Some characteristics of RC beams strengthened with GFRP

El-kholy, S.A.[1], Abdelwahab, R.K.[2], Metwally, K.A.[3], Abdullah, A.I.[4]

Abstract— in this study, the effect of strengthening RC beams in shear on its ductility, toughness, and strain in main reinforcing steel was studied. Beams were strengthened using GFRP-U strips. The variable studied were width of GFRP and spacing of such strips measured from centerline to centerline. Ductility in terms of mid span deflection was found to decrease as the GFRP surface area increases. The same result was reached at for toughness of specimens measured in terms of the area under the load deflection curves of the specimens. Maximum strain in reinforcing steel decreases with the increase of GFRP strip width or decrease spacing between GFRP strips, which could be attributed to the increase of specimens' stiffness.

Index Terms— RC beams, ductility, toughness, strain in main steel, GFRP fabrics and GFRP–U wrap

1 Introduction

Glass fiber reinforced polymer (GFRP) is being extensively in use for strengthening reinforced concrete beams in both flexure and shear. EL-kholy S.A et al [1] concluded that the strengthening of RC beams with GFRP U-wrap with presence of steel stirrups has increased the shear capacity of RC beams up to 40.09%. Amer M. Ibrahim et al [2] concluded that increasing the CFRP strip width will be directly proportioned with the beam load capacity and ductility, where decreasing the CFRP strip spacing showed improvement in stiffness beyond yield and increase in the ductile behavior of strengthened beams.

Ceroni, F [3] studied the performance of RC beams strengthened with FRP materials. He used CFRP laminates for strengthening the RC beams. He concluded that use of CFRP laminates increases the load carrying capacity but the ductility has reduced due to brittle failure caused by the occurrence of end debonding of FRP reinforcement. Anil, Ö. [4] mentioned that all CFRP arrangements improved the strength and stiffness of the specimens significantly. The failure mode and ductility of specimens were proved to differ according to the CFRP strap width and arrangement along the beam.

Atif M. Abdel Hafez [5] concluded that the ultimate shear capacity of RC beams can be increased significantly using CFRP–U strips; a maximum increase of 93% was obtained. For beams strengthened with the same amount of CFRP strips, increasing the number of fiber by decreasing the strip width has a slight effect on both carrying capacity and ductility of the beams.

Khair Al-Deen Bsisu et al, [6] multiple narrow strips of FRP will not add to the strength, but will reduce the deflection by reducing ductility. Dong et al. [7], Mentioned that there test results showed that the increase of the shear capacity of the GFRP or CFRP Strengthened beams lied between (31% and 74%). Al-Salloum et al. [8], studied the shear reinforcing effect of continuous and strip GFRP laminates bonded to the sides or sides and bottom of RC beams. The beam specimens were designed to have a deficiency in shear capacity. The results indicated that GFRP strips increased the shear strength of the tested specimens by about 10%; and GFRP continuous laminates increased the shear strength of the tested specimens by about 50%. Berset, J.D. [9], Perform a feasibility study on the use of composites to strengthen concrete beams in shear. Tests on beams strengthened in shear with various area fractions of GFRP showed a consistent increase in strength, stiffness, and ductility with increase in GFRP area fraction. The objective of this study is to investigate the role of GFRP strips, epoxy bonded to the beam web for strengthening of RC beams. Included in the study are effectiveness in terms of width and spacing of vertical-U jacket GFRP strips.

2 Experimental Programme

2.1 Test Specimens

A total of twelve (12) reinforced concrete beam specimens were tested. The beam specimens are divided into four groups, one group (G0) includes three control specimens (B01, B02 and B03); with internal steel stirrups. Three groups (G1, G2, and G3) include nine specimens with internal steel stirrups strengthened with vertical U-shaped jacket of GFRP strips with different width and spacing as given in table (1).

