Comparison Between the Effects of Straight And Hook Steel Fibers on Fresh and Hardened Characteristics of Concrete

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Abstract. This research looked into how steel fiber type and concentration influence Steel Fiber Reinforced Concrete (SFRC) mechanical properties. According to tests, the percentage of steel fibers in SFRC is directly related to compressive, flexural, splitting tensile, and direct tensile strength. Straight and hooked steel fibers with the same aspect ratio, 13 mm in length and 0.2 mm in width of straight steel fibers, and 35 mm long and 0.55 mm wide hook-end steel fibers were utilized. Three different percentages of fiber were used: 0.5, 1, and 1.5% by volume. Seven variants of concrete with different types and different percentages of steel fiber were created and evaluated. At 0.5, 1.0, and 1.5% fiber content, the compressive strength of a cube reinforced with hook steel fibers increased by 1.41, 11.52, and 20.81%, respectively, while the compressive strength of a cube reinforced with straight steel fibers increased by 7.27 and 20%, and 21.4% for the same percentages of steel hooked fiber. This indicates that the straight steel fibers are more effective than the hook steel fibers when increasing the compressive strength of the (SFRC). This means that (pressure force increases, albeit gradually). The concrete's splitting tensile strength may be significantly increased by introducing straight and hook steel fiber into the mixture. The tensile strength is improved by (52.78, 69.44, 122.22%) and (44.44, 62.8, 94.44%) when compared to the control concrete sample. Straight steel fibers increased flexural strength by (44.23, 61.54, 86.54%) compared to the control sample, and hook steel fibers increased flexural strength by (11.54, 28.85, 55.77%). When straight fibers are introduced to the control concrete sample, the direct tensile strength increases by about (54.17, 87.5, 162.5) %, and when hook fibers are added, the direct tensile strength increases by (45.83, 75, and 150%).

Keywords: Steel-fiber; Micro steel-fiber; Hooked; end steel-fiber; reinforced concrete.

1. INTRODUCTION

The ability of the concrete to withstand tensile stresses is weak, and it is known that low-level tensile forces can cause it to shatter readily. Adding fibers to the concrete mix is a commonway to change it. Fiber-reinforced concrete may have better mechanical properties if the fibers are mixed into the concrete (FRC) [1-8]. By altering the orientation and arrangement of the fibers withinthe concrete matrix, the Coarse Aggregate Maximum Size (CAMZ) modifies the FRC's mechanical properties. Despite the rise in fracture energy, the strength of tensile and modulus of elasticity for concrete samples dropped when the (CAMZ) rose from 3 to 14 mm [9]. The steel fiber specifications significantly impact the characteristics of FRC. When compared to concrete, FRC of a steel fiber length of 60 mm has greater flexural strength and fracture strength [10-11]. The usage of steel fibers to achieve desired outcomes is analyzed, and it is said that reinforcedsteel fibers are concrete by "DS EN 206-1.", according to another study [12]. This application improves the load-carrying capacity and energy dissipation potential, The deformation, residual rigidity, and cracking behavior of steel-fiber-reinforced concrete (SFRC) beams. Various study demonstrates that after cracking, SFRC beams considerably enhance.[13]. Fibers will be better in many ways, not just in terms of strength, structural accuracy, and condition after a crack [14]. Once cracks have formed, short, randomly placed fibers bridge over

