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Slurry Infiltrated Fiber Concrete as Sustainable Solution for Defected Buildings

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Abstract- *One of the new concrete technology applications that had to get increased importance as repairing and retrofitting technique is slurry infiltrated fiber concrete (SIFCON). This research aims to investigate some of the mechanical properties of SIFCON and its role in improving the useful life of normal concrete. The research consists of two parts; in the first part, three mixes are prepared with 0%, 1.5%, and 6% volume fraction steel fiber content. Compressive strength, flexural strength, total absorption and apparent density tests are made for each mix. In the second part, a composite section of normal concrete and SIFCON mix with 6% steel fiber is prepared. Different thicknesses of SIFCON layer had been casted to assess its benefits in repair and/or to strengthen of defected buildings. Flexural strength, toughness, ductility and load-deflection curve are examined for the composite sections. The results showed that the flexural strength of SIFCON with 6% steel fiber content increased up to 600% and 200% compering to those recorded with the reference mix and 1.5% steel fiber concrete respectively. The results also indicated that the increase of SIFCON layer thickness would improve the mechanical properties of the composite section. Also, the maximum increase in flexural strength was greater than four times the reference mix. Better behavior is also recorded in load deflection and toughness of SIFCON composite section.*

Keywords- *SIFCON, Slurry infiltrated concrete, steel fiber, strengthening of concrete, sustainable concrete.*

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1. Introduction

For global sustainability, the long life of reinforced concrete structures is essential. In the last two decades, many buildings in Iraq had been exposed to damage either due to war effect or due to the lack of maintenance and repair services. To rehabilitate these defected buildings and restore their mechanical properties, new techniques should be applied. One of these techniques is slurry infiltrated fiber concrete (SIFCON). It could be defined as a special type of steel fiber concrete (SFC) with a high volume fraction of fiber; it possesses high ductility and high mechanical properties. It is a high-performance cementitious composite, which exhibits outstanding strength and ductility. It is manufactured by first placing fibers in formwork molds and then infiltrating the fiber network with cement-based slurry. The infiltration is generally achieved by gravity flow assisted by external vibration, or by pressure grouting. Due to this procedure, much higher fiber volume fraction can be achieved in SIFCON [1]. The adding of SIFCON layers to the normal concrete beams increased the ultimate and the yielding loads by about 25%. Also, it causes an increase of 45% in the case of FRC composites. The increment in the SIFCON depth displayed good effect in the reduction of beam deflection [2]. By increasing the number of infrastructure facilities globally, the number of buildings exposed to damage is also increasing. Complete substitute of the defected building might increase overall costs, also, to waste the natural sources, especially when planning to improve the strengthening and performance of the structure. Lots of contemporary infrastructures are constructed of concrete. Over time, spoilage and change of purpose requisites simplify the need for new buildings. Destruction of existent and building of new systems is a highly priced, time exhaustion, and resource consuming operation [3].

2. Materials and Methods

This study is designed to investigate the possibility of using SIFCON to strengthening defected building as a sustainable solution. As mentioned earlier that SIFCON possess a special mechanical behavior illustrated through its high strength, superior ductility and crack arresting. The experimental program in this research consists of two parts as shown in Figure 1. In the first part of this study, three different mixes were cast, SIFCON mix contains 6% of steel fiber, steel fiber concrete contains 1.5% of steel fiber and references concrete mix with 0 steel fiber. Different mechanical properties were investigated for each mix .The second part of the study is focused on strengthening applications, where three different composites are made with different SIFCON thicknesses (15, 25, and 35mm). Flexural strength, toughness, ductility and load-deflection curve are examined for the composite sections.

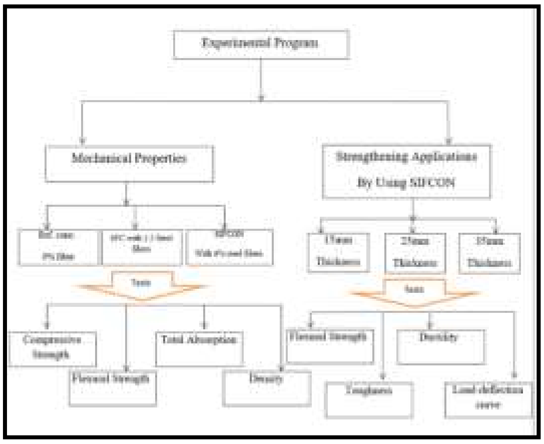

Figure 1: Flow Chart of the experimental program

3. Experimental Program

I. Materials

• Cement: Ordinary Portland cement type I had been used with chemical composition and physical properties presented in Tables 1 & 2 respectively which conformed to Iraqi Standard Specification No. 5/ 1984 [4] .

