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Some Parameters Affecting the Behavior of Strengthening of Rectangular R.C. Beams Failed in Shear by Using C.F.R.P.

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Abstract: *This paper exemplifies both the shear strengthening capacity and modes of failure of Reinforced Concrete (RC) rectangular shear beams bonded externally with carbon fiber reinforced polymer CFRP-U strips. Sixteen RC beams without internal shear reinforcement and four beams with internal shear reinforcement were tested; seven beams were kept as a control beams; whereas other beams were strengthened externally with CFRP-U strips. Test variables were (i)grade of concrete (ii) longitudinal tensile reinforcement ratio (iii) % of shear reinforcement (iv) orientation of CFRP strips (v)width of CFRP strips (vi) spacing of CFRP strips. Tests results show the effectiveness and shear capacity of CFRP strengthened specimens. The shear enhancement of CFRP strengthened beams varied between 17% and 127% over the control beams depending on various factors .This study confirms that the CFRP-U strips technique significantly enhances the shear capacity of reinforced concrete shear beams. The experimental results of the shear-CFRP strengthened beam were compared with the available theoretical results.*

1. INTRODUCTION

Strengthening of Reinforced Concrete (**RC**) structural members using externally bonded Fiber Reinforced polymer (**FRP**) fabrics have been attracted by many researchers. The demand to use the **FRP** fabrics or sheets is due to its better characteristics than other conventional materials. The major characteristics include high strength to weight ratio, high stiffness, light weight, flexibility and resistance to corrosion. Moreover, there are several other advantages attributed to their use including ease of bonding to curved or any irregular surfaces, easy to install on site without any special equipment, minimal traffic interruption, and less time consumption. In recent years, the exploitation of fiber reinforced polymer composites as external reinforcement is an evergreen technique of improving the structural performance of reinforced concrete structures.

Literature review reported that the flexural strengthening behaviour of reinforced concrete beams has been abundantly addressed. In fact the flexural strengthening mechanism of reinforced concrete beams was studied well but not complicated like shear mechanism. Shear failure of reinforced concrete beam is catastrophic and could occur suddenly without any advance forewarning. Many of existing RC beams have been found to be deficient in shear strength and need to be strengthened. Several factors need to be considered in shear deficient structure such as lack of shear reinforcement or reduction in steel area due to corrosion, increased service load than design, construction faults and old design codes. The CFRP strip technique is more economical compared to continuous wrapping system.

2. OBJECTIVES OF THIS STUDY

The overall objective of this investigation was to study both the shear strengthening capacity and modes of failure of reinforced concrete rectangular shear beams bonded externally with Carbon Fiber Reinforced Polymer (CFRP) strips under static loading. Specific *objectives are as follows*:

●Investigating the effectiveness of the CFRP strip technique on strengthening full-scale reinforced concrete rectangular beams without any internal shear reinforcement (i.e. no steel stirrups).

● Investigating how the factors such as (i) grade of concrete (ii) longitudinal tensile reinforcement ratio (iii) % of shear reinforcement (iv) orientation of CFRP strips (v) width of CFRP strips (vi) spacing of CFRP strips influence the shear capacity of the strengthened reinforced concrete beams.

●Comparing the shear capacity of CFRP strengthened beams with the available theoretical results.

3. EXPERIMENTAL PROGRAM

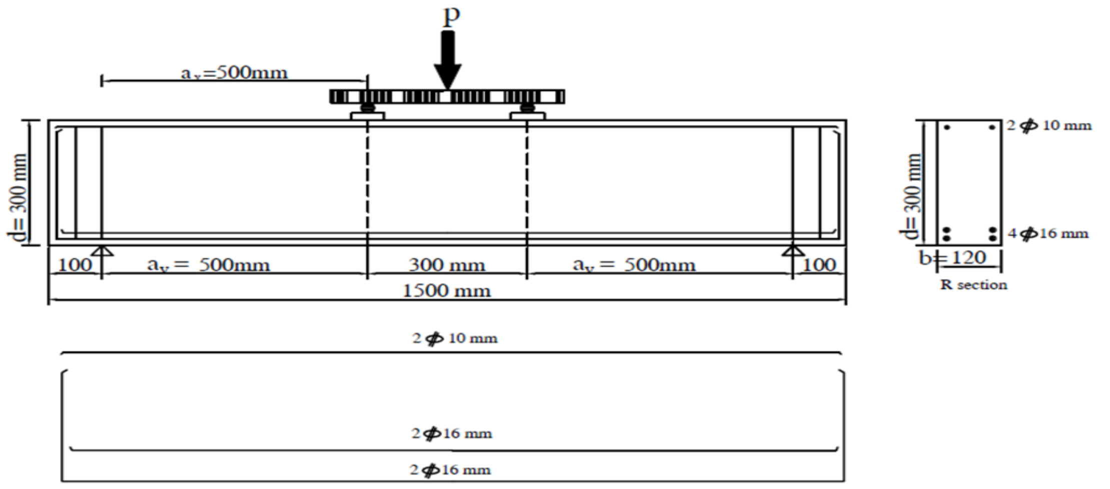
3.1. Tests spacimens

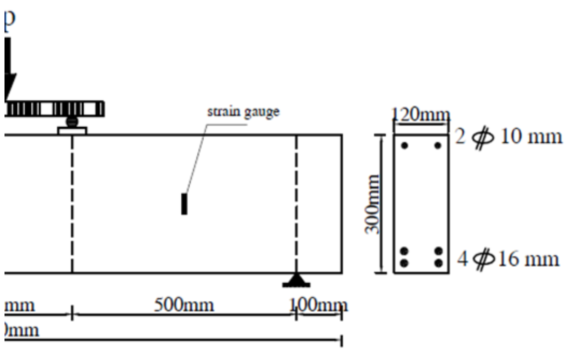
The test program includes twenty reinforced concrete beams. All tested beams having the same total length of 1500 mm and cross section of 120 mm width and 300 mm depth. The steel reinforcement of all beams was, four bars 16 mm diameter as tension reinforcement, two bars 10 mm diameter as compression reinforcement without any internal shear reinforcement, additionally to four beams with 8mm dia.@ 100mm and 300mm as internal shear reinforcement, details of reinforcement are as shown in figs.1.Shear span to effective depth ratio for all beams was kept constant ($a_v/d = 1.67$).

All beams were tested under two point of static load placed at 500 mm from the ends of two supports. Table 1and Fig.1 give summary of testing program and specimens details. The parameters investigated in this study included (i) grade of concrete (ii) longitudinal tensile reinforcement ratio (iii) % of shear reinforcement (iv) orientation of CFRP strips(β) (v) width of CFRP strips (W_f) (vi) spacing of CFRP strips (S_f).

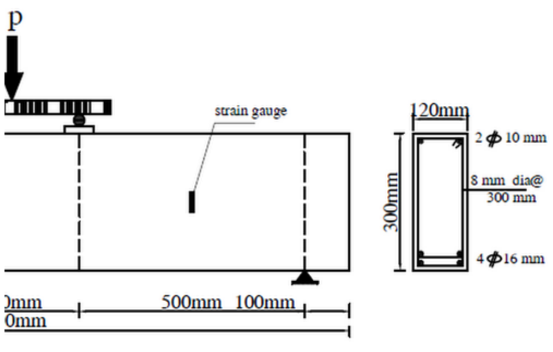
Table1: *Specimens details*

Group	Beam No.	Grade of Concrete Fc_{28} kg/cm2	longitudinal tensile reinforceme-nt ratio(μ%)	% of shear reinforcement ratio	Configuration of external strengthening		
					orientation of CFRP strips (β)	width of CFRP strips W_f	spacing of CFRP strips S_f
Group(I)	R1a	C250	2.22%	zero	-------	------	-------
	R2	C500	2.22%	zero	-------	------	-------
	R3	C700	2.22%	zero	-------	------	-------
	B1a	C250	2.22%	zero	90°	60 mm	135 mm
	B2	C500	2.22%	zero	90°	60 mm	135 mm
	B3	C700	2.22%	zero	90°	60 mm	135 mm
Group(II)	R4	C250	0.62%	zero	-------	------	-------
	R5	C250	1.11%	zero	-------	------	-------
	B4	C250	0.62%	zero	90°	60 mm	135 mm
	B5	C250	1.11%	zero	90°	60 mm	135 mm
Group(III)	R6	C250	2.22%	8mm dia.@300mm	-------	------	-------
	R7	C250	2.22%	8mm dia.@100mm	-------	------	-------
	B6	C250	2.22%	8mm dia.@250mm	90°	60 mm	135 mm
	B7	C250	2.22%	8mm dia.@100mm	90°	60 mm	135 mm
Group(IV)	B8	C250	2.22%	zero	45°	60 mm	135 mm
	B9	C250	2.22%	zero	60°	60 mm	135 mm
	B10	C250	2.22%	zero	90°	90 mm	135 mm
	B11	C250	2.22%	zero	90°	45 mm	135 mm
	B12	C250	2.22%	zero	90°	60 mm	180 mm
	B13	C250	2.22%	zero	90°	60 mm	100 mm

