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EFFECT OF STEEL FIBER PROPORTION ON SIFCON MECHANICAL PROPERTIES

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Abstract: Slurry Infiltrated Fiber Concrete (SIFCON) is a relatively new high-performance material that may be thought of as a high-fiber content version of fiber reinforced concrete. This matrix is comprised of flowing mortar that must penetrate the fiber network implanted in the molds sufficiently. SIFCON combines excellent mechanical properties with a high ductility and toughness grade. SIFCON is utilized in applications that demand a high degree of ductility and energy absorption, most notably seismic-resistant reinforced concrete structures and structures exposed to abnormal or explosive loads. Additionally, pavement overlays, prestressed beam repair, and structural reinforced concrete element restoration have all been effective. The main aim of this study is to determine the effect of hooked-end steel fiber and micro-steel fiber on the strength of SIFCON specimens exposed to flexural and splitting loading. Three volume fractions of steel fiber (8,10, and12) % were used in this investigation. By weight of cement in SIFCON slurry, the proportion of Silica Fume SF substitution was 10%. Flexural strength was determined by testing specimens of (100×100×500) mm, and splitting tensile strength was determined at 7 and 28 days using cylindrical specimens with dimensions (150mm × 300m).. The results obtained from these tests were compared with SIFCON containing micro steel fiber. The test results show superior characteristics of SIFCON containing hooked-end steel fiber, as compared with micro steel fiber. For example, the flexural strength and splitting strength are 24.89 MPa and 10.14 MPa, respectively for SIFCON with 8% hooked-end steel fiber and 17.51 MPa and 9.1 MPa for control specimens with micro steel fiber.

Keywords: *SIFCON, hooked –end steel fiber, Micro steel fiber, Splitting strength, Flexural strength.*

1. Introduction

Modern civil engineering advancements require the creation of new engineered materials with enhanced strength, toughness, durability, and energy absorption capability. Fiber reinforced concrete is a widely used structural material under a wide variety of loading combinations. Additionally, it improves construction efficiency and may potentially remove the requirement for traditional reinforcement. With extremely high compressive strengths, high or ultrahigh strength concrete remains a fragile material. The addition of sufficient fibers increases tensile strength and adds ductility [1–5].

While the fiber volume fraction in conventional fiber reinforced concrete (CFRC) and high-performance fiber reinforced concrete (HPFRC) is typically between 1 and 3%, certain special composites have fiber volume fractions ranging from 3% to 20% [6,7]. SIFCON (slurry infiltrated fiber concrete) composites combine excellent ductility and tensile strength with a composite of high strength. The mechanical

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properties of SIFCON have been thoroughly explored. It can also improve flexural toughness [8,9].

Giridhar et al. [2] investigated SIFCON's mechanical properties taking various length and amounts of steel fibers. In such study, two kinds of steel fibers were utilized taking various levels of aspect ratios. The first type has length 50 mm and diameter 1 mm, while the second type of fiber has 35 mm length and 0.55 mm diameter. The volume fraction used in this research was 4%, 6% and 8%. The split tensile strength was carried out for 8% volume fraction of steel fiber of length 35 mm. The flexure strength was carried out for 4%, 6% and 8% volume fraction for 35 mm length. It also deduced during that research that the low fiber length SIFCON produces higher compressive strength if compared with higher levels of fiber length SIFCON.

In SIFCON instances, cement-rich flowable slurry is employed as a binder, and the slurry's high cement content leads in not only high production costs, but also excessive hydration heat and potential shrinkage problems [1]. Substituting additional cementitious materials for cement appears to be a possible solution to these issues [1]. Additionally, inclusion of these elements may improve the longevity of SIFCON products by altering the microstructure of concrete and decreasing its permeability, therefore lowering water and water-borne salt penetration into concrete [10]. As a consequence, many researches has been conducted on the mechanical properties of SIFCON produced using fly ash as a cement replacement, but very little information is available on the properties of SIFCON produced using silica fume as a cement substitute.

Roa et al. [11] examined the effect of steel fiber volume percentage on the strength and stiffness properties of flexural-loaded slurry infiltrated fibrous concrete (SIFCON) slabs. (FRC) and normal concrete (PCC) slabs are used as reference slabs to investigate the results. The test findings suggest that SIFCON slabs have a higher strength, higher energy absorption, and more ductility than control specimens. SIFCON slabs with a greater fiber volume percentage (12%) perform better than other slab specimens. SIFCON using silica fume (SF) as a cement substitute has shown to have poor flexural behavior. Despite the fact that it is not cost effective in Iraq because cement is considerably cheaper, the results of SIFCON mixes including 10% SF by weight of cement into evaluate their effects on the strength of SIFCON under flexural loading. The impact of steel fiber volume fractions ranging from (8, 10, 12) % was also investigated.

