Flexural Behavior Of GFRP-Reinforced Concrete Beam Strengthened With Cast-In-Place Textile In Tension Zone With High Reinforcement Ratio

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ABSTRACT

TRM is usually composed of continuous textile fabrics embedded into a compendious matrix. This application has gained serious attention within the civil engineering scientific field due to several futures. These features are represented by good mechanical properties like the high strength of textiles, a considerable level of young's modulus, and a good bond between textiles and mortar.

The present experimental program investigates the flexural behavior of the GFRP bars reinforced concrete beams that include TRM layers at the top and bottom of its section. The section is of 200 mm in total height, 120 mm in width, and 1100 mm in center-to-center span. The specimens map comprises five specimens, two of these are referential (GFRP and steel reinforcement) and the others are TRM beams with two, four, and five textile layers respectively. The third, fourth, and fifth specimens are compared with the two referential specimens. These specimens are reinforced with a minimum reinforcement ratio and includes TRM at the section bottom (tension).

The experimental results exhibited that using two, four, and six TRM layers in the beams section top increases the first cracking load, service load, and rapture load respectively. In addition, the differentiation between GFRP and steel bars stress-strain curve caused a connective difference in flexural behavior. When the TRM layers are located in the section bottom (tension zone), the service load increased from 23.76% to 76.03% by increasing the number of layers to six while the stiffness increased from 14.66% to 27.19%. meanwhile, increasing TRM bottom layers to six decreased the ductility from 6.06 % to 18.69 %.meanwhile, increasing TRM bottom layers to six decreased the ductility from 6.06 % to 18.69 %. Finally, Using TRM top layers can change the mode of failure from tension to tension-compression.

Keywords: GFRP; Reinforced Concrete; Cast-In-Place; Textile; Minimum Reinforcement Ratio; Flexural Behavior

Introduction:

Advancements in building materials and technologies have prompted research into sustainable and efficient structural systems that prioritize durability, minimal material use, lightweight, and economic benefits. Resin-impregnated continuous fiber-reinforced polymers (FRP) composite, which has inherent corrosion resistance, has the potential to replace traditional steel reinforcement. However, its limited use can be attributed to two key engineering defects: low elastic modulus and lack of ductility in most available FRP materials. Compared to steel-reinforced concrete elements, FRP materials generally have much lower elasticity modulus, resulting in larger deflections and crack widths under service loads. Additionally, FRP often displays linear elastic tensile stress-strain relation up to failure, unlike steel-reinforced parts, which can compromise structural ductility even in well-designed parts. Therefore, this study aims to address some of the deficiencies in fiber-reinforced beams by increasing the initial crack load, enhancing bending capacity, and improving functionality and serviceability.

Textile-reinforced concrete technology

Reinforced concrete (RC) structures are susceptible to cracking, but the invention of textile reinforced concrete (TRC) has provided a viable solution. Research has shown that using TRC as the reinforcement material is an effective method of strengthening structures. Textile structures have been recognized as the primary reinforcement for fiber-reinforced composite applications due to their unique characteristics such as shape flexibility, easy handling, adaptability, and ability to create structurally complex designs. This is illustrated in Figure (1).

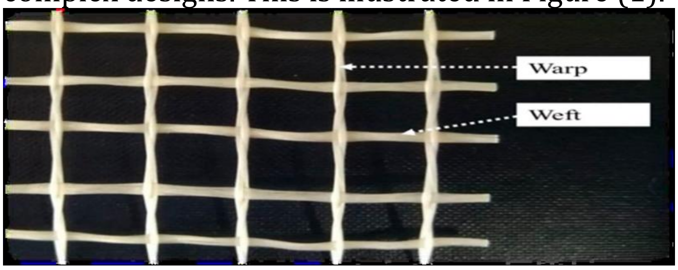

Figure (1) webs of double Glass textile [21].

RC offers a solution to several issues associated with fiber-reinforced polymers, including improving a structure's load-bearing and seismic resistance capacity and limiting the spread of cracks. In addition, TRC can be used for stay-in-place formwork components and can enhance a structure's strength by serving as a composite with its cast-in-place parts. A crucial consideration when using TRC is ensuring that it can bear loads jointly with RC, whether it is used to strengthen existing structures or stay-in-place formwork components. The addition of a TRC layer can alter the failure pattern of FRP RC beams or slabs and improve the sustainability of reinforced concrete. The main purpose of applying TRC is to increase the initial crack load, which raises applied stresses above those without it, enhance the bending, longitudinal, torsional, and shear load-bearing capacity, and improve functionality and serviceability.