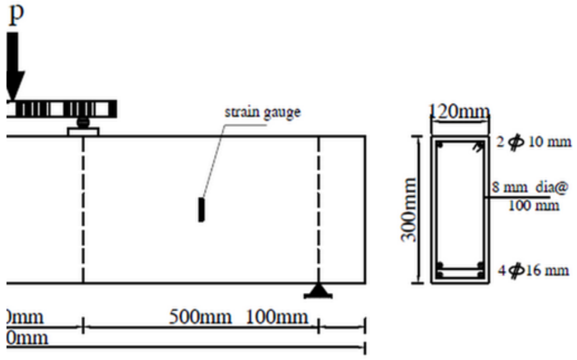




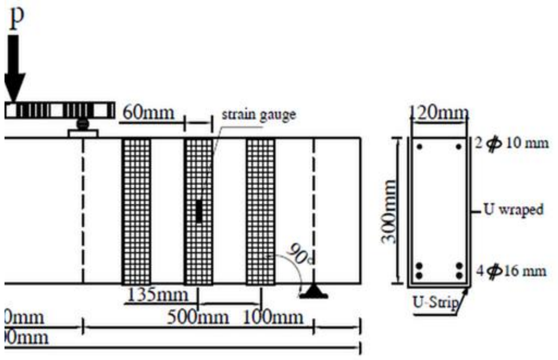
R_{1a}&R_2&R_3&R_4&R_5



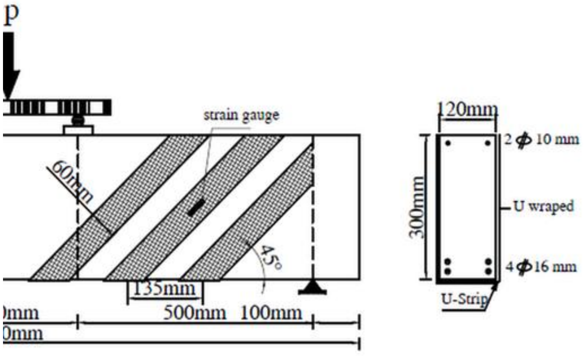
R_6



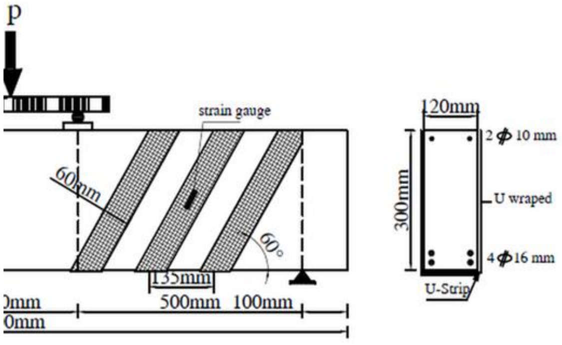
R_7



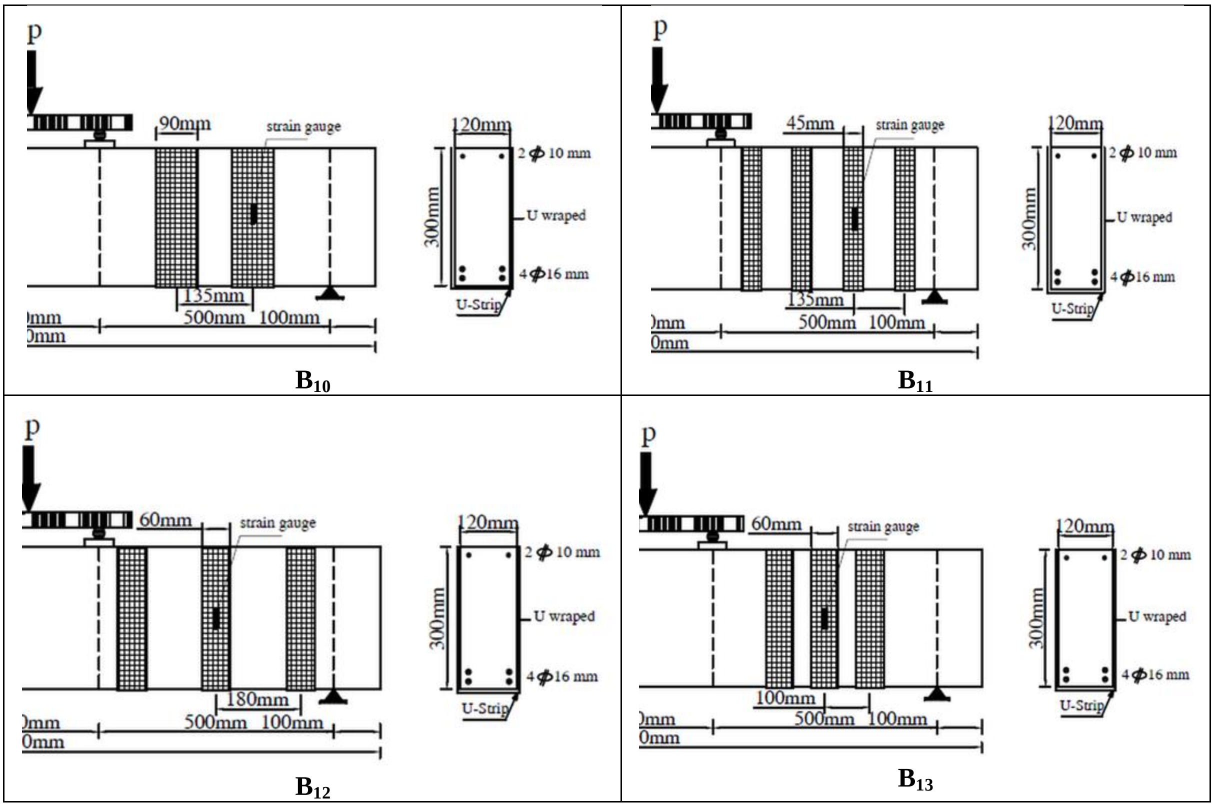
B_{1a}&B_2&B_3&B_4&B_5&B_6&B_7



B_8



B_9



B$_{10}$ **B$_{11}$** **B$_{12}$** **B$_{13}$**

Fig1. *Details of test specimens*

3.2. Materials

3.2.1. Used Materials for Concrete Mixes

- Cement: Ordinary Portland cement(O.P.C.
- Sand: the used sand had a specific gravity, volume weight and fineness modulus of 2.6, 1.6 t/m^3 and 2.95, respectively.
- Gravel: the used gravel was 20 mms maximum nominal size , and had specific gravity and volume weight of 2.65 and 1.65 t/m^3 respectively.
- Bazalt: the used Bazalt was 20 mms maximum nominal size , and had specific gravity and volume weight of 2.65 and 1.65 t/m^3 respectively.
- Admixture: 1- silicafum
  2- sikament F.F.3
- Water: natural drinking water.

3.2.2. Concrete Mixes

The constituent materials for a mix of 1 m^3 concrete by weight for each grade of concrete (Fc$_{28}$) kg. /cm^2 is as given below:

Grade of concrete Fc$_{28}$ (15*15*15) Kg/cm^2	Constituent materials for 1 m^3 mix by weight (Kg)					Water litre
	Cement	Fine aggregate (sand)	Coarse aggregate	Silicafume	Sikament F.F.3	
250	350	550	1290 (gravel)	---------	---------	192
500	450	550	1200 (bazalt)	100	14	145
700	550	500	1200 (bazaltt)	110	16	145

3.2.3. Steel Reinforcement

The used steel bars for stirrups were mild steel type with diameter (8 mm) of 3100 k.g./cm^{2}yield strength , and for the compression and tension reinforcement were high tensile steel type with diameters (10 mm, 16mm) of 3900 and 4100 k.g./cm^2 proof strength respectively.

3.2.4. External Bonded CFRP Strip

Uniaxial Carbon Fiber Reinforced polymer (CFRP) wraps were used to externally strengthen the shear spans of the beam, under a commercial name of sikawrap. Hex-230C. CFRP is available in rolled of 0.12 mm effective thickness, 300 mm width, and about 5000 mm length. According to the data provided by the CFRP supplier, the fabrics had an elastic modulus of 210000 N/mm^2, tensile (rupture) strength 2400 N/mm^2, and ultimate strain of 1.7%.

3.2.5. Adhesive Material

The adhesive material used in the test program with the CFRP strip is (Sikadur-330) consists of two components with ratio 1:3. The tensile strength at 10 days age was found to be 0.32 t/cm2. With (sikadur-41/31) used as epoxy mortar and primer.

3.3. Application of CFRP

Surfaces of the beam to be strengthened were roughened using a grinder, and the edges of the beam where the CFRP U- jackets were applied has been rounded in curved shape of about 30 mm diameter to reduce the stress concentration generated on the composite at the beam edges. After that, the concrete surfaces were cleaned by compressed air. An epoxy mortar (sikadur-41) of about 2.0 mm thickness was applied to bonding surfaces as substratum to the CFRP sheets, but before that a primer coat (sikadur-31) was applied first on the bonding surface to promote the adhesion between the concrete surface and the applied epoxy mortar. After about 24 hours a two-part epoxy adhesive (sikadur-330) was applied in a thin layer over the epoxy mortar and the precut CFRP sheets were placed over it. The sheets were pressed firmly and rolled uniformly by a roller to squeeze out excess epoxy and all air bubbles.

3.4. Test procedure

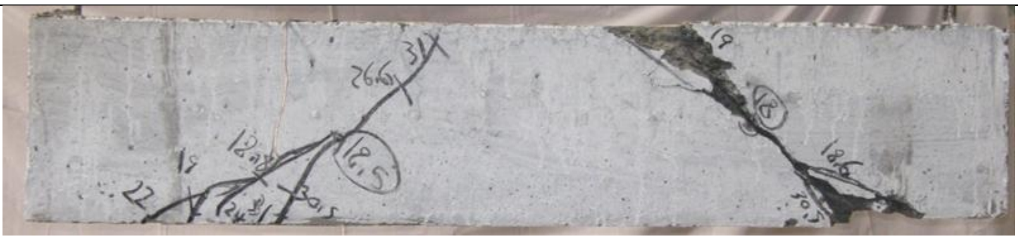
All beams were tested under two-points loading over a span of 1300 mm. The load was applied to the beams in increments. At each increment, the mid-span deflection, and the strains in middle height of some of CFRP U strips were measured by means of dial and electrical strain gauges. The crack initiation and propagation were monitored by visual inspection during testing.