2. Experimental Work

2.1. Materials

2.1.1. Cement

In this research, conventional Portland cement was utilized. It was made at Karbala,in Iraq, by the Lafarge firm and was marketed as (Tasluja). It was sourced from local markets. It was stored dry to prevent exposure to a variety of meteorological conditions. Chemical analysis and physical testing findings indicate that the utilized cement meets Iraq's requirements No.5-1984[12].

2.1.2. Fine aggregate

The size of the sand used in SIFCON slurry is critical. Ideally, it should have a small enough diameter to enable complete penetration without clogging the thick steel fiber. SIFCON mortars were prepared using fine sand that had been sieved using a 1.18 mm sieve to remove coarser particles. During the testing work, using this size of sand proved to be successful for all SIFCON combinations. It complies with Iraq standard 45/1984 Zone (2) [13].

2.1.3. Mixing water

All of the mixes and the specimen curing were carried out with tap water. The temperature fluctuates between 25 and 30 degrees Celsius.

2.1.4. Silica fume (SF)

Silica fume is an ultrafine substance composed of spherical particles with a diameter of less than 1 µm, on average approximately 0.15 µm. This reduces it to roughly 100 times the size of a typical cement particle. Silica fume's bulk density varies according to the degree of densification in the silo, ranging from 130 kg/m3 (un-densified) to 600 kg/m^3. Silica fume has a specific gravity of 2.2 to 2.3. Using silica fume in concrete has resulted in the creation of concrete that has enhanced compressive strength and also very high durability (ACI 234R-06, 2006). Blaine fineness is usually ranges from 15,000 to 30,000 m^2/kg and has been utilized as a partial cement substitute (10% by weight) and this is in accordance with the standards of (ASTM C1240-15).

2.1.5. Superplasticizer

This admixture was provided by the Sika Turkish company and known commercially as “Viscocrete-PC5930”. Such material is very useful in enhancing the resulted concrete performance and durability and meets the **ASTM C494-99** type GF. Such admixture improves the cement dispersion to a serious concern

2.1.6 Steel fiber

2.1.6.1 Hooked end steel fiber

The fiber of steel utilized in this research is 0.7mm in diameter and 35mm in length, with an aspect ratio of 50 and 7,800kg/m^3 in density. The strength of the tensile is 1100 MPa. Figure (1) show hooked end steel fiber.

Figure 1. Hooked -end steel fiber used in the present study.

2.1.6.2 Micro straight steel fiber

Properties of this fiber type include 0.5mm in diameter and 13mm in length, with an aspect ratio of 65 and 7825 kg/m^3 density. The strength of the tensile is 2400 MPa. Figure (2) show micro steel fiber.

Figure 2. Micro steel fiber used in the present study.

2.2. Mix Properties

A single slurry mix was utilized in this research to produce a SIFCON mix to satisfy the filling ability and in order to avoid segregation or leakage through the large fiber bed, flow and viscosity requirements must be met.

A minimum and maximum value were then utilized to calculate the fiber content of the mortar that was produced as a result of this procedure.

In their investigations, they used a mixing ratio of 1:1 (cement to sand) [10,14,15].

The weight ratio of w/b is 0.3, and silica fume is 10% of the cement weight to increase the mechanical characteristics of SIFCON. A super plasticizer equivalent to 1.5 percent of the cement's weight was employed. The proportions of the SIFCON mixes are detailed in Table (1).

Table 1. proposed mix proportions

W/b* ratio	cement kg/m^3	sand kg/m^3	SF 10% wt. of cement kg	water L/m^3	Super plasticizer 1.5% wt. of cement kg
0.3	855.9	951	95.1	299.5	12.83

* b = binder = (cement + silica fume)

Three percentages of hooked-end steel fiber were used, which are (8,10, and 12) %, where the minimum is 8% that can fill the mold with relatively little vibration time compared to the maximum of 12% where vibration is needed. Longer time is required to get full penetration into the fiber network. Whereas 10% was an intermediate value. The same applies to the control specimens (Micro straight steel fiber), which also contains three ratios (8,10, and 12) %.