The fibers are strong enough and attached to the material well enough that the matrix can handle large stresses over a large strain capacity after it has cracked [15]. RPC contains steel fibers but has no substantial aggregates. In essence, reinforced concrete is a more straightforward and cost-effective variant of concrete reinforced with steel fibers.Concrete's brittleness is changed with steel fibers, which help the material become ductile. By applying pinching strains at the crack points, fibers serve as a primary barrier to forming and propagating cracks [16]. A greater amount of fiber can further reduce the permeability of fracturedconcrete [17,18]. Steel fiber can be divided into five groups, depending on how it is produced andin what form: mill-cut, extracted melt, cut sheet, and cold-drawn wire. Around 90% of the fibers produced today are engineered (formed). The fiber morphology is adjusted (surface-textured, hooked,coned, spaded, crimped, and twisted) to improve the anchorage of fibers in concrete [19]. These particular steel fibers have irregular, rectangular, square, or circular cross-sections. The fibers are typically only applied in the batch factory after all the concrete aggregates have been blended. Fewpeople will request that the fiber be installed at the workplace, but QA/QC (quality assurance) may regulate the amount of fiber added. The maker of steel fibers will give instructions on how to mix and how much is needed to get the desired outcomes. This study's objective is to examine the influence of steel fiber parameters with the same aspect ratio (length, diameter, and shape) on FRC's workability, compressive, tensile, direct tensile, and flexural strengths. Consideration was given to the proposed fiber dosages of 0.0, 0.5, 1.0, and 1.5% by volume of concrete for each variety of fiber. In addition, this research examined and judged empirical relationships between the strengths of flexural, splitting tensile, and compressive for SFRC with varied fiber parameters [20]. Al-Baghdadi et al. [26] studied the relation between the size of coarse aggregate and fresh and hardened properties of concrete for synthetic and steel fibers and referred that the influence of fiber was more pronounced when the maximum size was increased. In recent years, the influence of different fiber types on the structural element (beams, slabs, and columns) was examined [8,20,27-29].

2. MATERIALS AND MIXING

2.1 Cement

In order to make the concrete, normal Portland cement (OPC) from a nearby facility was used. Tables 1 to 3 illustrate the cement's chemical composition and physical characteristics.

Table 1: Chemical analysis for cement.

Compound composition	Chemicalcomposition	Weight by percentage	According to (IQS N0.5/1984)
Lime	CaO	63.66	----
Silica	SiO_2	21.86	----
Alumina	Al_2O_3	3.96	----
Iron	Fe_2O_3	4.72	----
Magnesia	MgO	2.24	<5.00
Sulfate	SO_3	2.21	<2.50
Loss on ignition	L.0.I	1.20	<4.0
residue Insoluble	I.R	1.46	<1.5
Factor of Lime saturation	L.S.F	0.89	0.66 -1.02

Table 2: The main components of ordinary Portland cement.

Major compounds (Equations of Bogue.)	Weight by percentage of the cement
Tricalcium silica (C3S)	51.00
Dicalcium Silica (C2S)	23.28
Tricalcium lumina (C3A)	2.51
Tetra calcium aluminoferrite (C4AF)	14.36

Table 3: Physical attributes of cement.

Physical attributes		Value	According to Iraqi specifications (I.O.S.5/1984)
Time of setting (Vicats method)	Initial setting (hr:min)	4:24	≥00:45
	Final setting (hr:min)	5:32	≤10:00
Fineness (Blaine Method), m^2/Kg		314	≥250
Compressive strength, MPa	3 days	25.7	≥15:00
	7 days	29.68	≥23:00
Method of Soundness (Autoclave) %		0.15	≤0.8

2.2 Sand (Fine-aggregate)

Regular sand was used to mix concrete in this investigation. The sand was periodically cleansed andrinsed with water, then stretched out and allowed to dry in the air before use. Table 4 displays the outcomes of the estimations made. The accuracy ratings we obtained were in line with or better thanwhat Iraqi Specificati0n No. 45/1984 required. Table 5 defines many physical properties, including specific gravity, sulfate concentration, and sand absorption. This study was done inthe "civil engineering" lab at the University of Babylon.

Table 4: Classifying fine aggregate.

The size of sieve	Passing (%)	
	Fine aggregate	According to Iraqi specification No.45 /1984 for Zone
10 mm	100	100
4.75 mm	92	90-100
2.36 mm	81	75-100
1.18 mm	73	55-90
600 mm	55	35-59
300 mm	24	8–30
150 mm	7	100

Table 5. Physical attributes of fine aggregate.

