Flexural Behavior Of GFRP-Reinforced Concrete Beam Strengthened With Cast-In-Place Textile In Tension Zone With Minimum 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 bottom 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 %. Finally, Using TRM bottom 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:

Research on sustainable and effective structural systems which include qualities of durability, minimal material use, lightweight, and enhanced economic benefits has been stimulated by advancements in building materials and technologies. Because of its inherent resistance to corrosion, resin-impregnated continuous fiber-reinforced polymers (FRP) composite is a possible substitute for traditional steel reinforcement. Yet, it has very occasionally been used. Particularly, the low elastic modulus and lack of ductility regarding almost all available FRP could be connected to two important engineering defects in FRP materials [1]. The bulk of readily accessible FRP materials, with the exception of carbon fiber-reinforced polymer (CFRP), have elasticity modulus that are only 1/5 - 1/3 of those of steel. At a given reinforcement ratio [1], this causes bigger deflections and crack widths under the service loads when compared to the ones of its equivalent steel-reinforced concrete element. FRP frequently displays a linear elastic tensile stress-strain relation up to the point of the failure, on the contrary with steel-reinforced parts, which can lead to poor structural ductility even in the parts that have been adequately designed [1,2]. Because of this, the goal of this study is addressing a few of the flaws in the behavior regarding fiber-reinforced beams, such as raising the initial crack load so that the applied stresses are larger than in their absence, raising the bending capacity, and enhancing functionality and serviceability.

Textile-reinforced concrete technology

RC structures are prone to cracking. This issue has a workable solution thanks to the invention of TRC. The findings demonstrate that using TRC as the reinforcement material is a successful strategy for strengthening the structure [20]. Due to its distinctive qualities, such as shape flexibility, ease of handling, adaptability, and structural complexity [21,22], textile structures have long been recognized as the primary reinforcement for fiber- reinforced composite applications, as shown in Figure (1).

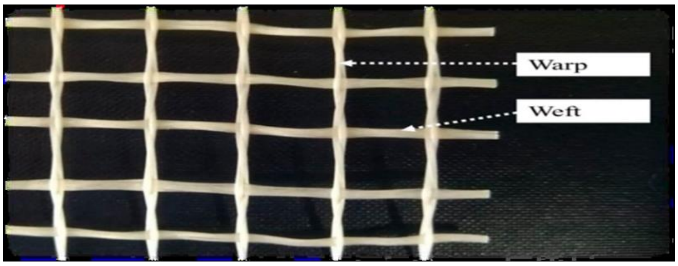

Figure (1) webs of double Glass textile [21].

TRC addresses a number of problems with fiber-reinforced polymers in addition to enhancing the structure's load-bearing and seismic resistance capacity and limiting the spread of cracks [20]. TRC could also be utilized for stay-in-place formwork components and might increase the structure's strength by acting as a composite with its cast-in-place parts [20]. The most significant issue is to make sure that RC and TRC could carry load jointly, regardless of whether it is used to strengthen present structures or stay-in-place formwork parts [20]. The TRC layer allows for the to change the failure pattern of FRP RC beams or slabs and improve the sustainability of reinforced concrete [23]. The application of TRC is primarily to enhance the initial crack load so that the applied stresses are higher than in the lack of it, increase the bending, longitudinal, torsional, and shear load-bearing capacity, and enhance functionality and serviceability [25].

Research importance

With the use of fabric- reinforced cementitious composites with stress hardening behavior, this study offers an alternate method for the enhancement of the serviceability and ductility of FRP- reinforced structural members. Therefore, the validation regarding the viability of upgrading the structural performance as well as the damage tolerance of structural elements through girder bending tests to demonstrate the enhancement in the energy dissipation ratio, crack width, structural bearing capacity, structural strains, damage level deflections, and failure modes, and to offer early understandings of the interactions between matrix (in the tension) and brittle reinforcement, which are helpful in enhancing overall FRP- reinforced structural elements' performance.

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).

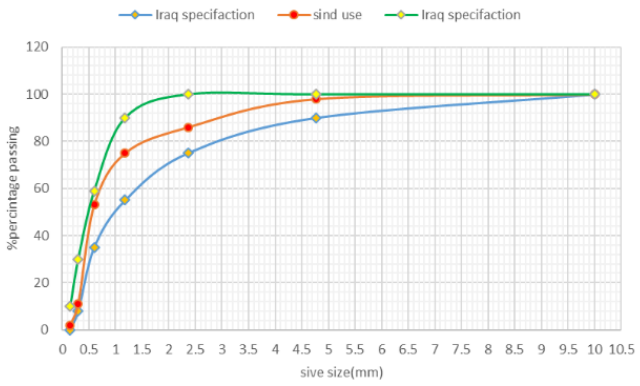

Figure (2) Grading curve for original fine aggregate.