2.3. Test of fresh properties of SIFCON

SIFCON assessment is crucial to SIFCON production in its fresh condition. The mortar must be high viscosity mortar enough to flow through the thick steel fiber matrix. EFNARC [16] reports that micro slump flow and V-funnel tests were conducted to evaluate slurry flowability, ability to fill and viscosity. The Mini slump flow test determines the flowability, segregation and homogeneity of the slurry. The testing mold is of 70 mm top diameter, height of 60 mm and 100 mm base diameter. SIFCON mortar requires a scatter diameter (240-260) mm. The other test for determining the slurry's viscosity was the V-funnel test, which takes about 7-11 seconds of flow duration [16]. The fresh characteristics of the SIFCON mixes are summarized in Table (2).

Table 2. Fresh properties of SIFCON mortar

V- Funnel Testing in Seconds	Mini Slump Flow in mm	Super plasticizer % wt. of cement kg
9.67	257	1.5%

2.4. Preparation of SIFCON Specimens for Casting and Curing

To begin the process of manufacturing SIFCON specimens, fibers were pre-placed in the molds, followed by the filling of cement mortar that must be workable enough to penetrate the thick matrix of the fiber-filled mold. The two- layer technique was used for incorporating the steel fiber in to the SIFCON matrix which found to be simpler and easier technique in actual practice than the single technique specially when using high volume fraction of steel fiber. This technique included inserting the fibers halfway into the mold, followed by partly filling the mold with mortar (half depth).

After that, the mold was vibrated to avoid honeycomb formation. This procedure was repeated for the second layer, during which the entire mold was filled to the required volume fraction, while a table vibrator vibration for (6-10) seconds was required for (8 percent), and (15-20) seconds for (10 percent), and (20-30) seconds for (12 percent), to ensure complete penetration of SIFCON mortar into the fiber pack.

The quantity of steel fiber to be placed in each mold is determined by the size of the mold, the required volume fraction, and the density of the steel fiber. Following casting, the specimens were stored in the laboratory for 24 hours before being demolded, labeled, and immersed in a tap water tank for 7 and 28 days, respectively, to cure.

2.5. Test of Hardened Properties of SIFCON Specimens

2.5.1. Splitting Tensile Test

The split tensile test was conducted in accordance with (ASTM C469/C469M, 2017) utilizing a digital testing equipment with a capacity of 2000 kN and a loading rate of 0.5 MPa/sec. A total of 12-cylinder specimens were cast using steel fiber (Hooked-end, micro straight). The test was performed at the ages of seven and twenty-eight days after cure. The specimen measured 150mm in diameter and 300mm in length. The specimen was loaded continually at a constant pace until it reached its maximal load. Figure (3) show splitting tensile testing.

Figure 3. Splitting Tensile Testing.

2.5.2. Flexural Strength Test

Flexural testing was performed in accordance with (ASTM –C1609) [17]. The size of the beam was considered to be (100 × 100 × 500) mm. The overall number of tested specimens were 12 beams. The flexural strength test is used to determine the maximum tensile load that the specimen can withstand without cracking. This is an indirect method of determining the tensile strength at failure or rupture modulus. Two-point loading was used to load the beam specimen. The specimen must be meticulously aligned with the loading device's axis. The load was raised continually until the specimen failed, and the specimen's maximum load at failure was recorded. Figure (4) show the modulus of flexural testing.

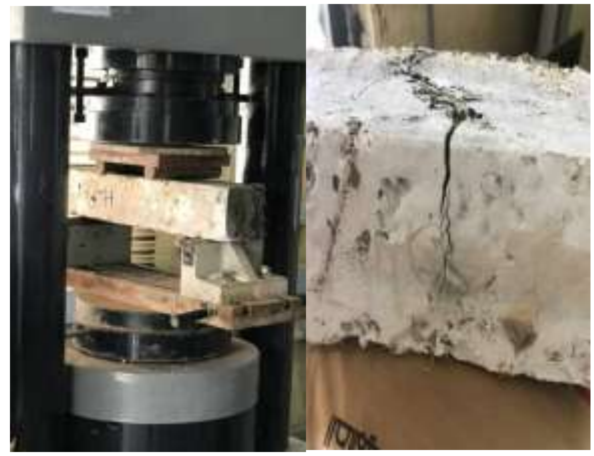

Figure 4. Flexural strength testing

4. Results and Discussion

4.1. The splitting tensile strength

Table (3) and Figures (5) to (7) show the effect of steel fibers type / amount that were taken in this study to the consequent splitting tensile strength in 7 and 28 days. The 8% steel fibers of SIFCON increased the consequent splitting tensile strength by 11.428% and 23.3% for 7 and 28 days respectively.

The 10% steel fibers of SIFCON increased the consequent splitting tensile strength by 27.09% and 25.65% for 7 days and 28 days respectively.

The 12% steel fibers of SIFCON increased the consequent splitting tensile strength by 39.63% and 39.81% for 7 and 28 days respectively.

