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Behavior Study of SIFCON-Reinforced Concrete Composite Brackets under Repeated Load

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Abstract

This study investigates the performance and ductility of concrete brackets made of normal concrete and fiber-reinforced concrete (SIFCON) composites. SIFCON was used to strengthen the brackets under monotonic and repeated loads. Eleven bracket specimens, including homogeneous and hybrid reinforced specimens, were tested. Two of them are control specimens tested under static load to determine the ultimate load for defining the repeated loads. The other nine specimens are classified into three groups based on the SIFCON reinforcement shape, with each group containing three steel fiber percentages (6%, 4%, 2%).Where in group A the SIFCON used for the entire volume of the bracket, in group B the SIFCON used in rectangle shape in tension zone of the bracket, and in group C the SIFCON used in trapezoidal shape.

The study focused on determining the maximum load capacity, load-deflection relationship, toughness, strain, first crack load, and failure mode of each specimen at the final stage. It is observed that using SIFCON had a significant effect on the structural response of concrete brackets. The strengthening increased the ultimate load capacity of the best tested model for group A under repeated load up to 3.2 times the control model's capacity after 21 loading cycles. In the group B&C the maximum load up to (2 and 1.8) times the control model's capacity after (17 and 13) loading cycles. There is also a substantial increase in absorbed energy and toughness of concrete brackets when using this type of reinforcement, up to 31 times for group A and (19 and 9) times for group B and C respectively . Additionally, a reduction in the width of concrete cracks was observed. The use of SIFCON resulted in an increase in the amount of endurance for repeated loads and an increase in the amount of strain. This is due to its higher strain capacity compared to normal concrete and its greater flexibility.

Keywords: *SIFCON, Bracket, Steel fiber, Strengthen, repeated, Monotonic.*

1- Introduction

Concrete brackets are critical load-bearing elements in construction that are prone to sudden shear failures. Past research has sought to enhance the structural performance of concrete brackets using fiber-reinforced polymers (FRP), steel reinforcements, and specialized concretes. However, these methods have limitations in improving ductility and ease of application in existing structures. This paper investigates the potential of slurry-infiltrated fiber concrete (SIFCON) to strengthen concrete brackets against brittle shear failure. SIFCON is a high-strength strain-hardening cementitious composite with

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superior tensile and shear behavior because a large volume percentage of uniformly dispersed steel fibers. [1]

While the effectiveness of SIFCON in flexural strengthening is well documented, experimental data on its shear strengthening capabilities is limited. This paper aims to address this gap through an experimental study on the structural response of SIFCON-reinforced brackets under realistic loading conditions. The results are expected to demonstrate that SIFCON jacketing can significantly enhance the shear strength and ductility of concrete brackets. This technique could provide an efficient strengthening solution for existing substandard brackets vulnerable to sudden shear failure. The findings will advance knowledge on the use of SIFCON for shear strengthening applications in new construction and the strengthening of existing infrastructure.

2- Experimental Program

An experimental programs consists of casting and testing 11 bracket models with the same dimensions. One model was made entirely of normal-weight reinforced concrete to serve as a control specimen. Four models were cast using SIFCON material. The remaining six models were made of normal-weight reinforced concrete and strengthened with SIFCON in different configurations. All of the specimens had a shear span-to-depth ratio of 0.89 and were designed in accordance with ACI 318-M-14 guidelines. [2]

According to the strengthening plan, the SIFCON-strengthened specimens were classified into three groups; each group had three specimens different in content of steel fibers (2%, 4%, and 6%) by volume. The first group was strengthened on all sides with SIFCON material. The second group was strengthened with SIFCON only in the critical shear spans in a rectangular pattern. The third group was strengthened with trapezoidal-shaped SIFCON enclosing the critical diagonal shear crack zone. All nine specimens were subjected to repeated loading cycles until failure. To see how well SIFCON improves shear strength and toughness, A control specimen was used to compare the behavior of the SIFCON-enhanced brackets.

2-1 Dimensions of specimens

The scale of the specimens under test was about a third of a bracket off from the real project design. The load was applied to the column linking the brackets during testing of the double brackets, and the reactions of the supports served as the loads applied to the brackets. The bracket's shear span from the face of the column was 200 mm. The bracket portion measured 150 mm in width and 200 mm in depth. 2 8 mm deformed longitudinal steel bars placed an effective 171 mm from the bracket's compression side served as the primary tension reinforcement, or Asc, for all brackets. At the end height of the bracket, the secondary reinforcement, Ah, consisted of a closed, horizontal stirrup-shaped piece of 1/8-mm deformed steel bar. The column segment was strengthened with four primary deformed steel bars measuring 12 mm in diameter and stirrups measuring 10 mm in diameter, spaced 100 mm apart. In all directions, the concrete cover was set at 25 mm. and the supports were placed 150 mm from the column face. Figure (1) displays the research specimen's specifics. As seen in Figure (2), the brackets were put through their paces while supporting the vertical load, P, on the top of the column. The weights applied to the bracket were represented by the reactions of the supports, or V.

