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Textile-Reinforced Mortar (TRM) Strengthened One-Way Reinforced Concrete Slabs

A B S T R A C T

The issue of upgrading and strengthening the reinforced concrete (RC) infrastructure has become of great importance. Recently, textile-reinforced mortar (TRM) was used in the field of structural strengthening. In the current study, using of TRM for flexural retrofitting of one-way reinforced concrete (RC) slabs was experimentally and theoretically investigated. The parameters examined included; the number of TRM layers (1, 3, 5 layers) and the strengthening configuration fully and partially). For this purpose, eight specimens were prepared and tested under three points- loading up to failure. The result showed that the TRM increases substantially the flexural capacity of RC slabs. The highest flexural capacity increase recorded was 103 %. It was also noted that increasing the number of retrofitting layers resulted in different increases in the flexural capacity. It was also shown that the strengthening configuration plays an important role in the effectiveness of the technique. The fully covered approach showed higher loading capacity than the partial cover technique provided that the same TRM layer is applied. Finally, the ultimate moment of the strengthened specimens was calculated theoretically and compared with that obtained experimentally. The results of calculations showed a good agreement between the theoretical and experimental results.

تقوية السقوف الخرسانية المسلحة ذات الاتجاه الواحد بواسطة مونة الاسمنت المقواة بالالياف النسيجية

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أصبحت مسألة تحديث وتقوية المنشاءات الخرسانية المسلحة ذات أهمية كبيرة. حديثا" تم استخدم واحدة من التقنيات المستخدمة للتقوية الخارجية تسمى مونة السمنت المقواة بالالياف النسيجية (TRM) في مجال التقوية الخارجية. في هذه الدراسة تم استخدام مونة السمنت المقواة بالالياف النسيجية (TRM) لزيادة قابيلة الانثناء لسقوف خرسانية مسلحة أحادية الاتجاه (RC). وشملت المتغيرات الداخلة في الدراسة عدد طبقات TRM (1و 3 و 5 طبقة) ومساحة التقوية (كليًا وجزئيًا). لهذا الغرض ، تم تحضير ثماني عينات وفحصها تحت حمل ثلاث نقاط - التحميل حتى الفشل. أظهرت النتائج أن إستخدام TRM يزيد بشكل كبير من مقاومة الانثناء للسقوف الخرسانية المفحوصة . حيث كانت أعلى زيادة في القدرة على الانثناء 103٪ مقارنة بالنموذج المرجعي (غير المقوى). كما لوحظ أيضًا أن زيادة عدد طبقات التقوية يزيد من مقاومة الانثناء للنماذج المفحوصة وحسب عدد الطبقات. وقد تبين أيضًا أن مساحة التقوية تلعب دوراً أساسياً في زيادة قابلية الانثناء. وعلى وجه الخصوص ، أظهرت النتائج ان التقوية الكلية لمساحة التقوية تزيد من مقاومة الانثناء بشكل اكثر من التقوية الجزئية بثبوت عدد طبقات الـ TRM . أخيرًا ، تم حساب ومقارنة العزم الاقصى للنماذج المقواة بشكل نظري ومقارنتها مع تلك التي تم الحصول عليها من التجارب . وقد أظهرت النتائج تطابق جيد بين النتائج النظرية والمختبرية في العزوم.

الكلمات الدالة: مقاومة الانثناء، الياف زجاجية، سقوف خرسانية أحادية الاتجاه ، مونة السمنت المقواة بالالياف النسيجية.

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1. INTRODUCTION

There is an urgent need to strengthening reinforced concrete structures. The reason behind that is the continues deterioration as a result of ageing, lack of maintenance and environmental conditions. Replacing these structures in the near future with new ones seems not a viable solution due to the time and cost issue. Therefore, an attention was drawn towards upgrading these structures using external strengthening Tetta et. al. [1]. Hence reducing the cost and saving the time also ensure that the structures can achieve their functions. As a result, the engineering designers have quickly moved towards the use of advanced structural materials for external strengthening.

Over the last three decades, Fiber Reinforced Polymers (FRP) is becoming significantly popular material for upgrading reinforced concrete (RC) members such as; beams, columns, and slabs. This technique involves applying fabric sheets to the structural member using an organic material as a binding agent such as epoxy resin. This composite can be applied to the tension face of the beam or slab, in the shear zone of beams and also for confining of concrete columns. The main properties of this composite according to Triantafillou et. al. 2006 [2] are: corrosion resistant, high strength with respect to its own weight, simple and fast in application, a negligible change in the structure's geometry due to small thickness.

Despite these super properties, FRP has drawbacks that have been observed which are basically related to the use of epoxy resins. These defects are: low permeability to water vapour, high cost, hazard for manual workers and poor bond with concrete substrate at high temperatures Triantafillou et. al. [2].

Almost a decade ago, a new composite material was suggested as an alternative to the FRP called Textile-Reinforced Mortar (TRM) Bournas et al. [3]. Textile Reinforced Mortar is a composite material consisting of modified cement mortar and fibers made from basalt, glass or carbon in form of mesh. The mortar used is a modified cement-polymer mortar with a mixing ratio of 8:1. The textiles used for strengthening has different geometry depending on the purpose they are manufactured for. Different acronyms are available in the previous studies such as: Textile Reinforced Concrete (TRC) Brameshuber (2006) [4] and Fibers Reinforced Cementitious Materials (FRCM) Carloni et al. (2016) [5].

The most important properties of TRM are: low cost, acceptable performance at high temperature levels, compatible with the concrete substrates, can be applied to the wet concrete surfaces and can be used at low temperatures weather Raoof et. al. (2017) [6] and Tetta and Bournas (2016) [7]. In recent years, a significant effort was directed to study the performance of TRM as external strengthening for: flexural strengthening of RC beams (Triantafillo and Papanicolaou (2005) [8]; D' Ambrisi and Focacci (2011) [9]; Elsanadedy et al. (2013) [10]); Babaeidarabad et al. (2014) [11]); Seismic strengthening of masonry-infilled RC frames with TRM (Koutas et al. (2014) [12]); Shear strengthening of reinforced concrete T-beams under cyclic loading with TRM or FRP jackets (Tzoura et al. (2014) [13]); Tensile capacity of FRP anchors in connecting FRP and TRM sheets to concrete (Bournas et al. (2015) [14]); RC beams shear-strengthened with fabric-reinforced-cementitious-matrix (FRCM) composite (Loreto et al. (2015) [15]); Structural performances of reinforced concrete beams strengthened in shear with a cement based fiber composite material (Ombres et al. (2015) [16]). However, a few research is available on the effectiveness of TRM in flexural strengthening of RC slabs in the literature. In specific, the flexural behavior of RC one-way slabs and two-way slabs strengthened by TRM was investigated by: Schladitz et. al. [17] who studied the flexural behavior of reinforced concrete slabs strengthened with TRM. The experimental investigations included testing five one-way reinforced concrete slabs measuring 7m, 1m, 0.23m (length, width, thickness), respectively. The parameters comprised; the number of TRM layers (one, two, three and four layers)

