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Flexural Behavior of Reinforced Concrete Beams Reinforced with 3D-Textile Composite Fiber

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ABSTRACT

Normal concrete is weak against tensile strength, has low ductility, and also insignificant resistance to cracking. The addition of diverse types of fibers at specific proportions can enhance the mechanical properties as well as the durability of concrete. Discrete fiber commonly used, has many disadvantages such as balling the fiber, randomly distribution, and limitation of the Vf ratio used. Based on this vision, a new technic was discovered enhancing concrete by textile-fiber to avoid all the problems mentioned above. The main idea of this paper is the investigation of the mechanical properties of SCC, and SCM that cast with 3D AR-glass fabric having two different thicknesses (6, 10 mm), and different layers (1,2 layers). As well as micro-steel fiber with 1.25% volume fraction was used. Sixteen rectangular reinforced concrete beam specimens have been tested to study the behavior of their flexural strength. The results concluded that utilizing 3D-TFs with mortar mixture gave significantly higher enhancement for the load-carrying capacity than the concrete mixture. The utilization of 3D-TFs and micro-steel fiber together in the SCM mix gave better results. The stiffness of the specimens was improved with increasing the thickness and the number of textile fiber layers.

Keywords: ductility, discrete fiber, 3D AR-glass, beams, and flexural strength.

سلوك العتبات الخرسانية المسلحة والمعززة بالألياف النسيجية المركبة ثلاثية الابعاد

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الخلاصة

الخرسانة العادية ضعيفة تجاه قوة الشد، ولديها ليونة منخفضة ومقاومة ضئيلة للتكسير. يمكن أن تؤدي إضافة أنواع مختلفة من الألياف بنسب محددة إلى تعزيز الخواص الميكانيكية بالإضافة إلى المتانة. تحتوي الألياف المنفصلة المستخدمة بشكل شائع على العديد من العيوب مثل تكتل (تكور) الألياف في الخليط الخرساني وكذلك التقيد في نسبة الالياف التي يمكن استخدامها. بناءً على هذه الرؤية، تم اكتشاف تقنية جديدة يمكن ان تعزز الخرسانة بواسطة ألياف النسيج لتجنب جميع المشكلات المذكورة أعلاه. الفكرة

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الرئيسية لهذه الورقة هي دراسة الخواص الميكانيكية للخليط الخرساني الذاتي الدمك SCC وخليط المونة الذاتي الدمك SCM المصبوب مع الالياف النسيجية الزجاجية الثلاثية الابعاد (3D-TFs) لها سمكان مختلفان (6، 10 مم)، واستخدام طبقات مختلفة (1،2 طبقة). وكذلك تم استخدام الألياف الفولاذية الدقيقة بنسبة 1.25 ٪. تم اختبار ستة عشر عينة من العتبات الخرسانية المسلحة المستطيلة لدراسة سلوك الانثناء. لخصت النتائج أن استخدام الالياف المنسوجة الثلاثية الابعاد مع خليط المونة الذاتي الدمك أعطى تحسنا لقدرة الحمل أعلى بكثير من خليط الخرسانة الذاتي الدمك. استخدام الالياف المنسوجة الثلاثية الأبعاد والياف الحديد معًا في خليط المونة (SCM) اعطى نتائج أفضل. تمت زيادة صلابة العتبات الخرسانية مع زيادة سمك وعدد طبقات الالياف النسيجية.

الكلمات الرئيسية: الليونة، الالياف المنفصلة، الالياف النسيجية الزجاجية الثلاثية الابعاد المقاومة للقلويات، العتبات، وقوة الانثناء.

1. INTRODUCTION

The advantages and the mechanical properties for the textile-reinforced concrete TRC have been proven when it was used as a strengthening material and also as a precast material **(Triantafillou and Papanicolaou, 2006) & (Bournas and Lontou, 2007).** As concrete be a composite of a closely spaced textile network structure, it is quite important to use a mix design with a small aggregate size. This type of mix conforms with the special demands of TRC production processes. In the same time mixed with the small aggregate size give chemical stability for the TRC used, because of this, this kind of mixture became finer and also more homogenous structure when compared with ordinary concrete, leading to improve the performance and the strengths as well as develop the durability characteristics **(Brockmann 2005).** Since the textile-reinforced concrete TRC usually bears flexural loads, it is very important to do an investigation about the behavior of this kind of material under flexural loads.

To understand the behavior of fiber-reinforced concrete composites at the extreme fibers zone, flexural testing must be performed. As well as, this test was used to calculate the necessary values for analyzing and design reinforced concrete beams. To provide perfect characteristics for the materials in the design process, the geometrical relationships among the stresses, and the microstructure for the test specimens, and also the boundary conditions should be agreed with the relationships in the product be designed **(Davis 2004).** The steel-fiber that use to reinforce concrete give a greater flexural strength comparing with the normal brittle concrete, that because of the steel-fiber affect the ductility.