1. Said Abd El-Fattah El Kholy, Prof, Civil Engineering Departmentam – Al Azhar University, Cairo, Egypt, and PH-01019181747. E-mail: said.elkholy2@yahoo.com
2. Abd El-Wahab R. K., Lecturer, Civil Engineering Departmentam – Al Azhar University, Cairo, Egypt,
3. Khalid Aly Metwally, Lecturer, Civil Engineering Departmentam – Higher Engineering Institute, 6th of October City, Egypt, and PH-01223166711. E-mail: khaledalymetwally@yahoo.com

TABLE 1

List of specimen's details

Beam*	d (mm)	W_f (mm)	S_f (mm)	d_f (mm)	Reinforcement bot			Reinforcement top			steel stirrups@ (mm)	(a/d) **
B01	380	---	---	---	3	∅	16	2	∅	10	Φ 6 @200	1.645
B02	380	---	---	---	3	∅	16	2	∅	10	Φ 6 @200	1.645
B03	380	---	---	---	3	∅	16	2	∅	10	Φ 6 @200	1.645
B11	380	40	100	350	3	∅	16	2	∅	10	Φ 6 @200	1.645
B12	380	40	150	350	3	∅	16	2	∅	10	Φ 6 @200	1.645
B13	380	40	200	350	3	∅	16	2	∅	10	Φ 6 @200	1.645
B21	380	60	100	350	3	∅	16	2	∅	10	Φ 6 @200	1.645
B22	380	60	150	350	3	∅	16	2	∅	10	Φ 6 @200	1.645
B23	380	60	200	350	3	∅	16	2	∅	10	Φ 6 @200	1.645
B31	380	80	100	350	3	∅	16	2	∅	10	Φ 6 @200	1.645
B32	380	80	150	350	3	∅	16	2	∅	10	Φ 6 @200	1.645
B33	380	80	200	350	3	∅	16	2	∅	10	Φ 6 @200	1.645

*Beam designation is wf sf

**Shear span to effective depth ratio

2.2 Materials Used

Sand with a fineness modulus of 2.58 and a specific gravity of 2.56 was used. The coarse aggregate used was dolomite of size (5-14mm) and a specific gravity of 2.74. Ordinary Portland cement (CEM I-52.5N) has been used. Potable water was used for both mixing and curing the specimens. Normal mild steel of 6 mm in diameter of grad 36/48 was used as stirrups, where high grad steel of 16mm in diameter and grad 45/70 was used as main steel. SikaWrap-430 G (E- glass fibers) white unidirectional woven glass fiber fabric has been used. Sikadur-330 is a two parts epoxy impregnation resin, Resin part A and Hardener part B (part A: part B = 4:1 by weight) has been used with a rate 1.2 kg/m^2.

2.3 Concrete mix design

The concrete mix was designed to obtain a characteristic strength of 30 N/mm^2 at the age of 28 days. The slump value varied between 50-60 mm. W/C ratios was 0.55,

2.5 Test procedure

All beam specimens were tested under four point static load over clear span 2050 mm by using hydraulic jack mounted on a steel frame in the R.C laboratory of Al-Azhar university .The Schematic of test setup is shown in Fig .(1). The load was applied in regular increments from zero up to the failure load. At the end of each load increment, readings from the load cell, LVDT and strain gauges were recorded through the data acquisition system.

3. ANALYSIS AND RESULTS

3.1 Ductility of strengthened beams

Ductility of reinforced concrete beams can be measured based on structural characteristics such as: mid-span deflection, curvature, or energy absorption capacity as represented by the area under the load-deflection curve. The displacement ductility (μD) considered here was measured as the ratio between maximum deflection (Δmax) (corresponding to 90% of the maximum recorded load) and the deflection corresponding to cracking load (Δcr) [10].

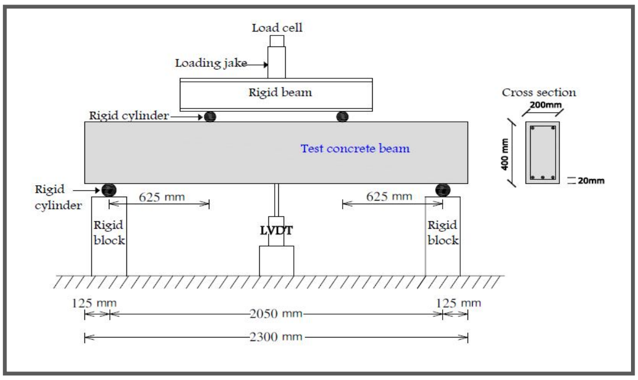

Fig. 1: Schematic diagram of test setup

The role of increase of surface area of GFRP fabrics as strengthening on decrease ductility was clear. The displacement ductility (μD) decrease with the increase in width of GFRP strips of the same spacing as shown in Fig (2), or decrease spacing between GFRP strips at the same width as shown in Fig (3). Table (2) shows the displacement ductility (μD) for the different tested beams that strengthened by vertical U- shape GFRP strips. In general, from table (2), it could be seen that the application of GFRP strips as strengthening material has reduce the ductility of RC beams. This could be attributed to the increase in stiffness of strengthened beams.

