



BEHAVIOR OF SCC BEAMS STRENGTHENED WITH CFRP UNDER SHEAR

Sarmad S. Abdulqader¹, Ragheed F. Makki² and Mohanad W. Mousa³

¹ Assistant Professor, Building and Construction Engineering Department, University of Technology, E-mail: saas7703@yahoo.co.uk

² Assistant Professor, Civil Engineering Department, Faculty of Engineering, University of Kufa, E-mail: Ragheed.Almutwali@uokufa.edu.iq

³ Postgraduate Student at Building and Construction Engineering Department, University of Technology, E-mail: mzad2010@yahoo.com

<http://dx.doi.org/10.30572/2018/kje/100109>

ABSTRACT

This paper presents an experimental study of structural behavior of self compacting reinforced concrete beams strengthened in shear by vertical CFRP strips. The experimental work consists of casting and testing of eleven simply supported reinforced concrete beams. One of the tested beam was un-strengthened to be considered as beams, while the remaining beams were tested after being strengthened using vertical CFRP strips. In this study, three parameters were considered, the configuration of CFRP sheets wrapping system, i.e. two sides, U-shape and full wrapped, effect of horizontal strap of CFRP strips to enhance the vertical CFRP strips and CFRP amount. The results showed that the presence of horizontal strap of CFRP strips on the vertical strips increases the shear capacity of the beams ranged between (3-27)% for beams with the same properties, while the increase in the ultimate loads ranged between (20-26)% and (39.5-46)% by comparison of wrapping system (two side with U-shape) and (two side with full wrapped) of CFRP strips, respectively.

KEYWORDS: Self-compacting concrete, Shear strength, Reinforced concrete, CFRP strips.

1. INTRODUCTION

Self-Compacting Concrete (SCC) is an important development in concrete technology. It is a new type of high performance concrete with the ability to flow under its weight and without the need for vibrations. Recently, a large local interest towards self-compact concrete has been derived ([Al-Mishhadani and Al-Rubaie, 2009](#)). SCC is a relatively new type of concrete that is highly flowable and non-segregating. It does not require vibration when it is cast; it is capable of flowing through narrow opening or extremely congested reinforcement, and it provides a void-free surface. It is known as self-consolidating concrete, self-leveling concrete, and high fluidity concrete ([Horta, 2005](#)). SCC flows like "honey" and has nearly a horizontal concrete level after placing. When SCC is placed in a form, its motion may be a creeping movement or a rapid flow. Because of this style of flow, the surface finish between the form and the concrete can be exceptionally smooth, creating a much-improved form finish over conventional concrete ([Dehn et al., 2000](#)).

The three main types of FRP used in the construction industry are: aramid (AFRP), carbon (CFRP), and glass (GFRP) ([Dolan et al., 2001](#)). The advantages of CFRP application includes a high strength to weight ratio, flexibility and available in long lengths, rapid execution on site, high elastic modulus, high dynamic strength, and no need for special equipment ([Dolan et al., 2001](#); [Athawale, 2012](#)). As stated in the ACI Committee 440.2R-08 ([ACI Committee, 2008](#)), there are three types of wrapping patterns are used to increase the shear strength of beams or columns as shown in [Fig.1](#). Completely wrapping system of FRP around the structural member on all sides is the most efficient and most common wrapping scheme for columns. However, the overall wrapping is not practical from the construction point of view in the case of beam applications where the integrated slab makes it impractical to completely wrap the member; the shear strength can be improved by wrapping the FRP system around three sides of the member (U-wrap) or bonding to two opposite sides of the member ([ACI Committee, 2008](#); [Khalifa, 1999](#)).

In all wrapping schemes, the FRP installation can be used continuously along the length of the member or spaced strips [Fig.2](#). The second alternative could be effective in improving the quantity of materials used. In particular, the shear resistance of reinforced concrete beams can be enhanced by bonding FRP shear reinforcement in the form of complete wraps, U-jackets and two side strips ([Chen et al., 2013](#)).

[Meshfeq, 2012](#) Test program consists of ten RC continuous (two-span) beams; the investigation includes parametric studies for CFRP sheet strengthening, such as their location (two, three and four sides), orientation, and keeping the amount of CFRP sheet for all strengthened beams constant.

2. EXPERIMENTAL PROGRAM

The experimental program consists of testing eleven simply supported beams molded by using SCC with two point loads. All beams have the same dimensions, flexural reinforcement, and shear reinforcements. These beams were designed to avoid the flexural failure, so that the failure is governed by shear. The variables investigated in this work included CFRP strips amount and distribution.

The specimens were divided into three groups (A, B and C). All Groups with (a/d) equals to 2.37. Ten SCC beams strengthened by CFRP, and the eleven beam were not strengthened by CFRP strips and selected as reference beam. All eleven beams were casted using SCC with compressive strength (f'_c) equals to 36.5 MPa.

2.1. Details of Test Beams

The overall length of beams is 1500 mm with a clear span of 1400 mm, whilst the width and height are 150 mm and 250 mm, respectively, as shown in [Fig. 3](#). All beams were longitudinally reinforced with two bars of 16 mm diameter and one bar of 12 mm diameter placed at the tension side with a clear cover of 25 mm. At the top face, two bars of 6 mm diameter were provided. For vertical shear reinforcement, deformed bars of 6 mm diameter were provided at a spacing of 250 mm center to center.