The effect of the number of textile-fiber layers on the flexural behavior of TRC beams that casting with mortar mixture was investigated. Simply supported beam specimens with dimensions of (150* 200* 2000 mm), have been strengthened with basalt-based textile-fiber with a different number of textile-fiber layers (10 and 5 layers). The beam specimens have been tested with four-point bending until failure occurred. The beams that reinforced with 5 and 10 layers of textile fiber gave an improvement in flexural strength about 39% and 91%, respectively, when compared with non-fiber beams. As well as, the increase in the number of textile-fiber layers from 5 to 10, led to rising the flexural strength by 133% **(Elsanadedy, et al., 2013).**

The effect of using steel fiber with TRC, as well as the increase in the textile-fiber layers was investigated. Plates specimens with dimensions of (300 mm length, 50 mm width, and 12 mm depth) were cast with basalt-textile fiber and tested under four-point bending. The test results showed an increase in flexural strength as well as toughness when increasing the number of textile fiber layers. Also, the addition of chopped-steel fiber was influencing the load at first crack, the load at post-crack, stiffness, and toughness **(Du, et al., 2018).**

An experimental study was investigated for the flexural behavior of (100* 100* 400 mm) beam specimens, by using two different types of textile-fiber (three-dimensional AR glass textile-fiber 3D-TRC and two-dimensional AR glass textile-fiber 2D-TRC) and compared the flexural behavior with those of hooked steel-fiber-reinforced concrete beams SFRC. Three cylindrical specimens have been tested to calculate the compressive strength (used the same compressive strength for both TRC and SFRC as a textile-fiber does not affect the compressive strength). The beam specimens were tested under four-points load. Also, linear-variable differential transformers devices LVDTs were used to determine the deflection. The results showed that the flexural strength and toughness for 3D-TRC was greater than 2D-TRC. Using 0.5% of steel fiber gave higher flexural strength and toughness than both 2D-TRC and 3D-TRC **(Yoo, et al., 2016).**

The effect of thickness and number of layers for three-dimensional textile fiber on the flexural strength was investigated. The flexural behavior has been studied with a self-compacting mortar mixture, reinforced with 3D textile-AR glass fiber with different thicknesses (6, 10, and15 mm). The specimens have been tested in two cases, the first was by using 1 layer of textile reinforcement and the other was by using 2 layers of textile reinforcement. The result was showed that (A) for 3D-textile glass fiber with 6 mm, the increment in the flexural strength at 28 days was 32% for one-layer reinforcement, and 68% for two layers reinforcement. (B) for 3D-textile glass fiber with 10 mm, the flexural strength increases about (34.19, 40.49%) when used one layer and two layers, respectively. (C) for 3D-textile glass fiber with 15 mm, the increase was about (50.6, 36.18%) with used one layer and two layers, respectively **(Gorgis, et al., 2018).**

All the research works mentioned above summarized the results of the effect of using two-dimensional and three-dimensional textile fibers on concrete specimens (Plate and beam), which has not reinforced with steel reinforcement. In this paper, we will present the results of the effect of flexural behavior on beam specimens reinforced with 3D textile fibers with the presence of steel reinforcement.

2. EXPERIMENTAL WORK

Sixteen simply supported beam specimens were prepared with dimensions of 1100 mm length,100 mm width, and 150 mm height. These beams were designed to fail in flexural according to **(ACI 318, 2014).** The sixteen specimens were divided into seven groups. These groups were different in terms of the type of mix, the thickness of 3D-textile glass fiber, and the number of fiber layers used. At first, the mix was self-compacting concrete SCC and the beams were reinforced by one layer of 3D-textile glass fiber. After that, the mix was changed to steel-fiber self-compacting concrete SFSCC by adding micro steel fiber with a volume fraction of 1.25% and also the beams were reinforced with one layer of textile glass fiber. Then, the first mix was used (SCC) with two layers of textile glass fiber. The fourth step was to change the mix to SFSCC by using 1.25% micro steel fiber as well as two layers of textile glass fiber. After that, the mix was self-compacting mortar SCM and the beams were reinforced by one layer of textile glass fiber. Then the same mix was used (SCM) with two layers of textile glass fiber. Finally, the steel-fiber self-compacting mortar SFSCM mix was used by adding 1.25% micro steel fiber and also using two layers of textile glass fiber.

2.1 Materials and Specimen Preparations

The detailed of the four-type mixture used is demonstrated in table 1. Ordinary portland cement was utilized. The used cement was undergone to both chemical and physical tests, and the results were confirmed and satisfied with the Iraqi standard specification **(I.Q.S No.5-1984).** Natural sand was used, the maximum size of sand particles was change with changing the mix type (9.5 mm for SCC mix and 0.6 mm for SCM mix). The chemical and physical tests for used sand were performed, its results were satisfied with the Iraqi standard specification **(I.Q.S No.45-1984).** Crushed gravel with maximum size 9.5 mm was used, its test results for both chemical and physical tests were satisfied within the limits of Iraqi standard specification **(I.Q.S No.45-1984).** Grey densified micro silica fume has been used as a pozzolanic additive to enhance the mechanical and rheological properties, 20% of silica fume has been used as a replacement from cement weight. The used silica fume has been conforming to the limits of (**ASTM C-1240-2015).** A high-performance concrete hyper plasticizer, called viscosity modifying admixture VMA know by product name (structure 520), has been used. The using of VMA helps to get the best performance for the workability of self-compacting concrete. Micro steel-fiber with 1.25% VF has been utilized in this work to enhance the ductility, as well as to study the effect of using textile fiber with steel fiber together. The properties of the micro steel-fiber used are demonstrated in **Table 2.** Three-dimensional textile AR glass fiber has been used as a strengthening material. The properties of this textile fiber are demonstrated in **Table 3.** The 3D textile-fiber structure in general consists of two layers of 2D textile fibers, these layers were connected by internal fiber yarns. in another mean, it consists of two layers one in the top and the other in the bottom which connected by internal yarn in the third direction (thickness). The presence of the yarns in the thickness helps to increase the volume fraction for the fiber, as well as the strengths in the third-direction have been increased with different applied loads. To allow the concrete and mortar mixtures to penetrate through the grid of the textile fiber, as well as to get good bond between the textile fiber and the mixture, the textile-fiber has been drilled (in the vertical direction) with rectangular holes (20* 25 mm) at a distance of 25 mm from center to center by using sharp cutting tool. The 3D- textile AR-Glass fiber was placed in the form of stripes (1050 mm length, 50 mm width) between the concrete layers. At first, the concrete mixture was placed in the mold at a height of 4 cm. After that, the fiber was passed inside the reinforcing steel. Finally, reinforcing steel was placed in the mold and ensured that it was well-anchored. Steel reinforcement and 3D-Textile fiber details are demonstrated in **Fig.1**