• Fine Aggregate: Natural fine aggregate from Al-Najaf city was used. Figure 2 shows the grading of sand; the sand was within zone 3 and passing through 1.18 mm sieve; this is to ensure a good infiltration of the slurry through the dense fiber network. The absorption, sulfate content, and specific gravity for the used sand are 1%, 0.45%, and 2.6 respectively. The used sand was in compliance with the requirements of Iraqi standard 45/1984 [5].

Table 1: Chemical properties of ordinary Portland cement

Chemical Composition		
Oxide	Ordinary Portland cement	Limits of Iraqi Standard Specification No. 5/ 1984
CaO	61.8	-
SiO_2	20.54	-
Al_2O_3	4.55	-
Fe_2O_3	3.55	-
MgO	3.67	≤5.0%
SO_3	1.65	≤2.8%
Na_2O	0.41	-
K_2O	0.28	-
L.O.I	2.1	≤4.0%
I.R.	0.7	≤1.5%
L.S.F.	0.75	0.66-1.02%
Main Compounds (Bogue's equations)		
C3S	55.13	-
C2S	17.30	-
C3A	6.05	-
C4AF	10.80	-

Table 2: Physical properties of ordinary Portland cement

Physical Properties	Ordinary Portland cement	Limits of Iraqi specification No.5/1984
Soundness by Autoclave %	0. 5	≤ 0.8
Fineness (Blaine method) cm^2/gm	3130	≥2300
Setting Time		
(Vicat's method)	2:45	≥45 min
Initial setting time, hrs: min	4:50	≤10 hrs
Final sitting time, hrs: min		
Compressive		
strength at 3days, MPa	18.6	≥15
7days, MPa	25.5	≥23

• Coarse aggregate: The used coarse aggregate was brought from Al-Najaf city. It was crushed gravel with a maximum size of 10mm and with grading as shown in Figure 3. The sulfate content, specific gravity and absorption are 0.1%, 2.7 and 0.6% respectively. The used coarse aggregate are followed to the requirements of Iraqi Standard No. 45/ 1984 [5].

• Steel Fiber (SF): Low carbon hooked end steel fiber (Figure 4) of diameter 0.6 mm and length of 35 mm giving aspect ratio of 58 was used. The tensile strength was 1060 N/mm2 and the density was 7800 kg/m3. Steel fiber properties are in compliance with ASTM A820 [6]. The fibers were oriented in the form randomly.

• High Range Water Reducing Admixture (HRWRA): A high-performance superplasticizer admixture based on polycarboxylic polymers is used which is commercially known as (Hyperplastic PC200). The high range water reducing admixture complied with ASTM C494-99 type A & G [7].
• Water: Tap water available from local sources was used for mixing and curing of specimens.

II. Mixes proportion and Mixing procedure

To meet the purposes of the recent work, the experimental program consisted of two parts; in the first part, three mixes are prepared as described in Table 3. For the normal concrete, all dry components are mixed for 3 minutes, then the HRWRA was dissolved in water and added to dry consistence and mixed for an additional 5 minutes. The same procedure is made with the SFC except that the SF is added randomly after ensuring a good homogeneity of the mix. For SIFCON the steel fiber is placed into the molds and then infiltrated with the slurry. The slurry is prepared by mixing cement, sand, water and HRWRA until a homogenous slurry is obtained. Figure 5 shows the casting of SIFCON. In the second part, a layer of different thickness of SIFCON (15, 25, and 35) mm is casted immediately after casting the normal concrete (both concretes in the fresh state). The cross-section dimensions of prisms remain (100 ×100) mm. Figure (6) shows the casting of a hybrid section.