Physical properties	Test results	Limits of Iraqi specification No.45/1984 for zone [2]
Specific gravity	2.67	-
Content of sulfate, SO_3	0.09%	≥0.5
Absorption	0.76%	-
Size of sieve	Passing %	
	Coarse aggregate	According to "Iraqi Specification No.45/1984"
14 mm	100	100

2.3 Gravel (Coarse Aggregate)

The largest size of crushed gravel (14 mm) was used in this investigation. The gravel was spread out, washed down multiple times, and dried in the air before being used. Table 6 summarizes the various coarse aggregate kinds. According to the findings, the coarse grades were up to snuff with IQS No. 45/1984 standards. Coarse aggregates' densities, sulfate loads, and water absorbency are listed in Table 7.

Table 6: Grading of coarse aggregate.

Size of sieve	Passing %	
	Coarse aggregate	According to" Iraqi Specification No.45/1984"
Passing %	100	100

Table 7: Physical attributes of coarse aggregate.

Physical attributes	Value	"Iraqi specificationNo.45/1984 for Zone" [2]
Specific gravity	2.66	-
Sulfate content, SO_3	0.6%	-
Absorption	0.043%	0.1%

2.4 Fibers

The SFRC used in this research is a hybrid of two different kinds of steel fiber. Figure 1 depicts microfiber (WSF0213) and hooked-end fiber (KF) (65/35) for easy comparison. This work recommended three different percentages for each kind of steel fiber. These are (0.5, 1, and 1.5%). Table 8 illustrates the physical features of steel fiber, while Table 9 displays the mixtures' proportions and composition.

Table 8: Physical characteristics of the steel fibers.

Product	Diameter (mm)	Length (mm)	Aspect ratio L/D	Yield strength (MPa)
Microfiber (WSF0213)	0.2	13	65	2500
Hooked fiber (KF 65/35)	0.55	35	64	900 ~ 2,200

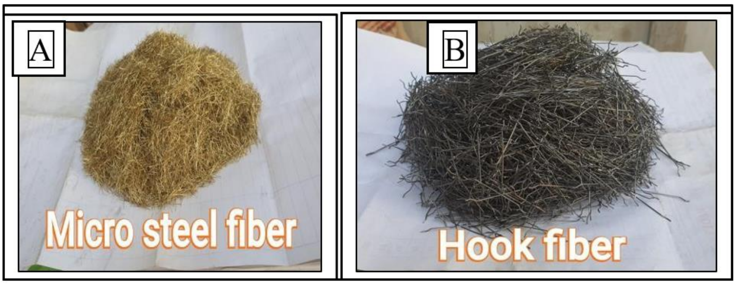

Figure 1: The shape of the steel fibers is straight and hooked.

Table 9: Mix proportions for all mixes.

Material	Quantity
Cement ($kg.m^{-3}$)	500
Fine agg. ($kg.m^{-3}$)	775
Coarse agg. ($kg.m^{-3}$)	825
Water ($kg.m^{-3}$)	190
Superplasticizer (1/100 kg cement)	5
Fiber amount (%) by volume	0.5
Fiber amount (%) by volume	1
Fiber amount (%) by volume	1.5

2.5 Mixing

The components were combined in a revolving apparatus. Sand, cement, and gravel are firstthoroughly blended. Water was then added as necessary after that. The fresh concrete gradually incorporates the fibers. A homogeneous mixture was created after initial mixing and collection,as shown in Figure 2. For every mix, the samples were split up into various groupings. Cylinders 10 cm in diameter and 20 cm long, prisms (10x10x40) cm, and direct examination samples have dimensions as shown in Figure 3. As shown in Figure 4, the test samples were degassed after one day and 28 days of treatment in the water tank, allowed to dry for one day, and then put through the tests. Testing methods such as cylinders are shown in Figure 5. Under uniaxial load, the device was used to evaluate the bending strength. By dividing the prism length into three equidistant regions to apply the flexural load, the flexural strength test was performed on prisms of (10x10x40) cm.