and TRM thickness (6, 9, 12 and 15 mm), respectively. One specimen was left un-reinforced as a reference. The other slabs were strengthened with a different number of TRM layers made of carbon fibers textile. It was found that, the maximum load of strengthened specimens showed remarkable improvement in the flexural capacity in comparison with the un-reinforced control specimen. The load-carrying capacity is improved with the increase of the number of carbon TRM layers. In specific, when 4-layers of TRM were applied a 3.5 times enhancement in the load carrying capacity was gained. Papanicolaou et. al. (2009) [18] studied the bending performance of two-way RC slabs strengthened with textile reinforced mortars (TRM). The size of the tested specimens was (2×2) m. The specimens were simply supported to the testing machine at all the corners. One specimen was un-strengthened as a control; whereas, the rest three specimens were strengthened by one and two layers of carbon TRM and the third specimen retrofitted with 3-TRM layers made of glass fiber textile. It was observed that, the ultimate load of the strengthened slabs was increased by (26%, 53%, and 20%) over that of the reference specimen. Finally, Koutas et. al. (2016) [19] examined experimentally the potential of using of textile- reinforced mortar (TRM) to improve the flexural capacity of two-way RC slabs. The parameters studied

included: (1) the strengthening configuration, (2) the number of TRM layers, (3) the presence of initial cracking at the tension zone of the slab (4) the type of textile fibers material (carbon versus glass). For that, six large-scale of reinforced concrete slabs were constructed and subjected to monotonic loading distributed at four points up to failure. It was concluded that TRM increases substantially; (1) the cracking load (2) the pre-cracking stiffness (3) the maximum load capacity of the tested specimens and (4) the post-cracking stiffness, while the effectiveness of the technique is greatly affected by the strengthening configuration.

Glass fiber textile is a low-cost material and has good durability Koutas et. al. (2016) [19]. Past studies on the flexural strengthening of one-way slabs were mainly focused on the use of carbon fiber textile for strengthening. In the current study, the glass fiber textile was used for retrofitting of one-way slab instead of carbon fiber. Also the number of layers that was used in this study was five TRM layers which is beyond the current limit of three TRM layers. The partial strengthening technique was also a new parameter that was adopted in this study, which has not been investigated so far.

2. EXPERIMENTAL PROGRAM

2.1. Specimens Details

A total of eight one-way slabs with 1200-mm length, 500-mm width, and 60-mm thickness were manufactured and tested as simply supported with a clear flexural span of 1000-mm Fig. 1a.

A reinforcement ratio ($\rho = 0.00673$) was intentionally chosen for designing of all slabs in order to simulate a slab with deficient reinforcement. The procedure for

design of reinforcement for the reference slab is presented in section 7. A 6 mm-diameter deformed bars were used for the internal reinforcement. The distance between the bars was 100-mm in transverse direction and 120 in longitudinal direction Fig. 1b. A 15mm concrete cover was used for all slabs.
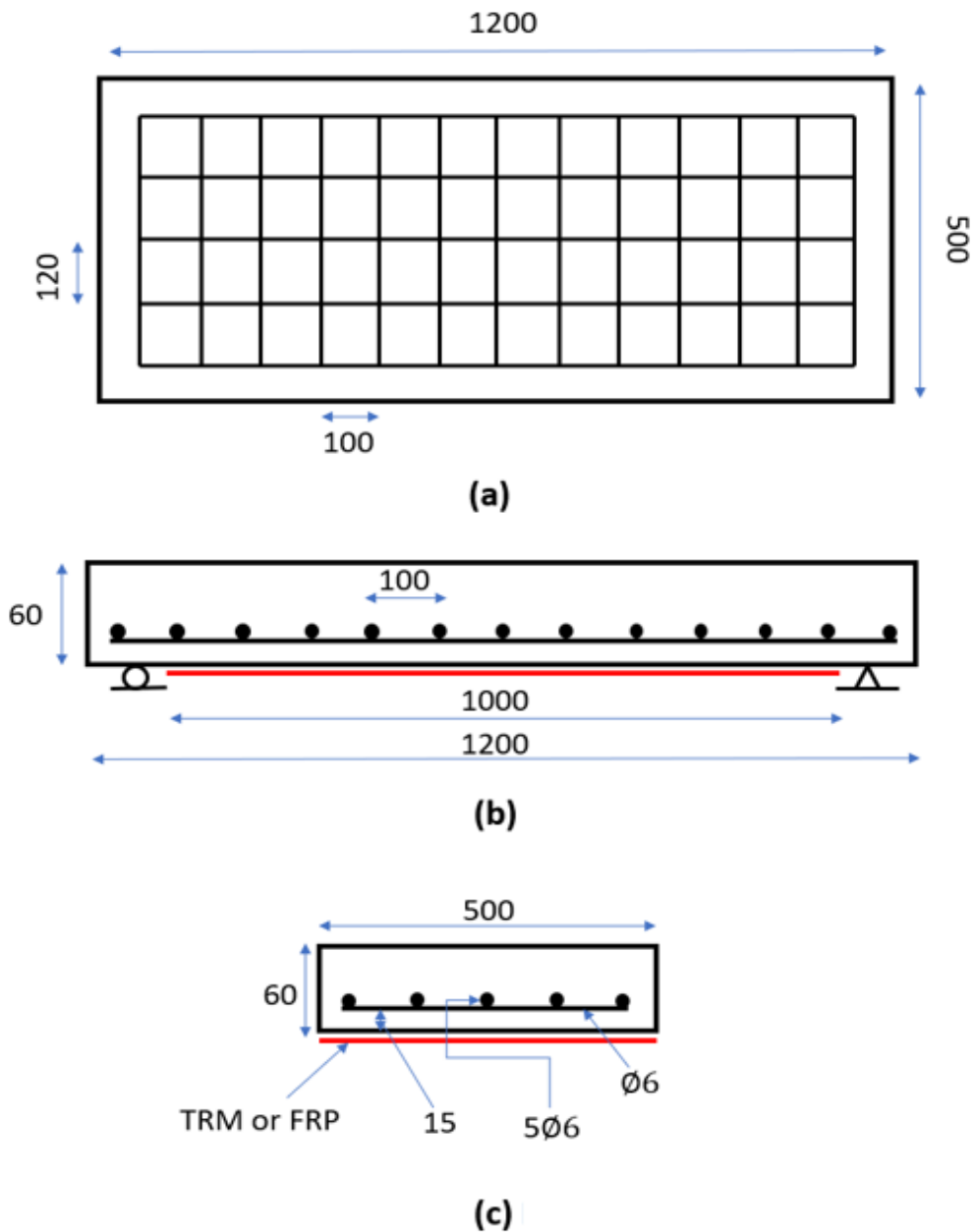
Fig.1 (a) top view, (b) longitudinal section and (c) Details of tested slabs and internal reinforcement (dimensions in mm).