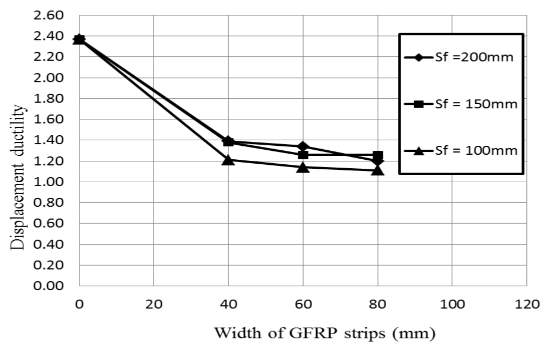

Figure (2): Effect of GFRP strips width on ductility

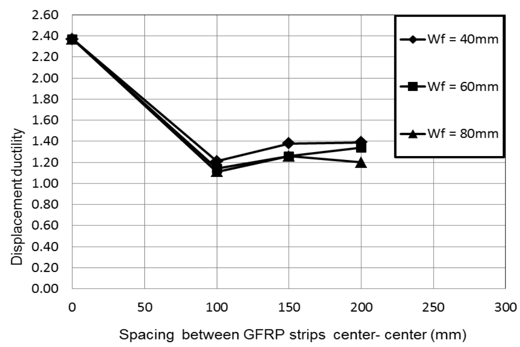

Figure (3): Effect of spacing between GFRP strips on ductility.

TABLE 2

Displacement ductility indices for beams strengthened with GFRP

Effect of S_f					Effect of W_f				
Data of tested beams		Ductility			Data of tested beams		Ductility		
Specimen	f_{cu} N/mm^2	Δ_{cr} (mm)	Δ_{max} (mm)	μ_D	Specimen	f_{cu} N/mm^2	Δ_{cr} (mm)	Δ_{max} (mm)	μ_D
B0	35.56	9.13*	21.59*	2.4	B0	35.56	9.13*	21.59*	2.4
B11	34.93	8.83	10.68	1.2	B11	34.93	8.83	10.68	1.2
B12	33.73	10.8	14.91	1.4	B21	34.67	7.18	8.19	1.1
B13	35.78	12.8	17.79	1.4	B31	34.13	5.32	5.91	1.1
B21	34.67	7.18	8.19	1.1	B12	33.73	10.79	14.91	1.4
B22	34.31	9.89	12.47	1.3	B22	34.31	9.89	12.47	1.3
B23	34.98	11.6	15.49	1.3	B32	34.71	7.24	9.09	1.3
B31	34.13	5.32	5.91	1.1	B13	35.78	12.77	17.79	1.4
B32	34.71	7.24	9.09	1.3	B23	34.98	11.56	15.49	1.3
B33	34.58	9.39	11.22	1.2	B33	34.58	9.39	11.22	1.2

* B0 is average of control beams B01, B02 and B03

3.2 Toughness of strengthened beams

Toughness of different beams, representing the energy absorption up to failure, is calculated as the area underneath the load-deflection curve for each beam. Table (3) shows the values of toughness for the different tested beams that strengthened by vertical U- shape GFRP strips. It could be noticed from table (3) that, the toughness decrease with increase of GFRP strips width at the same spacing, or decrease spacing between GFRP strips at the same width. In general, from table (3), it could be seen that the application of GFRP strips as strengthening material has reduce the toughness of RC beams. This could be attributed to the increase in stiffness of strengthened beams.

TABLE 3

Toughness for beams strengthened with GFRP

Effect of S_f			Effect of W_f		
Data of tested beams		Toughness	Data of tested beams		Toughness
Specimen	f_{cu} N/mm^2	$(kN.mm)x10^3$	Specimen	f_{cu} N/mm^2	$(kN.mm)x10^3$
B0	35.56	*٥,١٦	B0	35.56	5.16*
B11	34.93	٣,٢١	B11	34.93	3.21
B12	33.73	٣,٩٩	B21	34.67	2.33
B13	35.78	٤,٩٤	B31	34.13	1.77
B21	34.67	٢,٣٣	B12	33.73	3.99
B22	34.31	٣,٥٥	B22	34.31	3.55
B23	34.98	٤,٤٥	B32	34.71	2.97
B31	34.13	١,٧٧	B13	35.78	4.94
B32	34.71	٢,٩٧	B23	34.98	4.45
B33	34.58	٣,٥١	B33	34.58	3.51