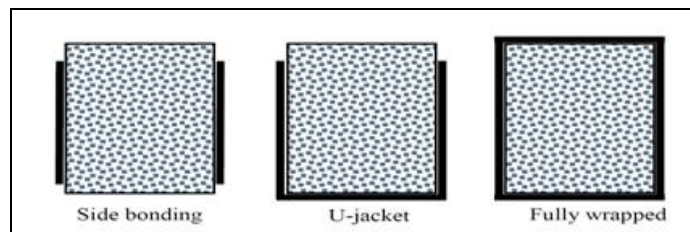


Fig. 1. Shear strengthening schemes with FRP composites ([Khalifa, 1999](#)).

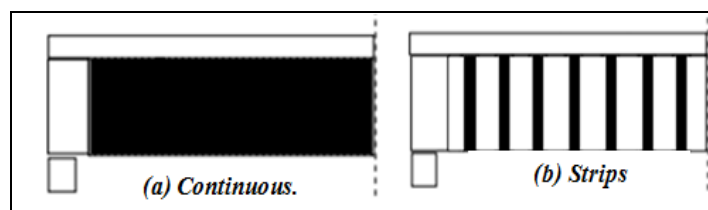


Fig. 2. FRP distributions (Chen et al., 2013).

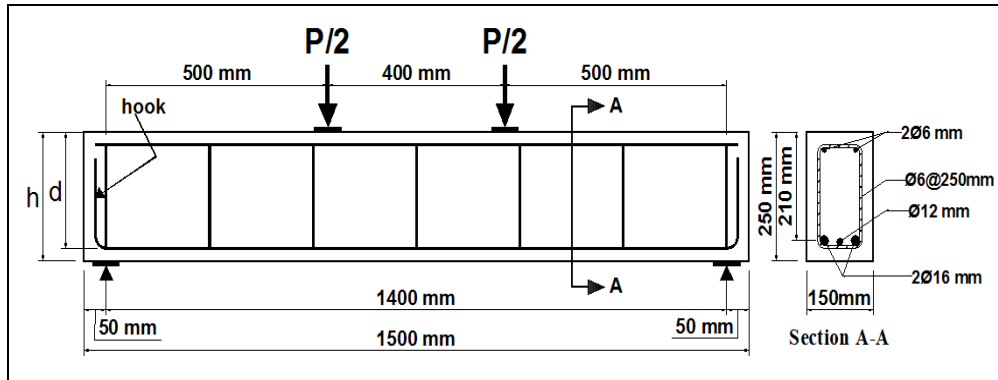


Fig. 3. Dimensions and details of tested beams.

2.2. Specimen Identification and Strengthening schemes

Strengthened beams schemes by one layer of CFRP strips with constant width (40 mm). The thickness of this strip was (0.166 mm) as provided by the manufacturers, it was chosen carefully based on the field conditions and the practical needs, mainly, economic and crack pattern. In this study, where the letter B indicates beam specimen, C indicates control specimen, the letter V indicates vertical strengthening, letter H indicates horizontal strengthening, the letter U Indicates U-shape strengthened, and the letter F indicates full warp strengthened. While the numbers (1, 2, 4, and 5) represent the number of strips. The first beam control (BC) has not strengthened by CFRP. The following strengthening layouts by CFRP were applied:

1. Group (A): contains four beams as following:

- i. Beam (BV₄ and BV₅) were provided with four and five vertical strips at each side, respectively; it was installed at angle of 90° along shear span, as shown in Figs. 4 and 5.
- ii. Beam (BV₄H₂ and BV₅H₂) were provided with four and five vertical strips at each side, in addition to two horizontal strip placed at the end of the upper and lower along shear span, as shown in Figs. 6 and 7.

2. Group (B): contains four beams as following:

- i. Beam (BV₄U and BV₅U) were provided with four and five vertical U-shape strips at each side; it was installed at angle of 90° along shear span, as shown in Figs. 4 and 5.

- ii. Beam (BV₄UH₁ and BV₅UH₁) were provided with four and five vertical U-shape strips at each side, in addition to one horizontal strip placed at the end of the upper along shear span, as shown in Figs. 8 and 9.
3. Group (C): contains two beams, (BV4F and BV5F), is provided with four vertical and five full wrapping strips each side; it was installed at angle 90° along shear span, as shown in Figs. 4 and 5.

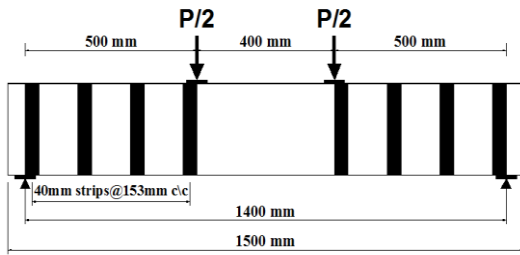


Fig. 4. Shear Strengthening for beams (BV4, BV4U and BV4F)