Research importance

This study proposes an alternative approach to improve the serviceability and ductility of FRP-reinforced structural members by utilizing fabric-reinforced cementitious composites that exhibit stress hardening behavior. The study aims to validate the effectiveness of this method in improving the structural performance and damage tolerance of the elements through girder bending tests. The tests aim to demonstrate improvements in energy dissipation ratio, crack width, structural bearing capacity, structural strains, damage level deflections, and failure modes. Additionally, the study aims to provide insights into the interactions between the matrix (in tension) and brittle reinforcement, which can be useful in enhancing the performance of FRP-reinforced structural elements overall.

Aims of the Research

To explore the Glass Textile Reinforced Concrete System Cast-in-place's effectiveness for strengthening RC beams in flexure. The following objectives were followed to reach the basic goal of the current study:

1. To obtain a specified level of mechanical strength, a mix design was examined and established for the cementitious matrix and reinforced concrete.
2. The preliminary mechanical tests for the material were made to understand the mechanical characteristics of the used mix design.
3. Two GFRP beams were cast as a reference to establish a baseline for building reasonable comparisons with other GFRP RC beams augmented with layer texture numbers.
4. two Groups of GFRP RC beams strengthening with textile reinforces were casted and tested to include.

Experimental program

Cement

Cement that has been utilized in the present study is Ordinary Portland cement (type II

CEM11/A-L 42.4 R) type (Karasta) LAFARGE Iraq. It has been stored in dry place for avoiding any exposure to various environmental conditions. The physical and chemical examinations of the cement have been performed in the Ministry of Construction and Housing & Municipalities Public /Building Research Directorate/the Structural Materials Laboratory.

Fine Aggregate

Natural sand has been utilized as the fine aggregate. grading of the fine aggregate is within requirements of IQ.S. No45/1984 as shown in Figure (2).

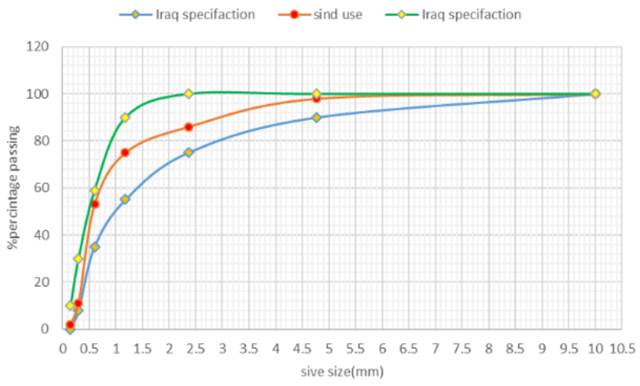

Figure (2) Grading curve for original fine aggregate.

Coarse Aggregate (Gravel)

Crushed gravel has been utilized for concrete specimens with a maximal size of 10mm. rushed gravel has been washed, and stacked in the air to dry the surface according to the test findings, coarse aggregate has conformed to requirements of IQ.S. No45/1984 1984 as shown in Figure (3).

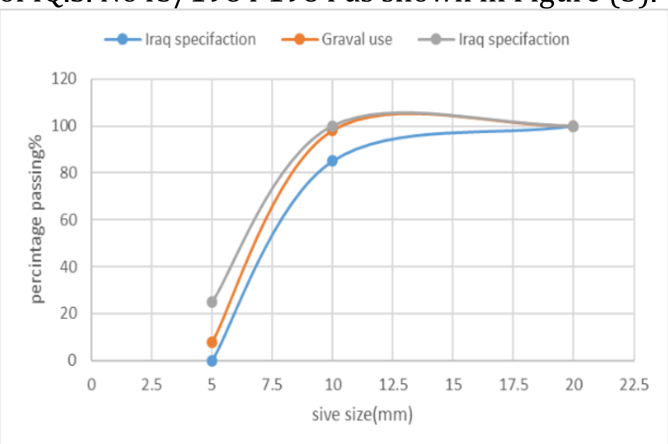

Figure (3) Grading curve for original Coarse aggregate.