Figure 2: The process of mixing ingredients with a rotary mixer.

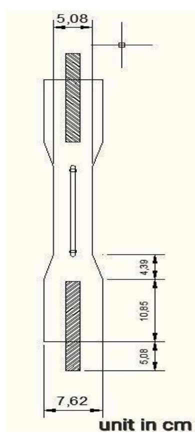

Figure 3: Dimension of the direct tensile test sample.

Figure 4: Sample molding for each examination model.

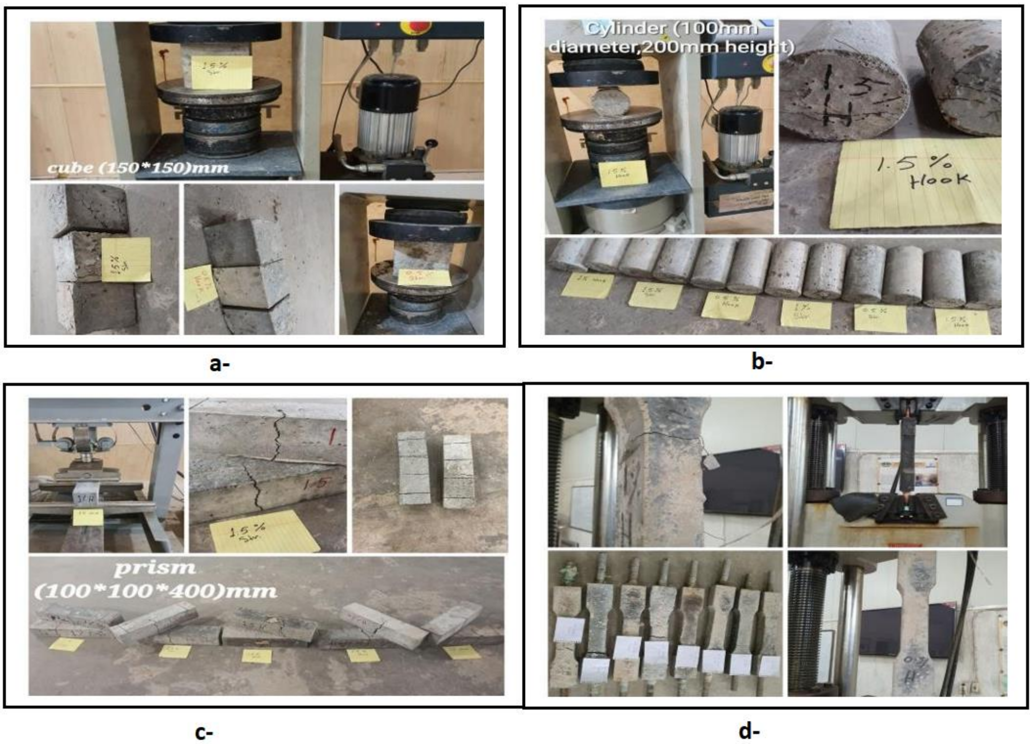

Figure 5: Samples test (a. Compressive test, b. Split test, c. Flexural test, and d. Direct test).

3. DISCUSSION OF THE RESULTS

3.1 Fresh Concrete Features

Slump flow testing is widely used for new SCCs nowadays. This analysis yields helpful data on the self-consolidation and uniformity of the concrete [21-23]. Slump flow testing was utilized to evaluate self-consolidating concrete due to smoothness. This strategy is extensively employed in labs and on construction sites to assess the cohesiveness of concrete. Concrete's workability and consistency can be gauged by averaging the diameters of two cones placed at right angles to oneanother after the material has flowed out of the slump cone. The self-consolidating concrete results are displayed in Table 10, confirming the predictions made by the literature [24,25]. Using both types of steel fibers (micro and hook) in varying percentages (0.5, 1.0, and 1.5%) raised the diameter while decreasing it by (6.04, 10.77, and 16.45%) and (4.85, 11.83, and 18.11%) respectively. Compared to the mixture without fiber, with a time of (5.8, 6.1, 6.8) sec and (5.7, 6.2, 7.2) sec, respectively). In addition, seven distinct concrete mixtures containing various amounts of steel fibers were created, as illustrated in Table 11.