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).

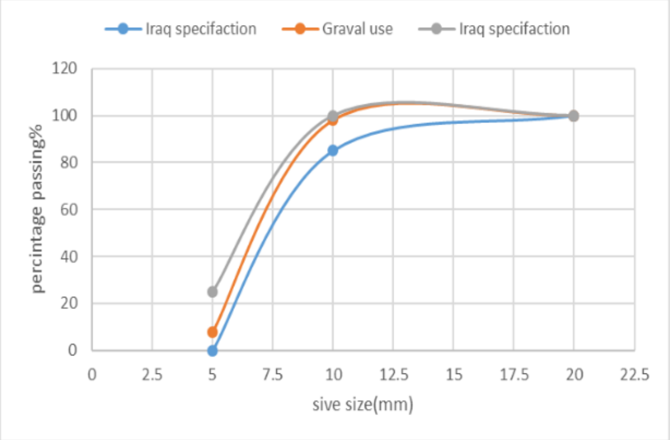

Figure (3) Grading curve for original Coarse aggregate.

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. (mm^2)*	*Yield stress (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	$2047Kg/m^3$

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).

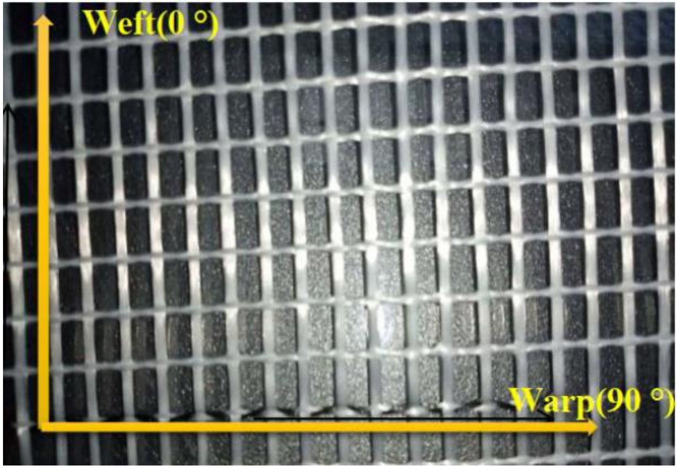

Figure (4) Alkali-resistant (AR) glass textile.

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).

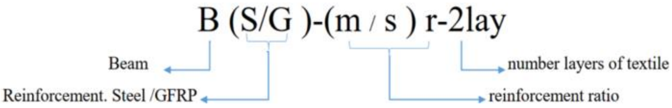

Figure (5) conventions encoded

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 other 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 tension faces, and was encoded with symbols (BG-mr-2lay; BG-mr-4lay; BG-mr-6lay) respectively.

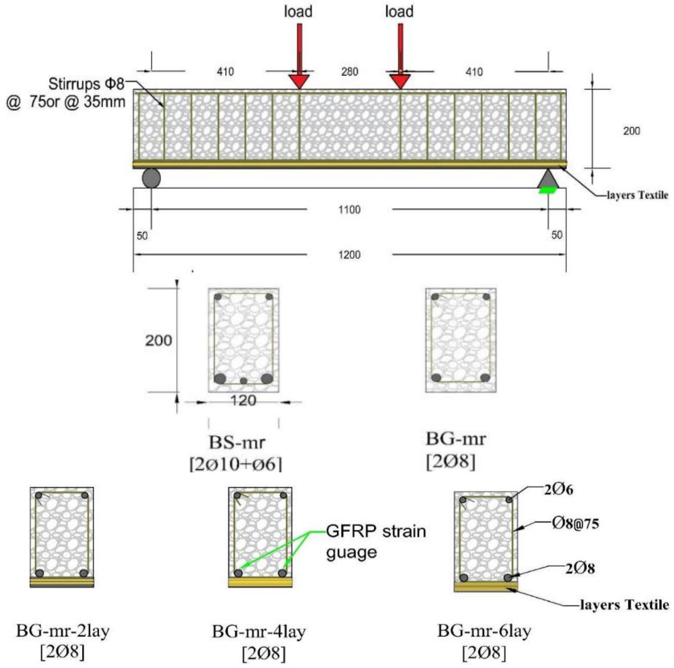

Figure (5) Reinforcement of the tension face with layers of AR-glass textile 2, 4 and 6 layers