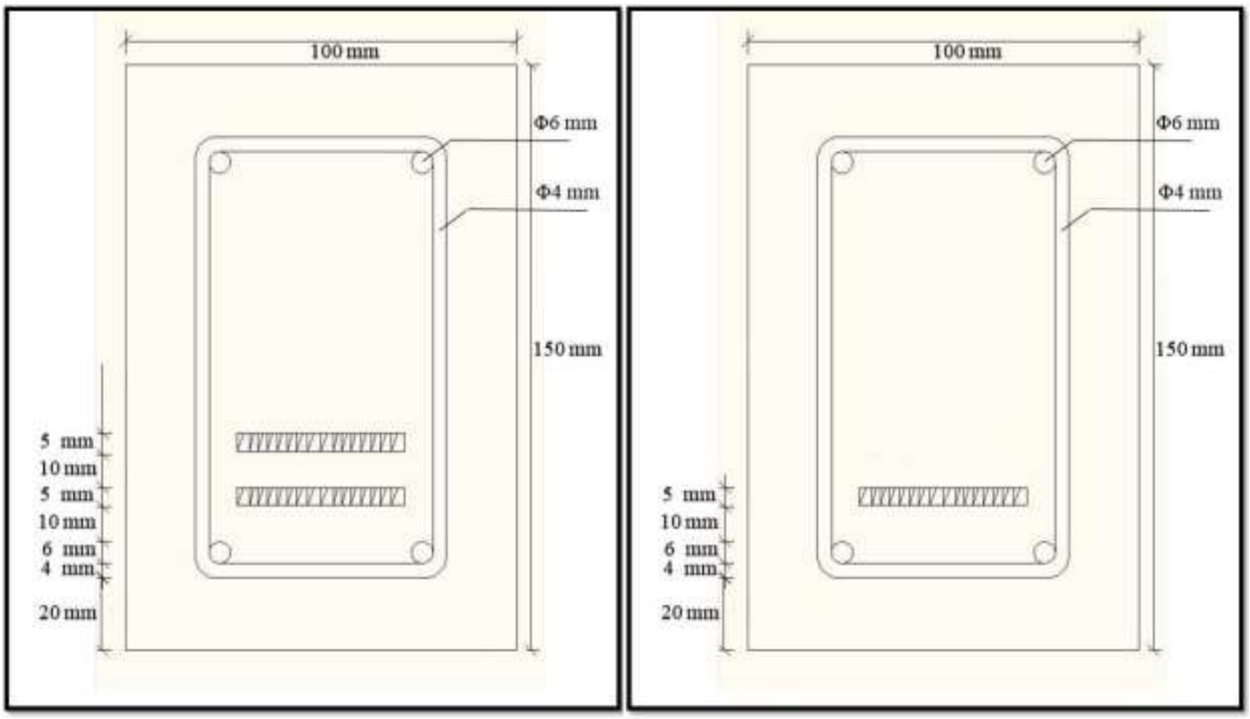


Figure 1. Steel reinforcement and 3D-Textile fiber details.

Table 1. Detailed of mixes used.

Mix symbols	cement	Fine aggregate	Coarse aggregate	Silica fume	Steel fiber	VMA	water	W/B
SCC	550	800	790	110	-	16.5	140	0.25
SFSCC	550	800	790	110	97.5	16.5	155	0.28
SCM	700	700	-	120	-	18	170	0.24
SFSCM	700	700	-	120	97.5	18	187	0.26

***SCC self-compacting concrete, SFSCC steel fiber self-compacting concrete, SCM self-compacting mortar, SFSCM steel fiber self-compacting mortar, W/B water to binder ratio**

Table 2. Properties of micro steel fiber used.

Property	Specification
Length	13 mm
Diameter	0.2 mm
Density	7800 kg/m3
Tensile strength	2600 MPa
Aspect ratio	65
Modulus of elasticity	250 GPa

Table 3. Properties of textile AR-glass fiber used.

Area Weight (g/m2)	Core Thickness (mm)	Density of Warp (ends/cm)	Density of Weft (ends/cm)	Tensile Strength Warp (N/50mm)	Tensile Strength Weft (N/50mm)
900	6	15	10	5500	9400
1480	10	15	8	6800	12000
1650	15	12	6	7200	13000

Surface Treatment	**Silicon Coated**
Width	1.3m or Made to order
Weave Type	Plain Woven
Yarn Type	E-Glass
Alkali Content	Alkali Free
Standing Temperature	260℃
Color	White
Specific stiffness	Extremely High
Acoustic insulation	Excellent
Wave transmittable	Well
Construction	Two layers and one hollow spacer
Weight/ area	From 820 to 2580g/m2

3. FRESH PROPERTIES

3.1 Slump Flow Test

The slump test for the SCM mix was different from the SCC mix. A miniature cone with a lower and upper diameter of 100 mm and 70 mm with 60 mm cone height was used for mortar paste. The relative flow area was calculated according to the following equation:

$$G_m = \left(\frac{D_m}{D_0}\right)^2 - 1 \qquad (1)$$

where:
Dm: The median value of vertically diameters that taken.
D0: The initial lower diameter of the cone is measured by mm.
In the case of a slump test for self-compacting concrete uses a cone with lower and upper diameter of 200 mm and 100 mm, respectively. The height of the cone is 300 mm. The precipitation test was conducted according to **(EFNARC, 2005).**

