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Flexural Performance of Reinforced Concrete Built-up Beams with SIFCON

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Built-up beam, Conventional concrete, Ductility, Energy dissipation, Flexural performance, SIFCON, Tensile strength.

ABSTRACT

The study deals with the effect of using Slurry infiltrated fiber concrete (SIFCON) with the reinforced concrete beams to explore its enhancement to the flexural capacity. The experimental work consists of the casting of six beams, two beams were fully cast by conventional concrete (CC) and SIFCON, as references. While the remaining was made by contributing a layer of SIFCON diverse in-depth and position, towards complete the overall depths of the built-up beam with conventional concrete CC. Also, an investigation was done through the control specimens testing about the mechanical properties of SIFCON. The results showed a stiffer behavior with a significant increase in load-carrying capacity when SIFCON used in tension zones. Otherwise high ductility and energy dissipation appeared when SIFCON placed in compression zones with a slight increment in ultimate load. The high volumetric ratio of steel fibers enabled SIFCON to magnificent tensile properties.

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1.Introduction

The cementitious composites can be described as one kind of concrete which contains finer components compared with conventional concrete (CC), especially the maximum size of sand particles, and the absence of coarse aggregate. But like CC these composites have a main deficiency which is brittleness. The addition of fibers overcome this imperfection comes with a new acronym as FRCC (fiber reinforced cementitious composite), with distinguishing development in mechanical properties particularly concerning the resistance of tensile forces. On the other hand, improve the employ of these properties in a structural member's behavior towards more ductility, durability, and energy dissipation. Generally, the fibers were added to FRCC as a volumetric ratio (Vf) of the mix limited, up to 3% concerning the problems of mixing and casting like, as balling and floating of the

fibers. Slurry infiltrated fiber concrete (SIFCON) had exceeded this limit of fibers started from 4% up to 20 %, presented a unique solution for these problems, particularly the balling of steel fibers. Whereas, the SIFCON fabrication is completely different from any other type of FRCC, which it had been done by replacing the fibers in the mold, then followed by adding slurry with vibration to ensure the slurry infiltration throw the fibers random grid. Columbus, Ohio at USA is the first place where Lankard Materials Laboratory developed SIFCON in 1979, by combining a big amount of steel fibers with a cement paste [1]. Later the slurry infiltration technique throws the layers of steel fibers was improved by Josifek and Lankard.[2], by providing the capability to increase the percentage of fibers. SIFCON had gained application spaces like as using it in earthquake-resistant structures, military constructions, airplanes manufacturing, and rehabilitation of reinforced concrete elements due to its perfect mechanical properties [3,4]. The structural designers and researchers found a solution by partially use of FRCC in the form of built-up members or retrofitted, influenced by the high cost of these composites with trying to utilize them in suitable locations.
Experimental researches have been adduced in the literature concerning using SIFCON as followed. Elnono et al. [5] studied the effect of the replacement of SIFCON instead of CC in beam-column joints with proving that this change leads to more efficiency and ductility. Al-Rousan and Shannag. [6] have investigated the use of SIFCON Jackets as external strengthening at the shear zone of RC beams, the study concluded that shear capacity of beams could be improved by increasing the thickness of jackets. Balaji and Thirugnanam. [7] studied the flexural behavior of built-up beams under the effect of cyclic load where SIFCON was placed as layers at various locations of the beam with conventional concrete. The results showed a high increase in the ductility, energy absorption, and load-carrying capacity of built-up beams comparing with a conventional concrete reinforced beam. Haritha and Saathappan. [8] presented a comparative study between the use SIFCON and ECC (Engineered Cementitious Composites) at the tension zone of built-up beams, and the study indicates that using of SIFCON leads to more flexural strength, stiffer behavior and reduce the width of the cracks comparing with ECC.
It was noticed that using SIFCON in reinforced concrete elements as a full section is uneconomically caused by the high cost of steel fibers. The use of SIFCON in chosen locations of the conventional RC beam could be an alternative solution in the direction of high strength and economy.
The study aimed to investigate the mechanical properties of SIFCON concerning the effect of steel fibers volume fraction (with Vf = 9%) comparing with SIFCON slurry and conventional concrete. Beside study the effect of using SIFCON layer (with different depth and position) on the flexural performance and capacity as well as to ductility, energy dissipation, and cracks patterns.