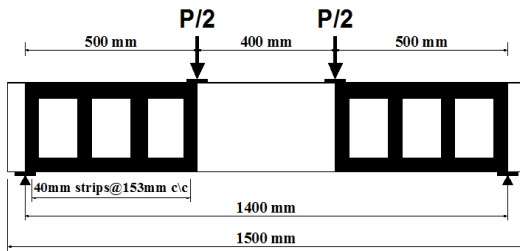


Fig. 6. Shear Strengthening for beam (BV4H2)

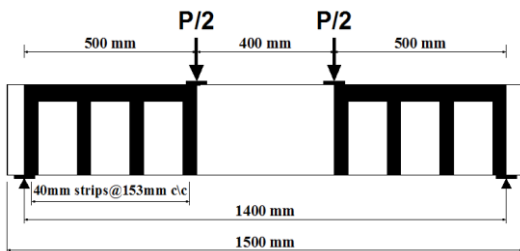


Fig. 8. Shear Strengthening for beam (BV4UH1)

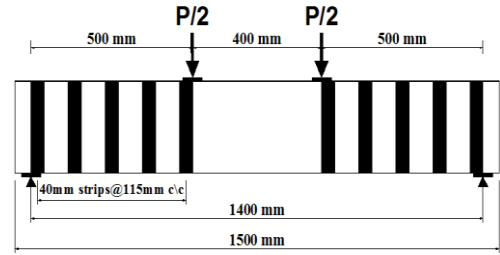


Fig. 5. Shear Strengthening for beams (BV5, BV5U and BV5F)

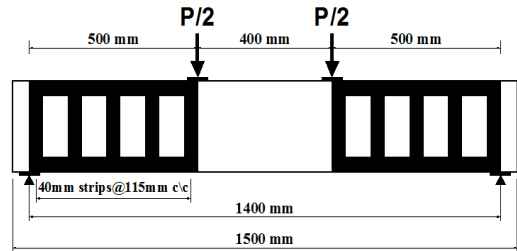


Fig. 7. Shear Strengthening for beam (BV5H2)

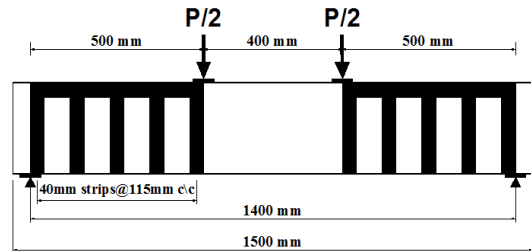


Fig. 9. Shear Strengthening for beam (BV5UH1)

2.3. Materials

The properties of cement, aggregate, admixture, carbon fiber reinforced polymer CFRP, and epoxy used in this investigation are presented in this section.

2.3.1. Cement

Ordinary Portland Cement OPC (Crista) was used in this study. It complies with the Iraqi specification (IQS) No. 5/1984 ([Iraqi Specification, No.5, 1984](#)). The laboratory test results of this type of cement illustrate its physical properties as: The compressive strength at 3 days and 7 days were equal to 19 and 28 MPa, respectively.

2.3.2. Fine Aggregate (Sand)

Natural sand from (Al-Akaidur) region was used for concrete mixes in this study. The fine aggregate was passing from the sieve (4.75 mm) maximum size and remaining on sieve (0.15 mm). The obtained results indicated that the fine aggregate grading was within the requirements of the Iraqi specification No. 45/1984 ([Iraqi Specification, No.45, 1984](#)). The main properties of the fine sand used are: The sulfate content equals to 0.08%, Absorption equals to 0.75%, and Specific gravity equals to 2.6.

2.3.3. Coarse Aggregate

The rounded coarse aggregate from Al-Niba'ee quarry is used with a maximum aggregate size of (14 mm). The results obtained indicate that the classification of coarse aggregates was within the requirements of the Iraqi Standards No.45/1984 ([Iraqi Specification, No.45, 1984](#)). The main properties of the fine sand used are: The sulfate content equals to 0.03%, Absorption equals to 0.5%, and the Specific gravity equals to 2.65.

2.3.4. Limestone Powder (LSP)

This substance is locally called as "Al-Ghubra", which was brought from the Darbindkhan plant area and has been used as a filler for concrete production for many years. It has been used to increase the concrete workability and early strength. The particle size of LSP less than 0.125 mm (sieve No.200) was used in the current research work.

2.3.5. Superplasticizer (SP)

In this work, superplasticizer was used to obtain fresh properties of SCC according to ASTM C494/C494M-15 ([ASTM C494/C494M-15, 2015](#)) types A and F, and commercially it is known as "GLENIUM54", the normal dose of Glenium54 is (0.5 - 2.5) liter / 100 Kg of cement.

2.3.6. Steel Reinforcing Bars

Deformed steel bars (16, 12, and 6) mm in diameter are used in this work. Three samples of each bar were tested under tension. The tensile tests of reinforcing steel were conducted according to ASTM A1064/A1064N-14 ([ASTM A1064/A1064N-14, 2014](#)) and ASTM

A615/A615M-15a (ASTM A615/A615M-15a, 2015). The mechanical properties of steel are listed in Table 1.

Table 1. Reinforcing Steel Properties*.