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 level as per BS-mr and BG-mr respectively. As per BS-mr, using GFRP with low reinforcement level as well as bottom TRM layers increased FCL by 1.88%, 15.13% and 21.52% for two, four and six layers respectively while these increasing rates reported 33.60%, 50.98% and 59.35% as per BG-mr for the same order of specimens.

It can be seen from these results that FCL showed a recognized increase for both comparisons. This can be attributed to the general increase in structural rigidity.

These rates are growing as the number of layers is progressed. In addition, the change rates of BG-mr comparison is higher than BS-mr due to the inherent difference in FCL levels.

Furthermore, TRM layers increased SL by 8.39%, 43.17% and 54.17% for two, four and six layers respectively as per BS-mr while these increasing rates reported 23.76%, 63.47% and 76.03% as per BG-mr for the same order of specimens.

As in FCL, both comparisons referred to the fact that the structural rigidity dictated a consequent increase in SL. The change rates is still also ore in BG-mr than in BS-mr.

For RL, TRM layers increased this value by .78%, 15.11% and 26.64% for two, four and six layers respectively while these increasing rates reported 25.00%, 40.00% and 53.01% as per BG-mr for the same arrangement of specimens. The effect of increasing TRM layers and the difference between the proposed comparisons are still same as FCL and SL as concluded obviously.

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-mr	14.87	/	56.27	/	78.08	/
BG-mr-2lay	15.15	1.88	60.99	8.39	80.25	2.78
BG-mr-4lay	17.12	15.13	80.56	43.17	89.88	15.11
BG-mr-6lay	18.07	21.52	86.75	54.17	98.23	26.64

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-mr	11.34	/	49.28	/	64.20	/
BG-mr-2lay	15.15	33.60	60.99	23.76	80.25	25.00
BG-mr-4lay	17.12	50.98	80.56	63.47	89.88	40.00
BG-mr-6lay	18.07	59.35	86.75	76.03	98.23	53.01

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-mr, using GFRP with low reinforcement level as well as TRM layers increased SD by 46.48%, 45.07% and 12.32% for two, four and six layers respectively while this value decreased by 35.28%, 38.38% and 57.02% as per BG-mr for the same order of specimens.

The value of SD in BG-mr is higher than BS-mr, this can be attributed to the difference in stress strain curve between GFRP and conventional steel bars. This behavior reflected that SD is increased with respect to BS-mr and decreased with respect to BG-mr. This means that the number of layers increased the stiffness of TRM beams (for GFRP comparison). The next section discusses the stiffness of beams effect.

Figure (5) shows the load deflection curves of the first group, the structural load deflection paths of the BS-mr 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 of the first group as per BS-mr

Specimen designation	*SD mm*	*Change in SD %*	*RD kN*	*Change in RD %*
BS-mr	2.84	/	11.96	/
BG-mr-2lay	4.16	46.48	7.74	-35.28
BG-mr-4lay	4.12	45.07	7.37	-38.38
BG-mr-6lay	3.19	12.32	5.14	-57.02

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

Specimen designation	*SD mm*	*Change in SD %*	*RD kN*	*Change in RD %*
BS-mr	4.22	/	8.36	/
BG-mr-2lay	4.16	-1.42	7.74	-7.42
BG-mr-4lay	4.12	-2.37	7.37	-11.84
BG-mr-6lay	3.19	-24.41	5.14	-38.52

