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# Experimental Investigation on the Bending Behaviour of Textile Reinforced Concrete (TRC)

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***Keywords*:**

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**A B S T R A C T**

Textile-Reinforced Cement (TRC) was used in structural retrofitting and strengthening existing structures. While at present, recent studies have turned around using TRC as an independent structural element. This research presented an experimental study on the flexural behavior of TRC plates. Several parameters were taken into account, specifically, (a) the number layer of textile fiber materials (1, 2, and 3); (b) the configuration of the reinforcement (together or interface); (c) thickness of TRC plate (50, 70) mm. This study included preparing and testing twelve specimens; two specimens were un-reinforced, whereas the rest ten specimens were reinforced by dry carbon fiber textile**.** The results found that increasing the number of layers for both reinforcement configurations led to increased flexural capacity. Increasing the thickness of the plate has a negative effect on the flexural capacity for both reinforcement configurations. Finally, the interface reinforcement configuration with thickness 50 mm or 70 mm had higher flexural capacity than the specimens with together reinforcement configuration.



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# دراسة مختبرية عن سلوك الانثناء للخرسانة المسلحة بالالياف النسيجية في درجة الحرارة المحيطة

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## الخلاصة

شائع جدا في مجال التقوية الخارجية للعناصر الانشائية. بينما في الوقت الحاضر ، **TRC** اصبح استخدام الخرسانة المسلحة بالالياف النسيجية المسلحة **TRC**كعنصر انشائي مستقل. في هذا البحث تم دراسة سلوك الانثناء لصفائح الـ **TRC** أتجهت الدراسات الحديثة حول استخدام الـ بالالياف الكاربونية الجافة وتم ألاخذ بنظر الاعتبار المتغيرات الاتية : (أ) عدد طبقات الالياف الكاربونية(2,1, و3)طبقات (ب) طريقة التسليح وترتيب طبقات الالياف الكاربونية (معا او مفصولة)؛ (ج) سماكة الصفيحة (50و70) مم. تضمنت هذه الدراسة اختبار اثنا عشر نموذج(نموذجان بدون تسليح والنماذج العشرة المتبقية تم تسليحها باستخدام الالياف الكاربونية النسيجية الجافة). تم اختبار سلوك الانثناء للعينات تحت اختبار الانحناء رباعي زيادة سمك الصفيحة له تأثير سلبي على زيادة قدرة .النقاط. أظهرت النتائج أن زيادة عدد الطبقات لكلا ترتيب التسليح يؤدي إلى زيادة سعة الانثناء الانحناء لكلا ترتيب التسليح. أخيرًا ، ترتيب التسليح المفصولة بسماكة 50 مم أو 70 مم يتمتع بقدرة انثناء أعلى من العينات المقابلة مع ترتيب التسليح معًا.

**الكلمات الدالة**: مونة الكونكريت المقواة بالالياف النسيجية, سعة الانثناء, نسيج من الياف الكاربون الجاف

## 1. INTRODUCTION

Through the last 100 years, reinforced concrete (RC) has been widely used in construction sectors. Reinforced concrete offers superior strength and stiffness. Although RC has these properties, drawbacks were observed, such as steel reinforcements are susceptible to corrosion, which can cause deterioration in the RC strength and performance. It is challenging to produce irregular shapes, such as architectural facades or curved shapes [1-5]. A decay ago, a new composite material called Textile-Reinforced Concrete (TRC) was proposed in construction sectors. TRC is a composite material consisting of a cement-based matrix with typically fine aggregate grain and high-performance fibers in the form of textile [6-9 ]. In recent years, considerable studies have been directed toward the use of TRC as a means of external strengthening or reinforcement of existing structures for the rehabilitation of old buildings; [10-24]. In the present, little research on the TRC was used as the independent structural element; the following section gives a brief overview of previous research on the use of TRC as structural elements.

### 1.1 Flexural Behavior of TRC Elements

Yin et al. (2013) [25] investigated the flexural behavior of textile reinforced concrete thin plate. Nine specimens were tested under a four-point bending test. The parameters were the thickness of plates (10, 20, 25) mm. It was found that as the thickness of the plate increase, the flexural capacity increase also. Volkova et al. (2016)[26] examined the flexural behavior of textile-reinforced concrete. Two specimens were reinforced with carbon and glass with one layer, while the third was not reinforcement as a reference specimen. The results indicated that applications of textile fiber provided a significant gain in the flexural capacity. The improvement in the glass and carbon reinforced specimen's fiber textile was 52% and 82%, respectively, compared to the control specimens. Zargaran et al. (2017)[27] investigated the minimum reinforcement ratio in TRC panels for flexural performance. The parameters were: fabrics mesh size (5 and 10) mm, type of fiber (twisted, untwisted). The results showed the specimens reinforced with mesh size 5 mm had better-bending performance in terms of ultimate strength and it was observed that the twisted yarns efficiency is 50% less than the non-twisted yarns. Du et al. (2018) [28] assessed the flexural behavior of basalt textile-reinforced concrete. Six specimens were tested. The parameters included the number of fiber layers. The results were found that as the number of textile layers increased, the flexural strength enhanced dramatically. You et al. (2020) [29] investigated the flexural behavior of steel textile-reinforced concrete. Six specimens of textile reinforced concrete (TRC) and one specimen of steel-reinforced concrete (conventionally reinforced) were tested. The parameters included a number of layers. The conclusions: It have been found that cracking occurs in TRC more than in RC. With the increase in the number of layers of textile reinforcement the bending performance increased. Chandrathilaka et al. (2020)[30] investigated in flexural performance of prefabricated ultra-high-strength textile reinforced concrete (UHSTRC). Eight specimens were tested. The parameters were the number of layers (1-3), textile material (carbon and basalt fiber textile), textile mesh density. It was found that increasing the number of textile layers improved the performance of UHSTRC. Carbon fiber textiles have been found to best performance compared to glass and basalt. When decreasing the mesh size by half, the 90% increase in ultimate flexural was observed. Li et al. (2020)[31] studied the flexural performance of TRC plates made of basalt fiber textile. Eight specimens of BTRC were reinforced with five layers of basalt textile. The result indicated the flexural properties of BTRC materials were improved by increasing the number of layers.

