Mechanical Characteristics of Slurry Infiltrated Fiber Concrete

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ABSTRACT

This paper presents and evaluates a new method for producing Slurry Infiltrated Fiber Concrete (SIFCON). A study was carried out to investigate the impact on the mechanical properties of SIFCON, where several cubes, cylinders, and prisms were cast to compare the proposed gradual and the traditional multi-layer method using the same mixing proportions: 6% straight steel fiber, cement, sand, 10% silica fume replacement, and 2.4% superplasticizer. The results showed that when using the proposed gradual mix method, compressive strength, splitting tensile strength, modulus of elasticity, and modulus of rupture improved by 15.21%, 8.06%, 9.07%, and 5.26% compared to the traditional multi-layer method.

Keywords-SIFCON; straight steel fiber; compressive strength; splitting tensile strength; modulus of elasticity

I. INTRODUCTION

Slurry Infiltrated Fiber Concrete (SIFCON) is one of the most popular repair materials, as it is similar to reinforced concrete in terms of dimensional changes, hardness, and durability. SIFCON can be employed in difficult-to-reach areas, the fibers between the old and new concrete produce a strong bond, and several repair approaches can be used to gain strength quickly [1]. In [2], various SIFCON slurry combinations were examined for their ability to penetrate fibers using flow cone and plate cohesion meters to forecast infiltration. SIFCON is created by first inserting fibers or a fiber mat into a mold. In some cases, the application of external vibrations may be difficult [3]. The fiber content should be spread or distributed on the surface of the formation to provide an acceptable degree of uniformity, by saturating the previously placed fibers with a paste or mortar slurry that is fluid enough to permeate the whole fiber network [4].

Four primary components should be considered when creating SIFCON: slurry quality and fiber volume, arrangement, and type. Fiber volume depends on the type of fiber used and the vibration exertion required for the appropriate compaction. Short fibers may pack denser than longer fibers, and higher fiber volumes can be accomplished with cautious and adequate vibration [5]. The compressive strength of cement mortar without fibers is approximately 28-35MPa after 1 day and reaches 50-70MPa after 28 days, while adding iron fibers increases its compressive strength to 40-80 and 90-160MPa, respectively, depending on the volume of the friction of steel fiber added [6]. The tensile strength of SIFCON is about twice the strength of the matrix, i.e. about 14MPa, and can reach more than 20MPa. In [7], the tensile strength obtained for various combinations of matrix composition, fiber types, and fiber volume fractions were between 4-16.1MPa. Stronger tensile properties can be achieved using a lower water-to-cement ratio due to the improved matrix bonding. The modulus of elasticity of SIFCON is slightly lower than in ordinary concrete due to the absence of coarse aggregates and the higher cement content in SIFCON matrices. The relationship between compressive strength and strain between 0 and 20% of the final stress was studied in [8-9].

The current study aimed to produce SIFCON in a faster and easier way and investigate the effect of the proposed method on mechanical properties such as compressive strength, modulus of elasticity, tensile strength, and modulus of rupture.

II. MATERIALS AND METHODS

A. Portland Cement

Ordinary Portland Cement (OPC) produced in Iraq under the Al Mass brand, conforming to Iraqi standards [10] was used.

B. Fine Aggregates

Natural sand from the region of Al-Ukhaider was used as fine aggregates. As this natural sand has a larger particle size to be used in mortar making, it was sieved using a 600μm sieve to separate the coarser particles, according to the IQS 45/1984 limitation zone 4 [11]. This size of sand proved to be successful for all mortar mixes during the experimental work.

C. Micro Silica Fume (SF)

SF is an ultra-fine material with spherical particles having approximately 0.15μm diameter. SF improves the cement paste microstructure and makes it more resistant to any form of external impact. In this study, MasterRoc MS610 SF, compatible with [12], was used at 10% replacement of cement weight.