2.Experimental Program

A total of six reinforced concrete beams with a cross-section of 125*200mm and a total length of 1600mm were designed according to the requirements of ACI 318M-14 [9] and tested under the influence of static flexure loading. The main longitudinal reinforcement of 2Ø16 mm bars was utilized while Ø8mm bar was used for shear resistance and 2Ø4mm at the top side was just used for supporting stirrups during the casting process, as shown in Figure 1 and 2.

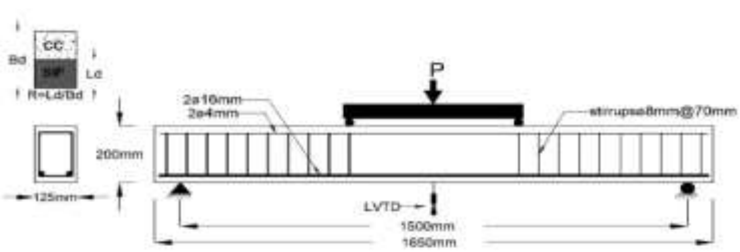

Figure 1: Beam details

Figure 2: Steel reinforcement details

I.Materials

Ordinary Portland cement conformed to ASTM C 150-15[10] and Iraqi Specification No. 5/1984 [11] was used for all mixes. Local natural fine aggregate (FA) and coarse aggregate (CA) (with a maximum size of 12 mm) were used, which obeyed with the requirements of ASTM C33-13[12] and Iraqi Specification No.45/1984[13]. Regarding the sand particles sizes which were used in SIFCON production, were 0-300 μm and 300-600 μm added by different percentage to get more homogeneity of SIFCON and control the micro cracks also getting more flowability of SIFCON slurry during the infiltration process. Silica fume conforms to ASTM C 1240-03[14] supplied by CONMIX, with a density of 2.2 g/cm3 and SiO2 content > 90% was used for casting the concrete. Superplasticizer is used for SIFCON production manufacturing by Sika and confirming the requirements of ASTM C494/C494M – 15 [15].

The types of steel fiber used in this study were hooked end as shown in Figure 3, with length (30mm), diameter(0.5mm), aspect ratio (60), and tensile strength (1200MPa) matching the requirements of ASTM A820 /A820M-04[16].

Figure 3: Hooked end steel fibers

The properties of used deformed steel bars were listed in Table 1. These bars were tested at the laboratory of production engineering and metallurgy department in the university of technology. They were matching to the requirements of ASTM A1064-14[17].

Table 1: Properties of steel bars.

Bar diameter (mm)	Actual diameter (mm)	*Fy* (MPa)	*Fu* (MPa)	E_s (GPa)
4	3.89	415	599	197.1
8	8.06	438	641	199.5
16	15.98	520	723	200.7

Where: (*fy*) is yield stress, (*fu)* ultimate stress and *(E_s)* modulus of elasticity.

II. Mix Properties

In this study, three types of concrete mixes were performed; the first one is for conventional concrete CC, and the second for SIFCON with steel fiber volumetric ratio 9%. The components of these mixes are listed in Table 2. The conventional concrete mix was designed following ACI 211.1-91[18] to obtain a minimum compressive strength of 40 MPa at 28 days without any admixtures. Concerning the third mix, which was SIFCON slurry without steel fibers, it is a self-compacting cement composite containing fine materials, used to prepare SIFCON 9% mix, as well as studying the effects of steel fibers presence.

Table 2: Mixes ingredients

Weight (kg/m^3)	Type of mix CC	SIFCON
Cement	500	850
Normal sand	600	-
Fine sand		
0-300µm	-	510
300-600µm	-	340
Gravel	1250	-
Silica fume		125
Superplasticizer	-	117
W/C	0.42	0.3
Steel fibers	-	702
		-

III. Casting Processes

The details of concrete beams are listed in Table 3, the reference beams (Ref No: 1 and Ref No: 2) were cast for comparing with the remaining beams.