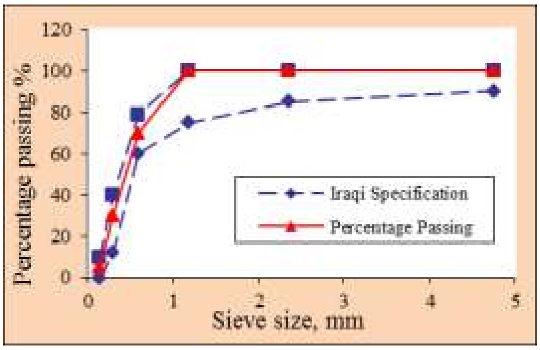

Figure 2: Grading of fine aggregate

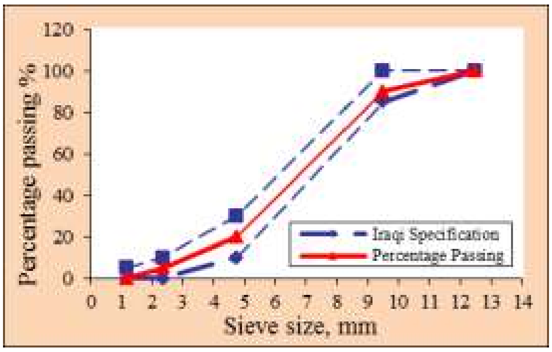

Figure 3: Grading of coarse aggregate

Figure 4: Steel fiber used in this research

Figure 5: the casting procedures of SIFCON

Figure 6: the casting procedures of hybrid section

4. Result and Discussion

I. Compressive Strength

The compressive strength test was determined according to B.S. 1881: part 116 [8] on 100 mm cube specimens. The test results for compressive strength at 28 days age are depicted in Figure 7. The result exhibited an increase in compressive strength of both SFC & SIFCON relative to the normal concrete. Although a higher increasing is recorded with SIFCON mix, the percentages of increase in compressive strength were 104% and 68% as compared with normal concrete and SFC respectively. This is attributed to the improved crack arresting ability of steel fiber.

II. Flexural Strength

This test was carried out on 100×100×400 mm prisms. The flexural strength was calculated by using simply supported prism with a clear span of

300 mm under two third point loading consistent with B.S.1881: part 118 [9].

Figure 8 shows the flexural strength test results at 28 days age for the 1st part of this research. It is clear that incorporating steel fiber has a beneficial effect in improving the flexural strength of the concrete mixes. SIFCON mixes had twice the magnitude of flexural strength of SFC and six times that of normal concrete mixes, which confirms the advance behavior of SIFCON under flexural stresses. The test results of the 2nd part of this research are presented in Table 4. It was clear that as the thickness of SIFCON layer in the SIFCON-normal concrete composites increase as the flexural strength of the specimens increased. The composite sections R3 with (35mm) thickness had the higher flexural strength of (14.7 MPa). This enhancement is due to the increase in tensile strength that resulted from the confinement effect of steel fiber [10]. Moreover, it was observed that the failure does not occur at the SIFCON laminate - concrete interface. This ensures that the composite action continues throughout the load spectrum.

III. Total absorption

This test was carried out with regards to ASTM C642 − 13 [11]. 100 mm cubes were used to determine the total absorption of the mortar specimens. The average of three cubes was recorded. Figure 9 signified that the addition of steel fiber to the concrete mixes had a miner effect on the total absorption. Although a slight reduction is found in the results of SIFCON mixes. This is attributed to the absence of coarse aggregate in SIFCON.

IV. Density

This test was conceded on 100 mm cube specimens by ASTM C642 – 13 [11]. The average apparent density of three cubes was recorded at 28 days age. The results are plotted in Figure 10. The results are consistent with expectations, where the use of steel fiber led to increasing the density due to its higher specific gravity.

Table 3: Mixes proportions

Mix	Cement Kg/m^3	Fine Agg. Kg/m^3	Coarse Agg. Kg/m^3	HRWRA % by weight of cement	Water L	W/C	SF Kg/m^3
Normal concrete	426	718	966	-	179	0.4	-
SFC	426	718	966	-	179	0.4	117
SIFCON	900	900	-	1	288	0.4	470

V. Load-Deflection Relationship

Load-Deflection behavior of the specimens could be observed in Figure 11 as a load-deflection relationship curve. The deflection was measured at the center point of prism span. The ultimate loads were recorded when the specimens would not sustain deformation any more at constant load, while the first crake load was recorded depending On visual monitoring. Table 5 shows a summary of the load – deflection test. As expected, reference prism failed suddenly in a brittle manner directly after the maximum load was reached, Figure 11. This behavior is attributed to the brittle failure of concrete in the absence of reinforcement. For all composite prisms, SIFCON absorbed the flexural tensile stress recognized to the bending action. The first crack is initiated at the bottom surface of the prisms once the flexural tensile strength of concrete is reached. It was observed that the increase in the thickness of SIFCON layer in concrete composite sections led to scenery increase in load carrying capacity and decrease in the total deflection of the prisms, in which R3 concrete composite showed higher load carrying ability (49 kN) and less deflection (4.30 mm).