* B0 is average of control beams B01, B02 and B03

3.3 Strain in main steel for strengthened beams

The longitudinal steel was the same in all Beams (3 Φ 16 mm) as main steel (steel area equals to 0.79% of concrete cross section area), and 2 Φ 10 mm as stirrups hangers. The relationships between the applied load and measured strain in main steel at mid span for the different tested beams are illustrated in in figures (4), (5) and (6). It is obvious from these figure that maximum strain decreases with the increase of GFRP strip width or decrease spacing between GFRP strips. Values of such decrease was calculated and presented in table (4). Such decrease attributed to the increase of specimens' stiffness.

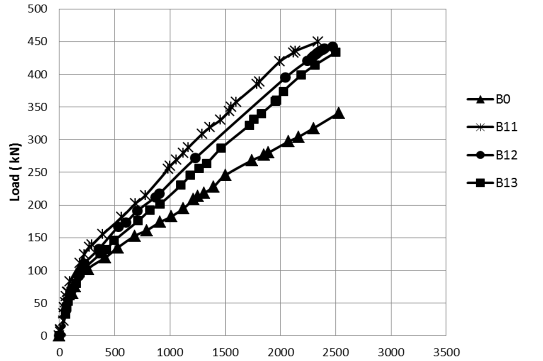

Figure (4): Relationship between Load and strain in main steel for B0, B11, B12 and B13

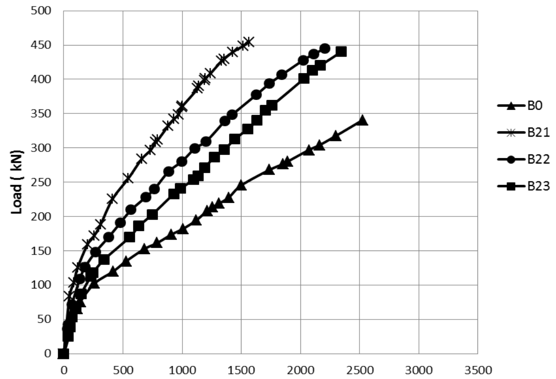

Figure (5): Relationship between Load and strain in main steel for B0, B21, B22 and B23

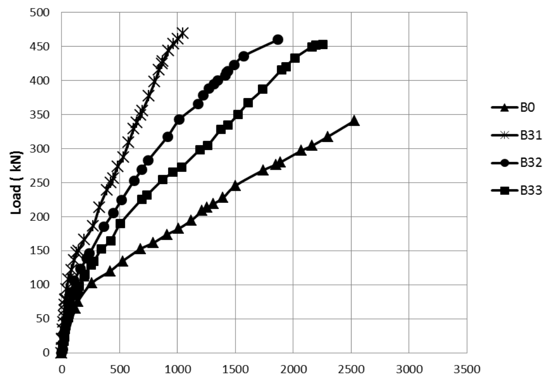

Figure (6): Relationship between Load and strain in main steel for B0, B31, B32 and B33

TABLE 4
Percentage of decrease in strain in main steel for strengthened beams

Effect of S_f		Effect of W_f	
Beam designation	% Decrease in strain	Beam designation	% Decrease in strain
B0	0*	B0	0*
B11	7.4	B11	7.4
B12	2.28	B21	38.05
B13	0.98	B31	58.44
B21	38.05	B12	2.28
B22	12.63	B22	12.63
B23	7.11	B32	26.2
B31	58.44	B13	0.98
B32	26.2	B23	7.11
B33	10.84	B33	10.84

4 CONCLUSION

Based on the experimental results the following conclusions could be drawn:

1. Extending GFRP strips as U–warp over the entire span of the beam reduces the deflection so that the ductility and toughness significantly decreased.
2. In general, it could be seen that the application of GFRP strips as strengthening material has reduce the ductility, toughness and strain in main steel of RC beams. This could be attributed to the increase in stiffness of strengthened beams.
3. The displacement ductility (μD) decrease with the increase in width of GFRP strips of the same spacing, or decrease spacing between GFRP strips at the same width.
4. The toughness decrease with increase of GFRP strips width at the same spacing, or decrease spacing between GFRP strips at the same width.
5. The maximum strain decreases with the increase of GFRP strip width or decrease spacing between GFRP strips.

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