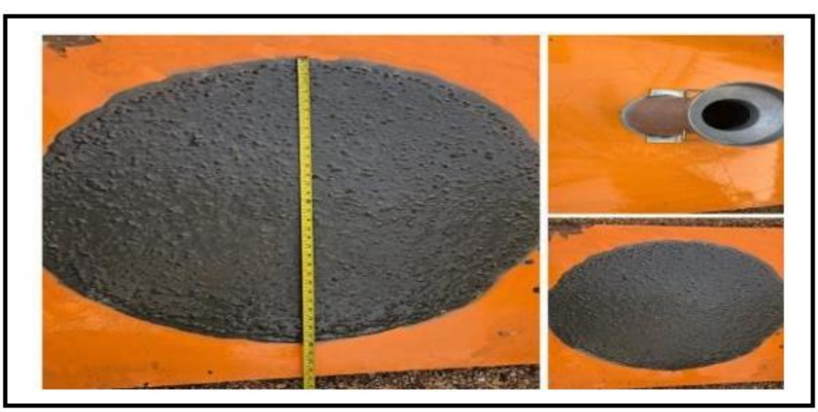

Figure 6: The slump flow test.

Table 10: Slump flow.

Index of Mix	Slump flow	
	D (mm)	T50 cm (sec)
Mix-R	845	5.6
Mix-M0.5%	794	5.8
Mix-M1.0%	754	6.1
Mix-M1.5%	706	6.8
Mix-H0.5%	804	5.7
Mix-H1.0%	745	6.2
Mix-H1.5%	692	7.2

Table 11: Mechanical features of fiber-reinforced concrete at 28 days for seven mixes.

Mix symbol	Vol. fraction of fibers V.f (%)	Compressive Strength (MPa)	Increasing w.r.t. Nc %	Tensile strength (MPa)	Increasing Percent w.r.t. Nc %	Direct Tensile strength	Increasing w.r.t. Nc %	Flexural Strength (MPa)	Increasing Percent w.r.t. Nc %
Nc	0	49.5	----	3.6	----	2.4	----	5.2	----
0.5m	0.5	50.2	1.41	5.5	52.78	3.7	54.17	7.5	44.23
1m	1	55.2	11.52	6.1	69.44	4.5	87.5	8.4	61.54
1.5m	1.5	59.8	20.81	8.0	122.22	6.3	162.5	9.7	86.54
0.5h	0.5	53.1	7.27	5.2	44.44	3.5	45.83	5.8	11.54
1h	1	59.4	20.00	5.9	62.88	4.2	75.00	6.7	28.85
1.5h	1.5	60.1	21.41	7.0	94.44	6.0	150.0	8.1	55.77

3.2 Hardened Concrete Testing

3.2.1 Influence of steel fiber on the strength of compression

Figure 7 illustrates the average compression strength of three cube specimens for all combinations with different fiber amounts (0.5, 1, and 1.5%) at 28 days. Increasing the percentage of fibers contributed to improving the compressive strength of concrete. At the same time, the cube's compressive strength increased gradually with hook steel fibers, as it increased by (1.41, 11.52, and 20.81%). It was found that the use of hook fibers produces better results in the development of the strength of compression for (SFRC) compared to the use of fine steel fibers, which were increased by (7.27, 20, and 21.41%), for the same percentages of fibers used for both types (0.5, 1, 1.5%) (this improves compressive strength but at a lower rate). Because it prevents cracks from spreading, the concrete's final compressive strength improved based on the steel fiber and mixture bond strength. Steel fibers could traverse the developing microcracks at the gravel-mortar interface, enhancing the strength of the concrete. The failure was gradual in the samples armed with fibers, while the failure was sudden in the samples of normal concrete.

