Studying Flexural Behavior of Reinforced Fibrous Self- Compacted Concrete T- Beams Strengthened with CFRP SHEETS

Arjan Fakhraldin Abdullah, Mazin Burhan Adeen, Alya'a Abbas Al-Attar

Abstract: —This research Studies the possibility of producing self-compacting concrete (SCC) containing Pozzolanic materials and reinforced with different types of fibers , 11% (by weight of cement) of silica fume were used and two types of fiber (Steel, Nylon) with different volume fraction , also it studies the structural behavior of the self-compacted reinforced T-section beams. The current study includes a practical program considers the effect of adding steel and nylon fibers to structural behavior of T- section self-compacting concrete such as compressive and tensile strength and flexural behavior represent by load-deflection curves, variables that which studied after obtaining the self-compacting was the volumetric ratios of fibers which used (0.2, 0.3 and 0.4) % ratios for steel and nylon and hybrid fiber. Also Rehabilitate the T- beams after failure in bending by strengthened it with carbon fiber strips (CFRP), and find out the effect of external strengthening by CFRP on the flexural resistance of concrete & reinforced concrete beams. The practical results of the current study indicated that when adding steel fiber to the self-compacted concrete it has shown a good effect of the increase in compressive, tensile and flexural strength, also it has effect of reducing deflection, this effect increasing by increase of the volumetric ratio of steel fiber. while adding of nylon fibers lead to a slight increase in compressive strength and this effect decrease by fiber content increasing and the addition of these fibers lead to a small increase in the tensile and bending strength , also adding hybrid fiber in all ratios lead to an improvement in hardened properties of self-compacted concrete .The results of repair by strengthening the beams with carbon sheets indicated that the carbon fibers had a noticeable effect in increasing the ultimate load in all beams and testing results showed that the flexural strength increased between (6.42% - 29.62%) for concrete beams, and between (9%-33%) for rehabilitated damaged concrete beams.

Keywords: —Fibers self-compact Concrete, Flexural Strength, CFRP, and Epoxy.

I. INTRODUCTION

Self-Compacting Concrete (SCC), which flows under its own weight and does not require any external vibration for compaction, has revolutionized concrete placement. SCC was first introduced in the late 1980's by Japanese researchers [1], it is highly workable concrete that can flow under its own weight through restricted sections without segregation and bleeding.

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*****Correspondence Author(s)
Mr. Arjan Fakhraldin Abdullah, Department of Civil Engineering, *u*niversity of Tikrit / College of Engineering.
Dr. Mazin Burhan Adeen Department of Civil Engineering, *U*niversity of Tikrit / College of Engineering.
Dr. Alya'a Abbas Al-Attar Technical College of Kirkuk.

Such concrete should have a relatively low yield value to ensure high flow ability, a moderate viscosity to resist segregation and bleeding, and must maintain its homogeneity during transportation, placing and curing to ensure adequate structural performance and long term durability. SCC offers many advantages for the precast, pre stressed concrete industry Low noise-level in the plants and construction sites.

- Eliminated problems associated with vibration.
- Less labour involved.
- Faster construction.
- Improved quality and durability.
- Higher strength.

And SCC mixes must meet three key properties:

- Ability to flow into and completely fill intricate and complex forms under its own weight.
- Ability to pass through and bond to congested reinforcement under its own weight.
- High resistance to aggregate segregation.

During the latest decade there has been a significant increase in using FRP (Fiber Reinforced Polymers) as a main material for external reinforcement in the construction industry, this is due to its properties and multiple advantages which makes it preferable to an iron mineral. The most obvious advantage of using FRP as concrete reinforcement is that it does not corrode in the same way as steel, which makes it an interesting reinforcing option and an optimum solution for the strengthening and rehabilitation of concrete structure in severe environmental condition.

Carbon fibers have received a considerable attention in recent years because of their high efficiency in producing ductile concrete. CFRP is a combination of carbon fibers and an epoxy resin matrix. CFRP laminates have unidirectional structural properties as they have very high strength and rigidity in the fiber direction and outstanding fatigue characteristics [2].

CFRP has considerably improved the flexural and the shear strength and the ductility enhancement of concrete structures. CFRP is used for strengthening and rehabilitation of beams, bridges, slabs and columns. CFRP is selected as strengthening materials because of its outstanding tensile strength and stiffness compared to those of other composite materials [3] . There are many nomenclatures on the CFRP such as (CFRP laminates, CFRP strips, CFRP plates, CFRP sheets and CFRP fabrics). Externally bonded CFRP sheet method is a suitable repair and strengthening method that is becoming an accepted practice for rehabilitating existing structures in the civilian sector.