Bar Diameter, mm	Modulus of Elasticity, MPa**	Yield Stress, MPa***	Ultimate Strength, MPa**
6	200000	533	664
12	200000	548	693
16	200000	572	748

* The test was carried by using the testing machine available in the Consulting Bureau Laboratory in College of Engineering University of Kufa

** Assumed value

*** Each value is an average of three specimens (each 40 cm length)

2.3.7. Carbon Fiber Reinforced Polymers (CFRP)

When CFRP is loaded in tension, it doesn't show any plastic behavior (yield) before rupture. Sika Wrap®300 C/60 was used to enhance external testing SCC beams. The mechanical properties of CFRP sheet are tabulated in Table 2.

Table 2. Technical Properties of CFRP Sheet*

Properties	Tensile strength, MPa	Elongation at break, %	Tensile modulus, GPa	Thickness, mm
Sika Warp®300 C/60	3900	1.5	230	0.166

*Supplied by the manufacturer

2.3.8. Bonding Materials

The most suitable adhesives with CFRP sheets are Sikadur®330. The adhesive type consists of two compounds, compound A (white) and compound B (gray). The mix ratio is 4: 1 as A: B. Its main characteristics as provided by the manufacturer are shown in Table 3.

Table 3. Properties of Adhesive Material*.

Properties	E-modulus, GPa
------------	----------------

	Tensile strength, MPa	Elongation at break, %	Flexural	Tensile
Sikadur®300	30	0.9	3800	4500

*Supplied by the manufacturer

2.4. SCC Mix Design

To meet the self-compacting requirements and the designed compressive strength, many trial mixes were conducted. The SCC mix is designed according to EFNARC (EFNARC, 2005). In the present work, the cement content was 350 kg/m³, fine aggregate content was 797 kg/m³, coarse aggregate content was 767 kg/m³, limestone powder content was 170 kg/m³, water content was 150 l/m³, the superplasticizer content was 4.2 l/m³ (1.2 liter per 100 kg of cement), and the w/c ratio was 0.43.

2.4.9. Mixing and curing of Concrete Batches

Mixing procedure is important to obtain the required workability and homogeneity of SCC. The method used to mix the materials was summarized as follows:

- The fine aggregate was added to the mixer with a quantity of one third from the (water and dosage of superplasticizer well as mixed together) and mixed for one minute.
- The powder (Cement and LSP) were added with one third amount from (water and dosage of super plasticizer which were mixed together). The mixture is then mixed for one minute.
- The coarse aggregate was added with the last one third amount of (water and dosage of super plasticizer which were mixed together), and mixing extends for one and half minute.

After the mixing process is completed, the main specimens are casted into molds without the need for vibration where the concrete molds are easily filled and interspersed between reinforcement bars without any segregation. The hardened specimens were demolded after 48 hours; burlap sacks were monitored and kept wet until twenty-eight full days passed.

2.5. Strengthening with CFRP

The strengthening system used in this work comprised of fiber strips, epoxy. All the strengthening processes were done after 28 days of moist curing for the beam specimens. Only the first specimen (BC) was kept without strengthening as control specimen, whereas the other ten beam specimens were strengthened with externally applied CFRP strips. The following different schemes illustrate the technique of this strengthening as shown in Figs. 4–9.

3. RESULTS AND DISCUSSION

The eleven beams were tested in this study, including one reference beam. While ten SCC beams strengthened by CFRP were divided into three groups. The cracking load, ultimate load, and mid span deflections at first cracking and ultimate stages are listed in Table 4. All beams were tested for shear failure.

Table 4. Experimental results of the tested beams.

groups	No.	Beam designation	Total applied load, kN				Mid-span deflection, mm		Percentage increase in ultimate load with respect to reference beam, %
			Pc(f)*	Pc(s)*	Pu	Pcr/Pu, %	$\Delta c(f)$	Δu	---
-	1	BC	20	25	152	16.45	0.93	8.86	15.13
A	2	BV4	25	30	175	17.14	0.9	8.97	25
	3	BV5	25	50	190	26.32	1.23	9.5	46.05
	4	BV4H2	25	50	222	22.5	1.16	10.05	54.61
	5	BV5H2	25	65	235	27.65	0.91	9.84	38.16
B	6	BV4U	25	40	210	19	1.09	9.92	57.89
	7	BV5U	30	40	240	16.67	1.06	10.88	51.32
	8	BV4UH1	35	50	230	21.7	1.05	9.86	62.5
	9	BV5UH1	40	55	247	22.27	1.12	10.14	62.5
C	10	BV4F	25	50	255	19.61	0.75	13.27	67.76
	11	BV5F	50	65	265	24.53	1.52	13.12	74.34

*Refer to load at initiation of first flexural crack.

** Refer to load at initiation of first shear crack.

3.1. General Behavior and Crack Patterns

In general, all the tested beams exhibited almost the same behavior from the initial loading up to the load causing failure. Cracking of each specimen was generally progressed as follows:

With the increase of loading a small flexure crack appeared at or near the mid-span of the beam, then it extended upward. With further loading, an inclined crack appears at shear zone approximately at the mid-length of load path.

It can be observed that the beams without strengthening showed almost the same crack pattern and failure mechanism as strengthened beams, but differ in the ultimate loads. The difference in cracking patterns depends on the amount and shape of CFRP sheets as shown in Figs. 10–13.