2.2. Concrete Mix

Trail mixes were carried out to get the targeted concrete compressive strength (25 MPa). The compression test was carried out according to BS 1881-108 [20] on cubes with dimensions of (150×150×150) mmm using compression machine of 2000 KN capacity. The obtained compressive strength was 24.7 MPa (average of three cubes). This result represents the average of three cubes that tested at the day of testing the specimens. The water cement ratio of the used mix was

$$\frac{w}{c} = 0.48$$

Table 1.

The proportion of the concrete mix.

Concrete material	Weight (kg/m^3)	Slump test (mm)
Cement	280	
Sand	890	45
Aggregate	1150	

2.3. Steel Reinforcement

A deformed 6 mm diameter steel bars were utilized as internal reinforcement. Tensile tests were carried out according to ASTM A615 M-05 a [21]. Three specimens were tested to evaluate the average yielding strength and the ultimate strength. The test results are listed in **Table 2.**

Table 2.

Tensile tests of steel reinforcement.

Bar diameter (mm)	Yield stress (MPa)	Ultimate stress (MPa)	Elongation %
6	672	715	6.1

2.4. Strengthening Materials

- Cement mortar

In this work, a modified cement mortar was used as a binding material. The mortar comprised cement and polymers with a mixing ratio of 8 cement to 1 polymer. According to the manufacturer datasheet, adding polymers can enhance the workability, increase initial time setting and provide a mix with high consistency. The mechanical properties (compressive and flexural strength) were determined at the day of testing. Mortar prisms with dimensions of (160 mm× 40 mm×40 mm) were tested experimentally. The testing procedure was conducted based on the recommendations provided by BS EN 1015-11 (1999) [22]. The test results showed that the average compressive strength of the mortar was 35.3 MPa whereas; the flexural strength of the mortar was 9.1 MPa.

- Textile Fiber Materials

The textile material which was used in this research for the external strengthening of RC slabs was glass fibers material. It was fabricated with bundles in two perpendicular directions with equal quantities Fig. 2. Information about the textile geometry the dimensions of the mesh, the weight per unit area, and the equivalent thickness, and the density per cubic unit (according to the provider datasheets), is also given in Fig. 2. It should be noted here that the thickness (t_f) of the glass fiber textile (G) in each direction was determined according to the ratio between the unit weight per unit area divided by the density of fibers.
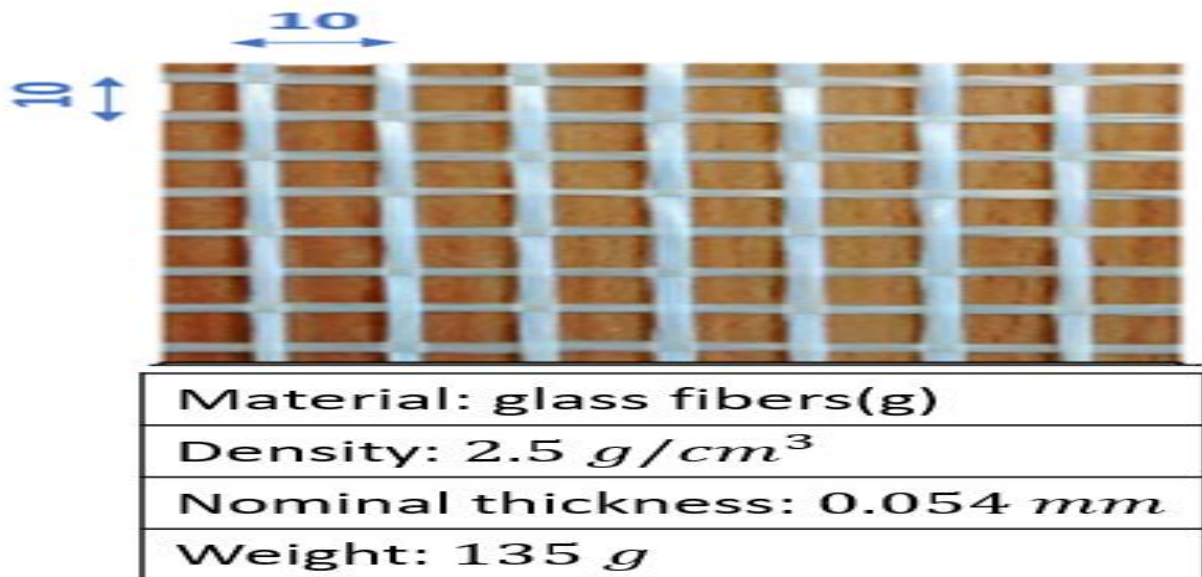
Fig. 2. Details of the glass fibers textile (dimensions in mm).