It is noted in previous studies that the primary focusing was on the number of layers. In the current study, many parameters were considered, namely; (a) the number of fiber textile layers (1, 2, and 3), (b) plate thickness (50 and 70 mm), and (c) the reinforcement configurations (i.e., together and interface).

## 2. EXPERIMENTAL PROGRAM

### *2.1 Specimens Details*

Twelve specimens (ten specimens reinforced by dry carbon fiber textile and two specimens non-reinforced) were manufactured and tested. The specimen's dimensions were (1000mm length, 300mm width). Many parameters were considered, namely; (a) the number of fiber textile layers (1, 2, and 3), (b) plate thickness (50 and 70 mm), and (c) the reinforcement configurations (i.e., together and interface). Details of the tested specimens are provided in (Figure 1a-c and Figure 2a, b).

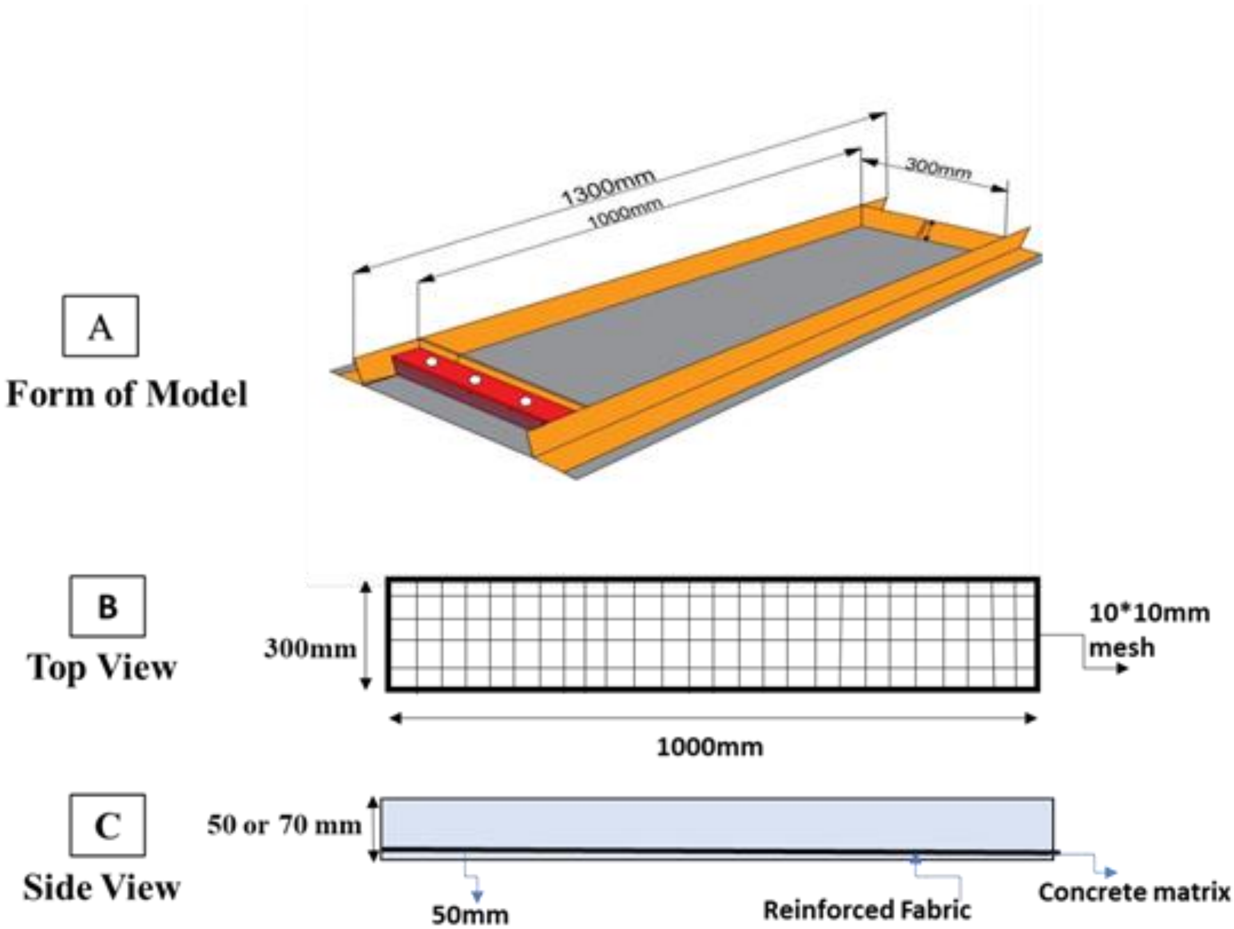