3.2.2 Influence of fiber parameters on splitting strength

The impact of steel fiber type on SFRC split strengths of tensile is depicted in Figure 8. SFRC is less likely to crack than regular concrete because of its higher strength of tensile. Upon examination, the failure was gradual in the fiber-reinforced samples, while the failure was sudden in the normal concrete samples. SFRC is less likely to crack than regular concrete because of its higher strength of tensile. When compared to the control concrete sample, the strength of the tensile of microfiber-reinforced concrete. When employing two different kinds of fibers (straight and hook), the increases are around (52.78, 69.44, and 122.22%) and (44.44, 62.88, and 94.44%), respectively. The friction bond betweenthe fibers and the mixture is likely to blame for the fact that steel yield is typically pulled after removalrather than ripped under tensile pressure. Micro-steel fiber was also discovered to increase concrete's compressive strength. One possible explanation for microfiber's apparent advantage to hook steel fiberis that it has a higher tensile strength.

3.2.3 Influence of fibers on direct strength of tensile

The direct strength of the tensile test is representative of how concrete might perform in a real-world setting, such as a bridge. Indirect methods of testing may not always be able to accurately determine the tensile strength of concrete, though. Depending on the type of steel fibers used, the direct tensile strength of steel fiber-reinforced concrete (SFRC) can range from very low to very high (as shown inFigure 9). The tensile strength along a straight line was improved by incorporating steel fiber into normal concrete. Microfibers improve the direct tensile strength of a control concrete sample by 54.17, 87.5, and 162.5 percent, and hook fibers increase the strength by 45.83, 75, and 150 percent. Upon examination, the failure was sudden in the normal concrete samples, while the failure was gradual in the fiber-reinforced samples.

3.2.4 Fibers' Impact on Flexural Strength

The probability that the steel fibers will disperse through the concrete diminishes somewhat with increasing fiber length. This case may be because the overall quantity of steel fibers addedto the mixture decreases, and the randomness of the fiber distribution in that region of the sample increases when the length of the steel fibers increases. Flexural strength was improved by (44.23, 61.54, and 86.54%) for fine steel fibers and by a range of (11.54, 28.85, and 55.77%) for hook steel fiber in comparison to the control sample. Table 9 displays such an occurrence. Loading the fibers before thematrix fractures and the interfacial contact between the matrix and the fibers is lost can increase the flexural strength of concrete. Prism testing was performed using micro and hook-type steel fibers. The steel fibers were able to be driven out during the breaking of the prism without causing the concrete to fracture since steel has a much higher tensile strength than concrete, as evident in Figure 10. When steel fiber content in concrete is increased, the material tends to become more flexible and long-lasting. The impact of steel fiber type on bending strength in SFRC is seen in Fig. (11). When the test prism reinforced with steel fibers was subjected to a bending force. The prism did not completely separate into two pieces because the steel fiber had been pulled out without breaking. This may be due to the steel fiber's high tensile strength, inherently greater than the concrete's weak tensile strength, whose behavior differs from that of the prism without reinforcement.

3.2.5 Flowability

The change of direction of the steel fibers within the matrix of concrete depends on the mechanical properties of the FRC. When hook steel fibers were added to regular concrete, the flow ability of the resulting SFRC decreased by as much as 10.52, 28.07, and 34.21% compared to that of the control mixture. However, when micro-steel fibers were used, the resulting SFRC displayed improved permeability (a decrease in reduction value of 7.89 to 23.68% and 29.82%), as shown in Table 12.

Table 12: Slump values for concrete mixes.