2.5. Tensile properties of glass fiber textile

A uniaxial tensile test was performed to characterize the tensile properties of the glass fiber. The test was performed on bare textile and TRM coupons. The coupons were manufactures to meet the requirements of ACI 440.3R-04 [23]. The tested coupons consist of a single layer of glass fiber textile. Three specimens (coupons) were tested for each case. The coupons had a length of 380 mm and width of 50 mm. Geometry of textile coupons are shown in Fig. 3a. A tensile testing machine with capacity of 50-kN was used for test. The load was applied monotonically at a rate of 1.5 mm/min Fig. 3b. The failure mode of the coupons was due to the rupture of the fibres at the mid-length of the specimen (Fig. 3c).
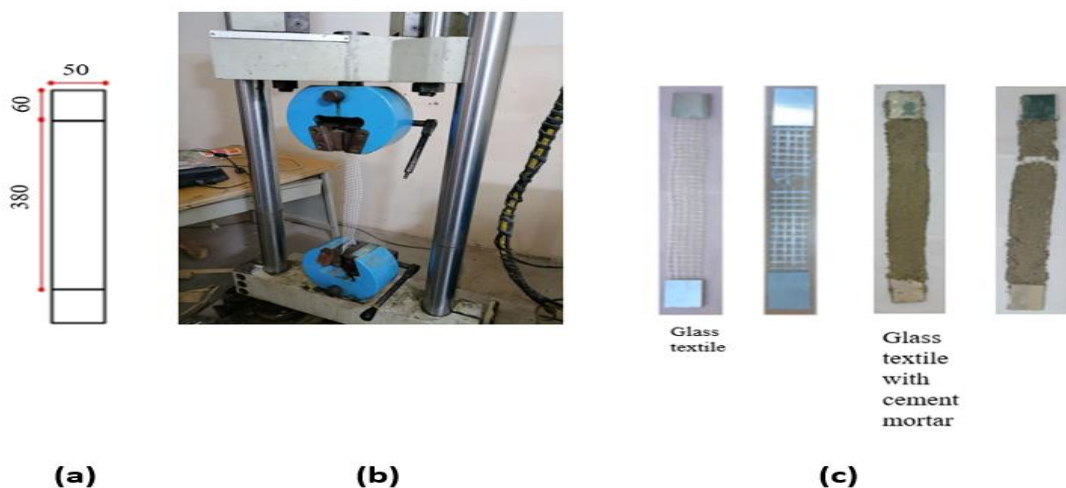

Fig. 3. (a) details of the textile coupons, (b) test setup (c) and the failed coupons.

The results (average of three coupons) of the tensile tests are presented in Table 3. It shows the results of the tested specimens including the tension characteristics of the textile fibres namely: the ultimate tensile stress (f_{fu}) and the ultimate tensile strain (ε_{fu}). It is worth noting that the maximum tensile stress was determined from the ultimate load recorded by the machine divided by the area of the transverse section of the textile fibres. Also, application of mortar to the glass fiber textile increased the ultimate tensile stress (f_{fu}) due to offering better bond between the rovings.

Table 3.

Tensile properties of the textile reinforcement coupons.

Textile name	f_{fu} (MPa)	ε_{fu}(%)
B_G[+]	571	1.769
TRM_G[++]	650	1.602

[+] The notation for bare textile coupons

[++] The notation for TRM coupons

2.6. Casting Procedure

Before casting the specimens, all moulds were cleaned and oiled. The steel mesh was placed in the mould prior to placing concrete. Each sample was vibrated by shaking table to get good compaction. The concrete's surface was then levelled off and finished with a trowel. After 24 hrs, the specimens were taken off the mould and cured with wet canvas.

2.7. Strengthening Procedure

The strengthening materials were applied to the tense side of the slabs at the entire length of the clear span. See Fig. 4a. The reinforcement procedure for strengthening system (TRM) consisted of the below steps:

- The surface of the concrete was roughened using roughening disk and then a grid of groves were made using a cutting disk, then the resulted surface was cleaned and wet with water Fig. 4b; (ii) a layer of cement mortar with 2-3 mm-thickness was added to the strengthened area Fig. 4c; (iii) the textile was affixed to the mortar, and was gently pressed with hand to ensure a good penetration with the cement matrix Fig. 4d.

- The same procedure was repeated when using more than one textile layers for strengthening system (TRM).

- A cover layer of mortar was applied over the last textile layer with approximately (2-3 mm) thickness and then levelled using trowel Fig. 4e.
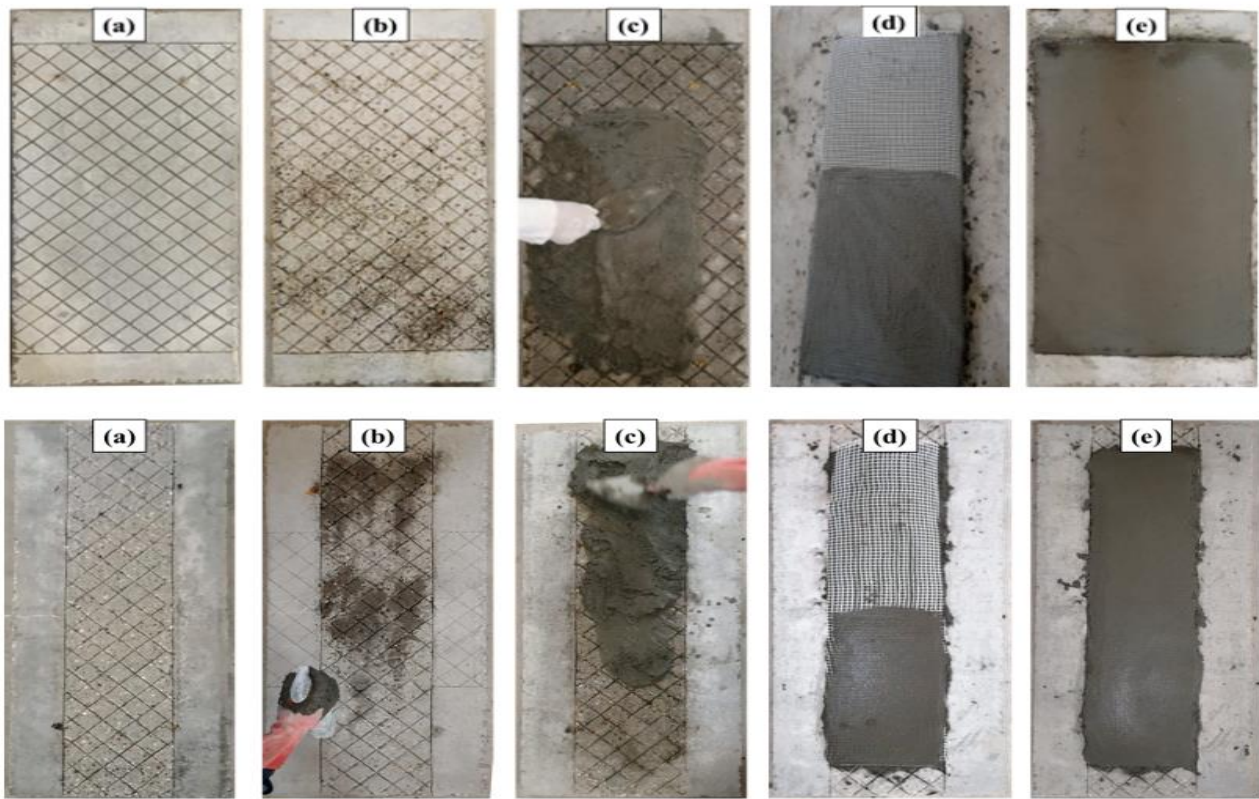
Fig. 4. Strengthening procedure for TRM retrofitted slabs fully and partially covered.