**Fig. 1.** (a) Steel mold details (b) Specimen geometry top view and (c) Specimen geometry side view.

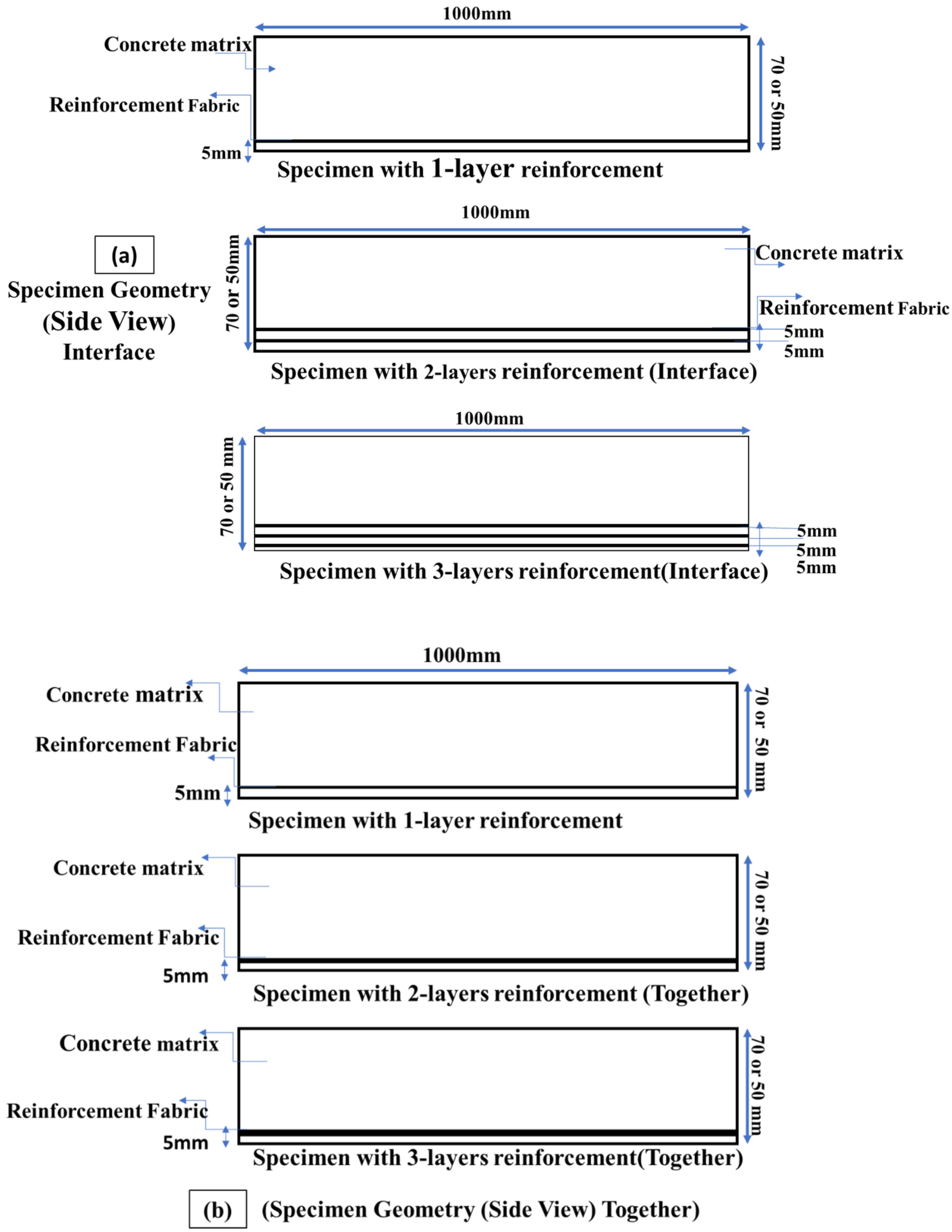



**Fig. 2.** (a) Specimen's reinforcement and details (side view) interface reinforcement configuration; (b) Specimen's reinforcement and details (side view), together with reinforcement configuration.

## 2.2 Materials

### *2.2.1 Cementitious matrix*

Table1 summarizes the matrix mix design. Cement following the Iraqi standard specifications (No. (5) (1984)) and (ACI 549) for cement testing. Sand with maximum aggregate size (2) mm identical to the Iraqi standard specification (I.Q.S., No. 45 (1984)) and (ASTM C778-17). Mineral admixtures included (fly ash and silica fume) were used as cement substitute materials added by 30% and 5.5%, respectively, by cement weight. Finally, a superplasticizer (meet the requirements of ASTM C 494-99) was utilized to reduce the water-cement ratio was added by 3% of the total weight of cement.

