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Enhancement of the Tensile Strength of Reinforced Concrete Beams Using GFRP

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Abstract: ***Use of externally bonded Glass Fiber Reinforced Polymer (GFRP) sheets/strips/plates is a modern and convenient way for strengthening of RC beams.***

GFRP can be classified as a type of composite material that is increasingly used in the construction industry in recent years. Due to their light weight, high tensile strength, corrosion resistance and easy to implementation makes these material preferred solutions for strengthening method of reinforced concrete structural elements. This paper presents the experimental results on the confining effects of GFRP wraps in the tension-zone of reinforced concrete RC beams. A total of 16 beam specimens were used in this study. The beam dimensions were 150 mm width, 150 depths, and 620 span lengths center to center with total length 700 mm. The test parameters include number of layers and width of GFRP. The GFRP laminates were applied 580 mm in length. The specimens were tested in four points bending to failure. This paper provides new information on the degree of GFRP enhancement for reinforced concrete members and the effect of the GFRP wrapping width and layers, and increase in capacity to prevent cracks in tension zone with and without GFRP wrapping. The results of tests have been evaluated and compared with international codes. Consequently it has been noted that the GFRP materials enhance both strengthening and ductility of reinforced concrete beam sections. When trying to utilize fiber polymer sheets, either made of carbon CFRP or steel SFRP, as external shear reinforcement attached on RC beams, their potential of high tensile strength is prevented by the GFRP sheets.

Keywords**— Composite Structure, Tensile Strength, GFRP, Strengthening, Experimental Tests, Reinforced Concrete Beam, Slip.**

I. Introduction

The tensile strength is one of the basic and important properties of the concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The cracking is a form of tension failure. The splitting tests are well known indirect tests used for determining the tensile strength of concrete sometimes referred to as split tensile strength of concrete. The test consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive platens. Due to the compression loading a fairly uniform tensile stress is developed over nearly (2/3) of the loaded diameter as obtained from an elastic analysis.

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. The flexural strength would be the same as the tensile strength if the material were homogeneous. In fact, most materials have small or large defects in them which act to concentrate the stresses locally, effectively causing a localized weakness. When a material is bent only the extreme fibers are at the largest stress so, if those fibers are free from defects, the flexural strength will be controlled by the strength of those intact 'fibers'. However, if the same material was subjected to only tensile forces then all the fibers in the material are at the same stress and failure will initiate when the weakest fiber reaches its limiting tensile stress. Therefore it is common for flexural strengths to be higher than tensile strengths for the same material. Conversely, a homogeneous material with defects only on its surfaces (e.g., due to scratches) might have a higher tensile strength than flexural strength. The material will fail under a bending force which is smaller than the corresponding tensile force. Both of these forces will induce the same failure stress, whose value depends on the strength of the material.

Serviceability of structural concrete members in terms of deflection and cracking is governed by the tensile strength of concrete, the amount and distribution of steel reinforcement in the tension zone. This will affect the durability of the structural member especially if exposed to aggressive environmental conditions such as high- humidity and deicing salts. The tensile strength of concrete is typically evaluated using: (1) splitting tensile strength method by splitting cylinders or (2) modulus of rupture by flexural testing. Modulus of rupture or splitting tensile tests is more common to determine the tensile strength of concrete. According to CSA-A23.3-94[1] code, the modulus of rupture or flexural tensile strength is calculated by equation (1), The equation includes a factor (λ), which has different values according to the effect of concrete density on tensile strength, according to ACI-318-2011[2] is calculated by equation (2), and according to IS 456-2000 [3] is calculated by equation (3);

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$$f_r = 0.6\lambda\sqrt{f_c^{'}} \ldots (1)$$

Where:
λ = 1.0 for normal density concrete.
λ = 0.85 for structural semi- low density concrete in which all the fine aggregate is natural sand.
λ = 0.75 for structural low -density concrete in which none of the fine aggregate is natural sand.