2.8. Test setup

After curing the strengthening materials, the specimens were painted with white paint so that cracks were easy to distinguish. The specimens were simply supported on both ends using stiff steel frame. The load was applied to the specimens under displacement control of 1.2 mm/sec using a universal testing machine named SANS that has a capacity 2000 kN up to failure. The recorded data was the mid-span deflection using a dial gauge with 0.01 mm accuracy and the applied load using a load cell with capacity of 500 kN Fig. 5.

The control specimens had the notation of CON. Whereas, the strengthened specimens followed the notation Gn_X; where G for glass, n; number of layers and X; strengthening configuration in which F for fully and P for partially. Details of the specimen's names, number of layers and strengthening configuration are presented in Table 3.
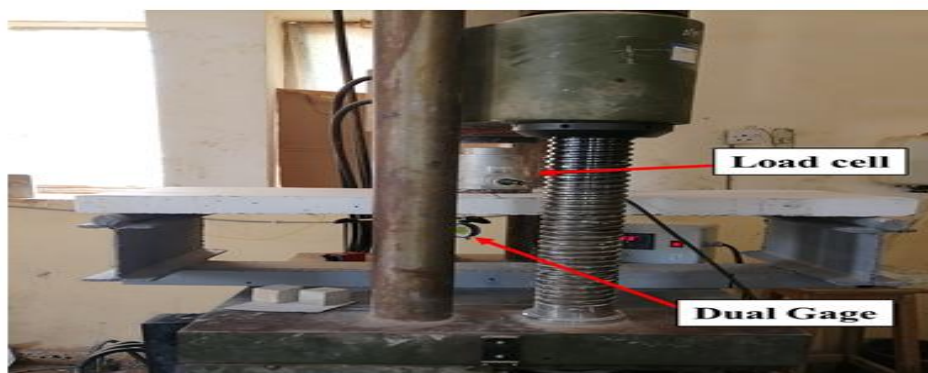

Fig. 5. Test set-up**.**

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Table 4.

Group of specimens (full covering and partial covering).

Specimen name	Number of layers	Strengthening configuration
G1_F	1	Full
G3_F	3	Full
G5_F	5	Full
G1_P	1	Partial
G3_P	3	Partial
G5_P	5	Partial

3. RESULTS

The results the experimental champions are listed in Table 5. This table includes that (1) The maximum obtained load (P_u), (2) The deflection at ultimate load (δ_u), (3) The stiffness at cracking stage (the tangent of the curve at the cracked stage), (4) The bending capacity increases as a result of retrofitting applications, (5) the mode of failure.

Table 5.

Summary of test results.

Specimens name	Load (KN)	Deflection (mm)		(4) Capacity increase (%)	(5) Failure mode [a]
	(1) Ultimate (P_u)	(2) Ultimate (δ_u)	(3) cracking stiffens		
CON	9.6	20	0.39	-	FF[+]
Fully covered TRM-retrofitted specimens					
G1-F	12.3	14	0.65	28	R[++]
G3-F	17.1	22.5	0.61	78	R
G5-F	19.5	20	0.82	103	R
Partially covered TRM-retrofitted specimens					
G1-P	11.0	16.0	0.58	15	R
G3-P	12.9	18.5	0.59	34	R
G5-P	16.2	23.5	0.60	69	R

[+] Flexural failure
[++] R: fibers rupture.

3.1. Load- Mid Span Deflection Curves

Fig. 6, shows the typical load – central deflection curves which were characterized by two different stages:
(1) First stage: un-cracked stage; a linear ascending branch up to concrete cracking; (2) second stage: cracking stage; a non-linear stage with continuous decreasing in the stiffness up to failure.

The load-mid-span displacement curve of the reference slab was included in both Fig.s for the sake of comparison (Fig. 6). The different of the load-central

displacement curves of the reinforced specimens with respect to the control specimens is related to the influence of the strengthening materials. This influence can be clearly seen in the second stages of the load-central span deflection. In specific, when the crack started to be developed and both the internal steel reinforcement and external strengthening were activated

and contributed the flexural resistance of the tested slabs increased.

The behavior of load- mid span displacement after reaching the ultimate load of all strengthened slabs was approximately the same; specifically, when the failure occurred, the load decreased suddenly to value of reference specimen indicated that the contribution of strengthening has been completely lost.
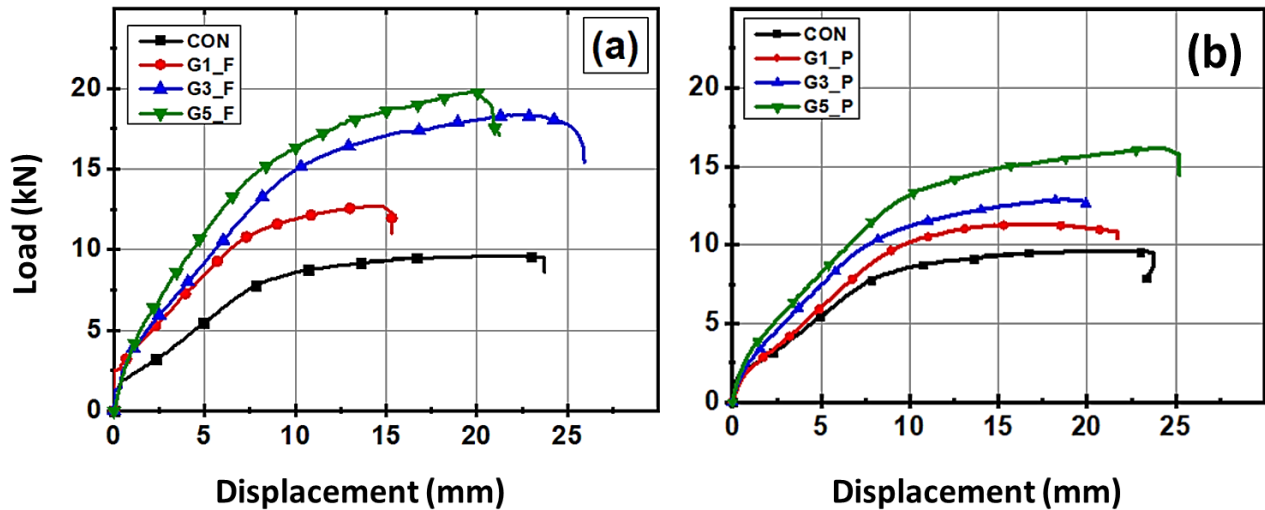
Fig. 6. Load mid-span displacement curves (a) Fully covered glass fiber textile strengthened slab with (1,3,5) layer of TRM. (b) partially covered glass fiber textile strengthened slab with (1,3,5) layer of FRP.