**Table 1**

The matrix mix design

| NO. | Component | Content (Kg/m$^3$) | Ratio% |
|---|---|---|---|
| 1 | Cement | 500 | - |
| 2 | Sand (0/2) mm | 1400 | 280 |
| 3 | Fly ash | 150 | 30 |
| 4 | Micro silica | 27.5 | 5.5 |
| 5 | Water | 200 | 40 |
| 6 | Superplasticizer | 15 | 3 |

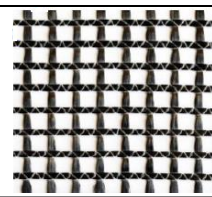
### 2.2.2 Textile reinforcement fabric

Carbon dry fiber textile was used in this study as internal reinforcement. The fabric grid size was 10 mm in both longitudinal and lateral directions. Table (2) show details of the textiles, such as mesh size, weight, density, tensile strength, and modulus of elasticity (according to the manufacturer datasheets).

**Table 2**.

Details of the textiles according to the manufacturer datasheets

| Dry Carbon Fiber Textile | |
|---|---|
| Nominal thickness (mm) | 0.095 |
| Weight: (g/m$^2$) | 170 |
| Mesh size (mm) | 10×10 |
| Density: (g/cm$^3$) | 1.75 |
| Tensile strength (MPa) | 4800 |



## 2.3 Casting Procedure

The molds were cleaned and lightly oiled on the inside to prevent hardened mortar from clinging to the inside of the molds. The mold was built with moveable plate parts of 5 mm thickness at both ends to stretch the textile mesh. The clear concrete cover was 5mm for all specimens. For the specimens with interface reinforcement configuration, a 5 mm spacing was left between each layer of textile. This was done by extending wires (fishing wire) along the transverse sides of the mold with very high tension to ensure that the spacing between the textile layers is 5mm. The cementitious matrix was prepared and then was cast into the mold. A shaking plate was used for vibration to penetrate the cementitious matrix with the textile mesh. Finally, the surface was leveled by a trowel, as shown in Figure3.

**Fig. 3**. Casting procedure for specimens

## 2.4 Test Setup

### *2.4.1 Tensile test of textile coupons*

To determine the tensile capacity of the TRC composite material. A uniaxial tensile test on three specimens of TRC coupons, made of a single layer for the type of fabric textile (carbon), was tested. The dimensions of the coupon were 520 mm length and width 50 mm; the coupon was fixed to the testing machine with a capacity of 30-kN using aluminum plates glued at the end of specimens with dimensions 60mm long and 50mm width (the load was applied at a rate of 2 mm/min up to fail due to rupture of the textile at the central region of the coupon as shown in figure 4a-d.


**Fig. 4.** Details of tensile tests on TRC coupons, (a, b): Model details, (c): Model's test setup, (d) Failure mode of textile coupon

### *2.4.2 Flexural Test*

A universal testing machine was used for the test with a capacity of 2000 kN. The load was applied at a loading rate of 1.5 kN/sec. The specimens were subjected to four points loading. A load cell was used to measure the applied load, and (LVDT) was fixed at the top of spacemen to measure the midspan deflection. A data logger was used to collect the test data from the test (i.e., load and mid-span deflection), as shown in Figure 5a-d.

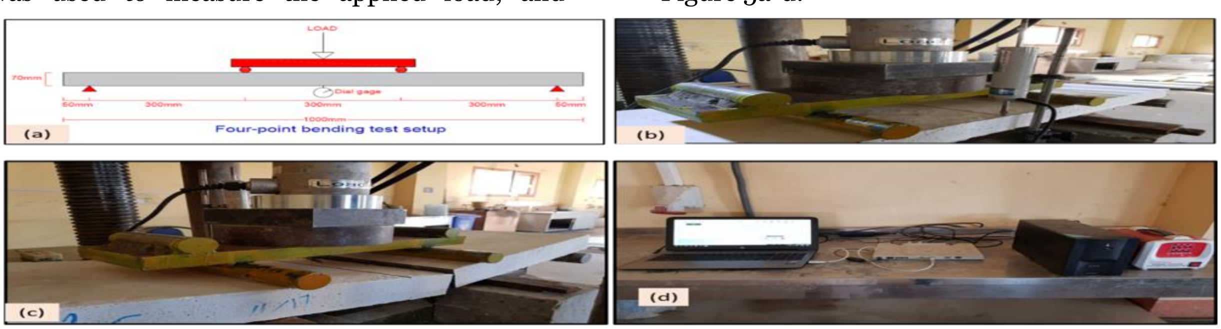



**Fig. 5.** Plate test (a)four-point bending test details, (b) model setup, (c) apply load up to failure (d)load and deflection monitoring by the data logger

## 3. RESULTS AND DISCUSSION

### *3.1 Results*

#### *3.1.1 Tensile Properties*

The tensile capacity of the textile reinforcement of the coupon was as follows: ultimate tensile load equal to 14.3 kN and ultimate tensile strength ($f_{fu}$) equal 2648 Map. It is worth mentioning that the maximum tensile stress was calculated by dividing the machine's ultimate load by the area of the textile fibers' transverse section. Testing took place according (ACI Committee 549).

#### *3.1.2 Flexural Test*

Table 3 provides the main results of all tested specimens included: (1) the maximum obtained load ($P_u$), (2) the deflection at the ultimate load ($\delta_u$), (3) increased bending capacity, and (4) failure mode. The notation used was Xn-Y-Z; where X indicates the type of fiber textile materials, n represents the number of layers, Y refers to reinforcement configuration, and Z refers to the thickness of the plate.