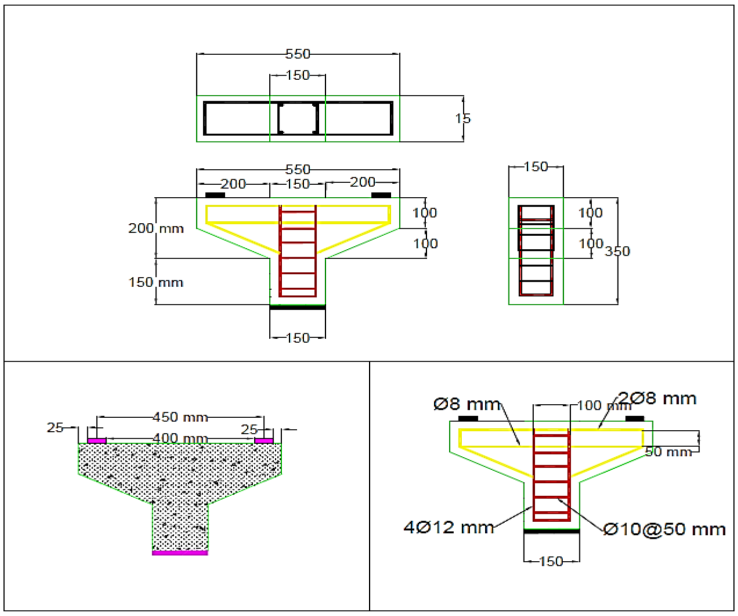


Figure (1) Dimension of bracket and detail of reinforcement steel bars

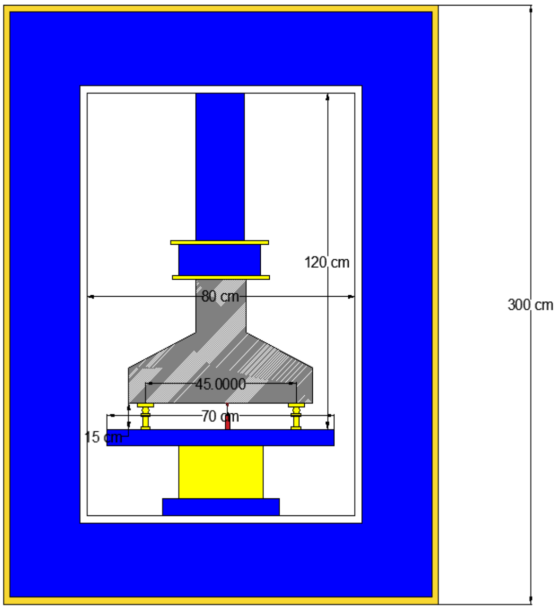


Figure (2) the brackets were tested in an inverted position

2-2 Technical strengthening

In the current study, experimental research discusses The way brackets behave structurally when using normal concrete and SIFCON in the presence of reinforcing steel. Fixed shape and dimensions for all brackets. Two specimens were tested, one of ordinary concrete with an average compressive strength of 21 MPa and the other of SIFCON with a steel fiber ratio of 6%, under a monotonous load. Nine brackets reinforced by SIFCON were tested under repeated loads. The models were divided into three groups according to the form of reinforcement, and each group contains different percentages of steel fiber. See table (1). Figure (3)

Tables (1): Details of the Tested Brackets.

Group	Bracket Designation	Loading Regime	Concrete Type	Percentage Of Steel Fiber
CONTROL	N.C	Monotonic	NC	0%
	S.C		SIFCON	6%
A	F.S.6	Repeated	SIFCON	6%
	F.S.4			4%
	F.S.2			2%
B	R.S.6	Repeated	SIFCON	6%
	R.S.4			4%
	R.S.2			2%
C	T.S.6	Repeated	SIFCON	6%
	T.S.4			4%
	T.S.2			2%

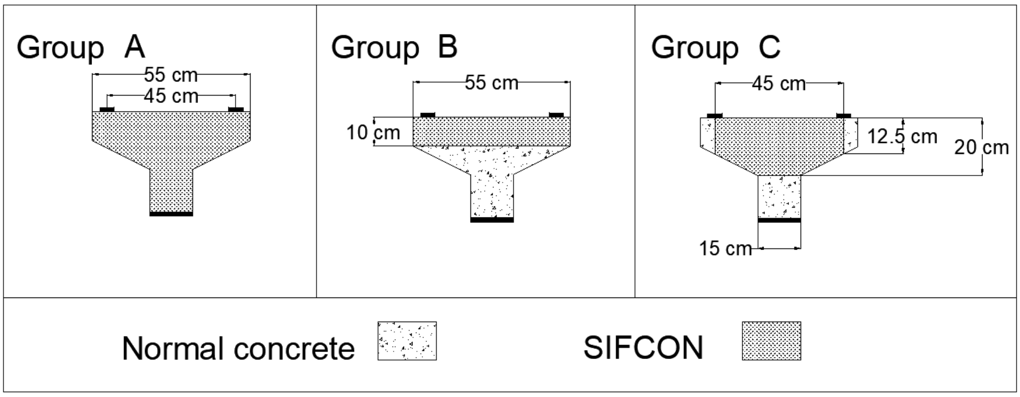
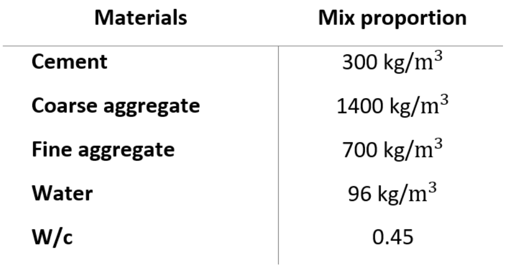


Figure (3) Shape of strengthening Brackets for The Three Groups

2-3 proportions of normal concrete mix

In this research, ordinary concrete was used with a mixing ratio of 1:2:4 and according to the weight ratios in Table (2), through which a strength of age 28 equal to (21 MPa) was obtained, and Splitting Tensile Strength (Fsp) is (2.05 MPa)

Table (2): Weight for mixing normal concrete



Materials	Mix proportion
Cement	300 kg/m^3
Coarse aggregate	1400 kg/m^3
Fine aggregate	700 kg/m^3
Water	96 kg/m^3
W/c	0.45

2-4 Slurry Infiltrated Fibrous Concrete (SIFCON)

Known as Slurry Infiltrated Fibrous Concrete, is an innovative and advanced construction material that combines the benefits of both concrete and fiber reinforcement. It is composed of a dense concrete matrix with a high volume fraction of closely spaced and uniformly distributed fibers. SIFCON offers remarkable strength, toughness, and durability properties, making it suitable for a wide range of structural applications. The fibers in SIFCON act as an internal reinforcement, enhancing its load-carrying capacity, crack resistance, and energy absorption capabilities. The slurry infiltration process ensures uniform distribution of the fibers within the concrete matrix, resulting in improved mechanical properties and superior performance compared to conventional concrete. SIFCON finds applications in various fields such as infrastructure development, precast elements, earthquake-resistant structures, and repair and rehabilitation of damaged structures. Its exceptional properties make SIFCON a promising material in the construction industry, contributing to the development of stronger and more resilient structures.