VI. Failure Mode

The crack patterns in each specimen were noted and analyzed during the test. Figure 12 shows the crack patterns of the prisms. The figure shows that failure did not occur at the SIFCON-concrete interface. This is proving that the composite section act as one unit [3]. None of the prisms exhibits premature brittle failure. (R1) prisms experience flexural failure. The (R2 and R3) prisms showed diagonal cracks at the bottom of concrete composite specimens, which conforms the shear deficiency of these concrete composite sections, while at the compression zone, the crack becomes more flatter and discontinues at some point. SIFCON laminate casting to tension face mitigate the coherent deformations of the prisms and prevent sudden failure modes although a considerably high ultimate load (49 kN) were recorded.

Table 3: Mixes proportions

Mix	Cement Kg/m^3	Fine Agg. Kg/m^3	Coarse Agg. Kg/m^3	HRWRA % by weight of cement	Water L	W/C	SF Kg/m^3
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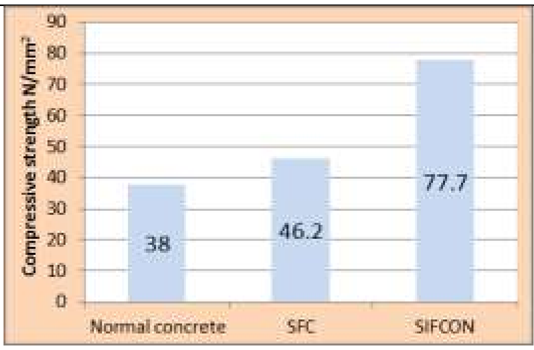

Figure 7: compressive strength at 28 days age

Figure 8: Flexural strength at 28 days age

Table 4: Test results of flexural strength for the composite section

Symbol ID	The thickness of laminate (mm)	Steel fiber %	Ultimate load (kN)	Flexural strength (MPa)
R	-	0	11.7	3.50
R1	15	6	29.1	8.73
R2	25	6	42.2	12.66
R3	35	6	49.0	14.7

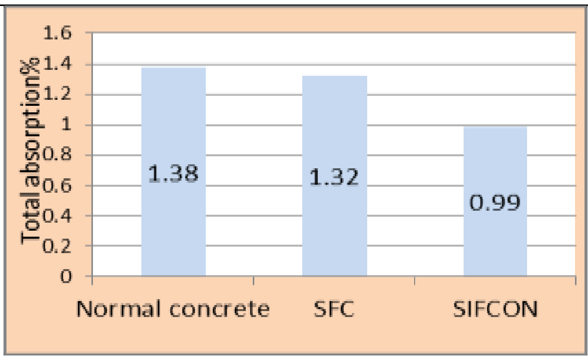

Figure 9: Total absorption at 28 days age

Figure 10: Apparent density at 28 days age

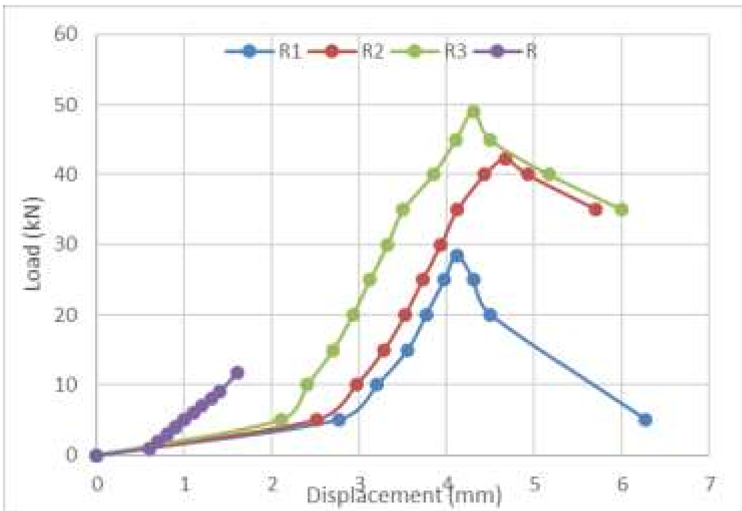

Figure 11: Load-Deflection behavior of the composite sections

Table 5: Summary of Load – Deflection Test results

Symbol ID	First crack stage		Ultimate stage	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
R	-	-	11.7	1.6
R1	26.0	3.99	29.1	4.11
R2	33.5	3.97	42.2	4.67
R3	40.6	3.86	49.0	4.30