The main advantages of CFRP may be summarized in the following points:

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1. Availability in any length and ability to be transported in rolls and Light weight.
2. Very high strength (E ≥ 230,000 MPa, tensile strength > 2400 MPa).
3. Reduced maintenance cost and construction periods.
4. Outstanding fatigue strength.

II. REVIEW OF LITERATURE

Al-Mahaidi , et al [4] in 2001 studied the behavior of three shear deficient T-beams strengthened using web-bonded CFRP plates. The experimental results have shown that repairing the beams with CFRP strips enhances their shear capacity.

Hasan , [5] in 2007 tested ten rectangular reinforced concrete beams in flexure to get the effect of amount of CFRP laminate strengthening and load history parameters on beams cracking behavior, concrete strain, ductility ratio, ultimate load, and failure mode, as well as a series of tests carried out on construction materials and control specimens. Experimental results obtained from the adopted strengthening technique showed significant effect of external high strength CFRP laminates on improving the behavior of reinforced concrete beams. For beams tested under monotonic loading, asignificant increase in ultimate load capacities was observed over the control beam with conventional reinforcement, in spite of reduction in their ductility ratios.

III. EXPERIMENTAL WORK

1. Materials:

The properties of materials used in concrete mixtures are given below.

1.1 Cement:

Ordinary Portland cement type (CEM II/A-L 42.5R , KARASTA) is used. It is tested per Iraqi standard Specifications I.Q.S No.5/1984 [6] , and has met all the requirements. The chemical and physical properties of this cement are presented in (Table 1).

1.2 Fine aggregate:

Natural sand with a 4.75-mm maximum size is used as fine aggregates. The grading of the sand conformed to the requirement of IQS No. 45/1984 - zone No. (3) [7]. Its sieve analysis results are given in (Table 2).

1.3 Coarse aggregate:

Coarse aggregate (river gravel) used in this study is 12.5-mm nominal size. It is tested per ASTM C33-01[8]; Its sieve analysis results are given in
(Tables 3).

1.4 Fibers:

Two different types of fiber are used. The first is the steel fiber manufactured by Bekaert - Dramix® ZP305 (Fig.1-a) and having a ‘trough’ shape with hooks at both ends , and glued in bundles. Steel fibers are 30 mm long and 0.55 mm in diameter (aspect ratio of 55), while the second is nylon fiber (Fig.1-b) of crimped shape and rectangular cross section (of dimension 0.8*0.5 mm) with length of 45 mm. In this investigation, three percentages by volume of concrete (0.2%, 0.3% and 0.4%) are used with mix proportion of 100-0%, 50-50% and 0-100% for each fibers percentage (steel to Nylon), the optimum volume fraction of fibers according to compressive , tensile and flexural strength will be taken into account in concrete mixes .

1.5 Super plasticizer:

A commercially available super-plasticizer Structuro 502 is used throughout this work as a (HRWRA) in all mixtures. Structuro 502 combines the properties of water reduction and workability retention. It allows the production of high performance concrete and/or concrete with high workability. Structuro 502 is a particularly strong superplasticizers allowing production of consistent concrete properties around the required dosage. The weight percentage (according to powder weight) is 3.3% in reference mix and it is same for all fibrous mixes equal to 4.5%.

1.6 Silica Fume:

Elkem Micro Silica MEYCO® MS610 is used as Silica fume. The used weight percentage (by cement weight) for all mixes is 11%. Silica fume is the one of the most popular pozzolanas, whose addition to concrete mixtures results in lower porosity, permeability and bleeding because their oxides (SiO_2) react with and consume calcium hydroxides, which are produced by the hydration of ordinary Portland cement. The main results of pozzolanic reactions are: lower heat liberation and strength development; lime-consuming activity; smaller pore size distribution [9].

1.7 Carbon Fiber Reinforced polymer (CFRP) strips:

Carbon fiber fabric laminate of type Sika Wrap Hex-230C and epoxy based impregnating resin of type Sikadur-330 have been used to externally strengthen the reinforced concrete T-section beams, as shown in Figure (2) and (3) , The properties of Carbon fiber laminate and epoxy used are shown in table (4)and (5) .