D. High-Range Water Reducing (HRWR) Admixture

HRWR admixture was used to provide higher workability to the slurry and sufficiently liquify it to flow through the thick fiber without creating honeycombs. This study used the DCP Master Glenium 54 high-performance concrete superplasticizer, which is free from chlorides and is compatible with [13].

E. Straight Steel Fibers

This study used straight micro-steel fibers made by the Ganzhou Daye Metallic Fibers Co. Ltd, China (Figure 1). Table I shows its chemical composition and properties.

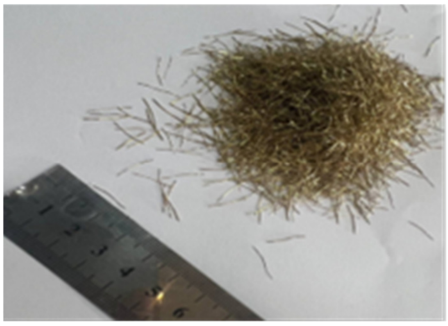

Fig. 1. Steel fibers used.

TABLE I. PROPERTIES OF STEEL FIBERS*

Property	Value
(D) Diameter(mm)	0.20
(L) Average length (mm)	13.0
Aspect ratio (L/D)	65
Tensile strength(N/mm^2)	2850
Density(kg/m^3)	7860
Color	Golden

*according to the manufacturer

F. Mix Proportions

In [14], many trail slurry mixtures were produced to find the mix proportion that has the best fresh state characteristics regarding fluidity, filling ability, and viscosity without bleeding, separation, or pockets in the dense fiber network to decrease the mechanical properties of SIFCON, since there are no standard guidelines yet for the production of SIFCON mixtures. Several studies have investigated the production of SIFCON mixtures. In most situations, the proportions of sand to cement were 1:1 by weight, so this ratio was adopted. Furthermore, several studies used cement content ranging from 800 to 1000kg/m^3 and recommended a weight ratio of less than 0.41 to produce the slurry. After many trials, specimens were cast with various mixes and tested after 7 days using standard Portland cement amounts of 973kg/m^3 with 10% replacement of SF. The water/binder (w/b) ratio was kept at 0.28 by the weight of the cementitious material, and the amount of water for each 1m^3 was 272.44kg/m^3. The Master Glenium R 54 HRWR was used at a ratio of 2.4% by weight of the cementitious material, and 6% of straight steel fiber. Table II shows the optimal mixes and their weight proportions for 1m^3. The concrete was poured into many layers before compacting with a tamping rod or a vibrating machine to exclude as much air as possible [15-17].

TABLE II. MIX PROPORTIONS FOR THE SIFCON.

Mix proportions	
Cement (Kg/m^3)	875.7
Sand (Kg/m^3)	973
Silica fume (Kg/m^3)10% rep	97.3
Gravel (Kg/m^3)	-
Steel fiber (%)	6
w/b or w/c ratio	0.28
SP (by wt. of binder) (%)	2.4
V-funnel test (sec)	10
Mini slump flow (mm)	260

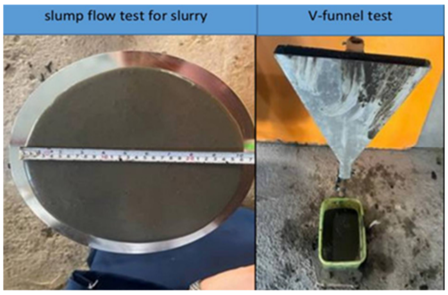

Fig. 2. Slump flow and V-funnel test.

G. SIFCON Producing Procedure

An increased mixing period is significant to achieve the desired efficiency and homogeneity of the slurry and allow the HRWR to reach its maximum capacity and get complete disposal of Silica Fumes (SF) by breaking up any agglomerated particles. An electrical drill mixer with a suitable pan was used for all specimen mixes. After cleaning the mixer of any residual hard and fresh materials, the sand was mixed with 1/5 water to hydrate it, followed by mixing the total amount of HRWR with 1/3 of water in 0.5 minutes, the binder material (cement with SF) was mixed in the mixer for 1 minute to spread the SF particles within the cement particles, and finally, the blinder was added to the mortar. Two thirds (2/3) of the mixing water was added to the mix and mixed for one minute. HRWR with 1/3 of a cup of water was mixed for about three minutes to achieve the best mix and the necessary flowability. Mixing the slurry took another minute.