2-4-1 CONSTITUENT MATERIALS

A- Cement

Ordinary Portland Cement which it available in the local market was used. The physical and chemical tests were conducted at the laboratories of College of Engineering at AI-Qadisiyah University. According to the test results of physical and chemical properties, the cement used is conformed to the requirements of the Iraqi specification (IQS NO. 5, 1984)[3]

B- Fine Aggregate (Sand)

As a fine aggregate, ordinary sand was utilized throughout the experiment. To make sure the slurry gets all the way through the thick steel fiber, the sand utilized was passed through a sieve (1.18 mm). It complies with Iraqi Standard No. 45-1984's standards [4]. Zone 2's specific gravity, sulfate content, and absorption are each 0.34%, 2.6, and 2%, respectively..

C- Silica fume (SF)

The BASF Company produces densified silica fume, also known as MEYCO/MS610 in the market, was utilized in this study to partially replace cement. It complies with ASTM C1240-05's requirements [12].

Table (3): Chemical and physical properties for silica fume

Chemical requirement	**value**
SIO3	minimum 85%
H2O	maximum 3%
Lose of ignition (LOI)	maximum 6%
Physical requirement	**value**
specific surface area	minimum 15 m2/g
pozzolanic activity index.7 days	maximum 105% of control
over size particles retained on 45 micron sieve	maximum 10%

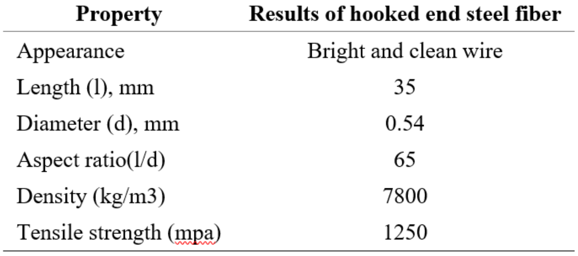
D- Super plasticizer

Super plasticizer was used to improve the workability of SIFCON Superplasticizer manufactured with trade name Glenium c54 by Master Builders was used in the present study. This superplasticizer is developed using nanotechnology based on second generation poly carboxylic ether polymers, the silica fume possesses a fineness of 21,000 m2/kg and complies with the specifications described in ASTM C 1240-03a. [6]

E- Steel Fiber

In this study, a steel fiber with a hooked end that measured 0.54 mm in diameter, 35 mm in length, 65 in terms of aspect ratio, and 1250 MPa in terms of tensile strength was used. In addition, the matrix's fiber placement was arbitrary. [5]

Table (4): Properties of steel fiber



Property	**Results of hooked end steel fiber**
Appearance	Bright and clean wire
Length (l), mm	35
Diameter (d), mm	0.54
Aspect ratio(l/d)	65
Density (kg/m3)	7800
Tensile strength (mpa)	1250

2-4-2 Mix Design

Many trial slurry mixes were done to find a SIFCON mixture that meets the requirements for proper filling, preventing any separation or seepage through the compact fiber bed, and making sure the right fluidity and viscosity. The appropriate range for the amount of steel fibers to be incorporated into the final mortar has been determined after careful consideration, encompassing both the minimum and maximum thresholds. The table labeled (3) displays the proportions of the ingredients used in the mixture, illustrating the ratios chosen for mixing. As recommended by EFNARC [7], these mortar qualities were evaluated using the Mini Slump Flow and V-Funnel tests. The small flow test is utilized to evaluate the mortar's resistance to segregation and followability. The base diameter, top diameter, and height of the mini slump flow testing device in use are 100 mm, 70 mm, and 60 mm, respectively. The recommended spread diameter range for SIFCON mortar is between 240 and 260 millimeters. Using the V-funnel test to determine the viscosity of the slurry, it was determined that a flow duration ranging from 7 to 11 seconds would be suitable for the mortar [7]. The EFNARC publication [7] contains information pertaining to the specific tests. As shown in figure (4), the SIFCON mortars possess a mini-slump flow of 257 mm and a V-flow of 9.5 seconds.

Table (5): Materials contents and proportions for SIFCON mixes

Mix	Cement (kg/m^3)	Sand (kg/m3)	Silica fume (kg/m3)	Steel fiber (%)	Super plasticizer /bonder %	W/b
SIFCON	870	965	96.5	6	2.4	0.22

Figure (4): Tests for SIFCON mortars using miniature slump flows and V-funnels

2-4-3 Test of Hardened Properties of SIFCON Specimens

Laboratory tests were conducted in the laboratory of the University of Al-Qadisiyah, College of Engineering, at the age of 28 days, after completing curing, inside ponds immersed in water at a temperature of 25 °C.

a- Compressive Strength

Cubes of dimensions (150 * 150 * 150) mm are used to determine (fcu) of different types of concrete, is conducted in accordance with ((BS 1881- part 116:2000) [13] and (ASTM C39/39M) [14] (three cubes from normal concrete and four cubes from SIFCON) which were used in the present study at age 28 days. Figure (4) show the range of compressive strength for all types of concrete.