Water

Using tap water in the concrete mixtures and during the treatment of different concrete models (cubes, cylinders, and prisms). without any treatments or additives.

Additives

The importance of additives such as Silica fume and Superplasticizer in the TRM layer to improve the toughness of TRM . Is enhanced by increasing the matrix density, improving workability of fresh concrete, reducing the amount of the cement, and possibly increasing the interfacial bond with the textiles, and the apparent effect on the strength and permeability of the matrix.

Silica fume

Gray silica fume from by-products has been used to produce ferrous metallic silicon. It is a highly reactive substance that enhances the properties of concrete. the silica fume used in the current experiment meets the standards of ASTM C-1240-05.

Slurry aggregates

The role of glass sand in fabric-reinforced concrete is very important in several cases for the purpose of increasing the impregnation of the mortar in the fabric slots to contribute to increasing the mechanical properties of the textile mortar and thus increase the ability of the textile mortar to withstand external stresses in addition to being one of the components TRM of the cementation mixture. In this study, two types of glass sand were used Sikadur® 504, Sikafloor®, and Sikadur® 507.

Super-plasticizer

A concrete Superplasticizer is also known as a High-range water reducer. It belongs to water-soluble synthetic organic materials which reduce the water cement ratio required to achieve certain stability in concrete and reduce cement content. In addition to reducing water, it also reduces the hardening components of various compound additives. Significantly increases the strength of concrete at different ages. Also, it can enhance the impermeability, freeze and thaw resistance and wear resistance of concrete and improve its toughness. In this study, a third generation poly carboxylate copolymer liquid was used, which is known commercially as ViscoCrete-5930L. It meets requirements for the Superplasticizer based on the ASTM-C494 Type G and Type F.

Reinforcement

Steel bars were used of different diameters of (6, 8, 10, and 12) mm. The tensile tests of all of those bars have given the characteristics that have been provided in Table (1) The testing bar results have met ASTM A-615/A615M -16 requirements for Grade 60 steel.

Table (2) Tension test results for steel bars in the present work.

Nominal diameter (mm)	*Actual diameter (mm)*	*Area. (mm²)*	*Yield stres (MPa)*	*Elongation (%)*	*Ultimate stress (MPa)*
6	5.92	27.53	508	2.6	635
8	7.87	48.65	497	13.25	622
10	9.88	76.67	508	8.108	635
12	11.9	111.23	524	7.767	655

Glass fiber Reinforcement Polymer (GFRP) bar

In this study, continuous spiral rib-type GFRP bars were used. With different diameters and strengths of (GFRP) as shown in Table (3), it was used as the longitudinal reinforcement of the test beams in accordance with ISO 10406.

Table (3) GFRP bars mechanical properties

Product Features	performance values
tensile strength	Min. 800 MPa
Young's modulus (the modulus of elasticity(	Min.50GPa
Tension adhesion to concrete	Min.12MPa
Resistance in an alkaline environment	Min.600MPa
For tensile adhesion to concrete in alkaline environment	Min.10MPa
transverse tensile strength	Min.200MPa
thermal expansion	2,2x 10" (1/°C)
Density	2047Kg/m³

Textile

The textile reinforcement structure is made of fibers of alkali-resistant (AR), and it is generally flexible. Classified as two-dimensional textiles (with open mesh formation) , laid in the warp direction and weft direction. As shown in Figure (4).

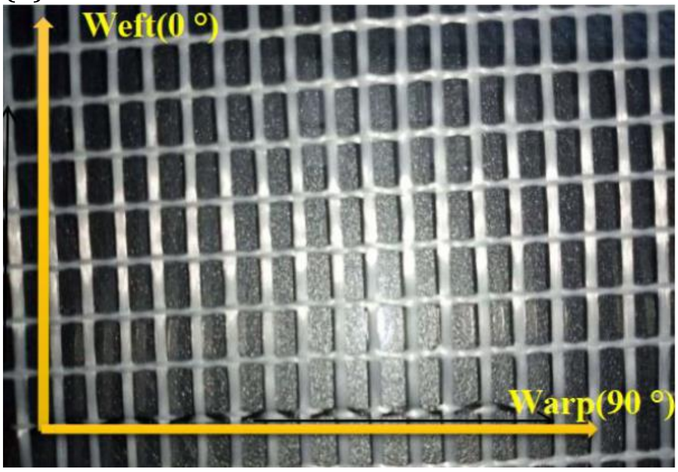

Figure (4) Alkali-resistant (AR) glass textile.