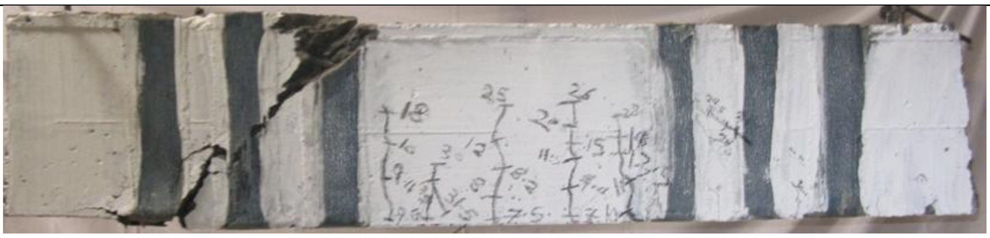
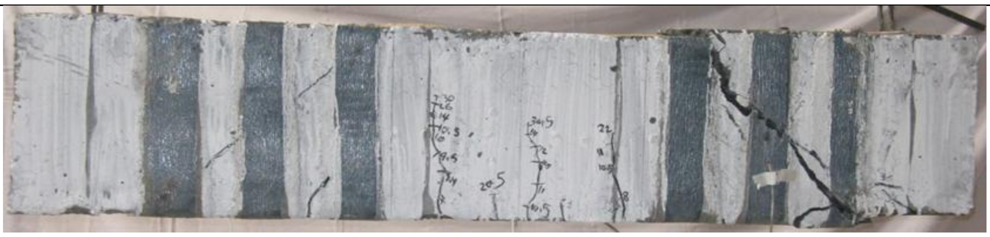
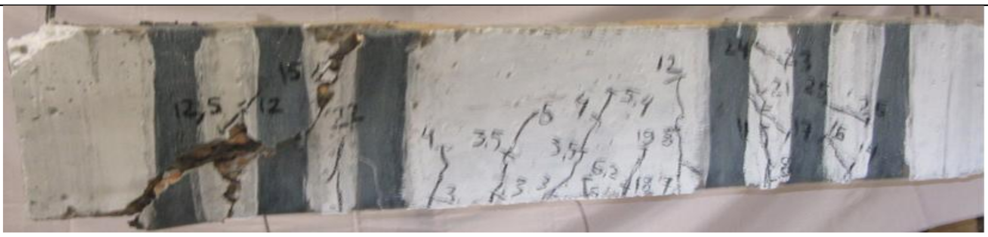
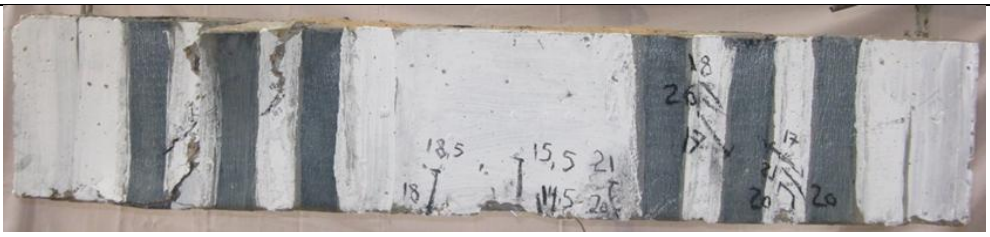
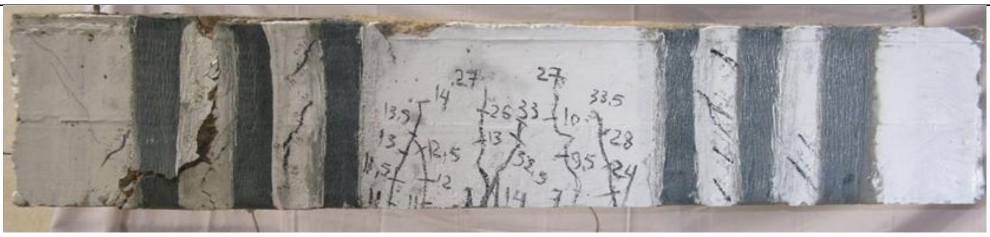
4. TEST RESULTS

BEAM NO.	**P_{crack}** (ton)	**$P_{ulitma\text{-}te}$** (ton)	**Max. ε_c**	**Max. $\varepsilon_{c.f.}$**	**Max. ε_s**	**Max. δ_u** mm Mid span	**δ_{cr}** mm	**Ductili-ty** $\frac{\delta_u}{\delta_{cr}}$%	**Tough-ness** *(Area under load-def. curve) mm.t.*	**Mode of failure**
R1a	**6.60**	**12.00**	**0.00022**	**--------**	**0.00075**	**3.53**	**1.36**	**259.5**	**22.15**	shear
B1a	**11.50**	**24.00**	**-------**	**0.00007**	**0.00011**	**4.62**	**3.15**	**146.7**	**56.47**	shear
R2	**13.50**	**24.00**	**0.00117**	**-------**	**0.00041**	**5.25**	**2.20**	**238.6**	**62.6**	shear
B2	**16.50**	**36.00**	**-------**	**0.00022**	**0.00009**	**6.80**	**3.55**	**191.5**	**140.3**	shear
R3	**14.50**	**32.00**	**0.00193**	**-------**	**0.00084**	**5.73**	**2.08**	**275.5**	**63.9**	shear
B3	**17.00**	**40.50**	**-------**	**0.00010**	**0.00051**	**7.20**	**3.8**	**189.5**	**193.7**	shear
R4	**5.00**	**10.50**	**0.00010**	**-------**	**0.00076**	**2.87**	**1.34**	**214.2**	**18.3**	shear
B4	**7.40**	**14.00**	**-------**	**0.00015**	**0.00101**	**3.83**	**1.91**	**200.5**	**32.13**	shear
R5	**5.40**	**11.50**	**0.00037**	**-------**	**0.00031**	**4.05**	**1.51**	**268.2**	**13.2**	shear
B5	**8.20**	**20.00**	**-------**	**0.00128**	**0.00032**	**5.30**	**2.30**	**230.4**	**39**	shear
R6	**8.20**	**22.50**	**0.00068**	**-------**	**.00015**	**4.81**	**1.45**	**331.7**	**62.8**	shear
B6	**12.50**	**31.50**	**-------**	**0.00011**	**0.00030**	**5.84**	**2.35**	**248.5**	**90.9**	shear
R7	**9.40**	**27.50**	**.000086**	**-------**	**0.00014**	**4.72**	**1.74**	**271.3**	**61.7**	shear
B7	**13.50**	**33.50**	**-------**	**0.00029**	**0.00011**	**8.22**	**3.42**	**240.4**	**148.8**	shear
B8	**15.00**	**27.00**	**-------**	**0.00011**	**0.00133**	**4.82**	**2.75**	**175.3**	**71.1**	shear
B9	**13.00**	**25.50**	**-------**	**0.00035**	**0.00013**	**5.53**	**2.62**	**211.1**	**57.8**	shear
B10	**12.00**	**21.5**	**-------**	**0.00023**	**0.00085**	**4.53**	**2.30**	**196.95**	**55.2**	shear
B11	**10.50**	**19.5**	**-------**	**0.00013**	**0.00012**	**4.45**	**2.15**	**206.9**	**47.3**	shear
B12	**10.00**	**21.50**	**-------**	**0.00017**	**0.00041**	**4.52**	**2.21**	**204.5**	**55.5**	shear
B13	**10.50**	**23.00**	**-------**	**0.00007**	**0.00089**	**4.24**	**2.45**	**173.1**	**51.8**	shear

4.1. W.R.T Failure Modes

In general, and as expected all test specimens failed mainly as a result of diagonal tension cracking (shear failure). Cracking pattern at ultimate load and failure modes of all beams are shown in Fig.2. Each specimen exhibited an initial flexural crack in the region of pure bending and subsequent additional flexural cracks formed in the central region. As applied load was increased a number of flexural and shear cracks were developed along the shear spans and one of them extended diagonally upward toward the loading point. Failure of controlled beams (R_{1a}&R_2&R_3&R_4&R_5&R_6&R_7) were sudden and by diagonal tension. In case of strengthened beams, the diagonal tension failure was preceded by CFRP strips bond failure and /or CFRP rupture, and the diagonal cracks occurred at a relatively higher load than for the control beam. All strengthened beams failed by concrete splitting and crushing behind the fiber strips. The splitting of concrete behind the strips caused these fiber strips to be ruptured or pushed out wards (debonding).

R_{1a}	
R_2	
R_3	
R_4	
R_5	
R_6	

R_7	
B_{1a}	
B_2	
B_3	
B_4	
B_5	
B_6	
B_7	

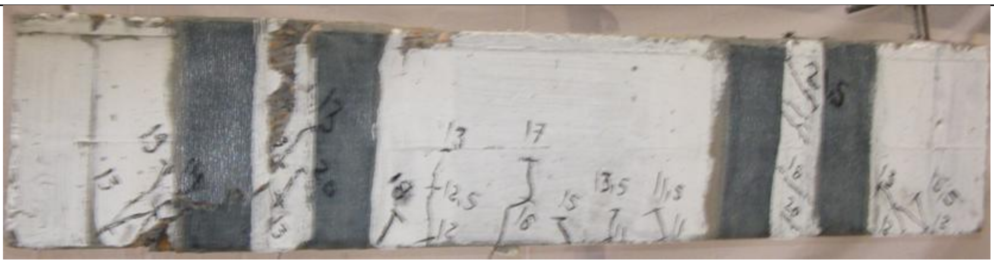
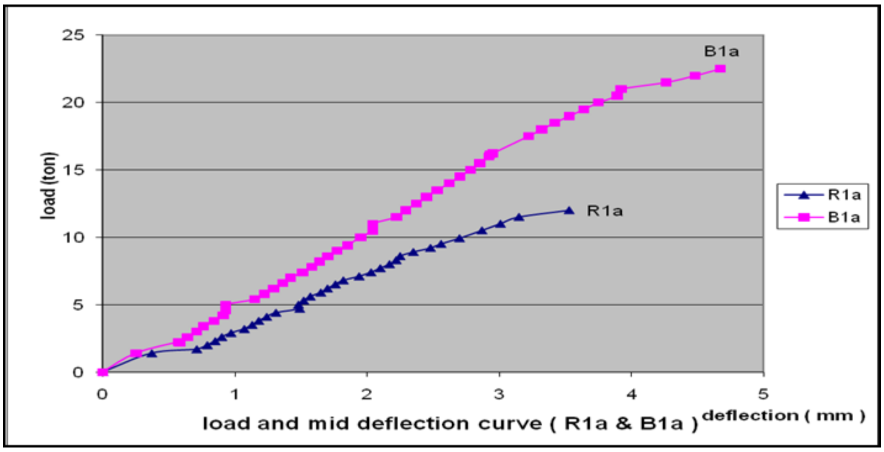
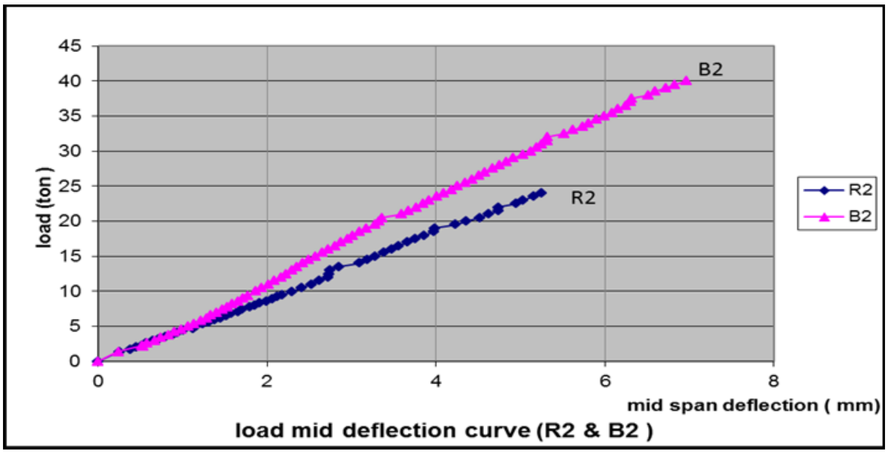
B_8	
B_9	
B_{10}	
B_{11}	
B_{12}	
B_{13}	