**Table 3.**

Summary of test results

| | Load (kN) | Deflection (mm) | | |
|---|---|---|---|---|
| **Specimens Name** | **(1) Ultimate (*$P_u$*)** | **(2) Ultimate ($\delta_u$)** | **(3) Flexural capacity increase (%)** | **(4) Failure mode*** |
| **CON50** | 2.34 | 0.44 | --- | S+F |
| **CON70** | 5.78 | 0.40 | --- | F |
| | | **Carbon_50** | | |
| **C1 _50** | 4.58 | 0.64 | 95.9 | R+F* |
| **C2_T_50** | 6.15 | 0.91 | 163.0 | R+F* |
| **C3_T_50** | 7.31 | 7.14 | 212.6 | R+F* |
| **C2_I_50** | 9.53 | 1.07 | 307.1 | R+F* |
| **C3_I_50** | 10.12 | 8.04 | 332.5 | R+F* |
| | | **Carbon_70** | | |
| **C1_70** | 10.70 | 0.94 | 85.2 | R+S* |
| **C2_T_70** | 12.61 | 0.77 | 118.1 | R+S* |
| **C3_T_70** | 13.70 | 5.45 | 137.1 | R+S* |
| **C2_I_70** | 13.77 | 1.38 | 138.2 | R+F* |
| **C3_I_70** | 14.31 | 1.28 | 147.6 | R+S* |

* F: Flexural Failure; R: Fiber Rupture; S: Shear Failure.

#### *3.1.3 Load – Midspan deflection curves*

The load – mid-span deflection curves of all tested specimens are presented in Figures 6a, b. For the control specimens (CON_50 and CON_70) (**Error! Reference source not found.**), the load-mid span deflection was characterized by a single-stage, namely, linear behavior up to fail due to the absence of reinforcement. For the reinforced specimens, the load-displacement curves had two different stages (**Error! Reference source not found.**) **Error! Reference source not found.:-** The **first stage:** the uncracked stage which was linear up to cement matrix cracking. **Second stage:** (with fluctuation) stage after concrete cracking, the stresses are transferred to the reinforcement layers with the continuous decrease in the stiffness until the failure occurred.