3.2. Ultimate Loads and Failure Modes

- *Control slab*

The reference control slab failed due to large bending cracks at the zone of the maximum moment. The failure mode was matching to the typical failure of slab with under reinforcement. See Figure 7. Failure was caused by yielding of the tension steel reinforcement and then

the concrete at the compression face was crushed. The ultimate load of the control specimen was 9.6 KN and the recorded mid-span displacement at that load was 20 mm. In the next section, the maximum load and the observed failure mode of the strengthened specimens will be discussed based on the pre-defined group.
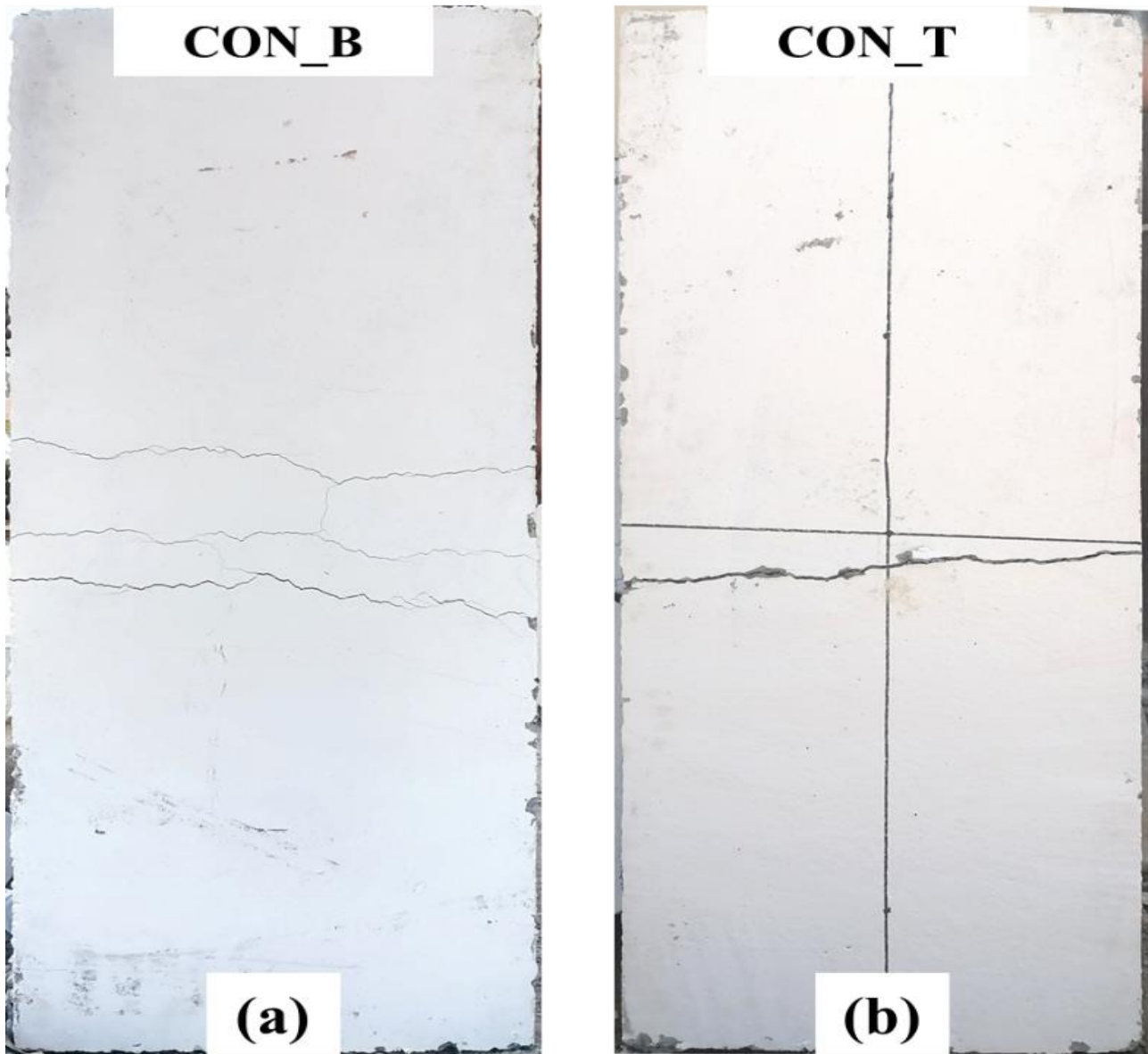
Fig. 7. The control specimen from the bottom (a) and from the top (b).

- ***GTRM Strengthened Specimens***

This group included the specimens strengthened fully and partially with G-TRM. The fully covered strengthened specimens (G1_F, G3_F, and G5_F) recorded an ultimate load of 12.3 kN, 17.1 kN and 19.5 kN for, respectively (Table 5). Hence the increasing in flexural capacity was 28 %, 78 %, and 103 %, respectively when comparing with the un-strengthened reference specimen. The dominant failure mode of this group was rupture of the textile fiber at the mid-span.

Such type of failure was due to the low tensile strength of the glass fibers (Fig. 8 a-c).