Table (6): Results of Compressive Strength at 28-Days for All Concrete Types

Type of concrete	Steel fiber Vf%	F_{cu} (MPa)	fc' (MPa)
NC	0	25.2	20.9
	0	28.2	23.4
	0	26.3	21.8
SIFCON	6	101.2	85.0
	4	84.3	69.1
	2	69.66	55.7
	0	25.8	21.41

b- Splitting Tensile Strength (Fsp)

The split tensile test was conducted following the guidelines of ASTM C496/C496M (2017)[15] At 28 days of age, a splitting tensile test is performed to examine the tensile strength of SIFCON with volumetric steel fiber ratios of (0%, 2%, 4%, and 6%), the test results for cylindrical specimens of (300*150) mm. The practical values showed that SIFCON has greater tensile properties as compared to normal concrete.

Figure (4-3) describes the effect of the steel fiber volumetric ratio on tensile strength. The significant increase in tensile strength for SIFCON (with different steel fiber contents) is due to binding fiber, which is found naturally, where the mechanism of fiber bridging led to the regulation of micro-cracks. On the other hand, the use of hooked end form of steel fiber results in an improvement in the bond between components of concrete [8].

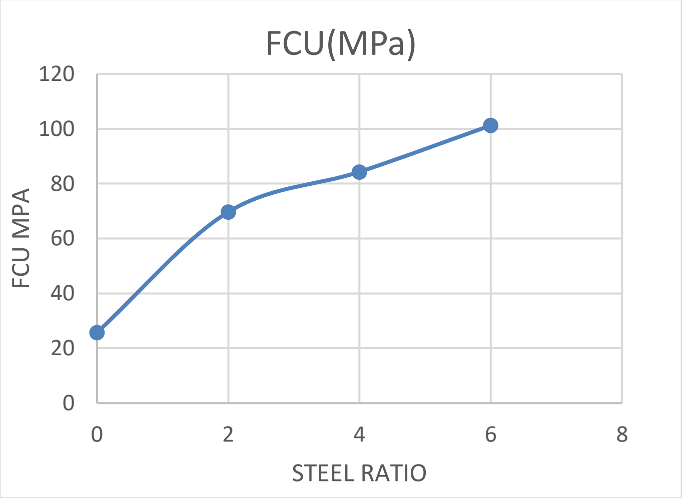


Figure (5): The Compressive Strength Results for SIFCON Specimens

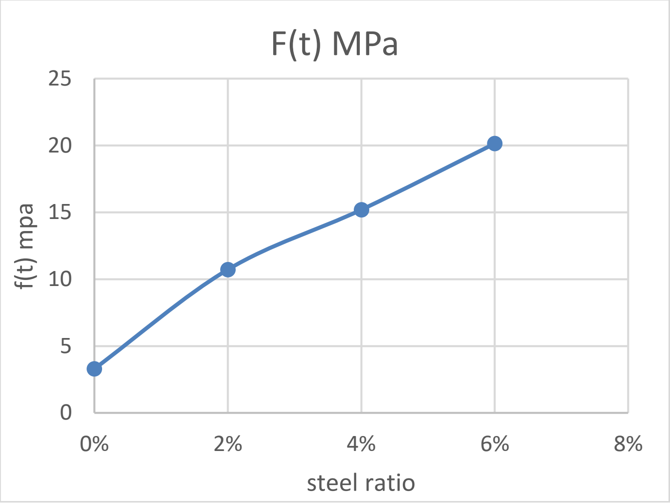


Figure (6): The tensile strength results for SIFCON specimens

3- Preparation of SIFCON Specimens for Casting and Curing

The pre-placement of fibers in the molds was the first step in creating SIFCON specimens. The molds were then filled with cement mortar, which had to be able to pass through the tightly packed fiber matrix. The SIFCON matrix was supplemented with steel fiber using the multi-layer approach. This method was discovered to be more practical and user-friendly than the single method, particularly when employing a large volume of steel fiber. This technique entailed inserting the fibers halfway into the mold and then partially filling it with mortar. The mold was then vibrated to prevent voids from forming. The use of an electric mixer is shown in the accompanying figure (7).

Figure (7) an electric mixer

To ensure that the SIFCON mortar has completely penetrated the fiber pack. Size, desired volume fraction, and steel fiber density all influence how much steel fiber should be used in each mold. The specimens were cast and then kept in the lab for 24 hours before being demolded, tagged, and examined.

The casting process for Groups B and C, which consist of normal concrete and SIFCON, was done by first pouring the normal concrete followed by spreading the steel fibers in a layer and placing the cementitious mortar, repeating until the required level was reached. Model B was cast vertically, which is closer to real-world practice, while Model C was cast horizontally. For Model C, the normal concrete was poured first and isolated temporarily using thin wooden boards. The steel fibers and cementitious mortar were then placed in layers then the wooden pieces were lifted and the face of the model was modified.

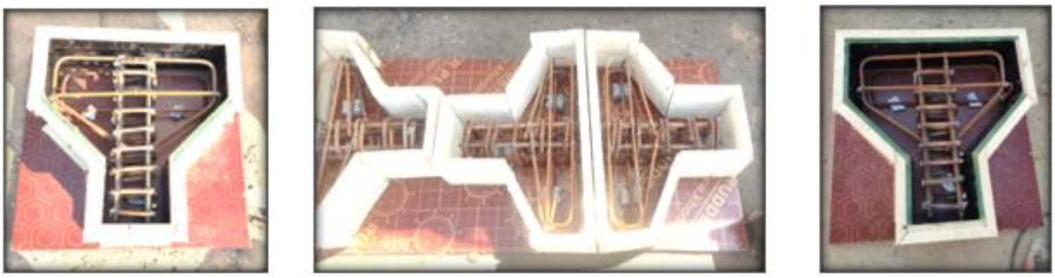


Figure (8) Wood molds

a b

Figure (9) (a) Grease the molds, (b) electric vibrator

Figure (10): Casting and Curing the specimens

4- Uni directional Repeated Loading Regime

The load control investigation approach was applied in the unidirectional repeated loading regime of this study. The control specimens' failure load during testing with a constant load, was used to figure out the planned repeated loading value. During The applied load is gradually increased after each cycle of loading until it reaches the required value. , which was a small portion of the failure load of the control specimen used in monotonous testing, and then the load is gradually dropped until it reaches zero . The cycles were repeated in line with the selected load history until failure occurred. The chosen percent’s were 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 95%. Each of these percentages will be used for three rounds, while the 95% will be used for one cycle [16].