2. Mixture proportions:

First, a control mixture (without fibers) is designed in accordance with the provisions of Standard Practice for Selecting Proportions for self-compact concrete containing silica fume [10] , Eight trial mixes were prepared by varying the filler content, fine to coarse aggregate ratio, cement , and super plasticizer content . Proportions of the trial mixes, determined using the absolute volume method, suitable mix of self-compacted concrete which gives maximum strength and Is identical to the standard specifications of EFNARC present in Table (6). After that, three percentages by volume of concrete (0.2%, 0.3% and 0.4%) are used with three mix proportion of 100-0%, 50-50 and 0-100% for each fibers percentage (steel to nylon). Thus, the total concrete mixes which contain fibers are nine. The Super plasticizer materials ratio is increase to 4.5% from 3.3% to keep flow ability of mix. Also, the silica fumes are kept at 11%, for FRC mixes.

Beams details: 3.

The experimental program consists of (10) T-section beams which contain deferent type of fiber and involving strengthening of beam with the CFRP straps after failure by using 60cm carbon fiber in the bottom face of T-section as show in fig (4) .

4. CFRP Installation:

The concrete surface at bottom faces of the T-section beams was cleaned from lousy materials by a surface cleaning machine. Firstly, the two-parts of epoxy (A and B) were mixed in 4:1 ratio. The epoxy mixer has been applied to the surface of concrete at location of CFRP strips in length of (60 cm) to fill the cavities.

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Also the epoxy mixer poured on surface of CFRP strips and these strips applied to the surface of concrete as shown in figure (5).

5. Testing:

The (60mm*300mm) flange + (100*100) web * 1000mm T-section beams are tested to investigate flexural strength. The beams were subjected to two-point loading as shown in figure (4), the loading rate was subjected using Universal machine with capacity of 5000 kN at a rate of 3 MPa/min. The specimen is tested at the age of 28 days and after the failure of the beams, opposite load applied on the beam to repair it by using carbon fiber sheet and test it again.

IV. RESULTS AND DISCUSSION

a. Compressive and tensile strength:

Table(7) show The results of compression tests and tensile strength that determined at the age of 28 days, as a means of quality control , Test results show that the addition of nylon fibers has minor effect on the improvement of the compressive and tensile strength values, but the addition of steel fibers has a major effect which is larger than the effect of nylon fibers. The maximum increase is for steel fiber fraction equal to 0.4% that is 10.5 % in compressive strength and 23.3% in tensile strength.

b. Flexural Strength:

The average results of the flexure tests are given in table (7) as a ultimate load. The flexural strength trend for steel and nylon fiber varies when fiber increased. The maximum increase ultimate load can be achieved for fiber percentage equal to 0.4% for steel fiber as similar to the case of split tensile strength. In general, for the all fiber percentage, the flexure strength of the FRC specimens increased as the steel fiber percentage increases and it can be seen that the addition of nylon fibers slightly increased the flexural strength.

c. Repair beams:

Table (8) and figure (6) shown result of repair beams, it indicate that the strength with carbon fiber sheet have increased the resistance of bending for beams and this increase varies with fiber contain figure (7 to 16) show the load deflection curves of failure and repair beam .

VII. CONCLUSIONS

1) It has found that the use of 11% by weight of cement Silica Fume as filler required a higher dosage of Super plasticizer of about 3.3% to achieve the maximum compressive strength at 28 days and match the requirements of specifications EFNARC.
2) The addition of Steel Fibers caused an increase in compressive and tensile strength of about 10.5% and 23.33% respectively at age of 28 days but addition of nylon fiber caused slightly effect.
3) Adding both type of fiber to SCC with different volumetric ratios leads to a clear improvement in the properties of hardened state, so there is a significant increase in the flexural strength for the concrete mix including 0.4% steel fiber equals to 29.62 % and for nylon fiber including 0.4% equal to 16.42 % and for hybrid fiber including 0.4% ratio equal to 23 % at 28 days .
4) Experimental results indicate that the use of CFRP sheets is satisfactory strengthening way for T- section beams. It gives up to 33% increment in ultimate load for reference beam and (28.5%, 19%, 17.8%) increment for steel and nylon and hybrid fiber respectively.