Details of the beams designations

1st symbol (B) for beam.
2nd symbol (S or G) for Reinforcement bar type (Steel or GFRP).
3rd symbol (m) and (s) for reinforcement ratio for (0.82ρb GFRP) and (0.52ρmax steel, 2ρb GFRP), respectively.
4th symbol (lay) layers textile reinforcement.
For example, the following code (BG-mr-2lay) indicates that the beam is reinforced with 0.3ρmax GFRP reinforcement ratio and Strengthened with two layers of textile. As in the shown Figure (5).

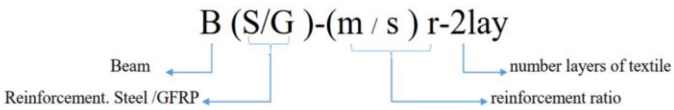

Figure (5) conventions encoded

Details of the Tested Beam

By following the design methods defined according to the American concrete institute (ACI 318RM-19 and ACI 440.1R -15) five concrete beams were cast using ordinary Portland cement, sand, natural gravel, and plasticizers in addition to water.
The experimental program consists of five specimens (Steel, GFRP, GFRP +Textile). It

includes one specimen with a steel reinforcement ratio (0.3ρmax), coded with a code(BS-mr) using steel longitudinal reinforcement at the bottom (2 Ø 10+ Ø 6) in the tension zone, and using steel bars (2 Ø6) at the top in the compression zone. Stirrups of Ø8 were placed at a spacing of 75mm centers in the two shear moment regions.

One specimen is reinforced with a GFRP ratio (0.82ρb), using GFRP longitudinal reinforcement at the bottom (2 Ø8) in the tension zone, and using GFRP bars (2 Ø6) at the top in the compression zone. Stirrups steel of Ø8 were placed at a spacing of 75mm centers in the two shear moment regions, no shear links were placed in the constant moment region (280mm span). The remaining three specimens are reinforced with a GFRP ratio (0.82ρb) and It was strengthened with AR-glass textile with two, four, and six layers placed on the compression faces, and was encoded with symbols (BG-mr-2lay; BG-mr-4lay; BG-mr-6lay) respectively.

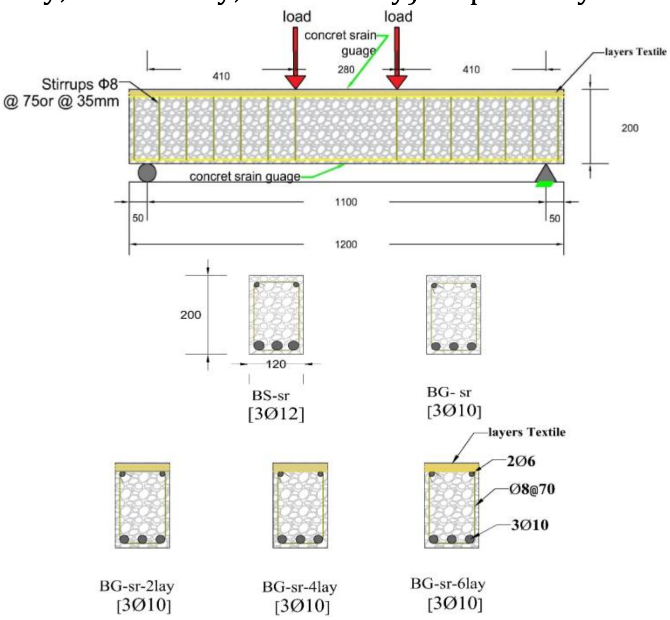

Figure (5) Reinforcement of the tension face with layers of AR-glass textile 2, 4 and 6 layers

Results and discussion

The needed comparisons are done in term of the structural performance of each specimens. This performance was characterized by First Cracking Load (FCL), Service Load (SL), Rapture Load (RL), Service Deflection (SD), Rapture Deflection (RD), Stiffness Index (SI), Ductility Index (DI) as well as failure pattern visual observation the load strain diagrams.

