and verified using references from IS 4031 (parts 1-5)

1.2.2 Aggregate size

The maximum size of aggregate will vary depending on the pavement's thickness and the average distance between uniformly spaced concrete fibers. The nominal maximum aggregate size for the majority of applications could be 20 mm. IRC:15, however, states that the maximum aggregate size cannot be greater than 31.5 mm. Adopting an appropriate aggregate classification method is required. Greater aggregate size may cause problems for the fibers to disperse uniformly. Additionally, macrofibers up to 1.0 percent by volume of steel fibers can be used with it.

Properties to be checked for aggregate:

a) Specific gravity
b) Impact test
c) Sieve analysis

Additionally, appropriate IS codes and IRCs must be verified to affirm physical characteristics.

1.2.3 Steel fibers

The ultimate tensile strength of steel fibers ought to be at least 800 MPa. Fibers can be twisted, hooked, or straight. Steel fibers with a hooked end and lengths of between 50 and 60 mm may be used to increase performance. The following parameters plays a crucial role in enhancing the mechanical properties of the Concrete.

a) Tensile strength
b) Aspect ratio
c) Density
d) Length & width

The above characteristics shall be specified by the manufacturer and confirmed with the references of respective IS codes as well.

Even the slightest changes in the variation of physical properties of the materials result in a complete change in the concrete's mechanical properties, which can ultimately lead to troubles for the structure or element in the future. This can result in less durability, ductility, compressive strength, flexural strength, etc. So, it is very essential to conduct proper tests on materials using well-equipped apparatus.

2. Experimentation

The focus of this study is the physical characteristics of the materials required to prepare SFRC. Various fundamentals tests were conducted on the essential materials to check if it sees fit within the boundaries of IS code limitations. I.S. codes provide huge range of values for the materials according to the need of usage.

2.1 Cement

For the concrete mix, OPC 43 grade cement is used, which has been allowed by IRC: SP:46-2013. These tests were carried out concerning IS 269 (2015) restrictions. Every result that was discovered fell within its ranges. The proclamation that the cement satisfies every requirement can be simplified.

Table 1

Sr. no	Properties	Test Results	IS Code Specifications (IS: 269; 2015)
1	Fineness	248	Min. 225
2	Normal Consistency (%)	29.5	
3	Soundness (Le Chatelier's) (Autoclave)	1.00 0.11	Max. 10 Max. 0.8
4.	Compressive strength (mPa) (72 ± 1 Hrs) (168 ± 2 Hrs) (672 ± 4 Hrs)	28.5 37.5 50.5	Min. 23 Min. 33 Min. 43, Max. 58
5.	Setting time (minutes) a) Initial b) Final	165 215	Min. 30 Max. 600
6	Specific Gravity	3.15	≥1

2.2 Coarse Aggregate

Coarse aggregate constitutes the largest of the materials used to prepare any concrete mix. That's why it is essential to verify the test results of coarse aggregate with the specifications as per the IS Code. The following are the tests performed on the coarse aggregate.

a) Specific gravity

Table 2

Sr. no	Description	Sample 1	Sample 2	Sample 3
1	Empty jar weight W_1	610	610	610
2	Empty jar weight + dry aggregate weight W_2	1443	1446	1447.30
3	W_1 + Dry aggregate + water W_3	2151	2150	2151.5
4	Water + jar W_4	1616	1616	1616
	Specific Gravity	2.79	2.76	2.76

The average value of the specific gravity of all three samples = $\frac{2.79+2.76=2.76}{3} = 2.77$

The specific gravity found to be 2.77, whereas the IS code specification says that it should be within 1-3. It can be said the aggregate falls under the allowable range as per IS 2386 (part 3)-1963. This suggests the aggregate can be utilized to prepare the concrete mix.

b) Sieve analysis:

According to IRC: SP:46-2013 guidelines, when assessing a fiber dosage of less than 1%, the maximum aggregate size for a homogenous distribution of steel fibers should be 20 mm.

Table 3

IS sieve	Retained weight (gm)	Cumulative retained (gm)	% of cumulative retained	% of passing	IS limit
40	0	0	0	100	100
20	462	462	9.24	90.76	85-100
10	4312	4774	95.48	4.52	0-20
4.75	163	4973	98.74	1.26	0-5
pan	63	5000	100	0	0
	5009		3.03		

To the limits established by the IS:383 1970 code provided for sieve analysis, the aggregate size is accurate. The particle distribution of each size of aggregate fulfils the range. So, it is clear that the aggregate is fit to use for the concrete mix using steel fibers.

c) Crushing value test

Because the pavement is at the surface course, the aggregate needs to be able to withstand the compressive loads that are placed on it. The aggregate's resilience to crushing under compressive load is analysed by this test.

W_1, Total weight of dry sample taken in cylinder (gm)= 3157

W_2, Weight of portion passing through 20mm IS sieve (gm)= 387

$$\text{Aggregate crushing value} = \frac{W_2}{W_1} \times 100$$

$$\text{Therefore, } \frac{387}{3157} \times 100 = 12.26\%$$

Considering that the crushing value was found to be 12.26% and that the value of crushing aggregate should, according to IS 2386(part 4):1963, be less than 30%, the aggregate may be able to endure surface course compressive loading.