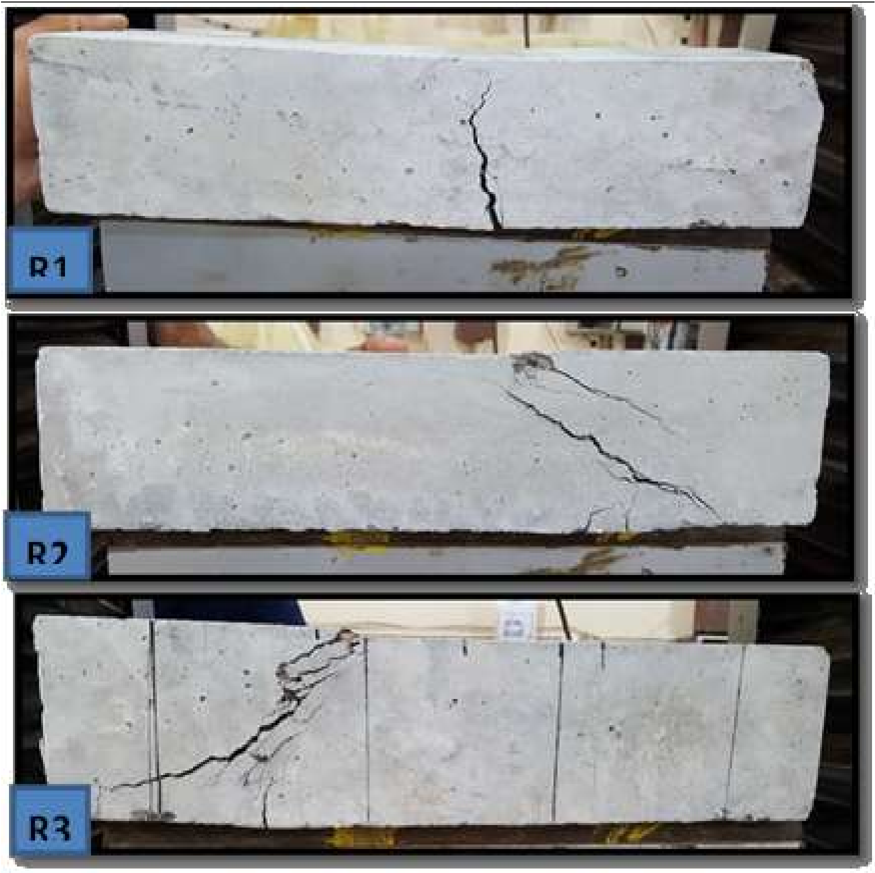

Figure 12: The failure pattern of testing prisms for mixes R1, R2, &R3

Table 6: results of toughness and ductility

Symbol ID	Toughness (kN.mm)	Increase percent (%)	Ductility factor
R	12.35	-	-
R1	90.415	632.11	1.03
R2	141.285	1044.01	1.18
R3	146.550	1086.64	1.11

VII. Toughness

The toughness was calculated from load deflection curve and according to JCI Standards [12]. The areas under load deflection curve of different mixes were presented in Table 6. The energy absorption characteristics of (35 mm) SIFCON laminate performed well among all other hybrid section specimens. When compared to reference prisms, hybrid specimens yield more energy, because the incorporation of higher volume fraction of steel fiber enhances the properties of the section.

VIII. Ductility

Table 6 illustrated the ductility factor of various specimens. The ductility factor can define as the ratio of maximum deflection at any load level to the deflection at first yield crack. However, the increase of ductility was not pronounced with the increasing of laminates thickness because of the dominant shear failure [13].

5. Conclusion

1. SIFCON layers casting to the tension face of prisms improve flexural strength considerably. Hybrid section exhibits an increased in flexural strength of 320 % for laminates with (35 mm) thickness.

2. Increasing the stiffness of the concrete composite section will significantly reduce the deflection at any load level.
3. By strengthening the prism, performance of the weak structure can be improved and it will protect many lives from sudden failure.
4. Energy absorption capacity (toughness) of SIFCON-concrete composite sections increase significantly with the increase of SIFCON laminates thickness. It reaches 1086.64 % of control prisms for (35 mm) SIFCON layer thickness.
5. The ductility of hybrid sections improved compared with control section; in contrast, the increment of SIFCON layer thickness has no great effect on ductility.

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