FCL, SL and FL

Tables (4) and Table (5) show the levels of FCL, SL and RL of the specimens with high reinforcement ratio level as per BS-sr and BS-sr respectively. With respect to BS-sr, using GFRP with high reinforcement level as well as top TRM layers increased FCL by 2.67%, 15.06% and 26.34% for two, four and six layers respectively while these increasing rates reported 27.45%, 42.83% and 56.84% as per BG-sr for the same order of specimens.

The levels of FCL are also increased for both comparisons as reported in the first group due to the same reason discussed earlier. The rates of change is still more with respect to BG-mr due to the difference in FCL level.

Moreover, TRM layers increased SL by 2.95%, 37.96% and 45.28% for two, four and six layers respectively as per BS-sr while these increasing rates reported 23.76%, 65.84% and 74.6476.03% as per BG-sr for the same order of specimens. As happened in the first group, increasing TRM layers number increase the related SL as per BS-sr and BG-sr for the same reason discussed in the previous group. The change rates are more as per BG-sr than in BS-sr. Turning to RL levels, TRM layers decreased this value by 1.14% for two layers and increased 11.61% and 21.99%, to four and six layers respectively as per BS-sr RL increased by 24.00%, 39.98% and 52.99% as per BG-sr for the same arrangement of specimens. The levels of FCL, SL and RL of this group are more than the corresponding value of the first group due to the difference in reinforcement ratio. Further research is needed to investigate percent of SL and FCL times RL when TRM is used.

Table (4) FCL, SL and RL of the first group as per BS-mr

Specimen designation	***FCL kN***	***Change in FCL %***	***SL kN***	***Change in SL%***	***RL kN***	***Change in RL %***

BS-sr	26.23	/	75.24	/	103.07	/
BG-sr-2lay	26.93	2.67	77.46	2.95	101.90	-1.14
BG-sr-4lay	30.18	15.06	103.8	37.96	115.04	+11.61
BG-sr-6lay	33.14	26.34	109.31	45.28	125.73	+21.99

Table (5) FCL, SL and RL of the first group as per BG-mr

Specimen designation	*FCL kN*	*Change in FCL %*	*SL kN*	*Change in SL%*	*RL kN*	*Change in RL %*
BG-sr	21.13	/	62.59	/	82.18	/
BG-sr-2lay	26.93	27.45	77.46	23.76	101.90	24.00
BG-sr-4lay	30.18	42.83	103.8	65.84	115.04	39.98
BG-sr-6lay	33.14	56.84	109.31	74.64	125.73	52.99

SD, RD and The Relevant Load Deflection Curves

Table (6) and Table (7) showed the variations of SD and RD for the both comparisons.

As per BS-sr, using GFRP with high reinforcement level as well as TRM layers decreased SD by 35.62%, 39.05% and 57.86% for two, four and six layers respectively while this value decreased by 7.89%, 12.80% and 39.71% as per BG-sr for the same order of specimens.

The difference between the GFRP and conventional steel bars dictated again that SD of BG-sr is higher than BS-sr. once again, this means that by increasing TRM layers, SD was increased with respect to BS-sr and decreased as per BG-sr as noted and reported in the first group. However, this confirms the fact that increasing TRM layers increased the stiffness of beams.

Figure (5) shows the load deflection curves of the, the structural load deflection paths of the BS-sr is rather conventional and comprises the known three phases. The 1st phase starts from zero loading to FCL levels. The 2nd Phase starts from FCL till SL which corresponds the steel reinforcement. The 3rd phase starts from SL till rapture (RL).

For the specimens that reinforced with GFRP bars (with or without TRM), the load deflection paths comprised three phases too. The first is from start to FCL, the second is started from FCL to SD. At this point, the load deflection paths showed clear plastic deformation inflection point. The last phase is started from SD till RL as in BS-mr but with less path length.