Mix. Sample	Slump (mm)	Percentage Reduce W.r.t NC %
Nc	114.00	……
0.5m	105.00	7.89
1m	87.00	23.68
1.5m	80.00	29.82
0.5h	102.00	10.52
1 h	82.00	28.07
1.5h	75.00	34.21

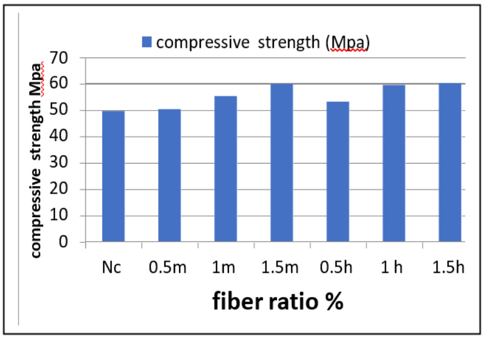

Figure 7: The strength of compression.

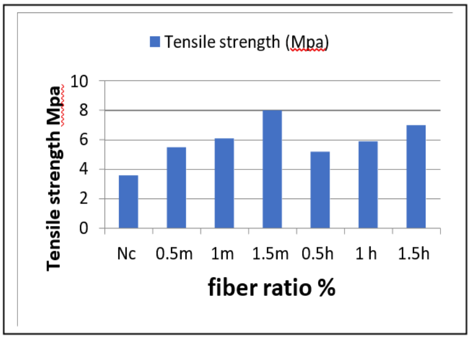

Figure 8: Splitting tensile strength.

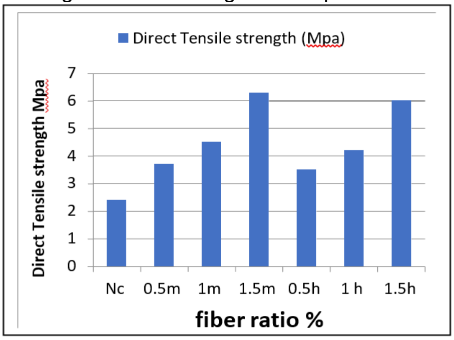

Figure 9: Direct tensile strength with different fiber amount.

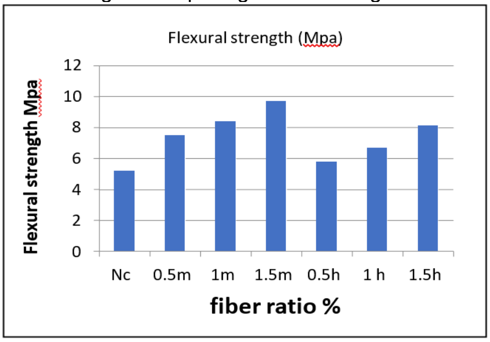

Figure 10: Flexural strength with varying fiber.

(a) Crack of a prism with micro steel fiber. (b) Crack of a prism with hook steel fiber.

Figure 11: Fiber pullout in concrete.

4. CONCLUSIONS

In this study, empirical studies were done to expound on the impact of steel fiber type and dosage on the properties of steel fiber-reinforced concrete (SFRC), including flowability, tensile strength, direct tensile strength, and compression strength. According to the exploratory work currently being done, Consequently, one might infer the following:

- A higher ratio of steel fibers in steel fiber-reinforced concrete (SFRC) makes the material less flexible. Slump is less influenced by adding straight-steel fibers to concrete than hook steel fiber.
- The fraction of straight- and hook-steel fibers in SFRC contributed positively to the material's compressive strength. An enormous boost in compressive strength resulted from the incorporation of straight-steel fiber. It found that straight-steel fibers increased SFRC's compressive strength more than hook steel fibers did, and the proportion increased with the amount of steel fibers.
- The strength of tensile of SFRC is greatly improved by the percentage of steel fiber utilized, whether hook steel fiber or straight steel fiber is employed. Yet, the impact of straight-steel fiber is far greater than hook-steel fiber. Perhaps the extraordinary strength of the tensile of the straight steel fiber is the result of the distribution of straight steel fiber being more regular than the hook steel fiber.
- When steel fibers are used, and for both types, there is a noticeable improvement in the bending strength of SFRC (small and hook types).

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