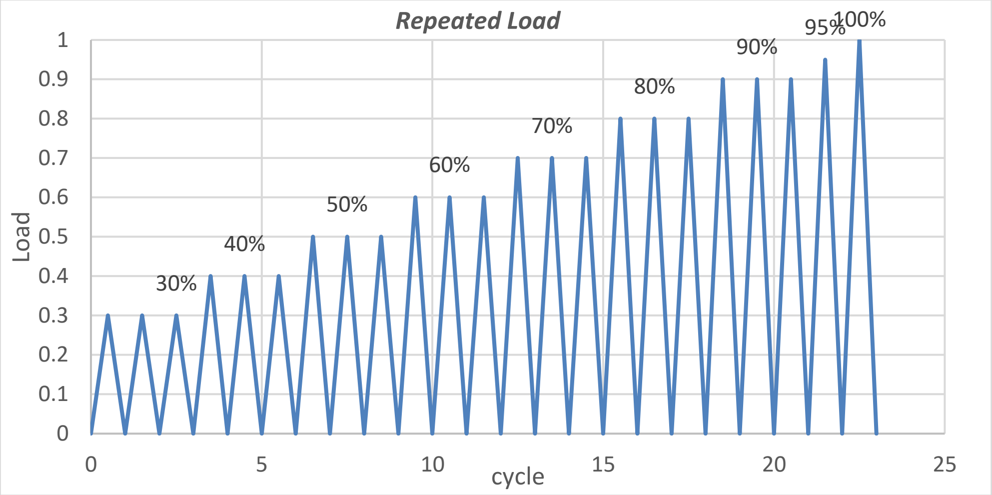


Figure (11) repeated load system

5- Test Results

This section will provide a summary of the experimental program's findings. The significance of the experimental variables will be assessed by comparing them. The best configuration should be chosen by carefully examining each failure load and cracking pattern. Following a thorough explanation of the behavior of the control specimens, a brief explanation of each of the other specimens' modes of failure is provided. Flexural cracks that started at the point where the tension face of the bracket and the face of the column met were the first to appear in all brackets. Vertical or diagonal cracks were the first to form, followed quickly by diagonal cracks. Table (6) displays the cracking load, ultimate load, failure modes, and ultimate stage deflection. A discussion of the findings for each group is presented in the sections that follow.

5-1 Control Bracket

5-1-1 Normal Concrete Control

One normal concrete bracket has been tested under monotonic load. Shear span to effective depth ratio (a/d) was (0.87), and the main tension reinforcement used was (2Ø8 mm), (1Ø8 mm) as horizontal closed stirrups. The ultimate load for this bracket was (146.4 KN) and it is noted that the form of failure is Shear failure. Consider the ultimate load from this specimen as a guideline when applying the repeated load to other specimens.

Figure (12) Normal Concrete Specimen (failure mode)

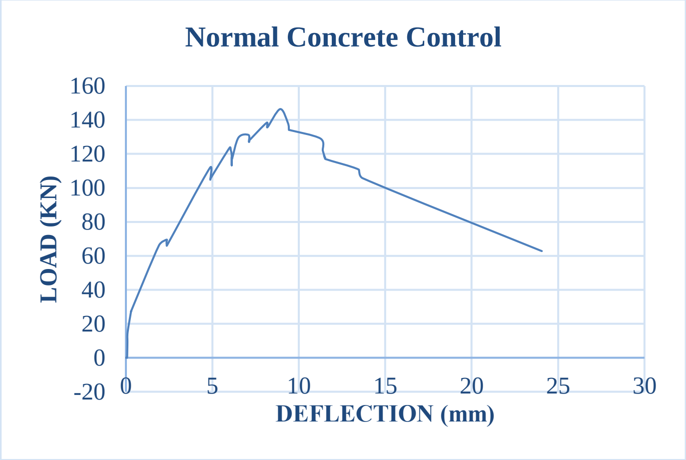


Figure (13): Load-deflection response for Normal Concrete Specimen

5-1-2 Full SIFCON Specimen (Control)

One full SIFCON bracket has been tested under monotonic load. The main tension reinforcement was (28 mm) and the shear span to effective depth ratio (a/d) was (0.87), (2∅8 mm) as horizontal closed stirrups. The ultimate load for this bracket was (502.1 KN) and it was noted that the form of failure was Flexural failure. Consider the ultimate load from this specimen as a guideline when applying the repeated load to other specimens.

Figure (14) Full SIFCON Specimen (failure mode)

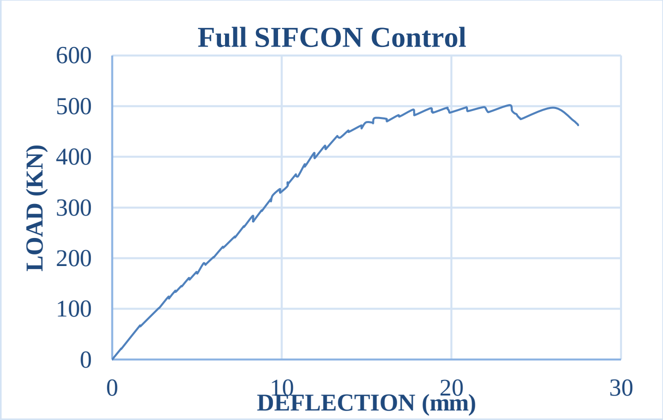


Figure (15): Load-deflection response for Full SIFCON Control

In the first specimen made of normal concrete, the tensile strength was relatively low (3 MPa) compared to the compressive strength (21 MPa). Therefore, the specimen failed in shear as the shear stresses exceeded the low tensile strength. However, in the second specimen containing SIFCON, the tensile strength was significantly increased (21 MPa) in addition to the higher compressive strength (85 MPa).This resulted in an increased tensile to compressive strength ratio, making the specimen more resistant to shear failure. Therefore, the type of failure shifted from shear failure to flexural failure, as the flexural stresses exceeded the flexural strength of the material due to its increased tensile resistance. The use of materials with high tensile strength like SIFCON increases the resistance of concrete elements to brittle failures such as shear failure.