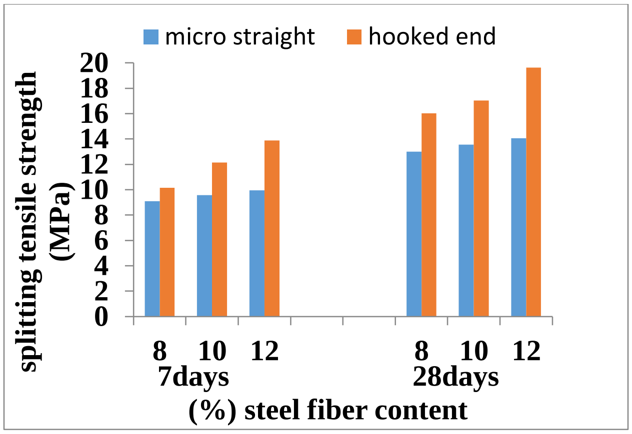

Figure 5. Splitting tensile strength levels at 7 days and 28 days

Table 3. Splitting tensile strength results

Type	Steel Fiber Amount %	Splitting tensile Strength in MPa
	7 days	
Straight*	8%	9.1
End Hooked		10.14
Straight*	10%	9.56
End Hooked		12.15
Straight*	12%	9.94
End Hooked		13.88
	28 days	
Straight*	8%	13
End Hooked		16.03
Straight*	10%	13.55
End Hooked		17.04
Straight*	12%	14.05
End Hooked		19.63

* Control specimens

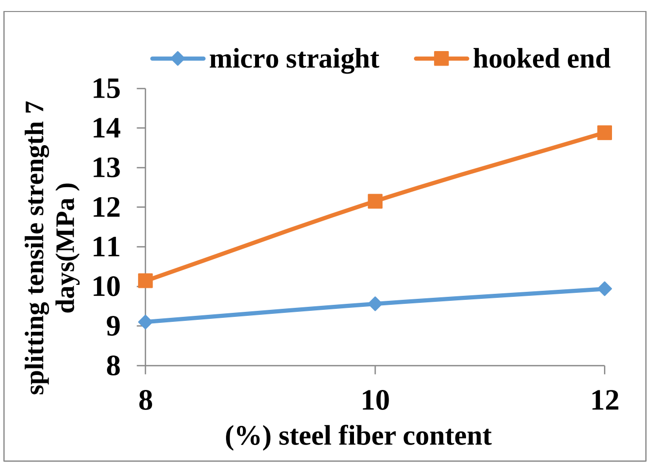

Figure 6. Splitting tensile strength at 7 days

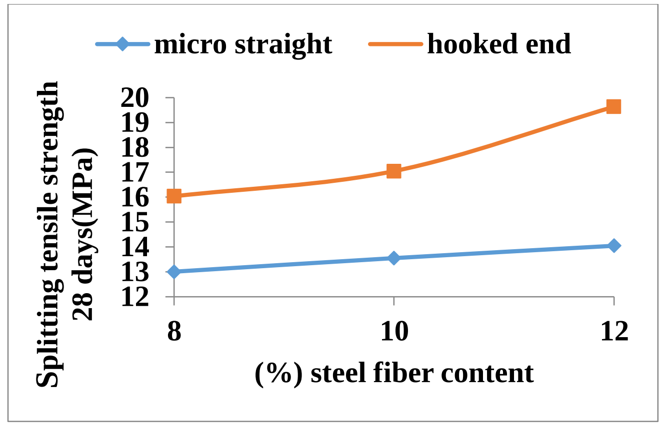

Figure 7. Splitting tensile strength at 28 days

The purpose behind the increase of splitting tensile strength in the SIFCON specimen with respect to normal concrete is the linking between the two sides of the failure surface of each specimen which adds additional mechanical tension strength.

4.2. Flexural Strength Results

Table (4) as well as Figures (8) to (10) illustrate the impact of steel fiber type and quantity on the relevant modulus of rapture after 7 and 28 days. The 8% steel fibers of SIFCON increased the consequent modulus of rapture by 42.66% and 28.75% for 7 days and 28 days respectively.

The 10% steel fibers of SIFCON increased the consequent modulus of rapture by 56.74% and 46.67% for 7 days and 28 days respectively.

The 12% steel fibers of SIFCON increased the consequent modulus of rapture by 41.65% and 32.16% for 7 days and 28 days respectively.