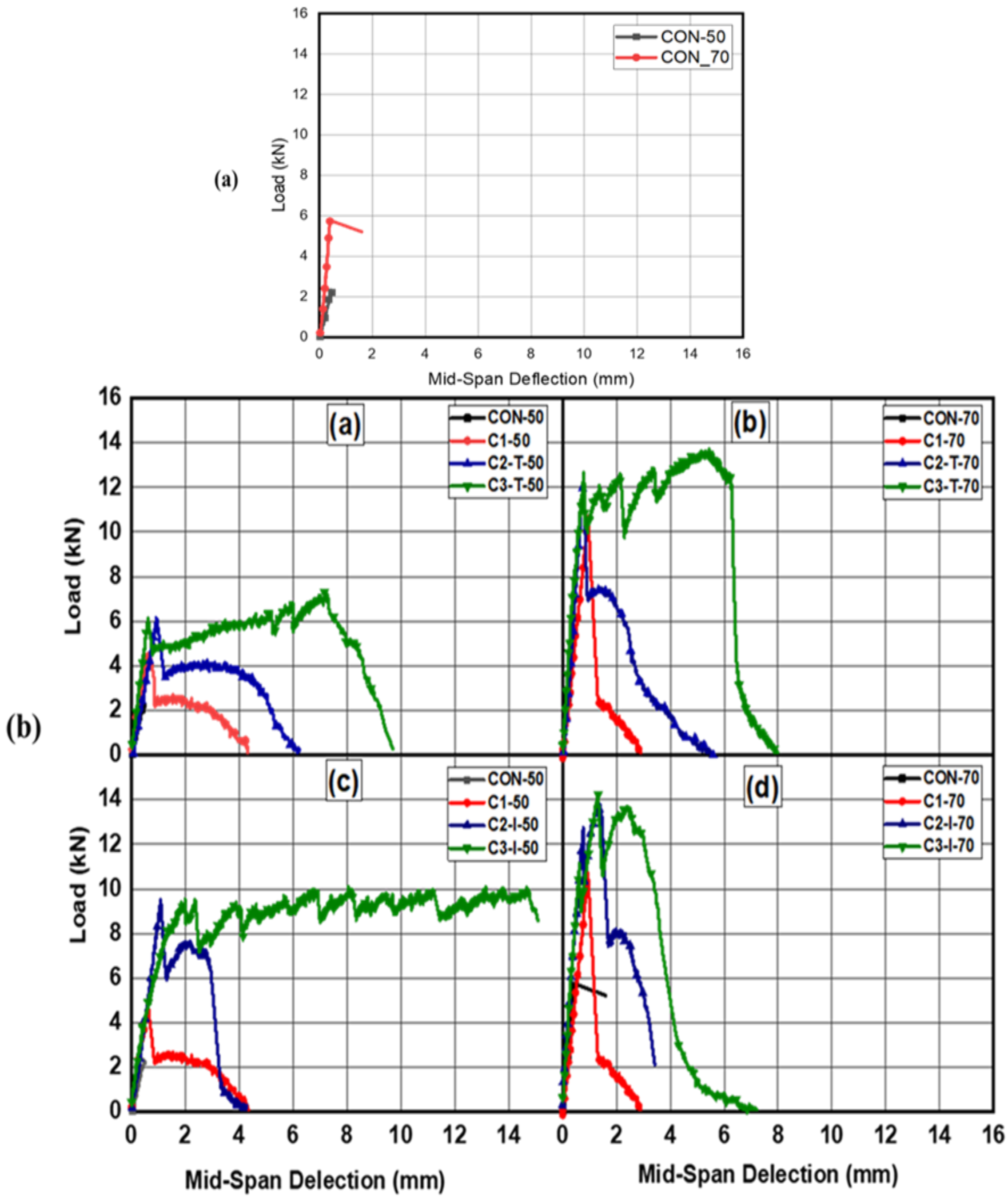



**Fig 6. (a)** Load- Midspan deflection curves of the control specimens;(b) Load versus Mid-span deflection curves

### *3.1.4 Ultimate Load and Failure Modes*

#### *3.1.4.1 Control Specimens*

The control specimens CON_50 and CON_70 recorded loads of 2.34 kN, 5.78 kN, respectively. The corresponding mid-span deflections were 0.44 mm and 0.40 mm, respectively. They failed in a brittle manner due to the absence of reinforcement. The failure mode of specimen CON_50 was a combination of flexural and shear due to the failure of the specimen under the application of loading. While the failure mode of the control specimen CON_70 was flexural as the failure was at the location of the maximum moment zone (Figure 7).


**Fig. 7. (**a**)** The failure mode for the control specimen with thickness50mm, (b) The failure mode for the control specimen with thickness70mm

#### *3.1.4.2 TRC specimens with together reinforcement configuration*

Starting with 50mm plate thickness, the recorded ultimate load was increased with the increase of the reinforcement layers. Specifically, the ultimate load recorded for specimens C1_50, C2_T_50, and C3_T_50 was 4.58 kN, 6.15kN, and 7.31 kN, respectively. Hence, the flexural capacity improvement due to reinforcement applications was 95.9 %, 163 %, and 212.6 %, respectively, compared to the non-reinforced control specimen CON_50. The failure mode of these specimens was flexure at the maximum moment zone. Failure started by the formation of a crack in the matrix at the center of the specimens. This crack propagated until it reached the reinforcement, which had slippage followed by partial rapture (Figure 8a-c). On the other hand, when the thickness of the plate was 70mm, the maximum observed loads of specimens C1_70, C2_T_70 and C3_T_70 were 10.7 kN, 12.6kN, and 13.7 kN. This reflects an increase in the flexural capacity of 85.2 %,118.1%, and 137.1%, respectively. A change in the failure mode of this group was observed compared with the counterpart specimens of 50mm thickness; in specific, a main crack in the matrix was generated under or closed the line of load application which developed and caused the textile rupture. Such type of failure would be called flexural failure. This type of failure happened due to the increase of the thickness from 50mm to 70mm (see Figure 8d-f)

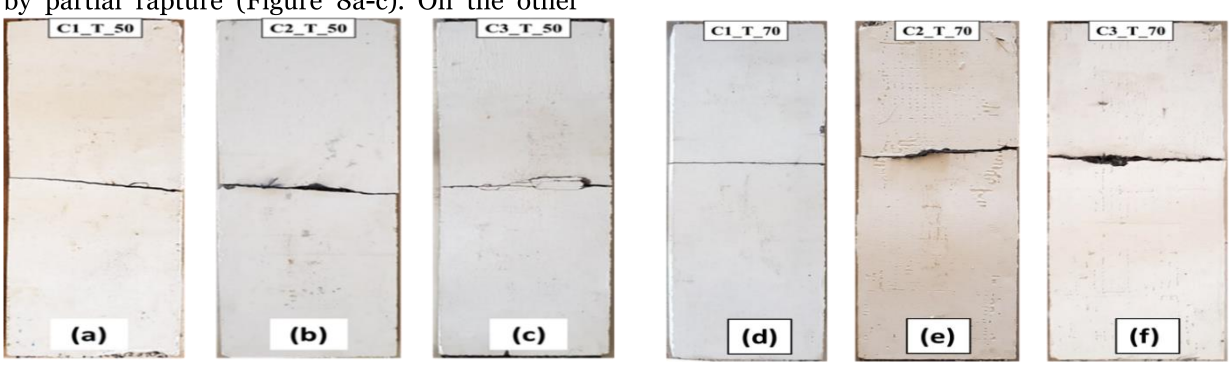



**Fig. 8.** The failure mode of specimens reinforced by together carbon fiber textile with a thickness (50 and 70mm)

#### *3.1.4.3 TRC specimens reinforced with interface reinforcement configuration*

Starting with A50-mm plate's thickness and then moving to 70-mm plate's thickness, the failure load of these specimens was significantly higher than the ultimate load of the control specimen. The ultimate loads of specimens C1_50, C2_I_50, and C3_I_50 were 4.58 kN, 9.53 kN, and 10.12 kN, respectively. Hence, the reinforcement system with fiber-textile carbon increased the flexural capacity by 95.9%, 307.1 %, and 332.5%, respectively. The failure mode for these specimens occurred in the region of the maximum bending moment (see Figure 9a-c). On the other hand, when the plate's thickness is 70 mm, the maximum loads recorded for specimens C1_70, C2_I_70 and C3_I_70 were equal to 10.70 kN, 13.77 kN, and 14.31 kN. This yields an increase in the flexural capacity compared to the control specimens C_70 of 85.2%, 138.2%, and 147.6% respectively, the specimens C2_I_70 the failure occurred in boundaries of an area maximum of bending moment, but the failure mode for C1_70 and C3_I_70 happened close to the shear failure zone (see Figure 9d-f)