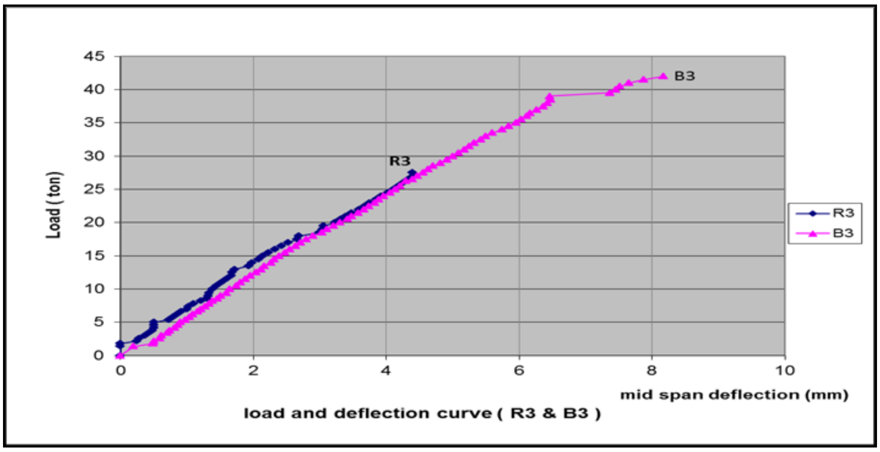
Fig2: *Crack patterns of tested beams*

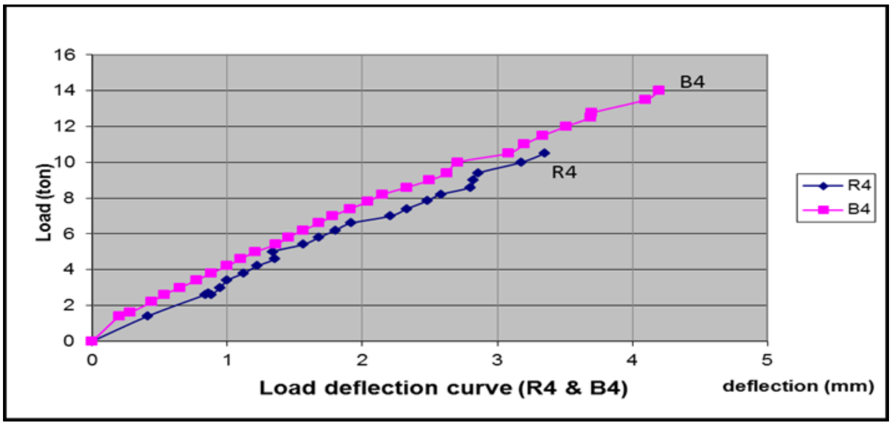
4.2. W.R.T Load-Deflection Curves

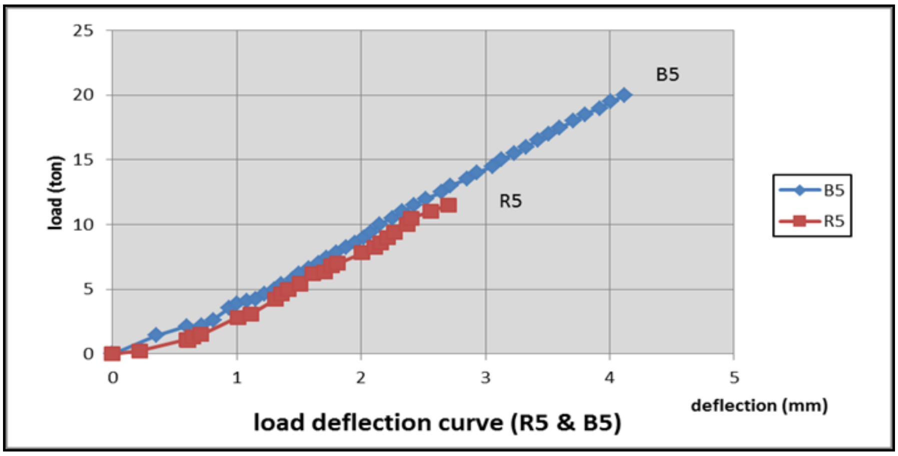
Load-mid-span deflection curves for all specimens are shown in Fig.3. It can be noticed that, the initial slope of all curves identical. This means that the provided external shear reinforcement (U-strips) did not increase the initial flexural stiffness of beam, but has a signification effect on both ultimate load and ductility. Fig.3show that grade of concrete, longitudinal tensile reinforcement ratio, % of shear reinforcement, orientation of CFRP strips, width of CFRP strips and spacing of CFRP strips influence the shear capacity of the strengthened reinforced concrete beams.

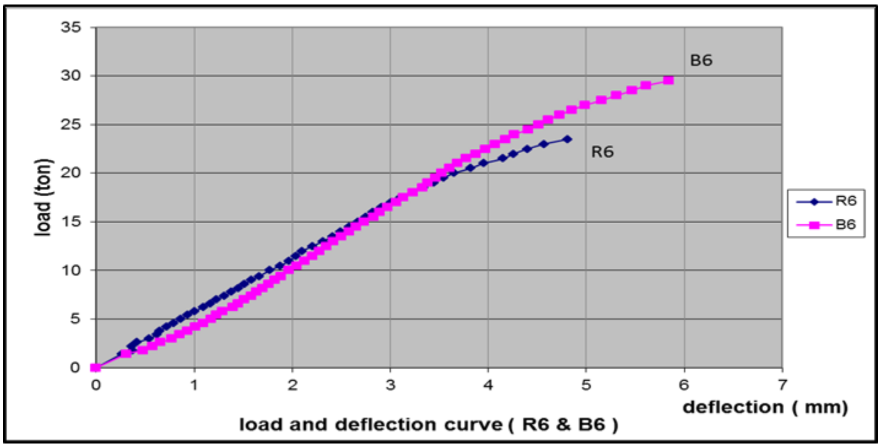

25
20
15
10
5
0
load (ton)
0
1
2
3
4
5
B1a
R1a
R1a
B1a
load and mid deflection curve (R1a & B1a)
deflection (mm)

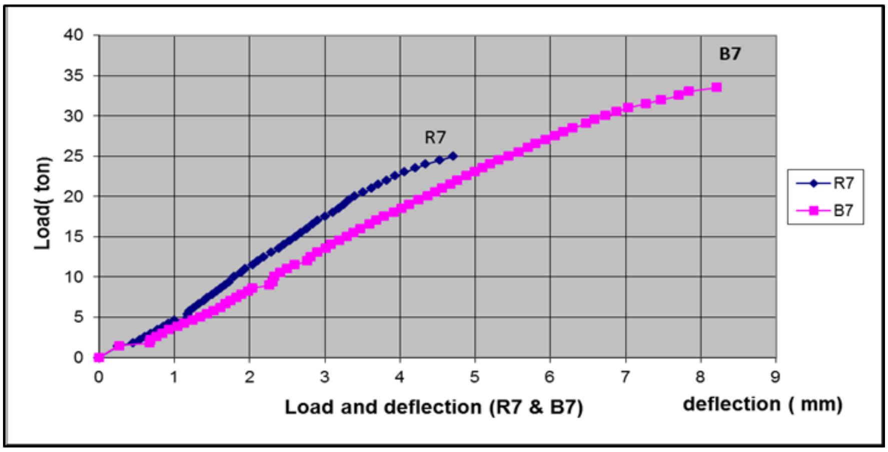

45
40
35
30
25
20
15
10
5
0
load (ton)
0
2
4
6
8
B2
R2
R2
B2
mid span deflection (mm)
load mid deflection curve (R2 & B2)

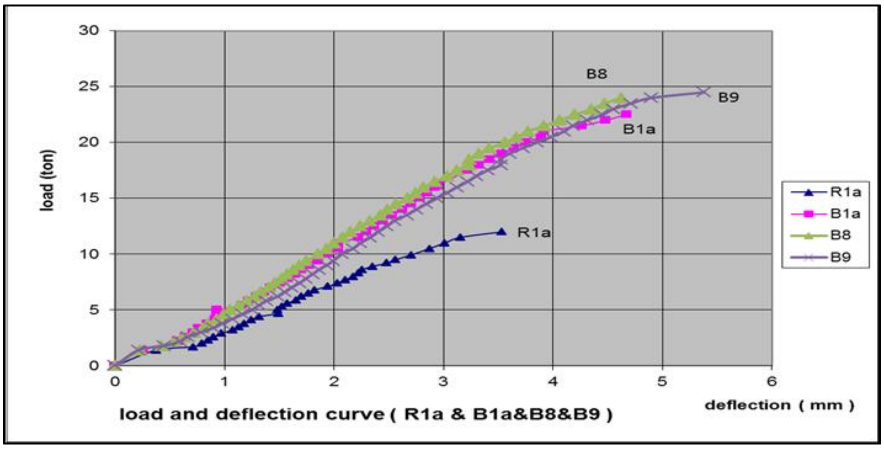

45
40
35
30
25
20
15
10
5
0
Load (ton)
0
2
4
6
8
10
B3
R3
R3
B3
mid span deflection (mm)
load and deflection curve (R3 & B3)