Table (6) SD and RD as per BS-mr

Specimen designation	*SD mm*	*Change in SD %*	*RD kN*	*Change in RD %*
BS-sr	2.84	/	11.96	/
BG-sr-2lay	4.16	46.48	7.70	-35.62
BG-sr-4lay	4.12	45.07	7.29	-39.05
BG-sr-6lay	3.19	12.32	5.04	-57.86

Table (7) SD and RD of as per BG-mr

Specimen designation	*SD mm*	*Change in SD %*	*RD kN*	*Change in RD %*
BS-sr	4.22	/	8.36	/
BG-sr-2lay	4.16	-1.42	7.70	-7.89
BG-sr-4lay	4.12	-2.37	7.29	-12.80
BG-sr-6lay	3.19	-24.41	5.04	-39.71

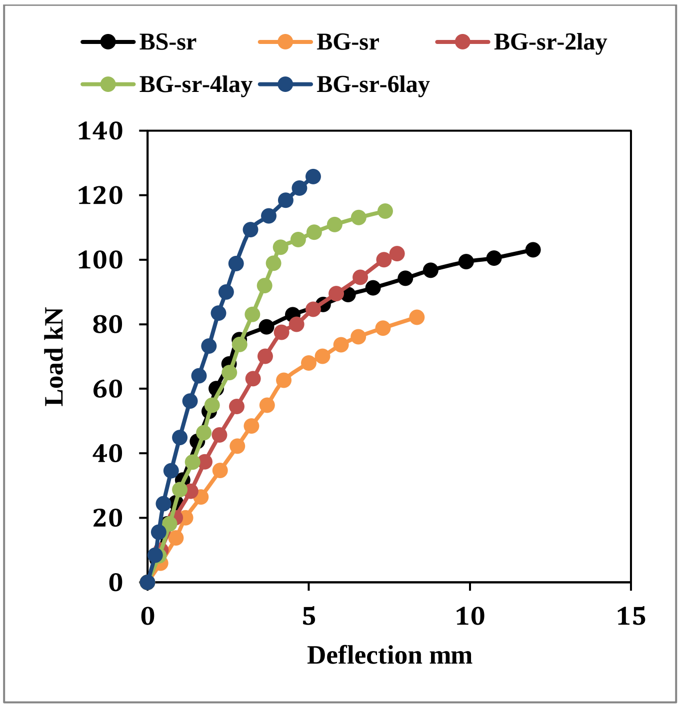

Figure (5) Load deflection curves

SI

Throughout the current study, the stiffness is characterized by the stiffness Index (SI):

SI= SL/SD ……………………..………………..(1)

Where :

SI= Stiffness Index (kN/mm).

SL= Service load (kN).

SD= Service deflection (mm).

Table (7) and Table (8) show the stiffness behavior. With respect to BS-sr, using GFRP with high reinforcement level as well as TRM layers decreased SI by 29.71% and 4.91% and % for two and four layers respectively while it increased by 29.33% for six layers. This index increased by 25.56%, 69.86% and 131.02% as per BG-sr for the same order of specimens.

As in the previous group, the SI levels of BS-sr is higher than BG-sr for the same reason discussed their. In addition, the SI levels foe TRM beams with two and four layers did not reach the BS-sr level and only the six layers specimen is able to exceed this level. With respect to BG-sr, the effect of TRM layers is also understood and clear. If each specimen is compared with the corresponding specimen of the first group, it is noted that the SI levels are high in the current group due to the existing reinforcement level.

Table (7) SI as per BS-mr

Specimen designation	***SD mm***	***SL kN***	***SI Kn/mm***	***Change in SI %***
BS-sr	2.84	75.24	26.49	/
BG-sr-2lay	4.16	77.46	18.62	-29.71
BG-sr-4lay	4.12	103.8	25.19	-4.91
BG-sr-6lay	3.19	109.31	34.26	+29.33

Table (8) SI as per BG-mr

Specimen designation	***SD mm***	***SL kN***	***SI kN/mm***	***Change in SI %***
BG-sr	4.22	62.59	14.83	/
BG-sr-2lay	4.16	77.46	18.62	25.56
BG-sr-4lay	4.12	103.8	25.19	69.86
BG-sr-6lay	3.19	109.31	34.26	131.02

DI

During this study, the ductility behavior of TRM beams is represented by the Ductility Index

DI=RD/SD …………………………….………….(2)

Where :

DI= Ductility index.

RD= Rapture deflection (kN).