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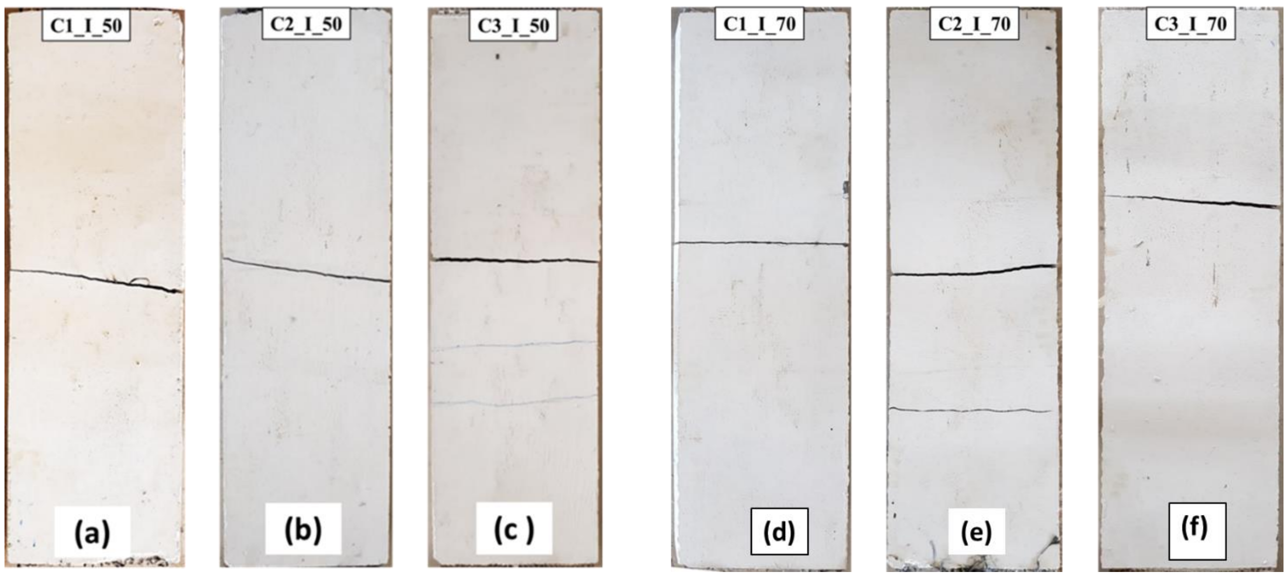


**Fig. 9.** The failure mode of specimens reinforced by interfaced carbon fiber textile with a thickness (50and70) mm

## *3.2 Discussion*

### *3.2.1 Number of Textile Fiber Layers*

#### *3.2.1.1 C_T_50 and C_I_50 Groups*

For the together reinforcement configuration specimens, doubling and tripling the number of layers (i.e., C2_T_50 and C3_T_50) resulted in an increase in the ultimate load by 1.34 and 1.60 times, respectively compared to one-layer reinforced specimens (C1_T_50). On the other hand, when the interface reinforcement configuration was adopted, the flexural capacity increased 2.08 and 2.20 times for specimens C2_I_50 and C3_I_50, respectively, compared to C1_T_50 (see Figure10a). This is attributed to the better stress distribution in the case of using interface reinforcement configuration.

#### *3.2.1.2 C_T_70 and C_I_70 Group*

For the together reinforcement configuration, doubling and tripling a number of layers resulted in an increase in the flexural capacity of 1.17 and 1.28 times, respectively, compared to specimen C1_70 (Figure 10b). On the other hand, when the interface reinforcement configuration for the specimens (i.e., C2_I_70 and C3_I_70) increased, the flexural capacity was 1.28 and 1.33 times with respect to specimen C1_70. It can be concluded that increasing the plate thickness reduced the flexural performance of the specimens. This is due to premature flexural failure under the line of a load of application for specimens that had plate thickness 70-mm. Hence, the tensile strength of the textile did not fully utilize.