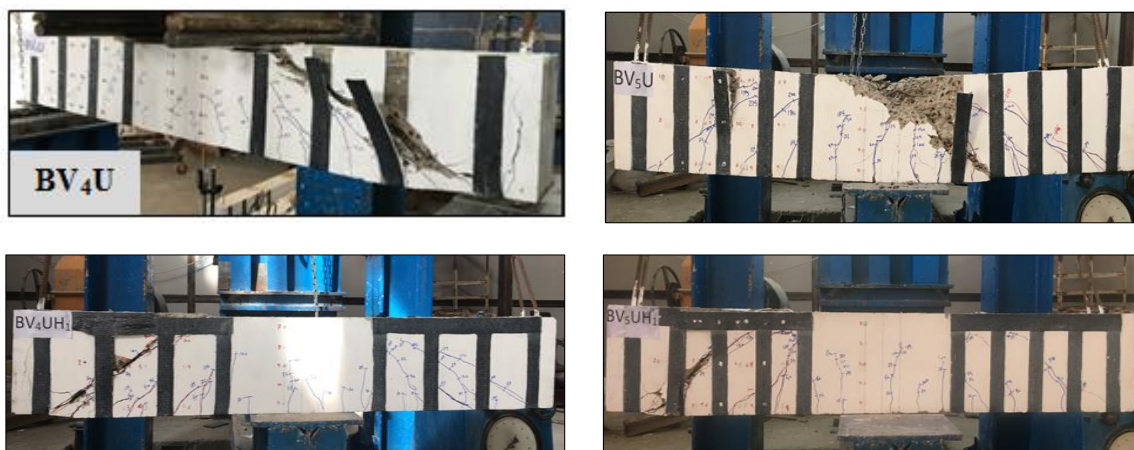
It was observed that the increase in cracking and final load was affected by the amount and shape of the strips. It was found that when using strengthened full wrapped of CFRP strips, the failure pattern was transformed from shear failure to flexural failure; this failure occurred in-group C.



Fig. 10. Crack pattern for the beams failed in shear for beam (BC).



Figs. 11. Crack pattern for the beams failed in shear for group (A).



Figs. 12. Crack pattern for the beams failed in shear for group (B).



Figs. 13. Crack pattern for the beams failed in flexural for group (C).

3.2. First Cracking and Ultimate Loads

The first cracking load increases with increase in the amount and shape of CFRP sheets as shown in Table 4. The diagonal crack that caused failure initiated suddenly from the last shear crack that became inclined and crossed mid depth, and then such a crack propagated simultaneously towards the load-point and towards the support along the tensile reinforcement (due to dowel action) causing a loss of bond and failure of the beam. External strengthening of SCC beams by CFRP sheets showed an improvement in the first cracking loads when compared with the control beam as shown in Table 4 with the same loading level.

From comparison of the four specimens in group A, it can be seen that the ultimate load carrying capacity increases with increasing of the vertical CFRP strips distributed between the support and the point of concentrated load. On the other hand, when the two horizontal CFRP strips were connected to the vertical CFRP strips to prevent the failure of the latter by de-bonding, an increase was made in the ultimate load comparing to the beams without horizontal CFRP strips. The specimens in this group failed suddenly by de-bonding and rupture of CFRP strips, while by comparison of the four specimens in group B, it can be seen that the ultimate load capacity is increased with the increasing of vertical U-shape CFRP strips distributed between the support and the point of concentrated load. On the other hand, when one horizontal CFRP strip was connected to the vertical U-shape CFRP strips to prevent the failure of the latter by de-bonding, an increase was made in the ultimate load compared to the beams without horizontal CFRP strip. The specimens in this group failed suddenly by de-bonding and rupture of CFRP strips. On the other hand, group C gave a better improvement in strength than previous groups. This improvement indicates the presence of CFRP strips in the form of a full vertical wrapping. Also, the presence of CFRP strips gave another advantage, as the shear cracks were small in width and spaced while the bending incisions were larger and deeper. That was the cause of the change pattern of failure from shear failure to the flexural failure, in addition to the crushing of concrete in the compression zone. Fig. 14 shows the results of groups (A, B, and C) tests conducted as given above and compared with BC (beam control). The percentage increase in ultimate load

with respect to reference beam are as follows: (15.13 to 54.61) % for group A, (38.16 to 62.8) % for group B and (67.67 to 74.34) % for group C.

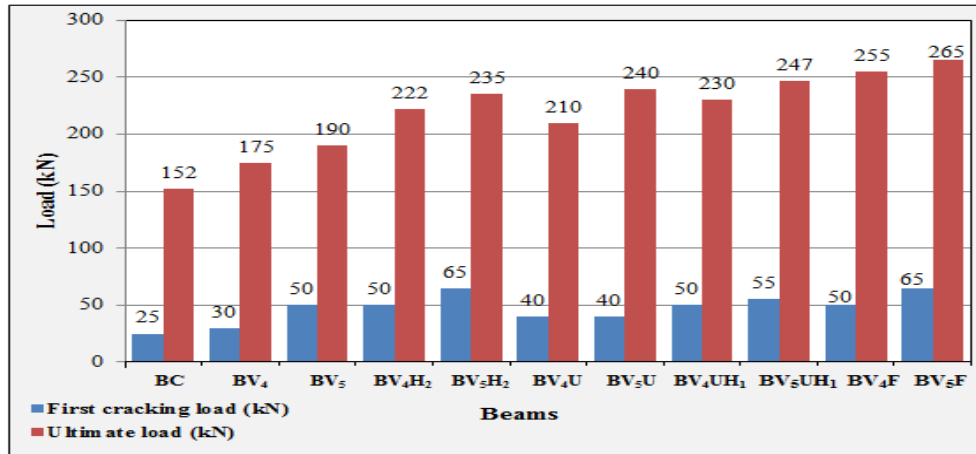


Fig. 14. First Cracking and Ultimate Loads for groups (A, B and C) with the reference Specimen (BC).