3.2 V-Funnel Test

This test was performed for the SCM mix by using a mini-funnel. Relative flow velocity was measured according to the equation:

$$R_m = \frac{10}{t} \qquad (2)$$

Where R_m is the relative flow velocity, t: the flow time of the concrete in the funnel measured in the second. Whereas the V-funnel test for the SCC was performed by funnel its dimensions were larger than that used for the SCM mix. The test was conducted according to **(EFNARC, 2005).**

3.3 L-Box Test

This test was performed to calculate the ability of self-compacting concrete to pass by passing it between three bars without any separation. This test was conducted according to **(EFNARC, 2005).**

4. HARDENED TESTS

4.1 Compressive Strength for Control Specimens

The compressive strength test for concrete was conducted in accordance with **(BS 1881: Part 116: 1989),** in 28 days by testing the cubic samples in dimensions (100x100x100) mm by the hydraulic pressure machine with a capacity of 2000 kN. The average value of the three samples was taken.

4.2 Splitting Tensile Strength for Control Specimens

The tensile test was performed for three cylindrical samples of dimensions: diameter * height (100 * 200 mm), respectively. The test was in accordance with **(ASTM C496 / C496M-2011),** by using the same hydraulic pressure machine that used for compressive strength. the average tensile strength was taken for every three samples for each mixture at the age of 28 days.

4.3 Flexural Strength for Control Specimens

The flexural strength of self-compacting concrete was tested by samples of dimensions (100 * 100 * 400 mm), By means of the flexural test machine with a capacity of 150 KN, where two points were loaded on the sample in accordance with **(ASTM C78-2002).**

5. FLEXURAL STRENGTH FOR BEAM SPECIMENS

Sixteen reinforced concrete beam specimens with dimensions of (100 * 150 * 1100 mm) were tested at 28 days under monotonic load by using a hydraulic machine having a capacity of 2000 kN. The beams were placed on two steel rollers (simply supported) and subjected to two concentrated loads. Plate 1. show the setup for the flexural test.

Plate 1. Setup of the beam for test procedure.

6. RESULTS AND DISCUSSION

6.1 Fresh Properties

The results of the tests for fresh concrete, which are the diameter of the slump flow test, time of V-funnel test, and the ratio of L- box tests are shown in Table 4. All results were within limits of the acceptance criteria suggested by **EFNARC (2002), EFNARC (2005)**.

Table 4. Fresh tests result of different mixes.

Mixes symbols	Slump flow test (mm)	V- funnel test (sec)	L- box test (H2/H1)	W/C	VMA (Kg/m3)
SCC	760	9	1	0.25	16.5
SFSCC	740	9	0.91	0.28	16.5
SCM	255	10	---	0.24	18
SFSCM	245	10	---	0.26	18

The addition of micro steel fiber to the self-compacting concrete mix SFSCC and self-compacting mortar mix SFSCM reduced the workability. The reason for the low workability is due to the presence of steel fibers that restrict the movement of the mixture and at the same time increase the friction between steel fiber and aggregates. Also, these fibers can be balled inside the mixture, thereby impairing the performance of workability for the concrete.

6.2 Hardened Properties

Table 5. demonstrates the test consequences of hardened properties for all mixes at the age of 28 days. The addition of micro steel fiber by 1.25% volume fraction led to increased compressive strength by 4% and 8% for SFSCC and SFSCM mixes, respectively, compared with the plain mixes. The results also demonstrated a rising in the splitting tensile strength by 18.7% and 14.7% for SFSCC and SFSCM mixes, respectively, when adding steel fiber. In general splitting tensile strength for mortar mixes were less than the concrete mixes, due to the use of fine materials in the mix and the absence of coarse aggregate, thus resulted in the loss of the process of the mechanical bond of granules of coarse aggregate, making the self-compacting mortar more brittle than self-compacting concrete. The presence of micro steel fiber contributed to the reduction of the cracks that actually occurred in the concrete structure. Also, micro steel fiber helped in changing over the properties of concrete from brittle to ductile concrete.

Table 5. Hardened properties for mixture used.

Mixes symbols	compressive strength (MPa)	splitting tensile strength (MPa)	Flexural strength (MPa)
SCC	47.91	5.27	7.98
SFSCC	49.84	6.26	21.23
SCM	50.79	4.28	6.41
SFSCM	54.86	4.91	15.06

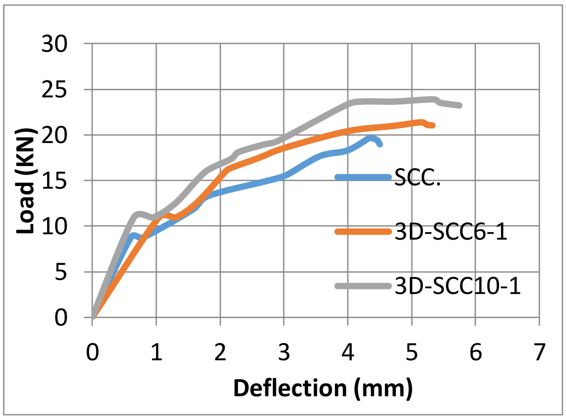
6.3 Flexural strength for beams specimens