According to ACI-318-11, for normal weight concrete, the average splitting tensile strength f_{ct} is approximately equal:

$$f_{ct} = 0.56\sqrt{f_c^{'}} \ldots (2)$$

According to IS 456-2000 is calculated by

$$f_{cr} = 0.7\sqrt{f_{ck}} \ldots (3)$$

Where
f_{ck}, is the characteristic cube compressive strength of concrete in MPa.
In general form, the formula is:

$$\text{Tensile Stress} = k\sqrt{\text{Compressive Strength}} \quad \ldots (4)$$

Where k, is a constant.
The tensile strength of concrete in flexure (modulus of rupture) is a more variable property than the compressive strength and is about 10 to 15 percent of the compressive strength [2]. Tensile strength of concrete in flexure is neglected in strength design. For members with normal percentages of reinforcement, this assumption is in good agreement with tests. For very small percentages of reinforcement, neglect of the tensile strength at ultimate is usually correct. The strength of concrete in tension, however, is important in cracking and deflection considerations at service loads.
Shear cracking begins from an interior point in a member when the principal tensile stresses exceed the tensile strength of the concrete. Flexure-shear cracking is initiated by flexural cracking. When flexural cracking occurs, the shear stresses in the concrete above the crack are increased. The flexure-shear crack develops when the combined shear and tensile stress exceeds the tensile strength of the concrete. Very little information is available on the confining effects of GFRP wraps on the tensile strength of reinforced concrete beams. In the present study, the effects of using GFRP on the tensile strength of concrete using flexural tensile strength. The main objectives of this study were to determine the tensile strength enhancement of GFRP wrapped reinforced concrete beams.
In 2012, G. C. Manos et.al [4], investigated the effective anchoring devices that, in combination with GFRP sheets attached as external shear reinforcement, can be applicable in realistic repair and strengthening schemes of prototype RC beams.

II. Test Program

A total of 16 reinforced concrete beam specimens were tested. The beam specimens were 700 mm long (620 mm span between supports), 150 mm wide and 150 mm deep. Steel distributions were used tension reinforcement (A_s=100 mm^2). RC beams were strengthened with GFRP strip in the middle of cross section with length 580 mm along the beam span. A summary of the test program is given in Table (1).
The specimen details are shown in Figure (1). The shear reinforcement was over designed to avoid shear failure in the beam and to ensure a more ductile flexural failure. The shear reinforcement consisted of 6 mm diameter stirrups spaced at 90 mm center to center in the shear span.

Table (1). Test Specimens

Spaceman Mark	Specimen No.	Width Ratio	Thickness Ratio (100%)
GFRP25mmL1	1	1/6	0.286
	2	1/6	0.286
	3	1/6	0.286
GFRP25mmL2	1	1/6	0.572
	2	1/6	0.572
	3	1/6	0.572
GFRP50mmL1	1	1/3	0.286
	2	1/3	0.286
GFRP50mmL2	1	1/3	0.572
	2	1/3	0.572
	3	1/3	0.572
GFRP100mmL1	1	2/3	0.286
	2	2/3	0.286
	3	2/3	0.286
GFRP100mmL2	1	2/3	0.572
	2	2/3	0.572
REFERENCE RF1	1	------	------
REFERENCE RF2	2	------	------

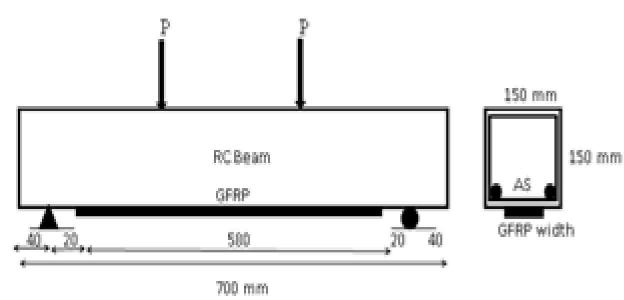

Figure (1). Test specimen reinforcement configurations.

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III. Material Properties

The concrete was mixed in laboratory. It had a specified compressive strength of 40MPa and slump of 10 mm. The tension reinforcing steel used was Grade 420 with yield strength of 420 MPa and modulus of elasticity of 200GPa. Same rebar sizes were used to get the same steel area 100 mm2, 2-No.8 mm bars for main reinforcement in tension. Bar for shear reinforcement and spacing of No. 4 mm on 90 mm centers. Table (2), gives material properties of the GFRP sheets used.

Table (2). Specifications for GFRP.