3.3. Load deflection Behavior

Experimental load versus mid-span deflection curves for these SCC beams are presented in this section as shown in Figs. 15–17. These Figures show that the load-deflection curve for the groups A, B, and C, whilst Fig. 18 shows the comparison of the load-deflection curves for SCC beams strengthened with CFRP for beams (BV4 and BV5) with (BV4U and BV5U), respectively, while Fig. 19 illustrates the comparison of the load-deflection curves for SCC beams strengthened with CFRP for beams (BV4H2 and BV5H2) with (BV4UH1 and BV5UH1), respectively. Fig. 20 shows the comparison of the load-deflection curves for SCC beams strengthened with CFRP for groups (A and B) with group C. Obviously, it was noticed that the presence of CFRP sheets affected the behavior of strengthened beams compared with the control beams by increasing the ultimate strength and reducing the ultimate central deflection.

The ultimate load for (BC) equals to 152 kN, and the value of deflection at this load equals to 8.86 mm. For group (A) the ratio of deflection for the strengthened beams to that of the control beams ranged were (0.221, 0.278, 0.313, and 0.388) for the beam specimens (BV4, BV5, BV4H2 and BV5H2), respectively. For group (B) the ratio of deflection for the strengthened beams to that of the control beams ranged were (0.315, 0.341, 0.397, and 0.422) for the beam specimens (BV4U, BV5U, BV4UH1 and BV5UH1), respectively. For group (C) the ratio of deflection for the strengthened beams to that of the control beams ranged were (0.352 and 0.37) for the beam specimens (BV4F and BV5F), respectively.

3.4. Shear Crack Width

Shear cracking load is defined as the load at which the first major inclined diagonal tension crack appears in the shear span. The crack is sudden and is usually originated at the middle of the shear span and propagates toward the support and loading point during subsequent increase in the applied load. Maximum crack widths along the major inclined crack in the shear span occurred almost at mid depth of the beam. Beams without CFRP strips exhibited considerably larger crack width at failure.

For each load increment, crack width of the major inclined crack at mid-depth of the beam was measured by means of crack detection pocket microscope. Figs. 21–24 show the behavior of the total applied load versus the maximum crack for control beam BC and beams for groups (A, B, and C).

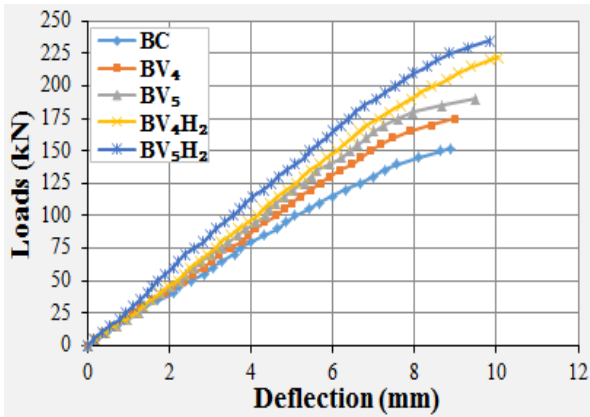


Fig. 15. Load-Deflection Curve for group A

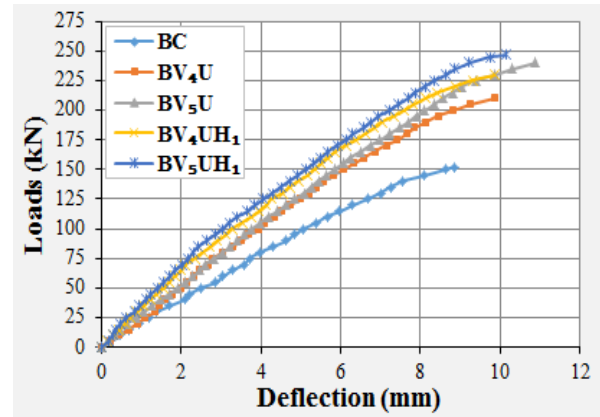


Fig. 16. Load-Deflection Curve for group B

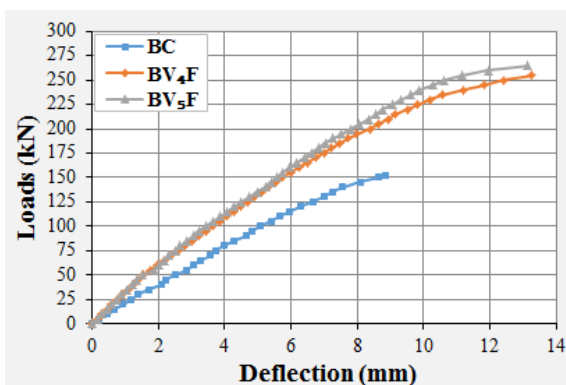


Fig. 17. Load-Deflection Curve for group C.