16
14
12
10
8
6
4
2
0
Load (ton)
0
1
2
3
4
5
B4
R4
R4
B4
Load deflection curve (R4 & B4)
deflection (mm)


B5
R5
load (ton)
0
5
10
15
20
25
0
1
2
3
4
5
deflection (mm)
B5
R5
load deflection curve (R5 & B5)


B6
R6
load (ton)
0
5
10
15
20
25
30
35
0
1
2
3
4
5
6
7
deflection (mm)
R6
B6
load and deflection curve (R6 & B6)


B7
R7
Load(ton)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6
7
8
9
deflection (mm)
R7
B7
Load and deflection (R7 & B7)


B8
B9
B1a
R1a
load (ton)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
deflection (mm)
R1a
B1a
B8
B9
load and deflection curve (R1a & B1a&B8&B9)

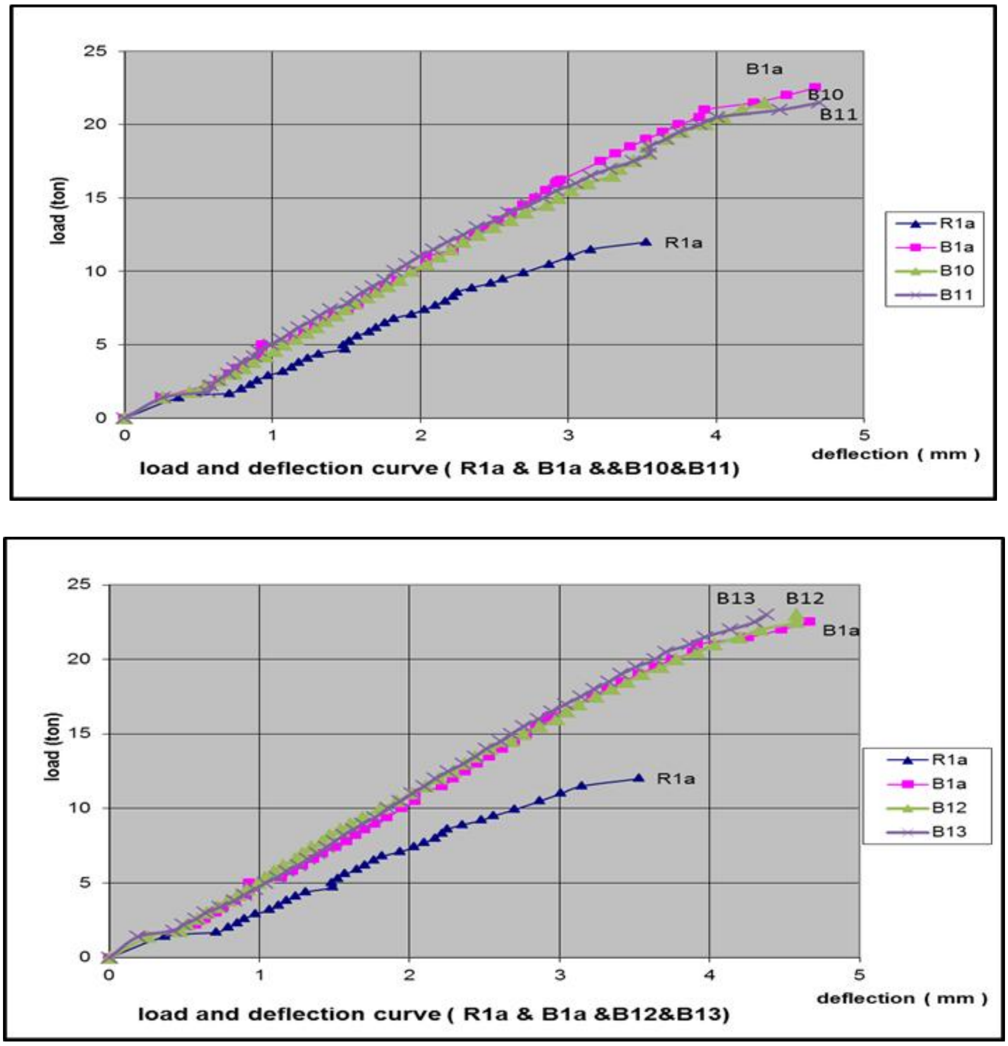
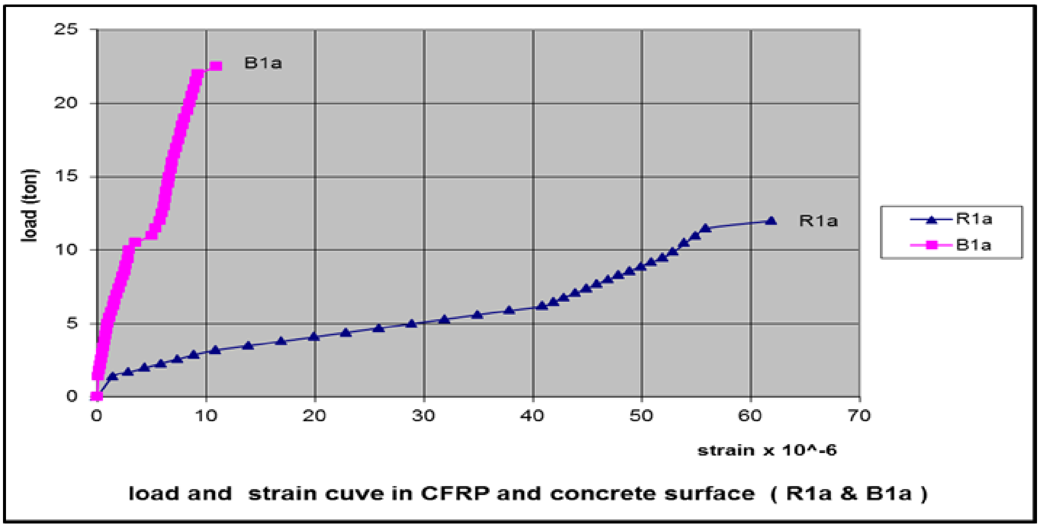
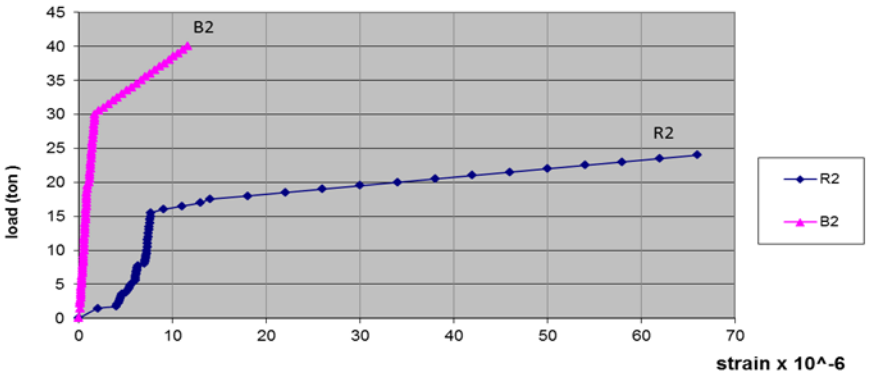


Fig3. *Load and mid-deflection curve for test beams*

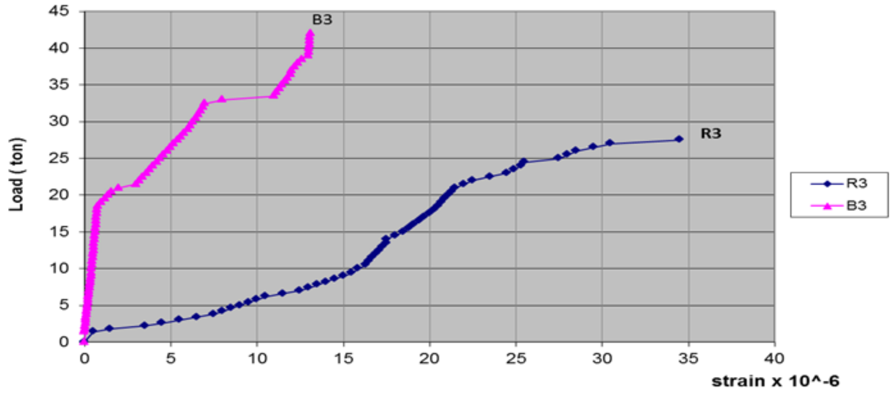
4.3. W.R.T Load -CFRP Strainscurves

Fig.4shows that the load versus vertical strain in carbon fiber sheet at mid-depth of sheet at a certain locations (see Fig.1). also the maximum strain (ε_{max}) recorded in these strips just before failure of beams :

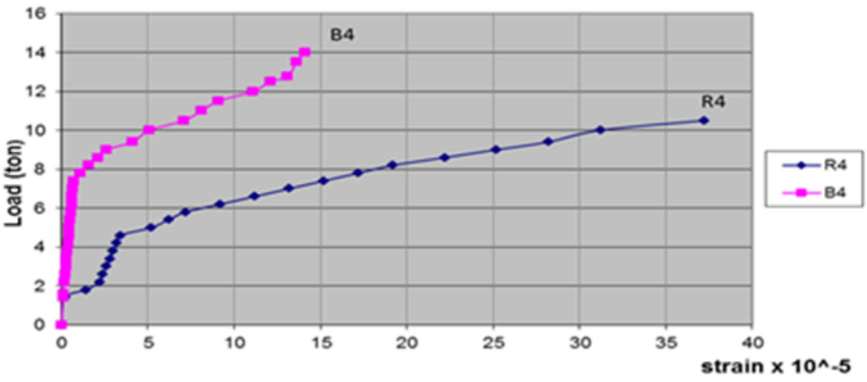




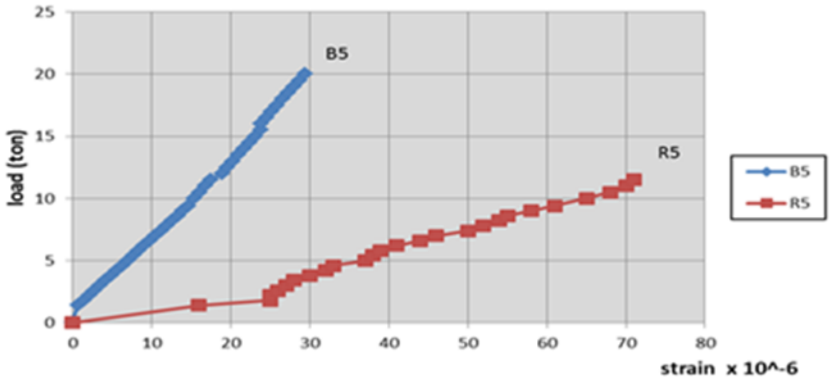
load and strain cuve in CFRP and concrete surface (R2&B2)