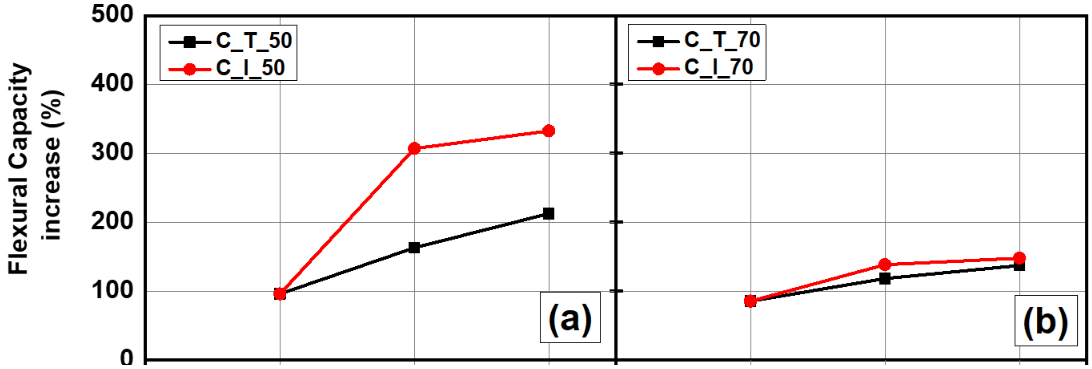


**Fig. 10.** Effect of the number of reinforcement layers on the flexural capacity increase

### *3.2.2 Reinforcement Configuration*

As shown in (Figure 11a), clearly, the interface reinforcement configuration had higher flexural capacity than the together reinforcement configuration. For the specimens with a plate thickness of 50-mm, the flexural capacity increase of specimens C2_I_50 and C3_I_50 was 1.9 and 1.6 times that the counterpart specimen C2_T_50 and C3_T_50, respectively. In particular, and as shown in (Figure11b), specimens C2_I_70 and C3_I_70 recorded higher flexural capacity of 1.2 and 1.1 times than the counterpart specimens C2_T_70 and C3_T_70, respectively.

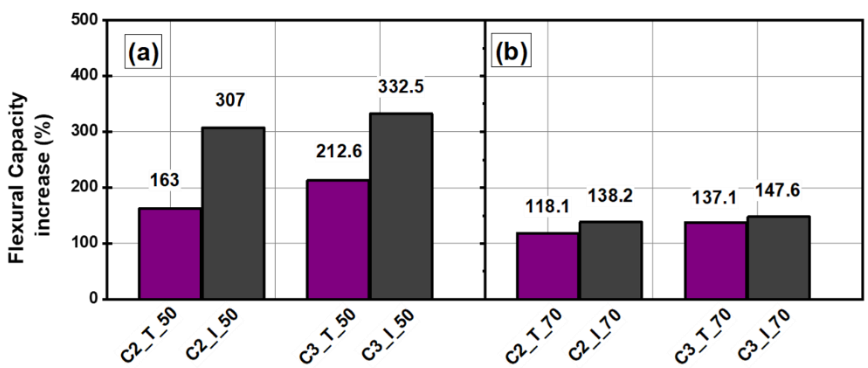


**Fig. 11.** Effect of reinforcement configuration on the flexural capacity increase

### *3.2.3 Thickness of thin plate*

As shown in (Figure12a), using plate thickness of 70-mm instead of 50-mm significantly reduces the flexural capacity for both reinforcement configuration (together and interface). In specific, the reduction in the flexural capacity for specimens C1_70, C2_T_70, and C3_T_70 was 11%, 28%, and 36%, respectively, compared to counterpart specimens C1_50, C2_T_50, and C3_T_50. When the interface reinforcement configuration has adopted, the reduction in the flexural capacity was even more. Particularly, the reduction in the flexural capacity for specimens C1_70, C2_I_70, and C3_I_70 were 11%,55%, and 56%, respectively, compared to counterpart specimens C_50, C2_I_50, and C3_I_50 (see Figure (12b. This is due to premature flexural failure under the line of a load of application for specimens that had plate thickness of 70-mm.

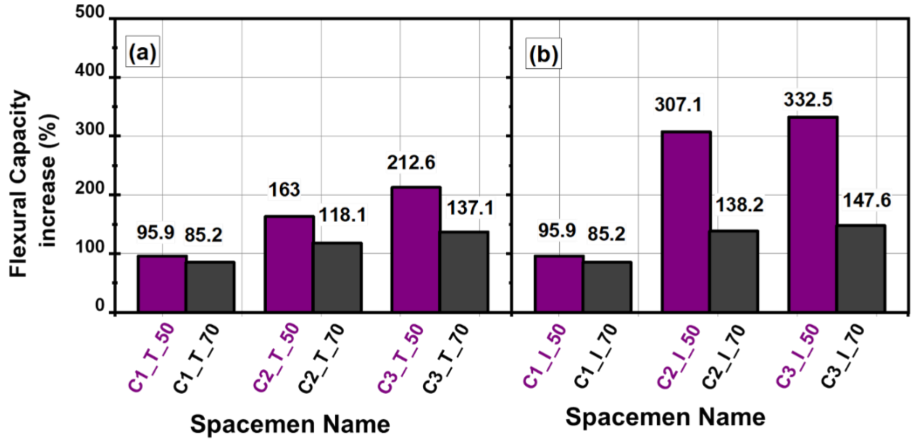


**Fig. 12.** Effect of thickness of plate on the flexural capacity increase

## 4. CONCLUSIONS:

1. In general, increasing the number of layers from one to two and three led to an increase in the flexural capacity. An increase of 307% and 332% was recorded for 50-mm thick specimens reinforced with carbon fiber textile and the interface reinforcement configuration, respectively.
2. Increasing the plate thickness reduced the flexural capacity increase regardless of the reinforcement configuration (together and interface). Particularly, the highest reduction in the flexural capacity was for specimen C3_I_70 and was 56% compared to counterpart specimen C3_I_50.
3. The interface reinforcement configuration had higher flexural capacity than the together reinforcement configuration in all number of layers (1, 2, and 3) and plate thicknesses (50 and 70) mm.

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