Table 3: Beams distribution

Beams	R	Description
Ref No:1	-	CC beam
Ref No:2	1	SIFCON beam
S-B-25%T	1/4	Built-up beam with 5 cm of SIFCON in tension zone
S-B-50%T	1/2	Built-up beam with 10 cm of SIFCON in tension zone
S-B-25%C	1/4	Built-up beam with 5 cm of SIFCON in compression zone
S-B-50%C	1/2	Built-up beam with 10 cm of SIFCON in compression zone

R character is referring to the ratio between the depth of SIFCON layer and the overall depth of the built-up beams. The specifications of these beams, such as dimensions, steel reinforcement, and geometry, are shown in Figure 1. The abbreviations **Ld** and **Bd** are referring to the depth of SIFCON layer and the beam, respectively as shown in Figure 1.

The casting of Ref No: 1 beam was carried out by putting CC into the mold as four successive layers with 5 cm depth for each one; a needle vibrator was used to vibrate each layer to get sufficient compaction. Ref No: 2 was made by SIFCON, casting process of this beam was done by replacing the fibers into the mold Through the steel reinforcement till reaching a 5 cm of depth full with steel fibers followed by adding SIFCON slurry, a good slurry infiltration obtained by using of the needle vibrator. This step repeated to complete the overall beam depth with a gap about 15 to 20 minutes consumed by the preplacing of the steel fibers as the above depth each time, while the slurry was prepared formerly. Regarding the casting of the remaining of built-up beams, which were done by a combination of the two previous casting processes. Firstly, cast the bottom layer by a required concrete type which may be from CC or SIFCON for demanded depth, then followed by casting the top layer which also may be from CC or SIFCON according to the design of built-beam. This process was done during about 45 minutes by possible speed to ensure good interaction between the layers before the initial setting of concrete. Figure 4 shows the casting process.

Figure 4: Casting process.

Control specimens were utilized for computing the mechanical properties of CC and SIFCON. The Compressive strength (*f'c*) was computed by using standard cylinders with a height of 200mm and diameter of 100 mm for CC, and cubes with 100 mm in each direction for SIFCON which were tested according to the requirements of ASTM C39/C39M-15a[19] and BS.1881: part 116[20] respectively. Regarding the splitting tensile strength (f_{ct}) and modulus of elasticity (E_c), standard cylinders with a high of 300mm and diameter of 150mm were used for getting the above mechanical properties, by following the instructions of ASTM C496/C496M-11[21] and ASTM C469-14 [22] respectively. The flexural strength (f_r) was determined by using prisms with 100mm as width and depth and 400mm as length according to the requirements of ASTM C78/C78M-15a [23]. Figure 5 presents examples of these tests which were performed at structural and concrete technology laboratories of the civil engineering department in the university of technology.

Figure 5: Controls specimens test

3. Beams Testing under Flexure

All beams were painted with white before test day and simply supported with a span of 1500 mm under the influence of two monotonic point loads applied by using a hydraulic machine with 1500 kN capacity at the structural laboratory in the university of technology, as shown in Figure 6.

Figure 6: Testing of beam.

The mid-span deflection with each 5kN increment of the load was recorded with LVDT (Linear Variable Differential Transformer Instrument) by touching the bottom face of the beam at the mid-span.
The yielding stage of the main longitudinal reinforcement bar was detected by using a strain gauge, with type FLA-6-11-3L product of Tokyo Sokki Company, JAPAN. This gauge was fixed on the bar after removing the ribs by grinding and cleaning followed by covering with special types of glue and tape, respectively, products from the same company as shown in Figure 7.
Data acquisition system named as (UCAM-550A Fast Data Logger) product of KYOWA Company, JAPAN, was used to collect results of deflections and strains from the above instruments, as shown in Figure 8.

Figure 7: Strain gauge installation.

Figure 8: Data acquisition system.