Table (6): Experimental Results of the Tested Specimens.

Group Specimen	Bracket Symbol	Steel fiber ratio (%)	NO.CICYLE at failure	Cracking Load Per Bracket (KN)	Ultimate Load Per Bracket (KN)	Deflection (mm) Δu	Cycle load FOR FIRST CRACK	Crack Width	Mode of Failure
Control Bracket	**S.C**	**6**	**--**	**170**	**502.1**	**23.43**	**C1**	**0.1**	**Flexural**
	N.C	**0**	**--**	**123**	**146.4**	**8.92**	**C1**	**0.45**	**Shear**
A	**F.S.6**	**6**	**c21**	**200**	**476.8**	**16.96**	**C6**	**0.15**	**Flexural**
	F.S.4	**4**	**c16**	**200**	**339.2**	**18.65**	**C4**	**0.23**	
	F.S.2	**2**	**c11**	**150**	**268.2**	**24.92**	**C2**	**0.35**	
B	**R.S.6**	**6**	**c15**	**197**	**295.6**	**29**	**C7**	**0.34**	**Flexural**
	R.S.4	**4**	**c14**	**200**	**306.9**	**24.86**	**C4**	**0.41**	
	R.S.2	**2**	**c10**	**150**	**254**	**29.94**	**C3**	**0.47**	
C	**T.S.6**	**6**	**c13**	**150**	**270.2**	**7.74**	**C6**	**0.43**	**Shear**
	T.S.4	**4**	**c7**	**150**	**166.7**	**6.1**	**C5**	**0.47**	
	T.S.2	**2**	**c6**	**100**	**176**	**5.41**	**C2**	**0.48**	

5-2 Test Results of Strengthened Specimens

To investigate the effect of using SIFCON on normal concrete brackets, three groups (A, B, and C) of brackets are strengthened by SIFCON as shown in Table (3-2) showing the places and forms of strengthening. Specimens in this groups are reinforced with (2-Ø8mm) as the primary reinforcement and (1- Ø8mm) horizontal stirrups on each side. The test results for these specimens are described in this section.

5-2-1 Test Results of Group A (full Strengthened with SIFCON

Group (A) Specimens (F.S.6), (F.S.4) and (F.S.2).

Regarding group (A), the model (F.S.6) is the best model in the group in terms of the ultimate load and in terms of the number of cycles it was examined under the influence of (21) cycles up to the ultimate load. While the worst model in group (A) is (F.S.2) in terms of the ultimate load and the number of cycles that failed Specimen It was observed in all three specimens that the form of failure was Flexural failure. The reason for this difference in results between specimens of the same group is due to the volume of steel fraction and its distribution within the model and the mechanism of correlation between steel fiber and other concrete components which generated a difference in compressive and tensile strength. As shown in the table (6)

a) Specimen (F.S.6) b) Specimen (F.S.4) c) Specimen (F.S.2)

Figure (16) Group (A) Specimens mode failure a- (F.S.6), b- (F.S.4), c- (F.S.2).

5-2-2 Test Results of Group B (Rectangular Strengthened with SIFCON (

Group (B) Specimens (R.S.6), (R.S.4) and (R.S.2).

Group B specimens showed that RS6 specimen had the highest ultimate load capacity and number of loading cycles, reaching 15 cycles, while RS2 was the weakest among them. The mode of failure for the three specimens was flexural failure in the mid span region between the two supports in addition to the failure that occurred in the confined region between the column and the strengthened area made of normal concrete. The reason for this difference in results between specimens of the same group is attributed to the steel fiber content, which resulted in variations in the compressive and tensile strength and their distribution within the specimen, as well as the bond mechanism between the steel fibers and other concrete constituents. As shown in Table (6)

a) Specimen (R.S.6) b) Specimen (R.S.2) c) Specimen (R.S.2)

Figure (17) Group (B) Specimens mode failure a- (R.S.6), b- (R.S.4), c- (R.S.2)

5-2-3 Test Results of Group C (Trapezoid shape Strengthened with SIFCON)

Group(C) Specimens (T.S.6), (T.S.4) and (T.S.2).

Regarding group (C), the model (T.S.6) is the best model in the group in terms of the ultimate load and the number of cycles it was examined under the influence of (13) cycles up to the ultimate load. While the worst model in group (C) is (T.S.2) in terms of the number of cycles that failed Specimen It was observed in all three specimens that the form of failure was shear failure. The reason for this difference in results between specimens of the same group is due to

- The volume of steel fiber which generated a difference in compressive and tensile strength Distribution within the model
- Mechanism of correlation between steel fiber and other concrete components
- The failure occurred within the bonding zone between normal concrete and SIFCON

As shown in figure (18)

a) Specimen(T.S.6) b) Specimen (T.S.4) c) Specimen (T.S.2)

Figure (18) Group(C) Specimens (T.S.6), (T.S.4) and (T.S.2) (failure mode)