For the partially covered G-TRM strengthened specimens (G1_P, G3_P, and G5_P), the recorded failure load was 11.0 kN, 12.9 kN and 16.2 kN for specimens, respectively (Table 4). The flexural capacity increase was 15%, 34% and 69%, respectively when comparing with the un-strengthened reference specimen. As in the case of fully covered GTRM specimens, these specimens were also failed due to textile fiber rupture (Fig. 8 d-f).
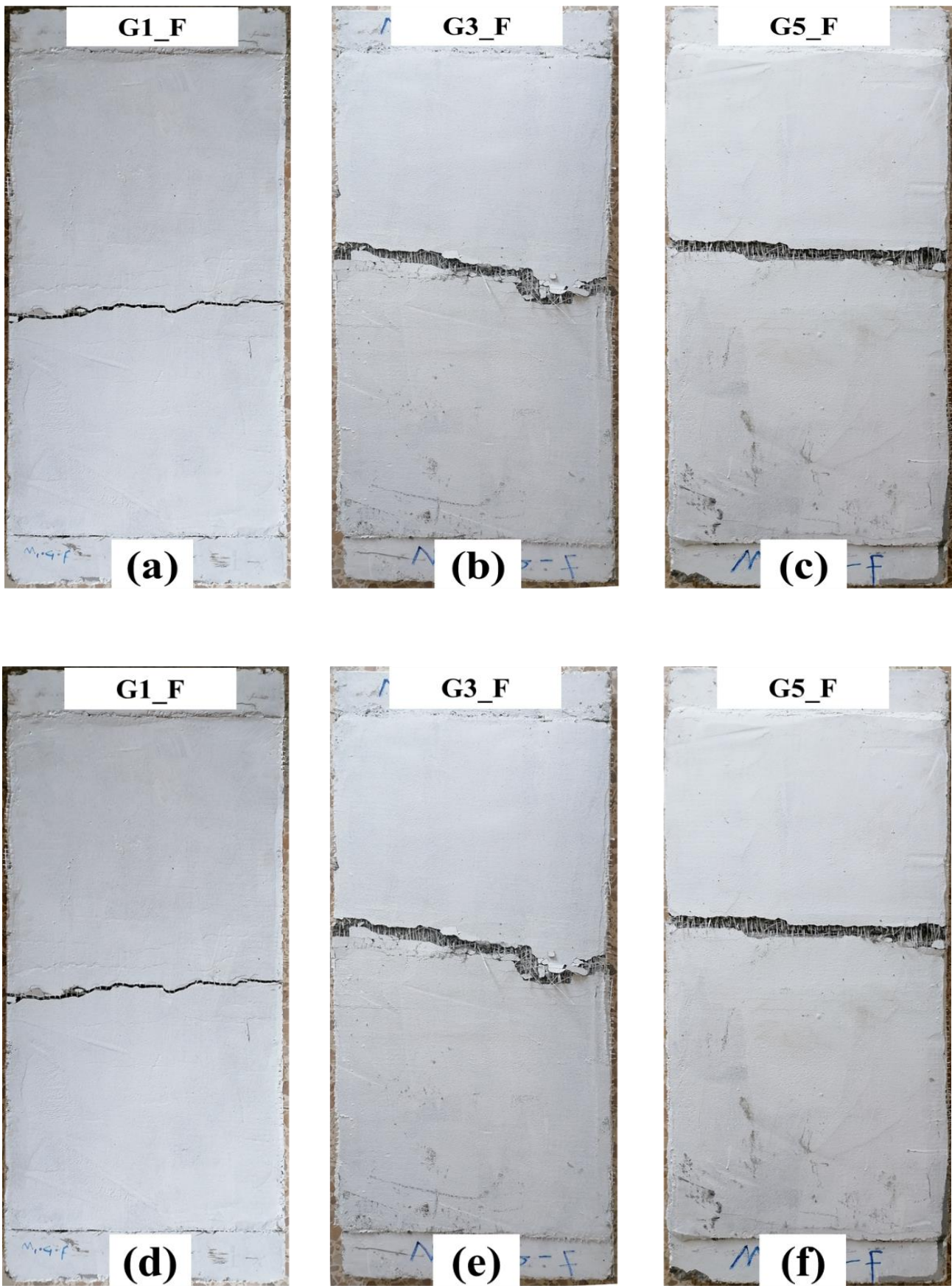
Fig. 8. Failure mode of the fully and partially GFRP strengthened slabs.

4. DISCUSSION

4.1. Number of Strengthening Layers

The impact of the number of layers on the slab's flexural capacity increase is reported in Fig. 9. Increasing the number of GFRP layers from one to three and five caused improving in the recorded strength capacity. In specific, the increase in the flexural capacity was 1.4, 1.6 times and 1.2, 1.5 times respectively with respect to one layer fully and partially GTRM specimen. For both strengthening systems, it is noted that the increase in the flexural capacity was almost the same when shifting from three to five layers. This is because, for all these specimens the failure mode was due to textile fibre rupture, hence a fully utilize for the tensile strength of the composite was achieved.
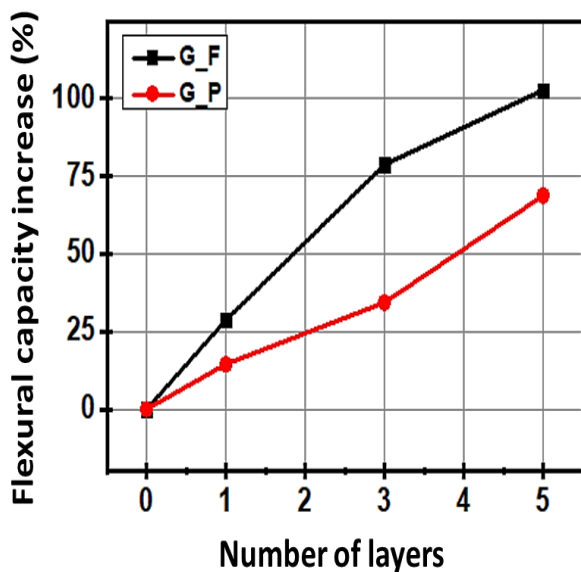

Fig. 9. Impact of the number of reinforcement layers on the maximum bending capacity increase: fully cover of glass fibre textile strengthened slab with (1, 3, 5) layer of TRM and partially cover of glass fibre textile strengthened slab with (1,3,5) layer of TRM.