The results of the tests of the ultimate load for beam specimens are demonstrated in **Table 6.** The Failure mode and crack pattern for SCC and SCM beams are shown in plate 2. and 3., respectively. From the results, when Comparing beam B2 with beam B1, the first crack load increased by 25.74% (10.94 kN) and the load at failure stage increased by 8.35% (21.38 kN). As well as, for beam B3 the first crack load increased by 25.74% (10.94 kN) and the load at failure stage increased by 21.03% (23.88 kN), as a comparing with B1. The reference beam (non-fibrous beam) exhibited brittle failure, while the fibrous beams were quite ductile. Fiber extensively increments the ultimate load of SCC beams. This improvement is because of the present of 3D-textile glass fibers, which connect cracks and exchange stress via the crack faces until the fiber yarns are drawn-out or broken. The presence of fiber in the tensile zone of the beam specimens helped to bear the load in the initial phase of the initiation and spread of cracks. When the applied loads are increases, the tensile stresses increase and the cracks become broader and the fibers begin to connect the cracks. The presence of micro steel fiber gave high enhancing in ductility of beams, also helped to reduce the amount and width of central cracks. The resistance for high loads was slightly increased with increasing the thickness of the textile glass fiber. when comparing beam B5 with beam B4, the first crack load increased by 7.74% (15.45 kN) and the load at failure stage increased by 8.61% (29.76 kN). Also, by comparing beam B6 with beam B4, the first crack load increased by 7.74% (15.45 kN). The load at the failure stage increased by 16.05% (31.80 kN). This behavior is generally recognized due to the action of fibers in reducing the crack energy around the crack surface, and this is required to stop the widen and spread of crack.

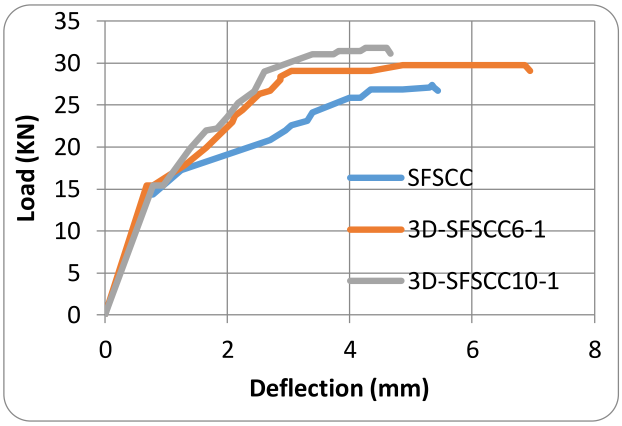
Table 6. Test results of the ultimate load for beams specimens.

Beam No.	Beam symbols	Group No.	Thick. of fibers (mm)	No. of layers	Load at first crack (kN)	def. at first crack (mm)	Ultimate load (kN)	def. at ultimate load (mm)	Increase % ultimate load (kN)	
									SCC	SFSCC
B1	SCC		/	/	8.70	0.78	19.73	4.34	/	
B2	3D-SCC6-1	G1	6	1	10.94	1.30	21.38	5.15	8.35	
B3	3D-SCC10-1		10	1	10.94	0.95	23.88	5.74	21.03	
B4	SFSCC		/	/	14.34	0.78	27.4	5.34	38.87	/
B5	3D-SFSCC6-1	G3	6	1	15.45	0.78	29,76	6.86	50.83	8.61
B6	3D-SFSCC10-1		10	1	15.45	0.95	31.80	4.60	61.17	16.05
B7	3D-SCC6-2	G3	6	2	12.94	0.95	24.16	9.47	22.45	
B8	3D-SCC10-2		10	2	12.94	0.69	24.72	8.12	25.29	
B9	3D-SFSCC6-2	G4	6	2	15.34	1.12	32.50	5.29	64.72	18.61

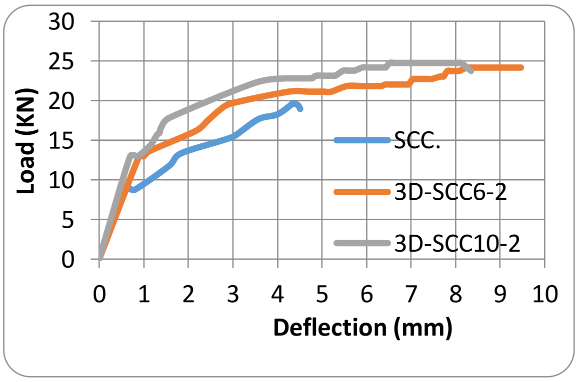
B10	3D-SFSCC10-2		10	2	15.50	0.6	32.59	4.34	65.18	18.94
B11	3D-SCM6-1	G5	6	1	12.5	1.3	21.77	15.63	7.29	
B12	3D-SCM10-1		10	1	12.5	1.21	25.16	14.1	27.52	
B13	3D-SCM6-2	G6	6	2	14.64	1.47	26.02	30.4	31.88	
B14	3D-SCM10-2		10	2	12.94	1.04	27.00	15.2	36.84	
B15	3D-SFSCM6-2	G7	6	2	10.37	0.43	35.70	8.90	80.94	30.29
B16	3D-SFSCM10-2		10	2	12.94	0.52	36.27	6.77	83.83	32.37