4. Results and Discussion

I.Mechanical Properties of Mixes

The mechanical properties of concrete mixes are listed in Table 4. The SIFCON slurry showed slight increments in mechanical properties compared with CC, which was affected by using fine sand and admixtures such as silica fume and superplasticizer. The contribution of a high percentage of steel fibers with the above factors leads SIFCON to reflect superior tensile features where the increments reach 400% and 600% regarding the splitting tensile strength and flexural strength respectively, comparing with CC, while the increments in compressive strength and modulus of elasticity were lower than those percentages, but were still considerable. The concept of using a volumetric ratio of steel fibers above 3% leads to improve the tensile properties of concrete only was emphasized by SIFCON.

Table 4: Mechanical properties of mixes

Type of mix	$f'c$ (MPa)	f_{ct} (MPa)	f_r (MPa)	Ec (GPa)
CC	39.355	3.501	3.986	29.835
SIFCON*	56.245	4.572	5.159	33.551
%*	42.989	30.591	29.427	12.455
SIFCON**	77.168	18.132	28.062	39.256
%*	96.081	400.17	600.04	31.577

*,** refers to SIFCON slurry and SIFCON with steel fiber volumetric ratio (V_f = 9%) respectively.
%* refers to the percentage of increase in mechanical properties of SIFCON mixes with respect to CC mix.

III.Loads Results

As previously explained about the effect of steel fibers on the tensile features of SIFCON, the loads results come towards an affirmation of this fact. Since the results reflected the efficiency of using SIFCON in tension zones further more than compression zones, for built-up beams comparing with Ref No: 1 beam with CC. The first crack load can be described as the load which causes a first visible crack, while the ultimate load can be described as beam failure load. The results showed a significant increase in the first crack loads and ultimate loads for Ref No: 2, S-B-25%T, and S-B-50%T beams comparing with Ref No: 1 beam. On the other hand, the first crack load was steady for S-B-25% C, and S-B-50% C beams with a slight increment in the ultimate load, as indicated in Table 5.

Table 5: Loads results

Beams	Pu (kN)	Pcr (kN)	%*	%**
Ref No:1	118	25	-	-
Ref No:2	191.22	75	62.205	200
S-B-25%T	169.65	65	43.771	160
S-B-50%T	186.323	N/A	57.9	-
S-B-25%C	142.19	25	20.5	-
S-B-50%C	156.9	25	32.966	-

% *, ** refers to the percentage of increase in (Pu) and (Pcr) concerning Ref No:1 beam respectively.
N/A not available.

IV.Load-deflection Relationship

The relationship between load and deflection at the midspan of the beam was recorded and drawn in Figures 9-11. The results showed high ductile behavior of the built-up beams with SIFCON at compression zones, proportionally with an increment of the layer depth, influenced by the high compressive strength of SIFCON when they were compared with CC beam (Ref No:1). The placing of the SIFCON layer in the compression zones of built-beams pushed them to behave as under reinforcement beam by more clearly. On the contrary of this, the built-up beams with SIFCON in tension zones showed stiffer behavior attributed by the high tensile strength properties of SIFCON, where the layers at such zones worked as additional reinforcement which was forced these beams to behave as over reinforced beams, with a significant increment in the ultimate load. Ref No:2 which was fully made by SIFCON also showed a high ductile behavior although of using of SIFCON at both compression and tension zones, where the effect of compressive properties had overcome on the effect of tensile properties of SIFCON.