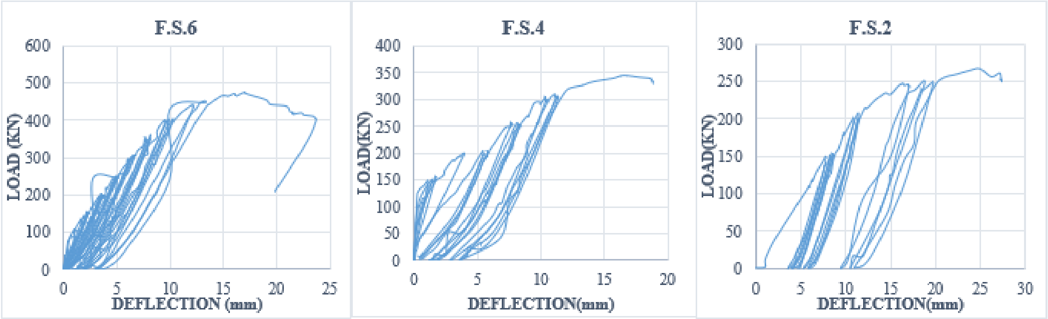


Figure (19): Load-deflection response for bracket in group (A)

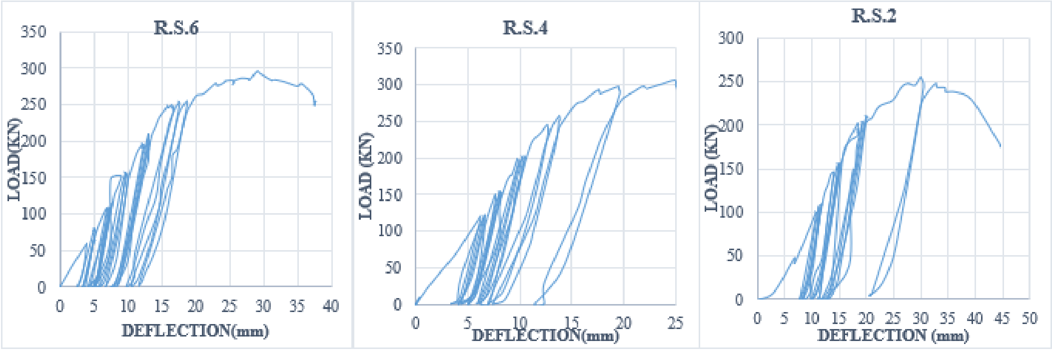


Figure (20): Load-deflection response for bracket in group (B)

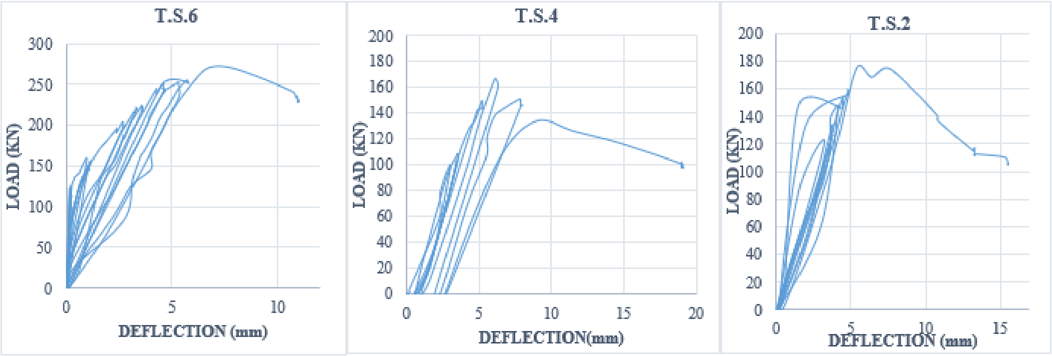


Figure (21): Load-deflection response for bracket in group (C)

5-3 Cracking Load and Crack Width

The first cracks in all brackets are shear cracks that start at or near the junction of the tension face of the bracket and the face of the column except the (R.S.6 &R.S.4) the first cracks are flexural cracks that start at or near mid distance between supports. The first crack width with the load is shown in Table (6).An increase in the width of the first crack was observed in each group with a decrease in the percentage of steel fiber, as in the figure (22). At the same time, there is a difference in the width of the crack between the three groups.

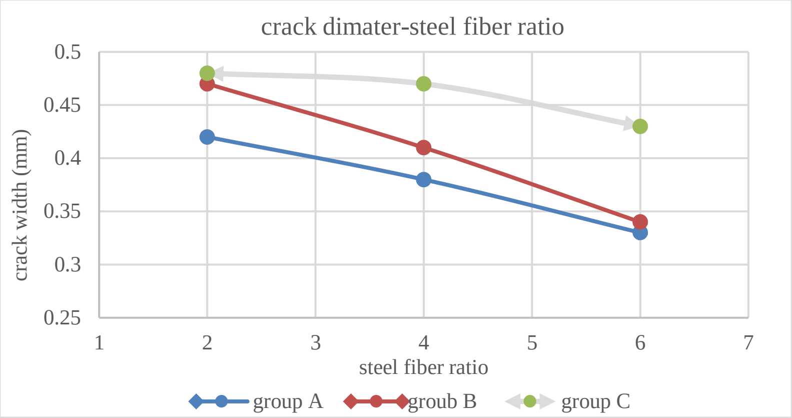


Figure (22) first crack width with steel fiber ratio

If the results in group A are compared with the control model NC, we notice a decrease in crack width in proportions .As for group B, there was a decrease in crack width only for steel fiber ratios (4%, 6%), while a 2% increase in it was shown in Figure (23). In group C, the crack width was increasing, and the reason is often attributed to the shape of the reinforcement, which formed a contact area between the regular concrete and the siphon, parallel to the failure line, as in Figure (23).