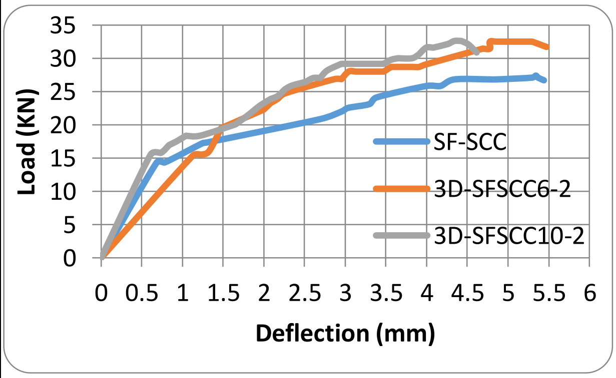
G1



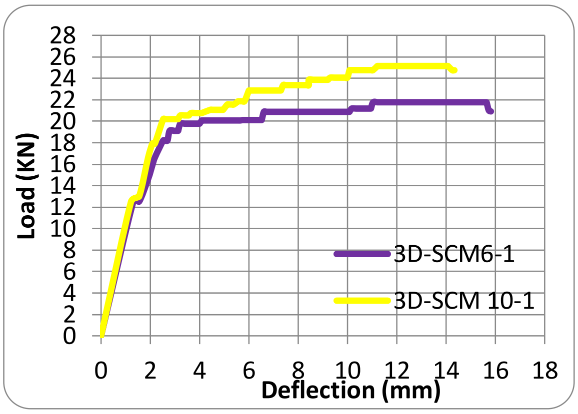
G2



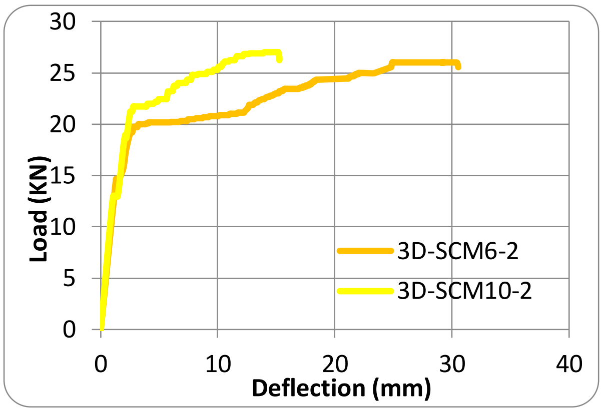
G3



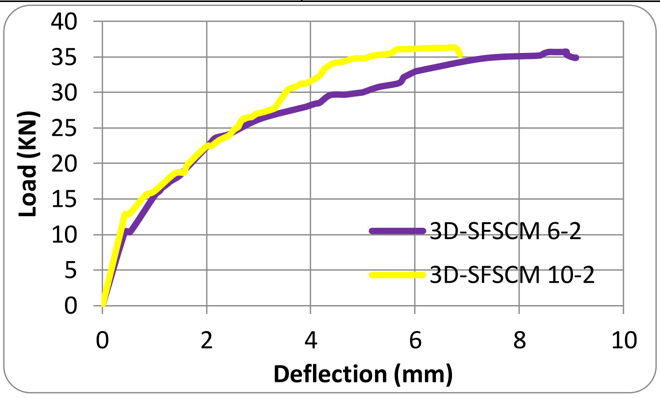
G4



G5



G6



G7

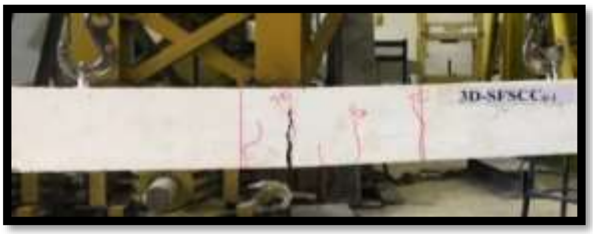
Figure 2. Load- deflection curves for the tested beam specimens.

B1-G1

B2-G1

B3-G1

B4-G2



B5-G2

B6-G2

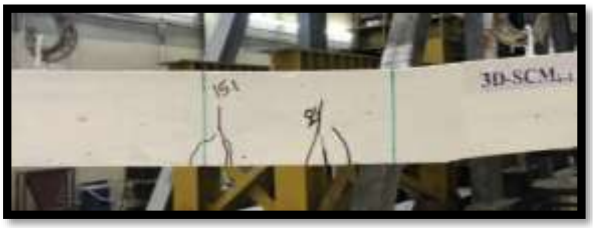
B7-G3

B8-G3

B9-G4

B10-G4

Plate 2. Failure mode and crack pattern for self-compacting concrete beam specimens.



B11-G5

B12-G5

B13-G6

B14-G6

	
B15-G7	B16-G7

Plate 3. Failure mode and crack pattern for self-compacting mortar beam specimens.

7. EFFECT OF STUDY PARAMETERS

7.1 Layers Thickness of 3D-TFs

- For G1, the beam B3 which reinforced with 10 mm textile fiber thickness exhibited greater ultimate load by 11.6 % than B2 which reinforced with 6 mm of textile thickness.
- For G2, the rising in the textile thickness from 6 mm to 10 mm for beams B5 and B6, respectively led to rising the flexural load by 6.8 %.
- For G3, the flexural strength increased by 2.3 % when increasing the thickness of the textile fiber from 6 mm to 10 mm for beams B7 and B8, respectively.
- For G4, the increase in the textile thickness from 6 mm to 10 mm for beams B9 and B10, respectively led to improving the flexural load by 0.3 %.
- For G5, the ultimate load improved by 15.6 % when increasing the thickness of the textile fiber from 6 mm to 10 mm for beams B11 and B12, respectively.
- For G6, the rising in the textile thickness from 6 mm to 10 mm for beams B13 and B14, respectively led to rising the flexural load by 3.8 %.
- For G7, the ultimate load enhanced by 1.6 % when increasing the thickness of the textile fiber from 6 mm to 10 mm for beams B15 and B16, respectively.