1) Multi-Layer Method

In this method, a layer of slurry is applied, followed by steel fiber sawing, a layer of mortar, and some fibers. This process was repeated until the fibers permeate the slurry [18]. After casting the cubic, cylinder, and prism forms, they were cured for 7 and 28 days, as shown in Figure 3.

Fig. 3. Casting SIFCON using the multi-layer method.

2) Gradual Mix Method

In this method, steel fiber was mixed with the slurry, where the calculated amount of fiber was added to the sample to be cast and added gradually with mixing until the mixture becomes homogeneous and the fibers permeate well with the slurry. Cubics, cylinders, and prisms were cast by this method and cured for 7 and 28 days, as shown in Figure 4.

Fig. 4. Casting SIFCON using the gradual mix method.

III. TESTING HARDENED SIFCON

A. Compressive Strength Test

Three 50×50×50mm cubes cast with both methods and cured for 7 and 28 days were used to investigate the compressive strength. A digital compression tester was used (1950kN) with 0.31MPa/sec rate of loadings, following the BS.1881:part 116 [19], as shown in Figure 5.

B. Splitting Tensile Strength Test

Samples of 100.0mm in diameter and 200.0mm in length were used for the splitting tensile strength test. A testing device with a capacity of 1950kN was used, and the tests were conducted following the ASTM C496/C496M 2017, as shown in Figure 6.

C. Modulus of Elasticity Test

The modulus of elasticity was measured using cylinders with diameters of 150.0mm and 300.0mm, following the ASTM C469, 2014. To avoid any weakening, the upper part of the cylinder was expertly completed and smoothed using an electric grinding machine. The samples were put in a hydraulic device that could handle 1950kN. The concrete cylinders were compressed to 40% of their ultimate compressive strength as seen in Figure 7.

Fig. 5. Compressive strength test.

Fig. 6. Splitting tensile test.

Fig. 7. Modulus of elasticity test.

D. Flexural Strength (Modulus of Rupture)

This test was carried out under [20], using 100×100×400mm prismatic beams tested as simply supported beams with third point load, with a steady loading rate of about 0.015MPa/sec with a maximum load of 150kN, as shown in Figure 8.

Fig. 8. Flexural strength test.

IV. RESULTS AND DISCUSSION

Table III shows the results for all tests.

TABLE III. RESULTS OF HARDENED SIFCON TESTS

	Compressive strength (MPa)		Splitting tensile strength (MPa)	Modulus of elasticity (GPa)	Modulus of rupture (MPa)
Curing period (days)	**7 days**	**28 days**	**28 days**	**28 days**	**28 days**
Multi-layer method	78.2	93	18.6	23.7	28.5
Gradual mix method	92.1	106	20.1	25.85	30

Each table value represents the average of 3 samples. Figure 9 shows the results in compressive strength of SIFCON between the two casting methods for 7 and 28 days of curing. The results of the sample tests show that the proposed gradual-mixing method of steel fiber with mortar is better than the traditional multi-layered. The compressive strength increased by 18.93% and 15.21% after 7 and 28 days, respectively, as fibers were distributed in a homogeneous way for the cubic volume, reducing the appearance of cracks and giving an equal dispersal for both internal and external stresses due to the progression of reinforcing network. Fibers filled the pattern size in the slurry, so the compressive strength of SIFCON increased. The purpose of the splitting tensile strength test was to examine the behavior of the SIFCON specimens in terms of strength and hardness. The splitting results were lower than the compression test for the same SIFCON cylinder [15]. The force on the area where the load is applied causes cracks to emerge faster, leading to the failure of the sample. The splitting test results of the SIFCON created using the proposed gradual mixing method were better than the multi-layer because the fibers were more homogeneous in distribution with the slurry, which linked the fibers to each other in the network. This reduced the appearance of cracks, provided additional strength, and improved the mechanical properties of the SIFCON. The difference between the two methods was 8.06%, as shown in Figure 10.