Generally, steel fibers are effective in reducing crack width and improving crack load in concrete. When used correctly, steel fiber acts as a bridge between microscopic cracks in concrete, promoting uniform stress distribution and reducing crack development. At low fiber volumes (<2%), the reduction in crack width is minor, but becomes more significant at higher volumes (4-6%). Fibers help transfer stresses across cracks through deboning and pullout resistance. This improves toughness and ductility

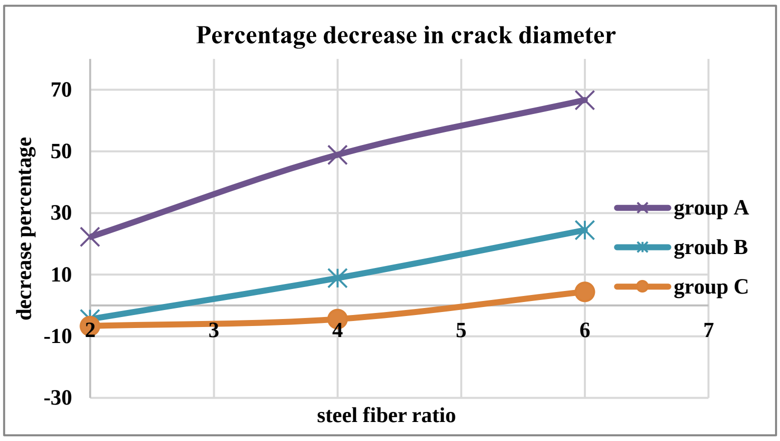


Figure (23) Percentage difference in crack width

6-Toughness

Toughness is one of the most important mechanical properties of materials, as it refers to the ability of a material to absorb energy and resist fracture when subjected to stresses and loads. Toughness is closely related to the Load-Deflection Curve, which shows the relationship between the applied stresses on a material and the resulting strains or deformations. The area under the Load-Deflection curve represents the total energy absorbed by the material. The larger this area, the more energy the material can absorb before breaking, and hence the higher its toughness. [9]

Typically, toughness is calculated by taking the total area under the curve in the case of static loading. However, in the case of cyclic or dynamic loading, the material exhibits an accumulated deformation with repeated loading, resulting in hysteresis loops in the curve. In this case, toughness is calculated from the sum of the areas of the hysteresis loops [10] .The higher the toughness of a material, the more durable and capable it is of withstanding stresses without breaking. Therefore, measuring toughness is extremely important for determining the performance efficiency and fracture resistance of engineering materials. Toughness in Brackets. The importance of measuring and studying toughness in reinforced concrete brackets comes from the fact that these structural elements are subjected to high loads and stresses. The higher the toughness of the bracket material, the more resistant it is to fracture when subjected to these loads and stresses during use in structures. Therefore, toughness measurement tests must be carried out on bracket manufacturing materials before they are used to ensure they can withstand design loads without breaking or failing. The results of these tests also help in selecting the most suitable materials that provide the highest levels of toughness and durability. Table (7) shows the toughness values for all brackets that tested under repeated loads. As compared to the control bracket.

Table (7) Toughness for all brackets under repeated loads

Bracket Symbol		Toughness KN.mm	Increase over NC bracket %
Control	**NC**	1800	--
	SC	6300	250
A	**FS6**	73500	3983.3
	FS4	4125	129.1
	FS2	2250	25
B	**RS6**	37500	1983.3
	RS4	5400	200
	RS2	3375	87.5
C	**TS6**	18000	900
	TS4	4050	125
	TS2	2400	33.3

The amount of toughness in all models is higher than the control model, and this is often due to the presence of steel fiber and the loading method that provides multiple rings that accumulate cumulatively on top of each other. The highest rate of increase was observed in group A of the fs6 model by 39 Weakness and the lowest in the same group for the specimen fs2 by 1.25 time and this discrepancy in the same group is due to the percentage of steel fiber as well as the number of cycle and the amount of deformation that occurred. Through the same table, we note that the best models that contain a percentage of steel fiber by 6% . This is because fibers can bridge both small and large cracks. This allows emerging loads to be transferred, which increases the maximum load and the area of load deflection curves [11]. The growth in load and improvement in stiffness beyond yielding may be the causes of the rising toughness. Therefore, it can be said that using steel fiber in composite brackets improves the specimens' ability to absorb energy as well as their ductility. In order to measure the areas under the curve of the load - deflection, artificial intelligence (Claude) was used. “Claude is a large language model (LLM) built by Anthropic. It's trained to be a helpful, honest, and harmless assistant ".The programs were fed values for the load-deflection curve and provided the application with information to accurately calculate areas under the curve. The results were checked for a number of samples and it was found that the application worked well. And the possibility of reliability in Toughness calculations for repeated loads

7- Conclusion

This study demonstrated the effectiveness of strengthening concrete brackets using Slurry Infiltrated Fiber Concrete (SIFCON). The experimental program evaluated different SIFCON strengthening configurations under realistic repeated loading. The key findings are:

- Full encasement with SIFCON provided the maximum enhancement in shear strength (226%) and ductility (95% increase in cycles to failure) compared to unstrengthen specimens.
- Partial SIFCON jacketing in critical spans also showed substantial improvements in strength and ductility over control specimens.
- SIFCON strengthening significantly reduced crack widths, by up to 70% compared to unstrengthen brackets.
- Brackets strengthened with higher volumes of steel fibers (6%) exhibited superior performance in terms of strength and toughness.
- The bond zone between concrete substrate and SIFCON jacket was identified as a critical area influencing failure mode.

The structural improvements demonstrate the excellent potential of SIFCON for strengthening concrete brackets susceptible to sudden shear failures. SIFCON jacketing is an effective technique to enhance shear strength, ductility and damage tolerance. Further research can optimize SIFCON strengthen configuration and explore durability under sustained loading. The findings provide an important basis for implementing SIFCON strengthening of substandard concrete brackets in construction and rehabilitation of infrastructure.

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