7.2 Number of Layers for 3D-TFs

- For 6 mm textile fiber thickness: the ultimate load exhibited high enhancing about 13 % when increasing the number of textile fiber from one to two for beams (B2-G1) and (B7-G3), respectively. Also, the beam (B9-G4), which reinforced with two layers of textile fiber exhibited greater ultimate load by 9.2 % than (B5-G2) which reinforced with one layer of textile fiber. The ultimate load also increased by about 19.5 % when increasing the number of textile fiber from one to two for beams (B11-G5) and (B13-G6), respectively.
- For 10 mm textile fiber thickness: the ultimate load exhibited slightly enhancing about 5.51 % when increasing the number of textile fiber from one to two for beams (B3-G1) and (B8-G3), respectively. Also, the beam (B10-G4), which reinforced with two layers of textile fiber exhibited greater ultimate load by 2.4 % than (B6-G2) which reinforced with one layer of textile fiber. The ultimate load also increased by about 7.3 % when increasing the number of textile fiber from one to two for beams (B12-G5) and (B14-G6), respectively.

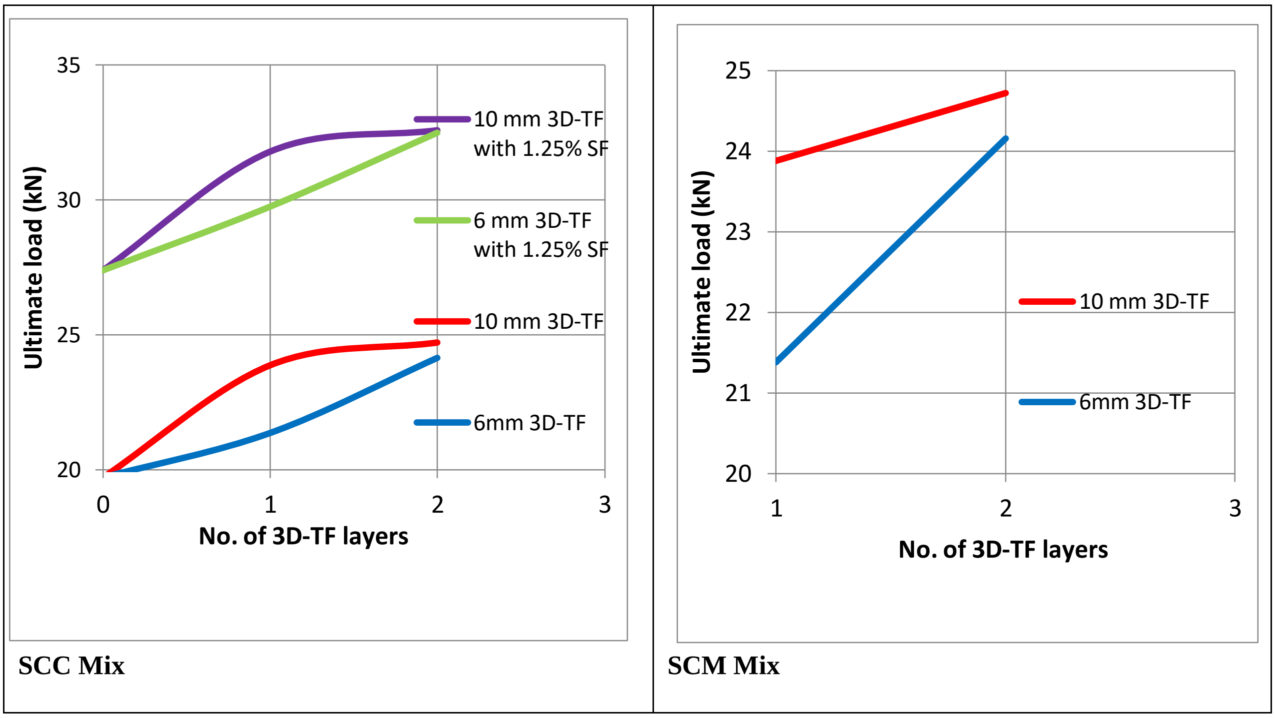


Figure 3. Relation between ultimate load and number of 3D-TF layers for SCC, SCM mixes.

7.3 Mix Type with 3D-TFs

By using a 6 mm thickness and one layer of textile fiber, the beam (B11-G5), which contained the SCM mix, gave ultimate load by 1.8 % than beam (B2-G1) which contained the SCC mix. Also, when using a 6 mm thickness and two layers of textile fiber, the flexural load increased by 7.7 % when changing the mix type from SCC to SCM for beams (B7-G3) and (B13-G6), respectively. By using 10 mm thickness and one layer of textile fiber, beam (B12-G5), which contained the SCM mix, gave a larger ultimate load by 5.4 % than beam (B3-G1) which contained SCC mix. Also, when using 10 mm thickness and two layers of textile fiber, the ultimate load increased by 9.2 % when changing the mix type from SCC to SCM for beams (B8-G3) and (B14-G6), respectively.

The results demonstrated that the behavior of using two layers of 3D-textile fiber, which has 6 mm thickness was the best when compared with 10 mm thickness. Also, the results showed that using 3D-textile glass fiber with a mortar mix gave significantly higher enhancing in the flexural load than the concrete mix. This is due to the usage of only fine aggregate and removes the coarse aggregate from the mixture. This helped the mixture to pass and penetrate the textile fiber mesh. In general, the using of a 10 mm thickness of 3D-textile fiber with the SCM mix gave the best results.

7.4 Using Micro-Steel Fiber with 3D-TFs

- In SCC mix with 6 mm thickness and one layer of textile fiber, the using of 1.25 Vf micro-steel fiber led to increasing the load by 39.2 % as a comparing between beams specimens without and with micro-steel fiber for beams (B2-G1) and (B5-G2), respectively. Also, for SCC mix with the same thickness but with two layers of textile fiber, the addition of 1.25 Vf micro-steel fiber led to enhance the flexural ultimate load by 34.51 % as a comparing between beams specimens without and with micro-steel fiber for beams (B7-G3) and (B9-G4), respectively.