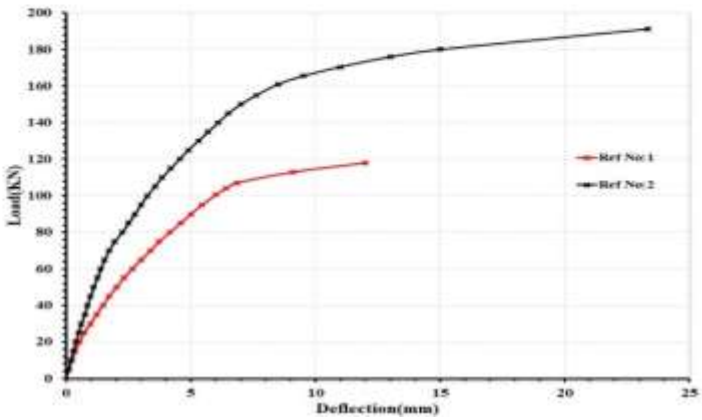

Figure 9: Load-mid span deflection relation of reference beams

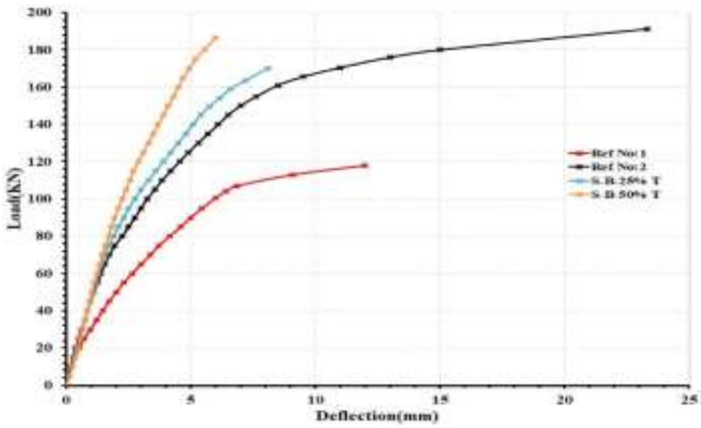

Figure 10: Load-mid span deflection relations of built-up beams with SIFCON in the tension zone

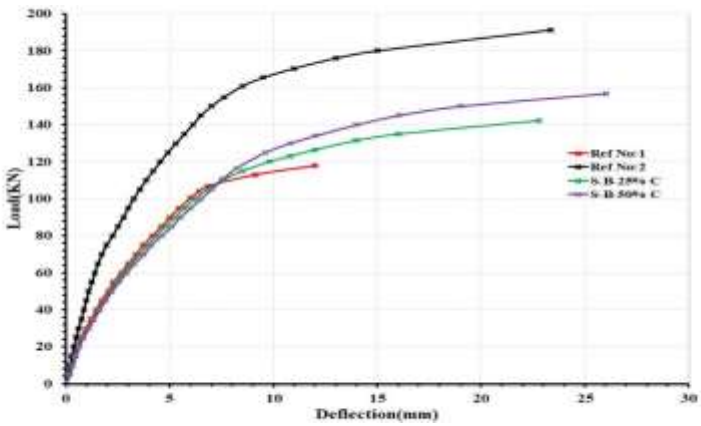

Figure 11: Load-mid span deflection relations of built-up beams with SIFCON in the compression zone

V.Ductility and Energy Dissipation

Ductility of reinforced concrete members can be described as the ratio of the mid-span deflection at the ultimate load (Δu) to the mid-span deflection at the yielding of steel (Δy), as Salmon et al. [24] reported. Table 6 shows the ductility results of the tested beams, which confirm the detected relationships between the load and mid-span deflection of these beams.

Table 6: Ductility results

Beams	Δy (mm)	Δu (mm)	μΔ	% μΔ
Ref No:1	6.85	12	1.751	-
Ref No:2	7.63	23.35	3.060	+74.757
S-B-25%T	6.1	8.1	1.327	-24.214
S-B-50%T	##	6	-	-
S-B-25%C	7.52	22.78	3.029	+72.986
S-B-50%C	8.2	26.01	3.171	+81.096

not yield.

The discussion of the energy dissipation concept necessary to get more understanding about the flexural performance of the beams. The Area under the load-mid span deflection curve represents the energy dissipation capacity. The results show high energy dissipation capacity for built-up beams with SIFCON in compression zones affected by the high compressive strain of SIFCON (ε_{cu}) which was reached to 0.00725 according to the modulus of elasticity test, which led these beams to sustained further more deflection till failure occurred by concrete crushing with increasing in the area under the curve as shown in Table 7 and Figure 12. This is an important parameter indicating the toughness provided by SIFCON as a consequence of the beam ductility.

Table 7: Energy dissipation results

Beams	Energy dissipation capacity(KJ)	%*
Ref No:1	1.033	-
Ref No:2	3.573	+200.441
S-B-25%T	0.913	-12.054
S-B-50%T	0.676	-34.872
S-B-25%C	2.510	+100.417
S-B-50%C	3.132	+200.017

%* refers to the percentage of increase or decrease in Energy dissipation capacity with respect to Ref No:1beam.