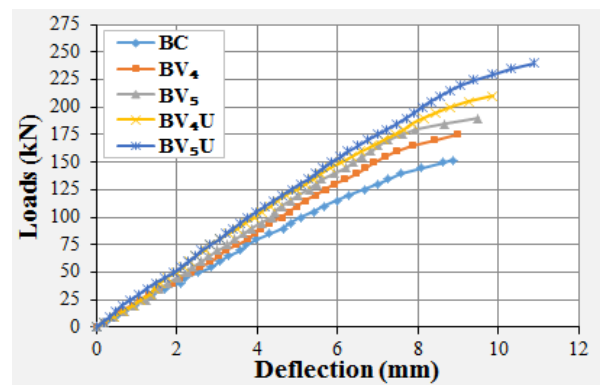


Fig. 18. Load-Deflection Curve of Specimens (BV₄, BV₅, BV₄U and BV₅U).

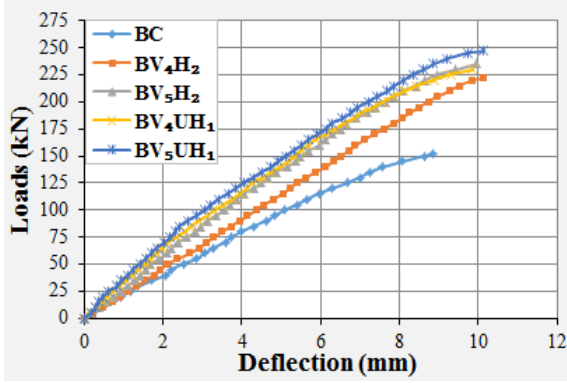


Fig. 19. Load-Deflection Curve of Specimens (BV₄H₂, BV₅H₂, BV₄UH₁ and BV₅UH₁)

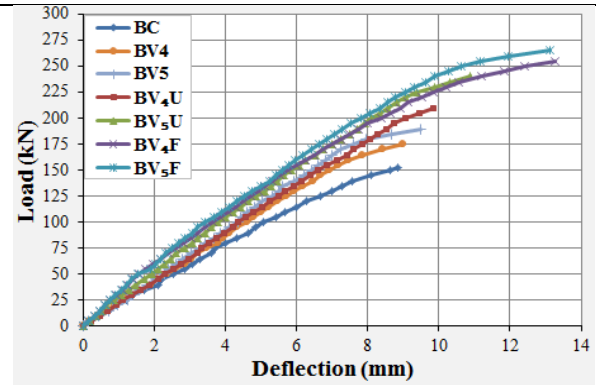


Fig. 20. Load-Deflection Curve of Specimens (BV₄, BV₅, BV₄U, BV₅U, BV₄F and BV₅F)

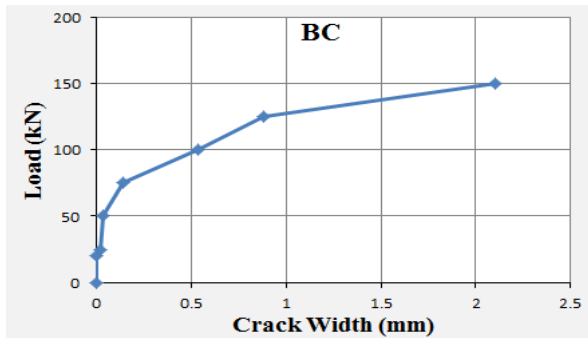


Fig. 21. Load versus crack width of BC.

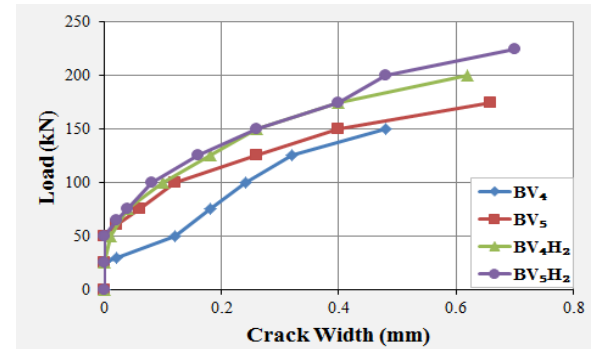


Fig. 22. Load versus crack width for group A.

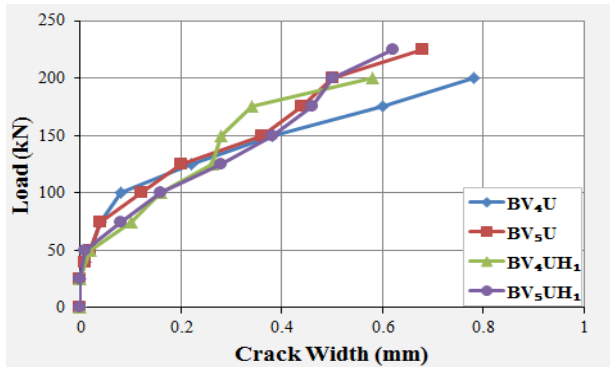


Fig. 23. Load versus crack width for group B.