Table 4. Flexural strength results

Type	Steel Fiber Amount %	Flexural tensile Strength in MPa
	7 days	
Straight*	8%	17.51
End Hooked		24.89
Straight*	10%	19.35
End Hooked		30.33
Straight*	12%	25.35
End Hooked		35.91

	28 days	
Straight*	8%	23.65
End Hooked		30.45
Straight*	10%	24.64
End Hooked		36.15
Straight*	12%	31.43
End Hooked		41.54

* Control specimens

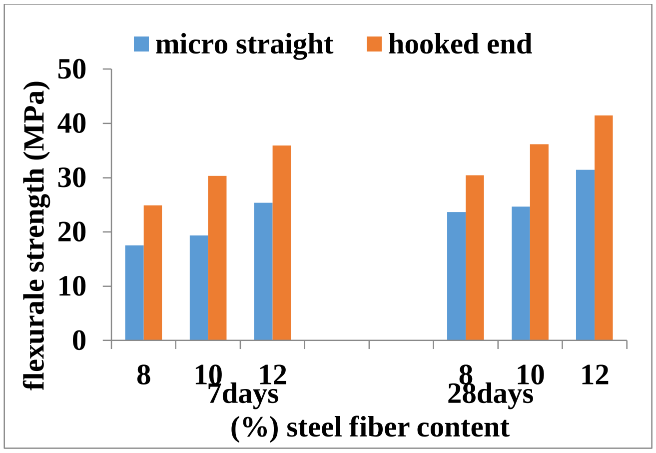

Figure 8. Flexural strength levels at 7 days and 28 days

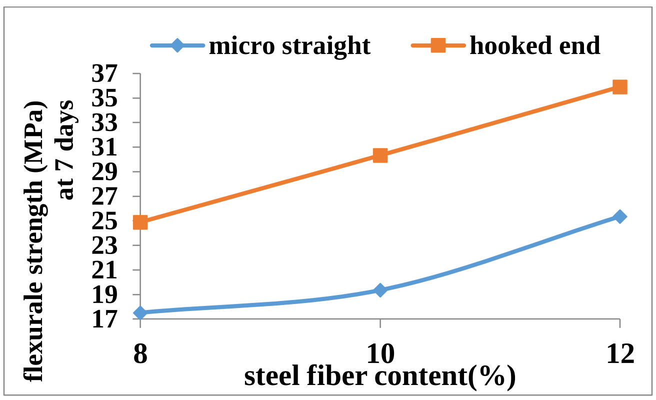

Figure 9. Flexural strength at 7 days

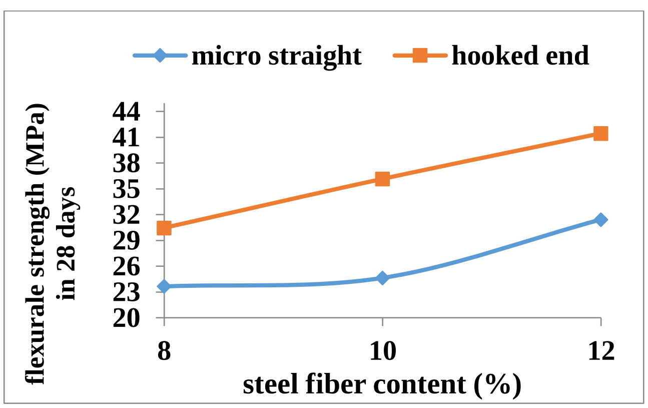

Figure 10. The Flexural strength at 7 days

From the results of the two examinations (splitting strength and flexural strength) , we notice an increase in the hooked-end steel fiber values over the micro straight steel fiber. The reason for the increase in the results is due to the shape of the ends of the hook, where the weak points are almost non-existent in addition to the strength of bonding inside the concrete in this type is higher than micro straight steel fiber.

5. Conclusions:

- Using "End Hooked" steel fibers in producing SIFCON enhanced the mechanical properties seriously.
- The "End Hocked" steel fibers showed good excellency (against "straight") concerning mechanical potential and its inherent good bridging role and high level of strength.
- When hooked -end steel fiber is used in place of micro straight steel fiber in the same volume fraction whether (8% or 10% or 12), the flexural strength and splitting tensile strength values rise by a (20 to 45) %.
- Because of the presence of weak points at the ends of micro steel fiber results in less strength to loads.
- Because of the curved ends of hooked-end steel fiber the correlation between the two sides of the failure of the samples increases.

Conflict of Interest

The authors confirm that the publication of this article causes no conflict of interest.

Acronyms and Symbols List

Description	Acronym
SF	silica fume
HPFRC	High Performance Fiber Reinforced Concrete
EFNARC	European Federation Dedicated to Specialist Construction

	Chemicals and Concrete Systems.
PCC	Plain cement concrete

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