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Er. Mr. arjan fakhraldin abdullah, born in 30th july1988 complete his B.Sc. at Tikrir University, engineering college, civil engineering department in 2010. Recently, he pursuing his M.Tech studying in structure engineering, civil engineering department *u*niversity of Tikrit / College of Engineering. (Iraq)

Dr. Mazin Burhan Adeen ;He complete B.Sc. Civil Eng. At University of Tikrit in (Iraq) 1995,M.Sc. in Civil Engineering at University of Tikrit in (Iraq) 1998, and Ph.D. in Civil Engineering atUniversity of technology-baghdad in (Iraq)2007,

Dr. Alya'a Abbas Al-Attar; she complete B.Sc. Civil Eng. At salahaldin University in (Iraq) 1994,M.Sc. in Civil Engineering at University of Tikrit in (Iraq) 1998, and Ph.D. in Civil Engineering at University of technology-Baghdad in (Iraq)2006.

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Oxides composition	Content %	Limit of Iraqi specification No. 5/1984
CaO	60.45	-
Al_2O_3	4. 65	8% Max
SiO_2	20.11	21% Max
Fe_2O_3	3.62	5% Max
MgO	4.1	5 % Max
SO3	2.33	2.5 %Max
Loss on Ignition, (L.O.I)	2.72	4 %Max
Insoluble material	1.33	1.5 %Max
Lime Saturation Factor (L.S.F)	0.89	(0.66-1.02)
Physical properties	**Test results**	**Limit of Iraqi specification No. 5/1984**
Specific surface area (Blaine method), (m^2/kg)	308	(230 m^2/kg) lower limit
Setting time (vacate apparatus) Initial setting, (hrs : min) Final setting, (hrs : min)	2hrs 15min 4hrs 10min	Not less than 45min Not more than 10 hrs
Compressive strength (kg/cm^2) For 3-day For 7-day	288 342	Not less than 150 kg/cm^2 Not less than 230 kg/cm^2

Table (1) Chemical Composition and Physical Properties of Cement.

Table (2) Grading of fine aggregate.

Sieve size	Cumulative retained%	Cumulative passing %	Limit of IQS No. 45/1984 for zone No. (3)
4.75-mm (No.4)	9.05	90.95	90-100
2.36-mm (No.8)	13.38	88.62	85-100
1.18-mm (No.16)	21.45	78.55	75-100
600-µm(No.30)	33.04	66.96	60-79
300-µm(No.50)	83.26	16.74	12-40
150-µm(No.100)	95.66	4.34	0-10

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Table (3) Grading of Coarse aggregate .

Sieve size	Cumulative passing %	Limit of ASTM C33-01
12.5-mm	96.94	90-100
9.5-mm	90.82	85-100
4.75-mm	24.49	10-30
2.36mm	0.00	0-10

Figure (1): a. Steel Fibers, b. nylon Fibers.

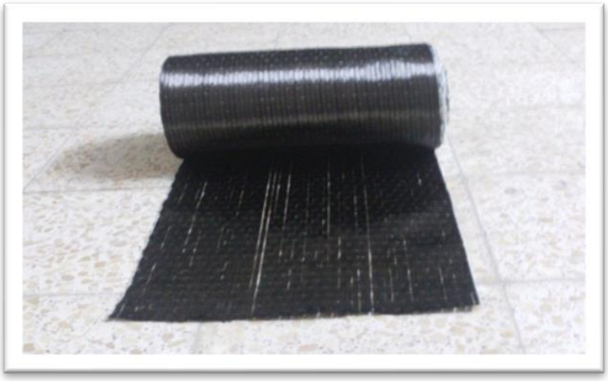

Figure (2)) CFRP strips (Sika Wrap Hex-230c)

Figure (3) epoxy resin (A + B) .

Table (4) Properties of carbon fiber strips.

1	Fiber type	High strength carbon fibers
2	Fiber orientation	0^0 (unidirectional)
3	Construction	Warp: Carbon fibers(99% of total a real weight) Weft: Thermoplastic heat-set fiber(1% of total a real weight
4	A real weight	225 gm/cm^2
5	Fiber density	1780 kg/m^3
6	Fiber design thickness	0.13 mm (Based on total area of carbon fiber)
7	Tensile strength	3500 N/mm^2
8	Tensile -E-modulus	230,000 N/mm^2
9	Elongation at break	1.5%