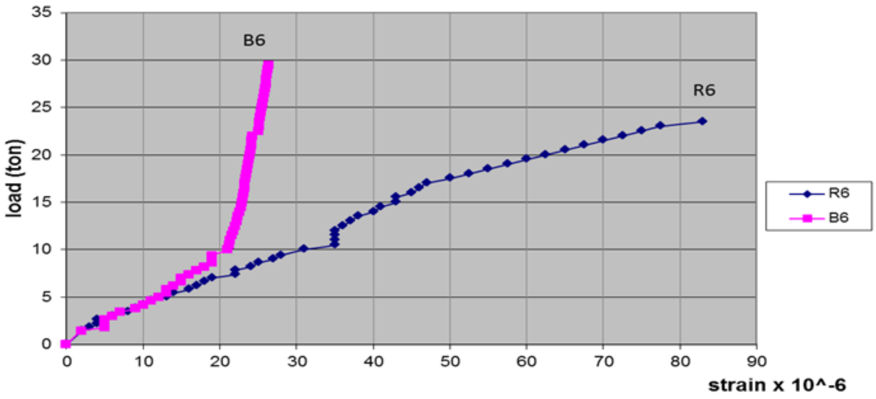
load and strain cuve in CFRP and concrete surface (R3 & B3)



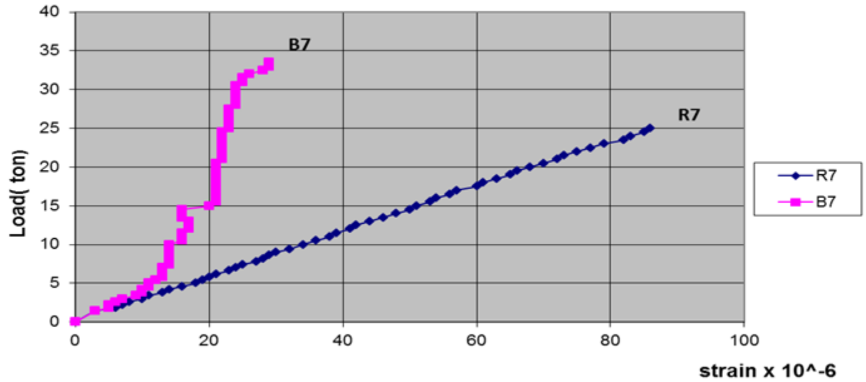
load and strain cuve in CFRP and concrete surface (R4 & B4)



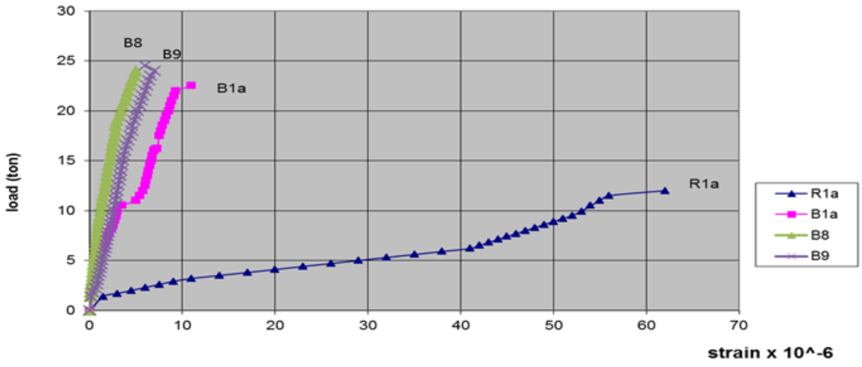
load and strain cuve in CFRP and concrete surface (R5 & B5)



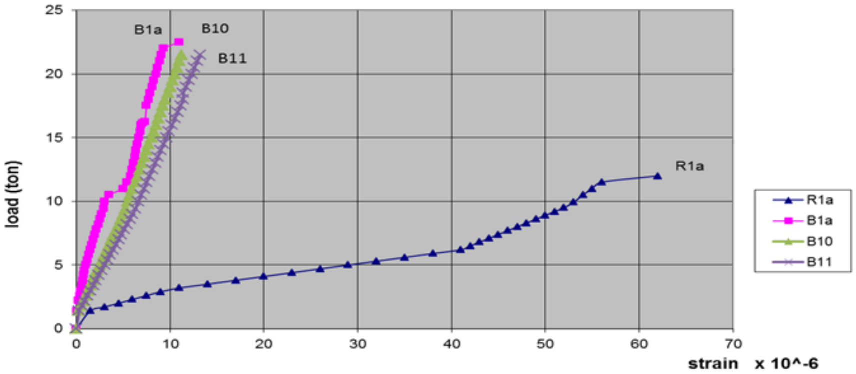
load and strain cuve in CFRP and concrete surface (R6 & B6)



load and strain cuve in CFRP and concrete surface (R7 & B7)



load and strain cuve in CFRP and concrete surface (R1a & B1a&B8&B9)



load and strain cuve in CFRP and concrete surface (R1a & B1a &B10&B11)

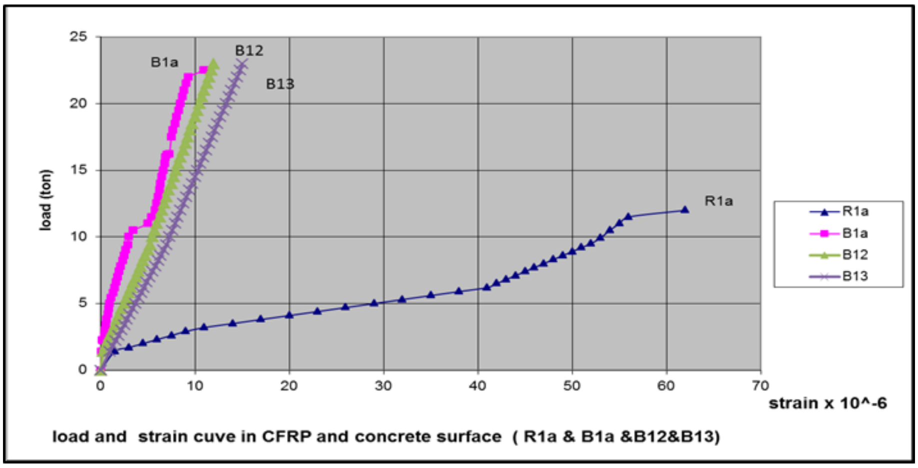


Fig4: *Load and Strain curve in CFRP and concrete surface for test beams*

5. DISCUSSION OF TEST RESULTS

The previous obtained test results showed that the behavior of strengthened of reinforced rectangular concrete beams failed in shear basically affect the following properties:

i- Cracking load.
ii-Ultimate load capacity.
iii-Mode of beam failure.
iv-Ultimate deflection.
v- Ductility of beams.
vi-Ultimate concrete strain of beams.
vii- Toughness of beams.

5.1.W.R.T Behavior of the Strengthened R.C. Rectangular Tested Beams

In case of beams strengthened with CFRP-U-strips, diagonal crack was always followed by CFRP deponding and / or rupture, and failure occurred at a load significantly higher than for un-strengthened beam. The increase in failure load was ranged from 17% to 127% over than the control beam

Suchmainly previous properties are mainly affected by chosen parameters in this research as:

(i) *Grade of concrete* Fc_{28}

ii) *Longitudinal tensile reinforcement ratio(μ %)*

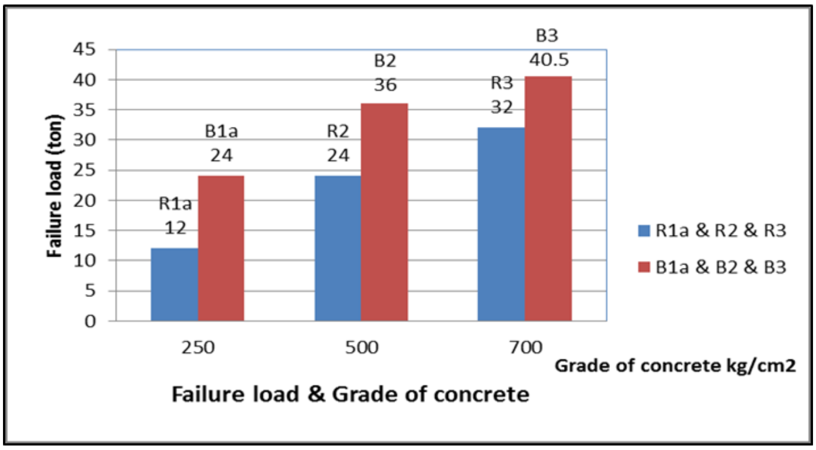
(iii) *% of shear reinforcement*

(iv) *Orientation of CFRP strips*(β)

(v) *Width of CFRP strips*(W_f)

(vi) *Spacing of CFRP strips* (S_f)

As follows:



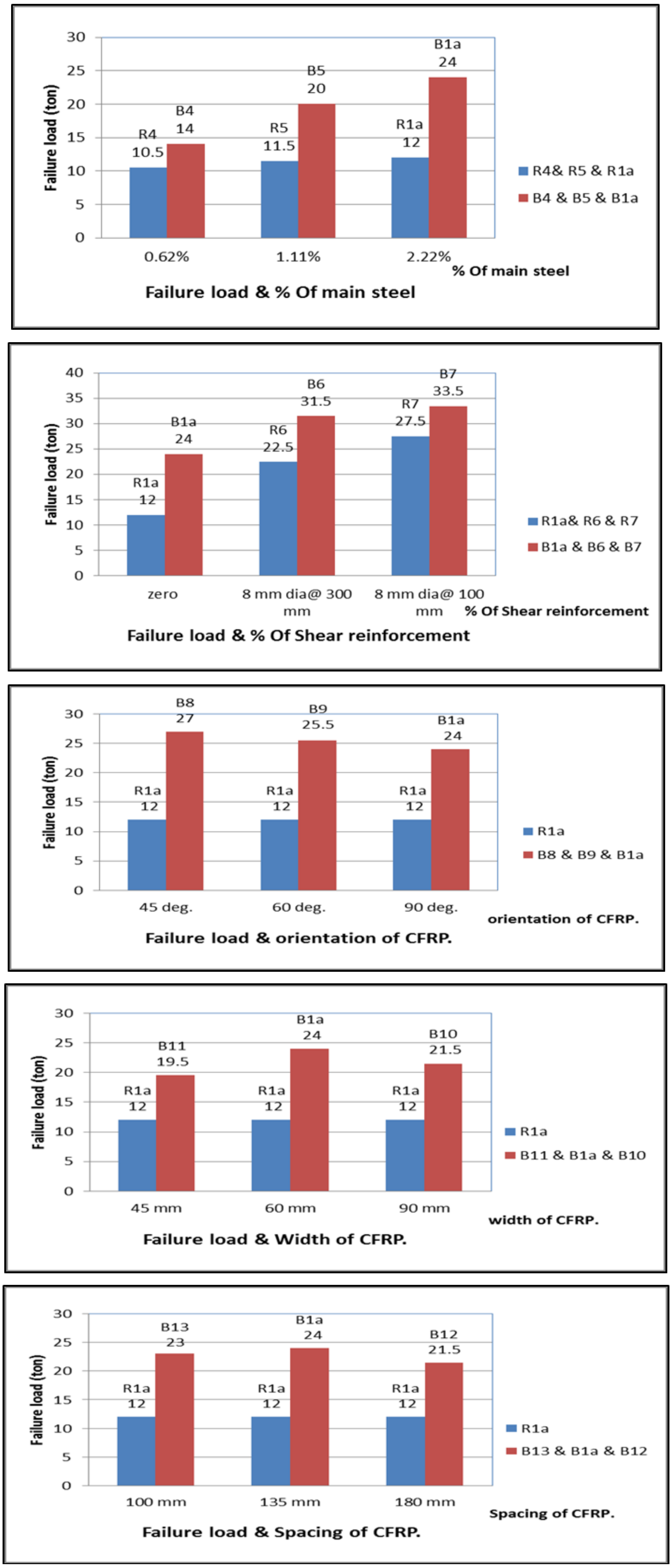


Fig5. *Failure Load (Shear Capacity) for test beams*

Table2: *% of shear enhancement for failure load*

BEAM NO.	Failure load (ton)	Contribution of CFRP strip(ton)	% of shear enhancement	Mode of failure
R1a	12.00	---------	-------	shear
B1a	24.00	12.00	100	shear
R2	24.00	---------	---------	shear
B2	36.00	12.00	50	shear
R3	32.00	---------	-------	shear
B3	40.50	8.50	26.56	shear
R4	10.50	--------	-------	shear
B4	14.00	3.50	33.33	shear
R5	11.50	-------	-------	shear
B5	20.00	8.50	73.91	shear
R6	22.50	-------	------	shear
B6	31.50	9.00	40.00	shear
R7	27.50	-------	-------	shear
B7	33.50	6.00	21.82	shear
B8	27.00	15.00	125	shear
B9	25.50	13.50	112.5	shear
B10	21.5	9.50	79.20	shear
B11	19.5	7.50	62.50	shear
B12	21.50	9.50	79.20	shear
B13	23.00	11.00	91.70	shear

Table 3: *% of shear enhancement for cracking load*

BEAM NO.	P_{crack} (ton)	Contribution of CFRP strip(ton) increasing cracking load	% of shear enhancement increasing cracking load	Mode of failure
R1a	6.60	-----------	-----------	shear
B1a	11.50	4.90	74.24 %	shear
R2	13.50	-----------	-----------	shear
B2	16.50	3.00	22.20 %	shear
R3	14.50	-----------	-----------	shear
B3	17.00	2.50	17.24 %	shear
R4	5.00	-----------	-----------	shear
B4	7.40	2.40	48 %	shear
R5	5.40	-----------	-----------	shear
B5	8.20	2.80	51.8 %	shear
R6	8.20	-----------	-----------	shear
B6	12.50	4.30	52.43 %	shear
R7	9.40	-----------	-----------	shear
B7	13.50	4.10	43.62 %	shear
B8	15.00	8.40	127.27 %	shear
B9	13.00	6.40	96.96 %	shear
B10	12.00	5.40	81.82 %	shear
B11	10.50	3.90	59.10 %	shear
B12	10.00	3.40	51.51 %	shear
B13	10.50	3.90	59.10 %	shear

5.1.1. W.R.Tgrade of Concrete Fc_{28}

The first crack for beams (B1a, B2 and B3) was observed in the region of center at middle third of the shear span between strips at load higher than those for control beams R1a, R2 and R3. The increase in cracking loads for these beams were 74.20%, 22.20% and 17.24%, respectively with observed shear cracks initiated at higher levels of loads and cut for middle strip CFRP for beams B2 and B3. The failure loads of these beams are bigger than those of the control beams R1a, R2 and R3 by ratio100%, 50% and 26.56 %, respectively. By using CFRP for these beams increase toughness and decrease ductility. These beams were failed in shear due to the major shear crack; Fig 2indicates the modes of failure for these beams.

5.1.2. W.R.T Longitudinal Tensile Reinforcement Ratio(μ %)

The first crack for beams (B4, B5 and B1a) was observed in the region of center at middle third of the shear span between strips at load higher than those for control beams R4, R5 and R1a. The increase in cracking loads for these beams were 48%, 51.8% and 74.24% respectively with observed shear cracks initiated at higher levels of loads, which could across the middle strip for beams R5 and failure in compression zone for B4 Increasing the applied load, the secondary flexural crack increases toward the point of load. The failure loads of these beams are bigger than those of the control beams R4, R5 and R1a by ratio 33.33%, 73.91% and 100 % respectively. By using CFRP for these beams increase toughness and decrease ductility, These beams were failed in shear due to the major shear crack; Fig 2 indicates the modes of failure for these beams.

5.1.3. W.R.T % of shear reinforcement

The first crack for beams (B1a, B6 and B7) was observed in the region of center at middle third of the shear span between strips at load higher than those for control beams R1a, R6 and R7. The increase in cracking loads for these beams were 74.24%, 52.43% and 43.62%, respectively with observed shear cracks initiated at higher levels of loads with split CFRP strip for beam B6 and cutting CFRP strip for beam B7, , the secondary flexural crack increases toward the point of load. The failure loads of these beams are bigger than those of the control beams R1a, R6 and R7 by ratio100%, 40% and 21.82 %, respectively. By using CFRP for these beams increase toughness and decrease ductility, These beams were failed in shear due to the major shear crack; Fig 2 indicates the modes of failure for these beams.

5.1.4. W.R.T Orientation of CFRP strips

The first crack for beams (B1a, B8 and B9) was observed in the region of center at middle third of the shear span between strips at load higher than those for control beam R1a. The increase in cracking loads for these beams were 74.24%, 127.27% and 96.96%, respectively with observed shear cracks initiated at higher levels of loads with split CFRP strip for beam B8. The failure loads of these beams are bigger than those of the control beam R1a by 100 %, 125 % and 112.5 %, respectively. By using CFRP for these beams increase toughness and decrease ductility, These beams were failed in shear due to the major shear crack; Fig 2 indicates the modes of failure for these beams.

5.1.5. W.R.T Width of CFRP strips

The first crack for beams (B1a, B10 and B11) was observed in the region of center at middle third of the shear span between strips at load higher than those for control beam R1a. The increase in cracking loads for these beams were 74.24%, 81.82% and 59.10%, respectively with observed shear cracks initiated at higher levels of loads at the shear span near the support, with split CFRP strip for beam B10 and B11. Increasing the applied load, the secondary flexural crack increases toward the point of load. The failure loads of these beams are bigger than those of the control beam R1a by 100 %, 79.20% and 62.50 %, respectively. By using CFRP for these beams increase toughness and decrease ductility, These beams were failed in shear due to the major shear crack; Fig 2 indicates the modes of failure for these beams.

5.1.6. W.R.T Spacing of CFRP strips

The first crack for beams (B1a, B12 and B13) was observed in the region of center at middle third of the shear span between strips at load higher than those for control beam R1a. The increase in cracking loads for these beams were 74.24%, 51.51% and 59.10%, respectively with observed shear cracks initiated at higher levels of loads at the shear span near the support, with split CFRP strip for beam B12 and concrete crushing for beam B13. Increasing the applied load, the secondary flexural crack increases toward the point of load. The failure loads of these beams are bigger than those of the control beam R1a by 100 %, 79.20% and 91.70 %, respectively. By using CFRP for these beams increase toughness and decrease ductility, These beams were failed in shear due to the major shear crack; Fig 2 indicates the modes of failure for these beams.