2.3 Fine aggregate

IRC: SP:46-2013 states that, depending on the size of the coarse aggregate, the fine aggregate content should range from 45 to 68% of the total aggregate. The overall percentage of fine aggregate varies between 50–68% and 45–60% for aggregate sizes of 10 and 20 mm.

a) specific gravity

After the test, the specific gravity value was found to be 2.7, although IS:2386 (part 3) 1963 suggests a value between 1-3. Therefore, this fine aggregate parameter satisfies the requirement needed to design the concrete mix.

Table 4

Sr. no	Description	Sample (gm)	Result	As per IS:2386 (part 3) 1963
1	Empty jar weight ($W_{1)}$	667	2.7	1-3
2	Empty jar weight + dry aggregate weight ($W_{2)}$	1168.5		
3	($W_{1)}$ + Dry aggregate + water ($W_{3)}$	1863		
4	Water + jar (W_4)	1546		

b) sieve analysis

Table 5

IS sieve	Retained weight (gm)	Cumulative retained (gm)	% of cum. Retained weight	% of passing	Percentage passing as per IS 383			
					Zone1	Zone2	Zone3	Zone4
10 mm	0	0	0		100	100	100	100
4.75 mm	7.1	7.1	0.71	99.29	90-100	90-100	90-100	95-100
2.60 mm	11.1	257.6	25.76	74.24	60-95	75-100	85-100	95-100
1.18 mm	246.5	629	62.9	37.1	30-70	55-90	75-100	90-100
600 mics	382.5	547.1	54.71	45.71	15-34	35-39	60-79	80-100
300 mics	164.6	316.5	31.65	68.35	5-20	8-30	12-40	15-50
150 mics	151.9	188.4	18.84	81.16	0-10	0-10	0-10	0-15
Pan	36.5	1000	100	0				
Total	1002		294.57					

Cumulative total percentage retained = 294.57%

The fineness modulus can be calculated as follows

F.M. = total cumulative percentage retained / 100

= 294.57/100 = 2.94

According to IS 383-1970, sand with a fineness modulus of 2.9 – 3.2 is considered coarser. It means a higher percentage of particles have a larger diameter.

2.4 Steel fiber

Fibers are distinguished into two types, i.e., micro and macro fibers. Fibers having a length of 12–40 mm and a diameter of less than 0.2 mm are said to be micro fibers. Whereas macro fiber's length varies from 30 to 60 mm and diameter is more than 0.2 mm. For enhancing performance, hooked-end steel fibers are on top priority. Fibers must have a tensile strength of over 800 mPa as per IRC 46 2013.

Table 6

length	diameter	Aspect ratio	Tensile strength	deformation	Appearance
50 mm	1.0 mm	50	1000 N/mm	Continuously deformed	Bright and clean wire

These are the physical characteristics of Hooked end steel fiber. Hooked-end steel fiber is mixed into the concrete mix in a disoriented form so that it uniformly distributes all over the mixture.

4. Result and conclusion

All of the material's physical properties were found through experimentation using a variety of methods, and they were also verified within the bounds of the relevant Indian standards.

4.1 Cement

a) It was noted that the cement's fineness was 248 m^2/kg.
b) Consistency was calculated to be 29.5.
c) Soundness was found to be 1.00 mm using Le Chatelier's method.
d) Compressive values for 3D, 7D, and 28D were to be 28.5, 37.5, and 50.5.
e) The initial and final times came to almost 165 and 215 minutes, respectively.
f) It was noticed that 3.15 is the specific gravity.

All these parameters were cross-checked regarding IS 269:2015.

4.2 Coarse aggregate

- An observed specific gravity of 2.77 was noted.
- The aggregate satisfies the requirements for passing by the guidelines, according to sieve analysis performed with IS sieves.
- The aggregate is appropriate for surface courses, as indicated by its crushing value of 12.26%.

The references IS:2386 (part 3): 1963, IS:383: 1970, and IS:2386 (part 4): 1963 were used to verify the values.

4.3 Fine aggregate

- The observed specific gravity was 2.7.
- The fineness modulus of the sand was found to be 2.94 following sieve analysis, indicating that it is coarser.

All of the values were confirmed by IS: 383: 1963 and IS: 2386 (part 4) 1963

4.4 Steel fiber

hooked end steel fiber with dimensions of 50 mm by 1.00 mm and tensile strength of 1000 mPa is advantageous for improving the mechanical characteristics of concrete constructions. According to IRC 46 (2013), macrofibers must have a tensile strength of at least 800 mPa and a length of 50–60 mm, and a diameter of more than 0.2 mm.

This study focuses on the significance of material testing while focusing on it. The primary objective is to accurately measure the materials in order to prepare a perfect and homogenous concrete mix. Moreover, a qualitative analysis of the materials was done. All of the materials required have undergone testing to ensure that they are suitable for use in pavement and steel fiber-reinforced concrete design mixes. in order to both achieve the required strength and enhance the mechanical qualities of the process.

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