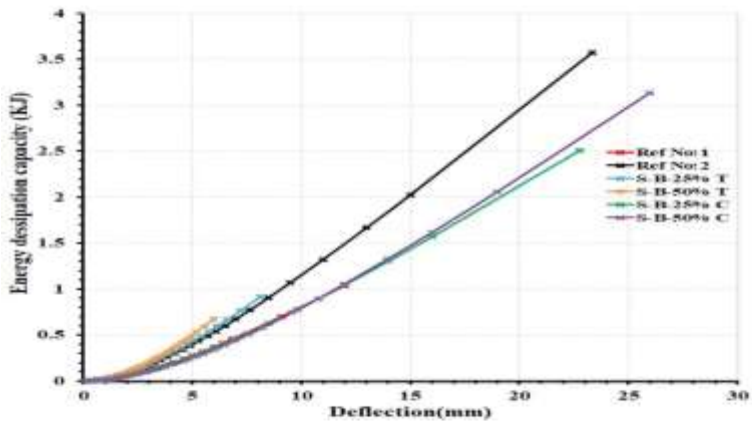

Figure 12: Energy dissipation capacity vs. mid-span deflection curves for the beams

VI.Failure Modes and Crack Patterns

Failure modes and Crack patterns of the examined beams are illustrated in Figure 13. All the beams failed by yielding of steel followed by crushing of the concrete at the compression zones, except S-B-50 % T beam, it failed by only crushing of the concrete. The main reinforcement did not reach to yielding stage influenced by additional tensile strength provided by the layer of SIFCON. The crushing process was varied from explosive crushing in CC to non-explosive crushing in SIFCON due to the existence of fibers. Regarding crack patterns of Ref No:1, S-B-25% C, and S-B-50% C beams, the Crack was initiated at the tension face of the middle third of the beam with expansion to the adjacent shear spans with further loading affected by the increase of the depth of SIFCON layer. While Ref No:2, S-B-25% T, and S-B-50% T beams showed a lees number of cracks proportionally with the increase of the SIFCON layer depth at the tension zones.

a) Failure mode of Ref No: 1 beam.

b) Failure mode of Ref No: 2 beam.

c) Failure mode of S-B 25 %T beam.

d) Failure mode of S-B 50% T beam.

e) Failure mode of S-B 25% C beam.

f) Failure mode of S-B 50% C beam.

Figure 13: Failure modes and crack patterns of all tested beams.

5. Conclusions

According to the above discussions about the experimental results, the conclusions can be drawn below.

1) It is possible to produce Slurry infiltrated fiber concrete (SIFCON) with a flexural strength of 28.062 MPa and splitting tensile strength of 18.132 MPa by using a high volumetric ratio of steel fibers. With the capability to get further enhancements in the above features by utilizing other types of steel fibers, which may lead to an increase in this ratio and therefore improve the tensile properties of SIFCON.

2) The compressive properties of SIFCON also influenced by the high volumetric ratio of steel fibers especially the compressive strain which was reached to 0.00725 compared with the same strain of CC which was 0.002, where represents a significant difference.

3) It is clearly shown that the first cracking load increases when using SIFCON at tension zones of the built-up beams, and in beam which was fully made by SIFCON. The increment of the first crack load of S-B-25% T beam was 160 %, comparing with Ref No:1 beam which was fully made by CC, while the increase in SIFCON layer depth in S-B-50 % T beam leads to minify the number of cracks, which affirm the increment of the first crack load, but it is not visible.

4) The results show the efficiency of using SIFCON at tension zones toward more load- carrying capacity proportionally with the increment in the SIFCON layer depth, further than use it in compression zones.

5) A high ductile behavior appeared when SIFCON was used at the compression zones of built-up beams, although of a slight increment in the load-carrying capacity if they were compared with built-up beams with SIFCON at tension zones since these beams sustained more deflections till the failure occurred by crushing of concrete with a high energy dissipation capacity.

References

[1]D.R. Lankard, " Slurry Infiltrated Fiber Concrete (SIFCON),"Concrete International, V. 6, No. 12, Dec. 1984, Pages 44-47.