Specific Gravity	2.56
Effective Fiber Strip Thickness	0.43 mm
Strain ultimate	0.0146
Young's Modulus of Elasticity	75900 MPa
Tensile modulus	60000 MPa
Tensile Strength	875 MPa
Density of Wrap	900 gms / m^2
Elongation at break	0.04

IV. Specimen Preparation

i. Concrete Surface Preparation

It is important to prepare the concrete surface to get effective bonding between the GFRP sheets and concrete. The surface has to be free from any unwanted particles, which prohibit the adhesion such as dust. To obtain the required surface condition, a hand held grinder was used to grind the surface on bottom side of the beam. Then the beams were covered with plastic sheets until the GFRP laminates were applied.

ii. Bonding GFRP Laminate

After surface preparation process of the beams was completed, GFRP material was cut to specific size. The precut GFRP laminate were impregnated with the epoxy resin and the concrete surface was also coated with the same resin to get efficient bonding. GFRP laminate were hand placed and pressed against concrete surface to ensure no air voids. The GFRP strengthened beams were left to cure at room temperature prior to load testing. The GFRP laminates were bonded with the fiber direction perpendicular to longitudinal axis of the beam. The reinforced beams were only wrapped in the middle zone of the beam.

iii. Test Set Up and Procedure

The beams were tested in four points bending over a span of 620 mm with loading points at 210 mm apart from supports.

During the test, load, mid span deflection and slip were measured up to failure. Loading was at rate of 5 kN/min. Figure (3), shows the loading frame and the specimen being tested.

Figure (3) Loading frame and the specimen setup.

V. Test Results and Discussion

i. Modulus of Rupture

Testing the control and strengthened concrete beams revealed an increase in the flexural strength and tensile strength of the GFRP strengthened concrete beams vs. the un-strengthened one, Table (3).

Table (3) Test results.

Spaceman Mark	Specimen No.	P (kN)	a (mm)	L (mm)	b (mm)	d (mm)	σ_{ct}.=PL/ (b*d^2) (MPa)
GFRP25 mmL1	1	31	310	620	150	150	5.69
	2	*20	310	620	150	150	3.67
	3	37.5	310	620	150	150	6.88
GFRP25 mmL2	1	38	310	620	150	150	6.98
	2	34	310	620	150	150	6.24
	3	32	310	620	150	150	5.87
GFRP50 mmL1	1	33	310	620	150	150	6.06
	2	38	310	620	150	150	6.98
GFRP50 mmL2	1	48	310	620	150	150	8.81
	2	49	310	620	150	150	9.00
	3	51	310	620	150	150	9.36
GFRP100 mmL1	1	46	310	620	150	150	8.45
	2	53	310	620	150	150	9.73
	3	44.5	310	620	150	150	8.17
GFRP100 mmL2	1	42	310	620	150	150	7.71
	2	49	310	620	150	150	9.00
REFERENCE RF1	1	24	310	620	150	150	4.40
REFERENCE RF2	2	25	310	620	150	150	4.59

Table (4) Comparison results.

The increase in strength is mainly due to the confinement effect provided by GFRP wrapping in the tension zone. As a result the apparent modulus of rupture increased in the GFRP wrapped

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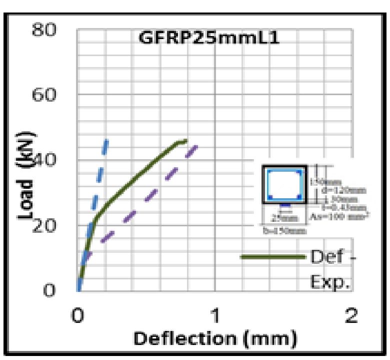
specimens. The theoretical modulus of rupture according to CSA, ACI, and IS codes using specified concrete strength of 40MPa is 3.45 MPa, 3.22 MPa and 4.42 MPa. Table (4), listed the effect of GFRP wrapping on modulus of rupture of RC concrete beams and the values of coefficient (k).

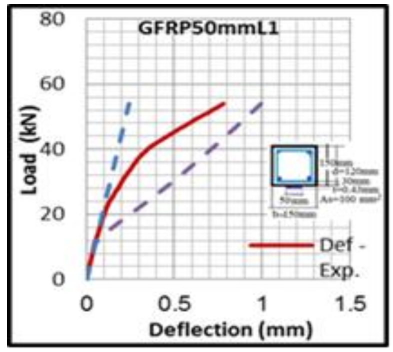
Figure (4) shows that there is a significant increase in the flexural strength of the RC concrete beams: beam strengthened with GFRP had 200% increases over the un - strengthened beam. This would be effective and significant to decrease the amount of cracks in structural concrete members.