- for SCC mix with 10 mm thickness and one layer of textile fiber, the addition of 1.25 Vf micro-steel fiber led to increasing the ultimate load by 33.2 % as a comparing between beams specimens without and with micro-steel fiber for beams (B3-G1) and (B6-G2), respectively. When using SCC mix with the same thickness but with two layers of textile fiber, the addition of 1.25 Vf micro-steel fiber led to improve the ultimate load by 31.8 % as a comparing between beams specimens without and with micro-steel fiber for beams (B8-G3) and (B10-G4), respectively.
- In SCM mix with 6 mm thickness and two layers of textile fiber, the using of 1.25 Vf micro-steel fiber led to increasing the ultimate load by 37.2 % as a comparing between beams specimens without and with micro-steel fiber for beams (B13-G6) and (B15-G7), respectively.
- Also, for SCM mix with 10 mm thickness and two layers of textile fiber, the using of 1.25 Vf micro-steel fiber led to enhance the flexural load by 34.3 % as a comparing between beams specimens without and with micro-steel fiber for beams (B14-G6) and (B16-G7), respectively.

8. FLEXURAL STIFFNESS (K) OF TESTED BEAMS

The flexural stiffness results were obtained from the load-deflection relationship, by calculating the slope ($\Delta F/\Delta\delta$) of the curve before the occurrence of the first crack. The results indicated that the stiffness of the beams specimens was increased by increasing the thickness and the number of textile fiber layers. At the same time, the addition of micro steel fiber gave a good enhancement and reduced the deformation under the load. The result also indicated that the using of 3D-textile fiber as a strengthing material with the SCC mix was better than the SCM mix.

Table 7. Flexural stiffness for tested beams.

Group No.	Beam No.	Beam symbols	Thickness of fibers (mm)	No. of layers	Flexural stiffness (kN/mm)
G1	B1	SCC	/	/	11.15
	B2	3D-SCC6-1	6	1	8.41
	B3	3D-SCC10-1	10	1	11.51
G3	B4	SFSCC	/	/	18.38
	B5	3D-SFSCC6-1	6	1	19.80
	B6	3D-SFSCC10-1	10	1	16.26
G3	B7	3D-SCC6-2	6	2	13.62
	B8	3D-SCC10-2	10	2	18.75
G4	B9	3D-SFSCC6-2	6	2	19.66
	B10	3D-SFSCC10-2	10	2	25.83
G5	B11	3D-SCM6-1	6	1	9.60

	B12	3D-SCM10-1	10	1	10.33
G6	B13	3D-SCM6-2	6	2	9.95
	B14	3D-SCM10-2	10	2	12.44
G7	B15	3D-SFSCM6-2	6	2	24.11
	B16	3D-SFSCM10-2	10	2	24.88

9. TOUGHNESS INDICES AND RESIDUAL STRENGTH FACTORS

The results of toughness indices were obtained from the load-deflection curves by dividing the area, which has a deflection of (3, 5.5, and 10.5) times the deflection at first crack, by the area of the deflection at first crack. The calculation conducted according to **(ASTM C1018-1997).** Fibers added to concrete to improve the toughness or energy absorption capacity. The results indicated that the toughness of the beams specimens was increased by increasing the thickness and the number of textile fiber layers. The results of the tested beams are listed in table 8.

Table 8. Toughness indices and residual strength factors.

Group No.	**Beam No.**	**Beam symbols**	**Toughness indices**			**Residual strength factors**	
			I5	I10	I20	R5,10	R10,20
G1	B1	SCC	10.8	18.5	37.3	154	188
	B2	3D-SCC6-1	5.3	12.4	30.6	142	182
	B3	3D-SCC10-1	4.9	14.5	***	192	***
G3	B4	SFSCC	6.5	14.6	29.7	162	151
	B5	3D-SFSCC6-1	5.1	12.6	30.4	150	178
	B6	3D-SFSCC10-1	5.2	15.4	33.5	204	180
G3	B7	3D-SCC6-2	4.7	13.1	29.3	168	162
	B8	3D-SCC10-2	3.8	13.3	34.8	190	215
G4	B9	3D-SFSCC6-2	6.8	16.9	***	202	***
	B10	3D-SFSCC10-2	5.3	15.6	33.7	206	181
G5	B11	3D-SCM6-1	6.7	15.3	34.4	172	190

	B12	3D-SCM10-1	6.5	16.1	37.2	192	211
G6	B13	3D-SCM6-2	6.3	15.5	32.6	184	171
	B14	3D-SCM10-2	6.2	15.9	36.6	194	207
G7	B15	3D-SFSCM6-2	13.3	20.1	43.3	136	232
	B16	3D-SFSCM10-2	7.4	19.2	50.9	236	317

10. CONCLUSIONS

Based on the results for this experimental study, it can be concluded that:

- All beams, which reinforced with textile fiber, presented a greater flexural load relative to the reference beams.
- The raising in the thickness of the textile fiber led to an improvement in the ultimate load for each of the concrete and mortar mixtures.
- The increase in the textile fiber layers led to an enhancement in the ultimate load.
- By increasing the textile fiber layer, the 3D-textile fiber, which has 6 mm thickness, gave a higher increment in the ultimate load than 10 mm thickness.
- The raising in the ultimate load is likely because of the good connection between the textile fiber and mixture.
- The changing in the mixture from concrete to mortar gave greater ultimate load improvement.
- In general, the tested beam specimens performed the same failure mode, and the cracks on the specimens have been located under the two loaded point.

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