4.2. Strengthening Configuration

As shown in Fig. 10, it is clear that the fully strengthened specimens had the highest flexural capacity performance than the corresponding partially strengthened specimens. In specific, the flexural capacity increase of the fully covered G-TRM strengthened specimens (M1_G_F, M3_G_F and M5_G_F) was 1.1, 1.3 and 1.2 times higher than the counterpart specimens M1_G_P, M3_ G_P and M5_ G_P, respectively. This is attributed to the fact that in fully covered strengthening configuration more textile fibers was involved in carrying the stresses transferred from concrete. Hence better stress distribution was achieved.
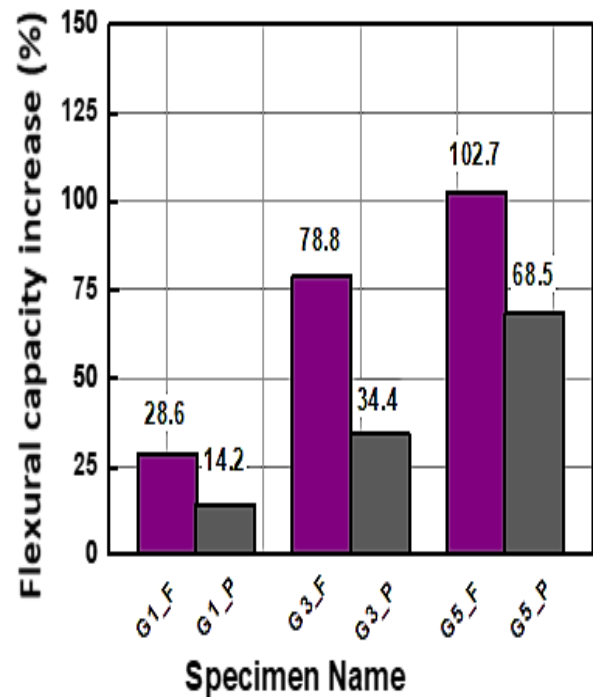

Fig. 10. Effect of strengthening configuration on the flexural capacity increase (%).

5. THEORETICAL CALCULATIONS

The theoretical ultimate moment of the strengthened specimens was calculated and compared with that obtained from experimental results. The procedure for calculation of the theoretical ultimate moment (M_{theo}) assumed that the stress in the fibers reached its ultimate moment (which confirmed from the failure mode), hence, the ultimate flexural moment due to application

of strengthening can be estimated from equilibrium of forces. Then, this moment is added to the theoretical ultimate moment resulted from the internal steel reinforcement. The procedure of these calculations can be summarized as follows:

1- The theoretical ultimate moment ($M_{theo}.$) was determined from the below equation:

$$M_{theo} = M_f + M_s$$

Where:

M_f is the moment resulting from the application of strengthening and M_s , is the moment resulting from steel reinforcement.

From equilibrium of forces

$$C = T$$

$$0.85 \, f_{c'} ab = (A_s * f_y) + (A_f * f_{fu})$$

From equilibrium of forces (a) be found for each specimen.

The arm of the moment for both steel reinforcement and fiber can be found through

For steel $= d - \dfrac{a}{2}$

For fiber $= h - \dfrac{a}{2}$

2- The moment due to steel reinforcement (M_s) was found theoretically as shown below

$$M_s = A_s * f_y * (d - \frac{a}{2})$$

3- The moment due to application of strengthening (M_f) was obtained from the below equation:

$$M_f = A_f * f_{fu} * (h - \frac{a}{2})$$

Were:

f_{fu} – is the ultimate tensile stress given in Table3.

A_f –is the area of fibers$= n * b_f * t_f$

Where n is the number of TRM/FRP layers, (b_f) is the width of the TRM/FRP (500 mm for the fully strengthening and 250 for the partial strengthening) and (t_f)is the thickness of textile fiber for one layer.

The thickness of the textile fiber (t_f) can be calculated as follows:

$$w_g = 135g \; ; \gamma_g = 2.5 \frac{g}{cm^3} \; ; A_f = 10000 cm^2$$

$$\therefore t_g = 0.054mm$$

The experimental moment can be calculated from the shear diagram for each specimen as follows:

$$M_{exp} = \frac{Pl}{4}$$

Table 6 lists the values of the experimental and theoretical ultimate moment. This table also includes the ratio of the theoretical ultimate moment ($M_{theo}.$) to the experimental ultimate moment ($M_{exp}.$). As shown in this table that the ratio of the theoretical ultimate moment ($M_{theo.}$) to the experimental ultimate moment ($M_{exp.}$) shows an acceptable agreement. This is mainly related to the assumption that the stress in the fibers reached its ultimate. Hence, for the design purposes, the coupon test can be used to estimate the moment gained from

application of strengthened and then added to that moment of the un-strengthened RC slab.

Table 6.

The ratio of theoretical moment on experimental moment.

Specimen name	Theoretical moment (M_{theo})	Experimental moment (M_{exp})	$M_{theo}/M_{exp.}$
CON	2.2	2.4	0.9
M1_G_F	2.7	3.1	0.9
M3_G_F	4.4	4.3	1.0
M5_G_F	6.0	4.9	1.2
M1_G_P	2.2	2.8	0.8
M3_G_P	3.1	3.2	1.0
M5_G_P	4.0	4.1	1.0

6. CONCLUSIONS

1. Generally, applications of TRM resulted in an increase in the flexural capacity of RC slabs. In specific, the fully covered strengthened specimens (G1_F, G3_F, and G5_F) recorded increasing in flexural capacity of 28 %, 78 %, and 103 %, respectively, comparing with the un-strengthened reference specimen. Whereas, the partially covered G-TRM strengthened specimens (G1_P, G3_P, and G5_P), showed a flexural capacity increase of 15%, 34% and 69%, respectively compared to the un-strengthened reference specimen.

2. Increasing the number of strengthening layers significantly improves the bending capacity of RC slabs. In specific, applying three and five layers provided an enhancement in the ultimate carrying capacity of 1.4, 1.6 times and 1.2, 1.5 times, respectively compared to one layer fully and partially strengthened with GTRM.

3. The fully strengthened specimens had higher flexural capacity performance than the corresponding partially strengthened specimens. The flexural capacity increase of the specimens M1_G_F, M3_G_F and M5_G_F had 1.1, 1.3 and 1.2 times higher capacity increase compared to the counterpart specimens M1_G_P, M3_ G_P and M5_ G_P, respectively.

4. The dominant observed failure mode was rupture of the textile fibers at the maximum moment zone.

5. When the failure of specimens due to rupture of the textile fibers, once, the gain of the ultimate moment can be estimated due to application of strengthening using direct tensile test of TRM coupons.

6. The theoretical calculation of the ultimate moment showed a good agreement with that ultimate moment calculated experimentally. This is mainly related to the failure mode which was due to textile fiber rupture. Hence the ultimate tensile of the TRC coupon can be used to calculate the moment resulted from application of strengthening.

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