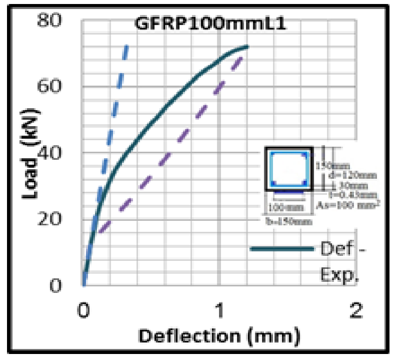
Table (4) Comparison results.

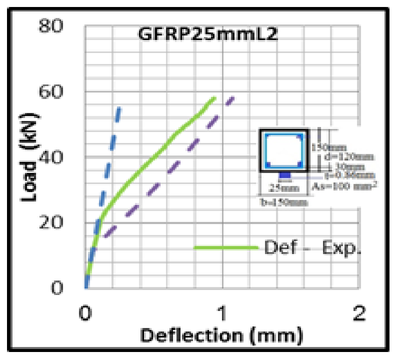
Spaceman Mark	Spec. No.	CSA-A23.3-94 Tensile strength (MPa)	ACI-318-11 Tensile strength (MPa)	IS 456-2000 Tensile strength (MPa)	Study Tensile strength (MPa)	k study	k average
GFRP 25mmL1	1	3.45	3.22	4.42	5.69	0.90	
	2	3.45	3.22	4.42	*3.67	0.58	
	3	3.45	3.22	4.42	6.88	1.08	0.99
GFRP 25mmL2	1	3.45	3.22	4.42	6.98	1.10	
	2	3.45	3.22	4.42	6.24	0.98	
	3	3.45	3.22	4.42	5.87	0.92	1.00
GFRP 50mmL1	1	3.45	3.22	4.42	6.06	0.95	
	2	3.45	3.22	4.42	6.98	1.10	1.03
GFRP 50mmL2	1	3.45	3.22	4.42	8.81	1.39	
	2	3.45	3.22	4.42	9.00	1.42	
	3	3.45	3.22	4.42	9.36	1.48	1.43
GFRP 100mmL1	1	3.45	3.22	4.42	8.45	1.33	
	2	3.45	3.22	4.42	9.73	1.53	
	3	3.45	3.22	4.42	8.17	1.29	1.38
GFRP 100mmL2	1	3.45	3.22	4.42	7.71	1.21	
	2	3.45	3.22	4.42	9.00	1.42	1.32
REFER-ENCE RF	1	3.457	3.22	4.42	4.40	0.69	
	2	3.457	3.22	4.42	4.59	0.72	
Average k							1.19

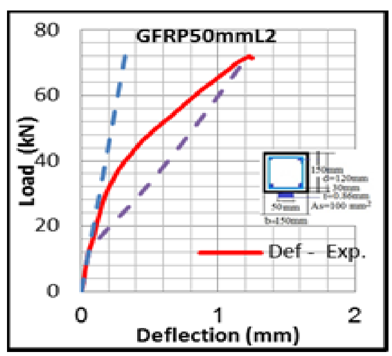
*Unexpected failure.