10	Fibric length / roll	≥ 45.7 m
11	Fibric width	305/610 mm
12	Shelf life	Unlimited
13	Package	1 roll in card board box

Table (5) Properties of epoxy resin

Density	1.31 Kg/L mixed (Comp. A+B)
Mixing ratio (A:B) by weight	1:4
Pot life	+15°C :90 min. +35°C :35 min.
Open time	+35°C :30 min.
Viscosity	Pasty, not flow able.
Application temperature	Substrate and ambient temperature: +15°C to +35°C
Adhesive tensile strength on concrete	Concrete fracture after 1 day (>15°C), on sandblasted substrate
Tensile strength	(Curing 7 day, +23°C)= 30 N/mm^2
Flexural-E-Modulus	(Curing 7 day, +23°C) = 3800 N/mm^2

Table (6) Concrete Mix Proportions.

Mix	Filler %	Str. 502 %	Quantities of Mix Ingredients (Kg/m3)								
			Water Kg	Powder		w/cm ratio	FA	CA	Str. 502 Kg	Density Kg/m3
				Filler Content (Kg/m3)	Cement					
SCC	11%	3.30%	170	49.5	450	0.34	900	750	16.48	2335.98

Table (7) Compressive & Tensile Strength and ultimate load for different volume fraction ratios.

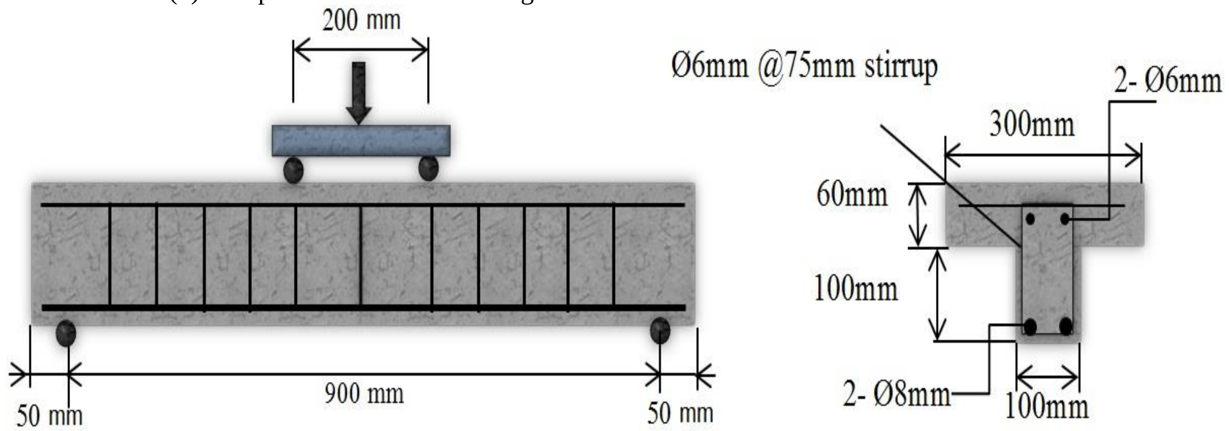

Figure (4) T-section beam details.

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Figure (5) beams rehabilitee.