5.2. Evaluation of the Shear Capacity of the CFRP Strengthened Beam

In customary shear design approach, the shear strength of a reinforced concrete section may be computed by adding the contribution of shear strength of the concrete and steel reinforcement. But in the case of beam with externally bonded FRB sheets the nominal, shear strength may be formulated by the addition of a third component to account for the contribution, of FRP sheet to the Shear strength. For RC beam strengthened, with, externally bond composite, material, the nominal-shear, strength of the externally strengthened concrete section is expressed as follows*:*

$$V_n = V_c + V_s + V_f \tag{1}$$

In 2003, the ACI committee 440 proposed FRP contribution to shear strength of the FRP bonded beams. The shear contribution of the FRR shear rein for cement can be computed by the following equation:

$$V_f = \frac{A_f f_{fe}(\sin\beta + \cos\beta) d_f}{s_f} \tag{2}$$

In this equation, the component tensile stress in the FRP reinforcement at ultimate is replaced by effective strain times the tensile' modulus of FRPE_f

$$f_{fe} = \varepsilon_{fe} E_f \tag{3}$$

The effective strain ε_{fe} is the maximum strain that can be achieved in the FRP system at the ultimate load and is governed by the failure pattern of FRP strengthened beam. . The subsequent equations provide direction to determine the effective strain ε_{fe} for different configuration of FRP wrap used for shear strengthening of reinforced concrete members

$$\varepsilon_{fe} = 0.004 \le 0.75\, \varepsilon_{fu} \text{(for completely wrapped members)} \tag{4}$$

$$\varepsilon_{fe} = k_v \varepsilon_{fu} \le 0.004 \text{(for bonded U-wraps or bonded face plies)} \tag{5}$$

The bond reduction coefficient k_v is a function of the concrete strength, the type of wrapping scheme used, and the '"stiffness of the wrap. The bond reduction coefficient can be computed as follows:

$$k_v = \frac{k_1 k_2 L_e}{11.900 \varepsilon_{fu}} \le 0.75 \tag{6}$$

The active bond length L_e is the length over which the majority of the bond stress is maintained. The length is given by equation

$$L_e = \frac{23{,}300}{(n t_f E_f)^{0.58}} \tag{7}$$

The bond reduction coefficient also relies on two modification factors, k_1 and k_2, that accounts for the concrete strength and the type of wrapping scheme used respectively. Expressions for these modification factors are given as follows.

$$k_1 = \left(\frac{f_c'}{27}\right)^{\frac{2}{3}} \tag{8a}$$

$$k_2 = \frac{d_f - L_e}{d_f} \qquad \text{(For U-wraps)} \tag{8b}$$

$$k_2 = \frac{d_f - 2L_e}{d_f} \qquad \text{(For two sides bonded)} \tag{8c}$$

The comparison of experimental and theoretical results of the control and initially strengthened beams are shown in Table 4. It can be seen that the experimental values of the strengthened beams B1a,B2,B3,B4,B5,B6,B7,B8,B9,B10,B11,B12 and B13were relatively greater than theoretical values by (0.0 to 130%).From the overall discussion, it can be concluded that the predicted theoretical results of the rectangular beam without internal shear reinforcement *but with external CFRP* shows reasonable accuracy with the experimental results.

Table4: *Summary of comparison of experimental and theoretical results*

Experimental results			***Theoretical results (ACI 440 format)***			
BEAM NO.	**Failure load (ton)**	**Shear force (ton)**	**V_c (ton)**	**V_s (ton)**	**V_f (ton)**	**$V_n=V_c+V_s+V_f$ (ton)**
R1a	**12.00**	**6.00**	**3.80**	**----**	**----**	**3.80**
B1a	**24.00**	**12.00**	**3.80**	**----**	**3.40**	**7.20**

R2	**24.00**	**12.00**	**5.20**	**-----**	**----**	**5.20**
B2	**36.00**	**18.00**	**5.20**	**-----**	**3.40**	**8.60**
R3	**32.00**	**16.00**	**6.20**	**-----**	**-----**	**6.20**
B3	**40.50**	**20.25**	**6.20**	**------**	**3.40**	**9.60**
R4	**10.50**	**5.25**	**3.80**	**----**	**----**	**3.80**
B4	**14.00**	**7.00**	**3.80**	**----**	**3.40**	**7.20**
R5	**11.50**	**5.75**	**3.80**	**-----**	**----**	**3.80**
B5	**20.00**	**10.00**	**3.80**	**---**	**3.40**	**7.20**
R6	**22.50**	**11.25**	**3.80**	**4.30**	**----**	**8.10**
B6	**31.50**	**15.75**	**3.80**	**4.30**	**3.40**	**11.50**
R7	**27.50**	**13.75**	**3.80**	**6.20**	**----**	**10.0**
B7	**33.50**	**16.75**	**3.80**	**6.20**	**3.40**	**13.40**
B8	**27.00**	**13.50**	**3.80**	**------**	**4.40**	**8.20**
B9	**25.50**	**12.75**	**3.80**	**------**	**4.20**	**8.00**
B10	**21.5**	**10.75**	**3.80**	**-------**	**4.90**	**8.70**
B11	**19.5**	**9.75**	**3.80**	**-------**	**2.90**	**6.70**
B12	**21.50**	**10.75**	**3.80**	**-------**	**2.95**	**6.75**
B13	**23.00**	**11.50**	**3.80**	**------**	**4.10**	**7.90**

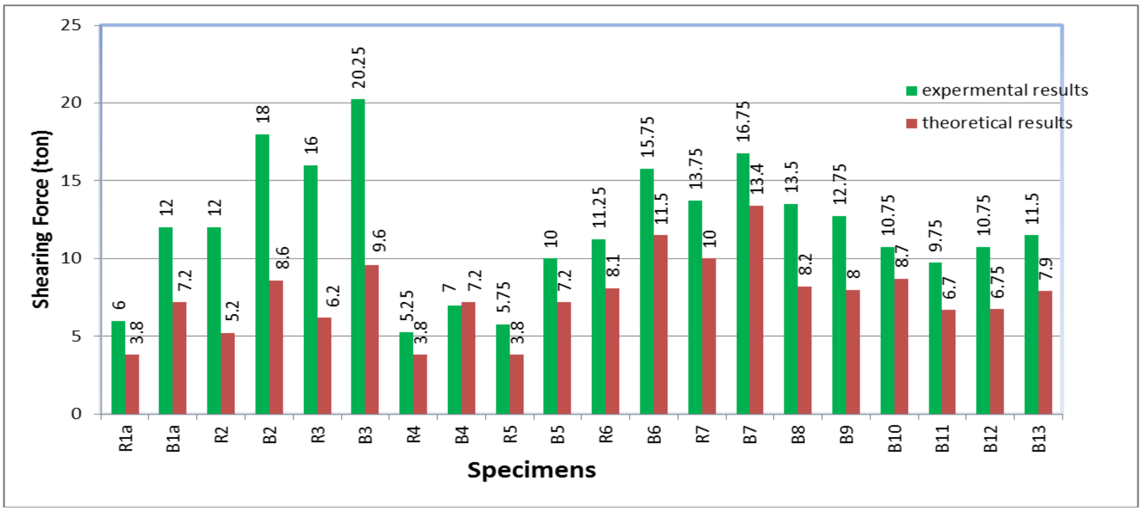


Fig6. *Comparison of experimental results with theoretical values of controlled and strengthened beams*

6. CONCLUSIONS

This paper presents the experimental results of R-beams bonded externally with CFRP fabric strips. Following conclusions are deduced from the experimental investigation:

1. Experimental results have shown that the overall increase in shear strength of the CFRP strengthened beams ranged between 17% and 127% over the control beam. From this result, it was concluded that the externally bonded CFRP strip technique significantly increase the shear strength of RC beams with internal steel stirrups
2. Increasing grade of concrete increases the ultimate shear capacity of the strengthened beam of (efficiency) CFRP.
3. Increasing the longitudinal reinforcement ratio by 100% increases the ultimate shear capacity of the strengthened beam up to 20%.
4. The shear capacity of the external bonded CFRP rectangular beams without internal shear reinforcement shows reasonable efficiency more than rectangular beams with internal shear reinforcement.
5. Experimental results indicate that the specimen with 45/135 degree inclined L-CFRP strips gained better enhancement of 16 % greater than the vertical CFRP U-strips, With decreasing the angle of inclination from 90° to 45°, the shear strength increases till reaching the optimum angle of inclination of 45°.

6. Increasing the number of the bonded laminates enhances generally the behavior of the beam leading to an increase in both cracking and ultimate shearing loads; meanwhile it decreases the induced deformation and achieving a brittle mode of failure.
7. It was found that increasing the spacing of CFRP strip reinforcement by 33% decreases the shear capacity of the strengthened beam to 17%.
8. After repair with CFRP laminates, an enhancement in crack behavior of the original beams was achieved in general for different used schemes.
9. Using the CFRP laminates decreases width, length and the propagation of the original shear cracks, which appeared in the preloading stage in the critical shear zone.
10. Increasing the spacing between the laminates till reaching 0.5 d (the best spacing), improves the behavior of the tested beams in controlling the shear cracks and increases the resistance of the cross section to the external loads with decreasing the accompanied measured deformations.
11. using CFRP strips increase toughness and decrease ductility of beams.

7. RECOMMENDATIONS

From the pre-described analysis for the test results and the above conclusions, it is recommended for the future research work the following topics:

1. The effect of the CFRP technique for both repairing and strengthening for reinforced concrete beams having T-section
2. The behavior of reinforced concrete beams strengthened with various advanced composite materials under dynamic and repeated loads.
3. The effect of chemical attack on the CFRP strengthening system for reinforced concrete elements.
4. The effect of high degree of temperature (fire resistance) on the CFRP strengthening system for reinforced concrete elements.
5. Theoretical analysis for modeling of reinforced concrete elements combining concrete, steel reinforcement and CFRP laminates.
6. The behavior of heavily damaged reinforced concrete beams strengthened with various advanced composite materials
7. The behavior of over reinforced concrete beams strengthened with various advanced composite materials

Nomenclature			
A_f	$2nt_fw_f$	n	number of FRP plies or layers
b_w	width of beam	t_f	thickness of FRP
d_f	effective depth of FRP fabric equal to the effective	s_f	spacing of FRP fabric strips
E_f	tensile modulus of FRP	w_f	width of FRP fabric strips
f_c'	compressive strength of concrete cylinder	v_c	nominal shear strength contributed by concrete
f_{fe}	tensile stress in FRP at ultimate	v_s	nominal shear strength contributed by steel
k_v	bond reduction coefficient	v_f	nominal shear strength contributed by FRP
K_1	bond reduction coefficient for concrete strength	ε_{fe}	effective FRP strain
K_2	bond reduction coefficient for wrapping scheme	ε_{fu}	ultimate FRP strain
L_e	active bond length	β	angle between the principle fiber orientation and the longitudinal axis of the beam
ε_c	Strain of concrete surface	$\mu\%$	Longitudinal tensile reinforcement ratio
ε_s	Strain of longitudinal tensile reinforcement	δ_u	Max mid-span deflection at failure load
f_{c28}	compressive strength of concrete cube 15*15*15 after 28 days	δ_{cr}	Mid-span deflection at cracking load

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