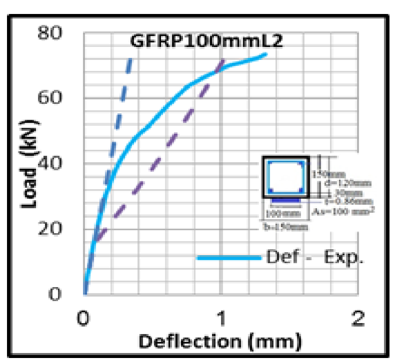












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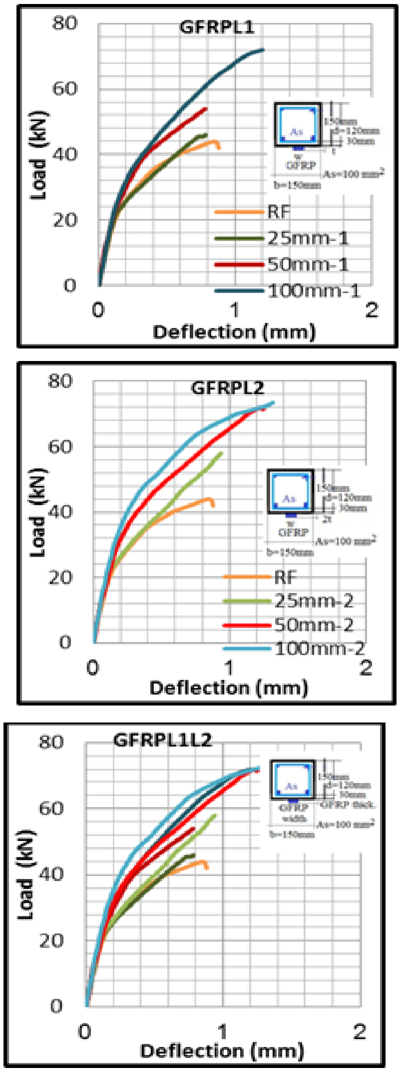

Figure (4) Load – deflection behavior of all specimens.

ii. Cracking pattern

Typical patterns of cracking in composite beams under four points loading consisted of vertical cracks near the center-line in the initial stage of loading and subsequent diagonal cracks near the support location at failure, see Figure (5). As the load was increased following pattern was observed. In all the specimens' first crack was observed in central region of the beam, where moment is uniform and maximum. The crack propagated vertically upwards and more cracks initiated with location of cracks shifting towards supports. Cracks near the supports propagated diagonally and finally the specimens failed in shear.

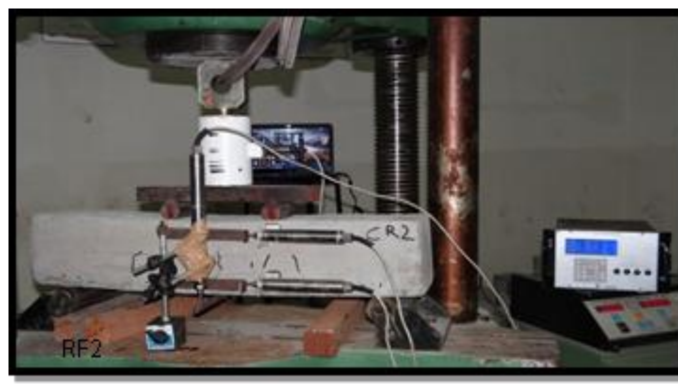

Figure (5) Specimens cracks pattern.

VI. DISCUSSIONS AND CONCLUSION

This paper investigated GFRP wrapping on the flexural behavior of reinforced concrete beams to enhance the tensile strength of reinforced concrete beams. Based on the study, several conclusions can be made:

i. Using GFRP in the flexural member as confined materials can minimize the amount of cracks and eventually enhance the performance of the structure.

ii. Tensile strength of concrete beams can be increased around 150 % by confinement with GFRP.

iii. GFRP confinement was more effective when a large number of layers used to enhancement the serviceability and flexural response.

iv. GFRP confinement was more effective when the width of layer around one – half of beam width to enhancement the serviceability and flexural response.

Further testing is recommended to investigate the use of full wrapping diagonal and U- wrapping on confinement, the direction, and orientation of GFRP wraps, grade of concrete, and type of cement and distribution of steel reinforcement

Acknowledgement

The author would like to thank everyone, just everyone.

References

i. National Building Code of Canada, CSA-A23.3-94

ii. ACI 318M-11, Building Code Requirements for Structural Concrete (ACI 318M-11) an ACI Standard and Commentary

iii. Indian Standard, PLAIN AND REINFORCED CONCRETE CODE OF PRACTICE (Fourth Revision), Tenth Reprint APRIL 2007, BIS2000.-IS 456 (2000): Plain and Reinforced Concrete - Code of Practice [CED 2: Cement and Concrete], Tenth Reprint APRIL 2007.

iv. G. C. Manos, K. Katakals, C. G. Papakonstantinou and G. Koidis, "Enhanced Repair and Strengthening of Reinforced Concrete Beams Utilizing External Fiber Reinforced Polymer Sheets and Novel Anchoring Devices", 15 WCEE, LISBOA 2012.