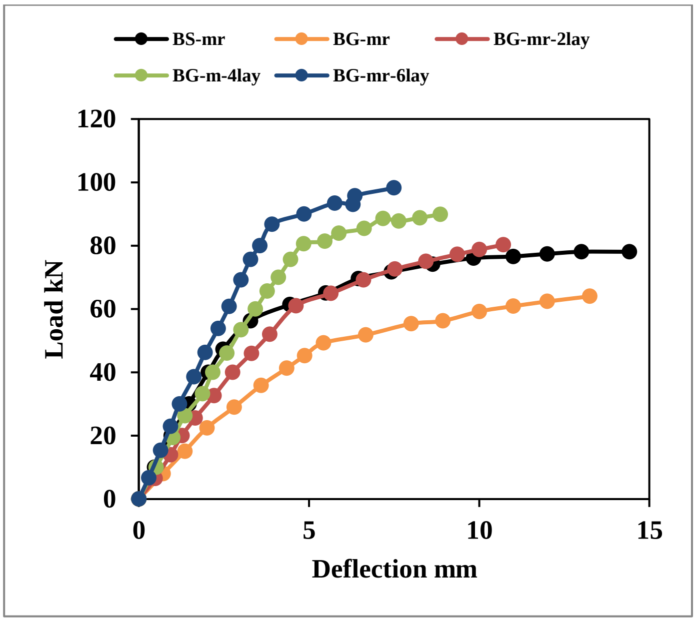

Figure (5) Load deflection curves

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 of the first group. With respect to BS-mr, using GFRP with low reinforcement level as well as TRM layers decreased SI by 26.00% and 1.31% for two and four layers respectively while it increased by 37.25 for six layers. This index increased by 25.51%, 67.38% and 132.79% as per BG-mr for the same order of specimens.

In general, the SI level of BS-mr is higher than in BG-mr due to the corresponding levels of SD and SL. The TRM beams with two and four SI level layers did not reach BS-mr while six layers specimen are able to exceed SI level of BS-mr. Turning again to the second comparisons, the effect of TRM numbers is still understood. However, further research is needed to correlate number of layers and the relevant SI.

Table (7) SI of the first group as per BS-mr

Specimen designation	*SD mm*	*SL kN*	*SI Kn/mm*	*Change in SI %*
BS-mr	2.84	56.27	19.81	/
BG-mr-2lay	4.16	60.99	14.66	-26.00
BG-mr-4lay	4.12	80.56	19.55	-1.31
BG-mr-6lay	3.19	86.75	27.19	+37.25

Table (8) SI of the first group as per BG-mr

Specimen designation	*SD mm*	*SL kN*	*SI kN/mm*	*Change in SI %*
BG-mr	4.22	49.28	11.68	/
BG-mr-2lay	4.16	60.99	14.66	25.51
BG-mr-4lay	4.12	80.56	19.55	67.38
BG-mr-6lay	3.19	86.75	27.19	132.79

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 within the first group. As per BS-mr, using GFRP with low reinforcement level as well as TRM layers decreased DI by 55.82%, 57.48% and 61.76% for two, four and six layers respectively while this value decreased by 6.06%, 9.60% and 18.69% as per BG-mr for the same order of specimens.

Generally, it is highly recognized that DI level of BS-mr is more than BG-mr due to the differentiation in SD levels as discussed earlier. The rate of change with respect to BG-mr is less than BS-mr due to the relative approach in boundary conditions. The effect of layers is also understood in term of DI when these numbers increased, DI levels decreased due to the general increase in beams strength (SD and even RD). another research programs should be devoted to investigate the degree of correlation between number of layers and DI levels.

Table (9) DI of the first group as per BS-mr

Specimen designation	*SD mm*	*RD mm*	*DI kN/mm*	*Change in DI %*
BS-mr	2.84	11.96	4.21	/
BG-mr-2lay	4.16	7.74	1.86	-55.82
BG-mr-4lay	4.12	7.37	1.79	-57.48
BG-mr-6lay	3.19	5.14	1.61	-61.76

Table (10) DI of the first group as per BG-mr

Specimen designation	*SD mm*	*RD mm*	*DI kN/mm*	*Change in DI %*
BS-mr	4.22	8.36	1.98	/
BG-mr-2lay	4.16	7.74	1.86	-6.06
BG-mr-4lay	4.12	7.37	1.79	-9.60

BG-mr-6lay	3.19	5.14	1.61	-18.69

Cracking Pattern and Failure Mode

For BS-mr, the mode of failure is pure tension failure and the cracking paths conventional. For BG-mr, the failure is also pure tension but the cracks have begun to approach the compression face. The mode of failure for TRM specimens was clearly changed to tension-compression while the cracking paths reached the extreme fiber of compression and crushing is obvious. However, the cracking numbers are so close and there are no clear logical order between these numbers and numbers of TRM layers. The intended patterns are shown in Figure (6).

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 bottom 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 bottom decreases the related beam stiffness and decreases ductility.
- Using TRM bottom layers can change the mode of failure from tension to compression.

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