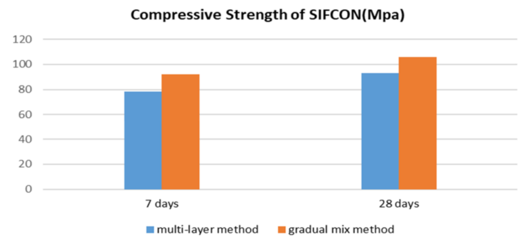

Fig. 9. Compressive strength of SIFCON.

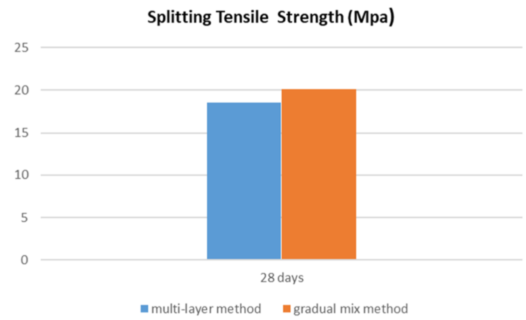

Fig. 10. Splitting tensile strength of SIFCON.

Fig. 11. Cylinder after test.

The elastic modulus is very important because it describes the hardness of the material and is affected by the type of concrete, the proportions of the materials used, and their quality [22]. Figure 12 shows the modulus of elasticity for both the production methods used. It can be observed that there is a clear improvement of 9.07% when using the SIFCON gradual mixing pouring method. This also shows that the coefficient of elasticity is in fact stress on strain because stress includes strength. SIFCON produced by gradual mixing homogenized the fibers with the slurry without leaving a weak area for the premature failure of the sample, as the fibers occupied the width of the crack after the failure of the sample. Figure 13 shows the modulus of the rupture of prisms cast by the two methods. The gradual mix method gave higher results than the multi-layer method by 5.26%, as the steel fibers in the matrix slurry intertwined with each other in the prism, making it difficult to crush. Figure 14 shows that the interlacing of the fibers with each other in the crack area reduced the crack width.

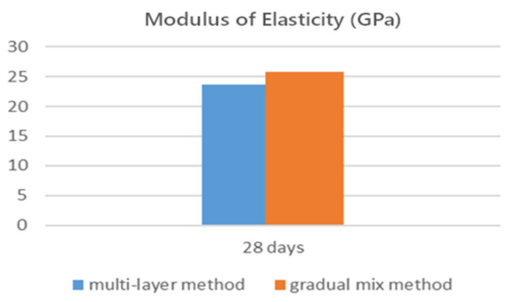

Fig. 12. SIFCON modulus of elasticity.

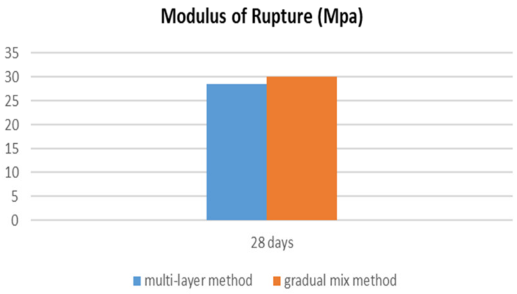

Fig. 13. Modulus of rupture results.

Fig. 14. Prism after test.

V. CONCLUSION

This study proposed a faster and easier casting method for SIFCON using straight steel fibers. The experimental investigation showed that the proposed gradual mixing method improved compressive strength by 15.21%, splitting tensile by 8.06%, modulus of elasticity by 9.07%, and modulus of rupture by 5.26% compared to the traditional multi-layer method. Although the fibers are small and light in weight, the proposed mixing method made the mixture homogeneous and prevented them from descending. The fibers were distributed in a way that increased SIFCON's bearing capacity. The failure mode for both casting methods was the same.

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