SD= Service deflection (mm).

Table (9) and Table (10) showed the variations of DI. As per BS-sr, using GFRP with high reinforcement level as well as TRM layers decreased DI by 56.06%, 57.96% and 62.47% for two, four and six layers respectively while this value decreased by 6.52%, 10.61% and 20.20% as per BG-sr for the same order of specimens.

As in the previous group, the DI level of BS-sr is more than that of BG-sr due to the same reason mentioned in the first group. Additionally, the rates of change are still more as per BS-sr due to such differentiation. The effect of TRM layers is also understood when the increasing the layers numbers decreased the ductility due to the strength gain. If each specimen is compared with the corresponding in the first group, the DI levels are low due to the difference in the reinforcement ratio and the resulted strength.

Table (9) DI as per BS-mr

Specimen designation	***SD mm***	***RD mm***	***DI kN/mm***	***Change in DI %***
BS-sr	2.84	11.96	4.21	/
BG-sr-2lay	4.16	7.74	1.85	-56.06
BG-sr-4lay	4.12	7.37	1.77	-57.96
BG-sr-6lay	3.19	5.14	1.58	-62.47

Table (10) DI as per BG-mr

Specimen designation	***SD mm***	***RD mm***	***DI kN/mm***	***Change in DI %***
BS-sr	4.22	8.36	1.98	/

BG-sr-2lay	4.16	7.70	1.85	-6.52
BG-sr-4lay	4.12	7.29	1.77	-10.61
BG-sr-6lay	3.19	5.04	1.58	-20.20

Cracking Pattern and Failure Mode

For BS-sr, the conventional compression failure mechanism was observed while the cracking begin at the crushing of concrete. Some additional tension cracks begin in accordance with crushing failure and the other cracks accompanied such failure. The same failure mode was observed for BG-sr and the number of cracks are more.

For TRM, the compression failure is rather aggressive in the two layers specimen than in four and six layers. The cracks number effect does not reveal any indicative relation with TRM layers numbers. Figure (6) shows the failure pattern of this group.

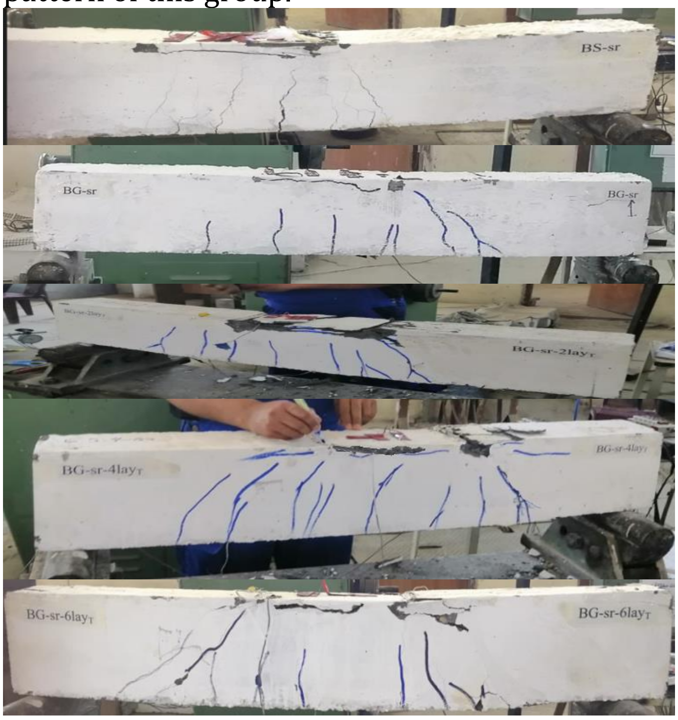

Figure (6) The cracking pattern

Conclusions

The following are the main conclusions that can be extrapolated from the current experimental program.

- Using TRM layers in beams section top increases the structural rigidity and the related first cracking load, service load and rapture load.
- The difference in stress strain characteristics cause service deflection of GFRP reinforced beams to be more than that of conventional steel bars.
- Increasing TRM layers in beams section top decreased the relevant service deflection.
- Increasing TRM layers in beams section top decreases the related beam stiffness and decreases ductility.
- Using TRM top layers can change the mode of failure from tension to compression.

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