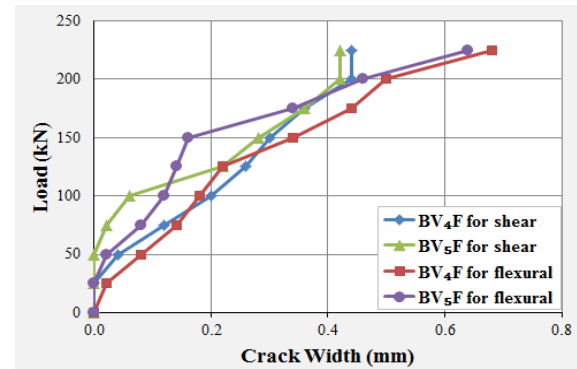


Fig. 24. Load versus crack width for group C.

4. CONCLUSIONS

The following points have been reached in this research:

1. The experimental test results confirmed that the strengthening technique of CFRP system is applicable and can increase the shear capacity for strengthened SCC of RC beams. In this study, the ultimate load capacity of the strengthened beams ranged between (15 % to 74%) over the ultimate load capacity of the reference beam (BC), while increase in ultimate loads

ranged between (20-26)% and (39.5-46)% by comparison of wrapping system (two side with U-shape) and (two side with full wrapped) of CFRP strips, respectively.

2. A decrease in the width of cracks due to presence of CFRP sheets occurred. The ranged is between (77-87.6)% of the crack width of the control SCC beams.
3. Experimental tests of the eight SCC beams strengthened with and without horizontal CFRP strips indicated that the presence of end horizontal CFRP strips increased the shear capacity of the beams by 26.9%, 23.7%, 9.5%, 2.9% for beams with the same properties. This is attributed to increasing the effective length of the CFRP strip which works as a link between the top compressive zone and the bottom tension zone. This is similar to the steel stirrups functioning to prevent the propagation and widening the diagonal shear cracks. Therefore, rupturing failure of the horizontal CFRP strips will occur.
4. The decrease in deflection for SCC beams depends on the amounts and shape of CFRP sheet of self-compacting concrete used in strengthening these beams.

5. REFERENCES

ACI Committee 440.2R-08, "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures," American Concrete Institute, Michigan, USA, July 2008, 80pp.

Al-Mishhadani, S.A. and Al-Rubaie, M.F., "A Data Base for Self Compacting Concrete in Iraq," Department of Building and Construction Engineering, University of Technology, Iraq, Eng. & Tech. Journal Vol.27, No.6, 2009, PP. 1203-1218.

ASTM C494/C494M-15, "Standard Specifications for Chemical Admixtures for Concrete", Developed by ASTM Subcommittee C09.23, Vol. 04.02, West Conshohocken, PA, USA, 2015.

ASTM A1064/A1064N-14, "Standard Specifications for Carbon-Steel Wires and Welded Wire Reinforcement, Plain and Deformed, for Concrete ", Developed by ASTM Subcommittee A01.05 on Steel, Stainless Steel, and Related Alloys, Vol.01.04, West Conshohocken, PA, USA, Approved in November, 2014, Published in November, 2014.

ASTM A615/A615M-15a, "Standard Specifications for Deformed and Plane Carbon-Steel Bars for Concrete Reinforcement", Developed by ASTM Subcommittee A01.05 on Steel, Stainless Steel, and Related Alloys, Vol. 01.04, West Conshohocken, PA, USA, Approved in January 2015, Published in March 2015.

Athawale Parth B.E., "Analysis of Factors Affecting Effective Bond Length for Fiber Reinforced Polymer Composite Laminate Externally Bonded to Concrete Substrate," MSc. thesis, Texas Technical University, May 2012.

Chen, G.M, Teng, J.G., and Chen, J.F., "Shear Strength Model for FRP-Strengthened RC Beams with Adverse FRP-Steel Interaction," *Journal of Composites for Construction*, ASCE, Vol.17, No.1, 2013, pp.50-66.

Dehn, F., K. Holschemacher, and D. Weisse, "Self-Compacting Concrete Time Development of the Material Properties and the Bond Behavior," *LACER* No. 5, 2000, pp.115-123.

Dolan, C.W., Hamilton, H.R., and Nanni, A., "Design Recommendations for Concrete Structures Prestressed with FRP Tendons," FHWA Contract, Final Report, Vol. 1, August 2001.

EFNARC, (2005): European Federation Dedicated to Specialist Construction Chemicals and Concrete systems "The European Guidelines for Self-Compacting Concrete Specification, Production and Use", May 2005.

Horta, A., "Evaluation of Self-Consolidating Concrete for Bridge Structure Applications," MSc. Thesis, Georgia Institute of Technology, 2005.

Iraqi Specification, No.5, "Portland cement", Baghdad, 1984.

Iraqi Specification, No.45, "Aggregate from natural sources for concrete and construction", Baghdad, 1984.

Khalifa, A.M., "Shear Performance of Reinforced Concrete Beams Strengthened with Advanced Composites," PhD. Thesis, University of Missouri-Rolla, Center for Infrastructure Engineering Studies (CIES), 1999.

Meshfeq, M-R. M., "Experimental and Theoretical Investigation of Shear Strengthening of R/C Continuous Beams Using Externally Bonded CFRP Sheets," MSc. Thesis, College of Engineering, University of Babylon, Iraq, 2012.