[2].C. Josifek, and D.R. Lankard, " SIFCON: Slurry Infiltrated Fibrous Concrete," Proceedings of the Symposium on Fiber Reinforced Concrete, Madras, India, Dec. 1987, Pages 715-723.

[3].M. Sonebi, L. Svermova, and J.M. Bartos , "Factorial design of cement slurries containing limestone powder for self-consolidating slurry infiltrated fiber concrete" ACI material journal, Vol. 101, No. 2, March-April 2004, Pages 136-145.

[4].P. Deepesh, and K. Jayant, "Study of mechanical and durability properties of SIFCON by partial replacement of cement with fly ash as defined by an experimental based approach" International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5, Issue 5, May 2016, pp.7.

[5].M. E. Elnono, H. M. Salem, A. M. Farahat, and A. H. Elzanaty, “Use of slurry infiltrated fiber concrete in reinforced concrete corner connections subjected to opening moments.” Journal of Advanced Concrete Technology, Vol. 7, No. 1, 2009, Pages 51-59.

[6].R. Z. Al-Rousan, and M. J. Shannag, “Shear Repairing and Strengthening of Reinforced Concrete Beams Using SIFCON.”Journal of The Institution of Structural Engineers, Vol.14, June 2018, Pages 389-399.

[7].S. Balaji, and G. S. Thirugnanam, “Behaviour of Reinforced Concrete Beams with SIFCON at Various Locations in the Beam,” KSCE Journal of Civil Engineering, Vol.22(1),2018, Pages 161-166.

[8].Haritha.BP, and V. Saathappan, “Comparing Flexural Performance of Concrete Composite Beams with “SIFCON” and “ECC,” International Journal of Applied Engineering Research, ISSN 0973-4562, Volume 14, Number 12, 2019, Pages 34-39.

[9].ACI Committee 318, “Building Code Requirements for Reinforced Concrete (ACI 318M-95) and Commentary (ACI 318RM-95)”, American Concrete Institute, Detroit, 1995.

[10] ASTM C150M-15, “Standard Specification for Portland Cement,” Annul. Book. ASTM Stand, 2015, 8p.

[11] Iraqi Specification, No. 5/1984, “Portland cement,” Ministry of Planning, Central Organization for Standardization, and Quality Control, 1984.

[12] ASTM C33M-13, “Standard Specification for Concrete Aggregates,” 2013, 11p.

[13] Iraqi Specification, No.45/1984, “Aggregate from Natural Sources for Concrete and Construction,” Ministry of Planning, Central Organization for Standardization, and Quality Control, 1984.

[14] ASTM C 1240-15, “Standard specification for silica fume in cementitious mixtures,” 2015, 7p.

[15] ASTM C494/C494M –15, “Standard specification for chemical admixtures for concrete,” Vol. 04.02, 2015, 10p.

[16] ASTM A820M-11, “Steel fibers for fiber-reinforced concrete,” 2011, 4p.

[17].ASTM A1064M-14, “Standard specification for carbon-steel wire and welded wire reinforcement, plain and deformed for concrete,” 2014, 11p.

[18] ACI Committee 211.1-91, “Standard practice for selecting proportions for normal, heavy weight, and mass concrete”, 1991.

[19] ASTM C39/C39M - 15a, “Standard test method for compressive strength of cylindrical concrete specimens,” Vol. 04.02, 2015, 7p.

[20] British Standard 1881, Part 116, “Method for determination of compressive strength of concrete cubes,” British Standards Institution, 1881,1989, pp.3.

[21] ASTM C496/C496M - 11, “Standard test method for splitting tensile strength of cylindrical concrete specimens,” Vol. 04.02, 2011, 5p.

[22] ASTM C469/C469M – 14, “Standard test method for static modulus of elasticity and poisson’s ratio of concrete in compression,” Vol. 04.02, 2014, 5p.

[23] ASTM C78/C78M - 15a, “Standard test method for flexural strength of concrete (using simple beam with third-point loading),” Vol. 04.02, 2015, 4p.

[24] C.G. Salmon, J.E Johnson, and F.A Malhas, “Steel structures: design and behavior,” Pearson Prentice Hall, 5th ed, New Jersey, 2009.