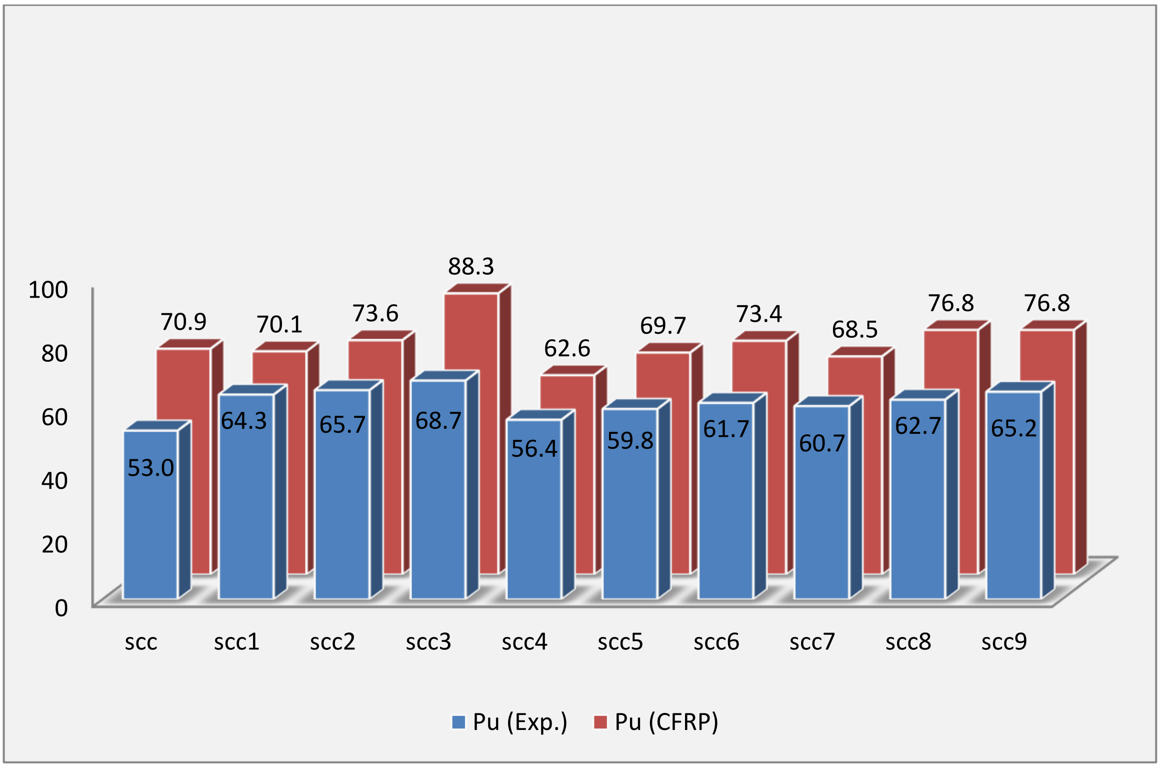

Figure (6) self-compacted and CFRP beams bar chart.

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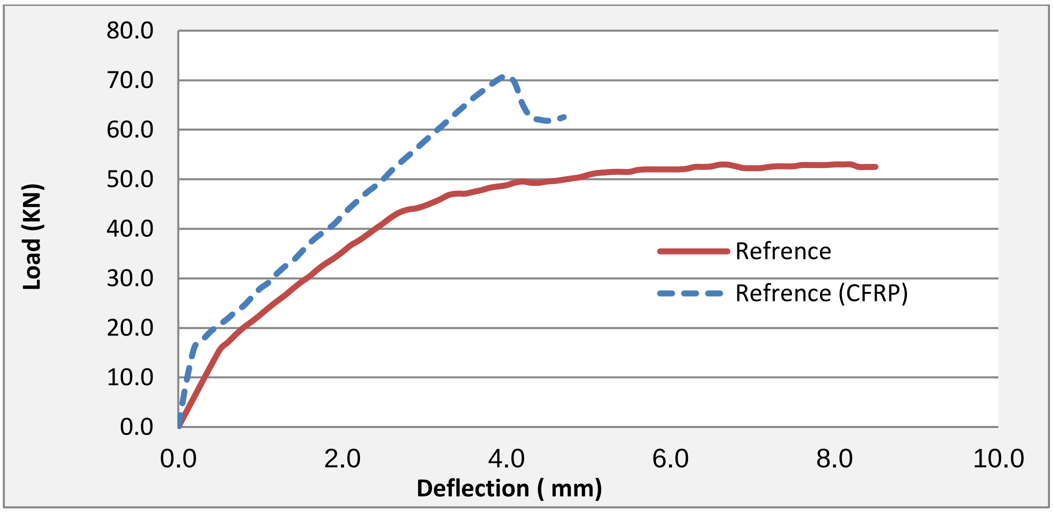
Table (8) ultimate load & CFRP ultimate load for different volume fraction ratios.

Percent of increase %	Ultimate Load(CFRP) (kN)	Ultimate Load(EXP.) (kN)	Fibers percentage NF%	SF%	V_f %	Mix No.	Group No.
33.8	70.9	53	0	0	0	Scc	Ref
9	70.1	64.3	0	100	0.2	Scc1	G1
12	73.6	65.7	0	100	0.3	Scc2	
28.5	88.3	68.7	0	100	0.4	Scc3	
11	62.6	56.4	100	0	0.2	Scc4	G2
16.6	69.7	59.8	100	0	0.3	Scc5	
19	73.4	61.7	100	0	0.4	Scc6	
12.9	68.5	60.7	50	50	0.2	Scc7	G3
22.5	76.8	62.7	50	50	0.3	Scc8	
17.8	76.8	65.2	50	50	0.4	Scc9	



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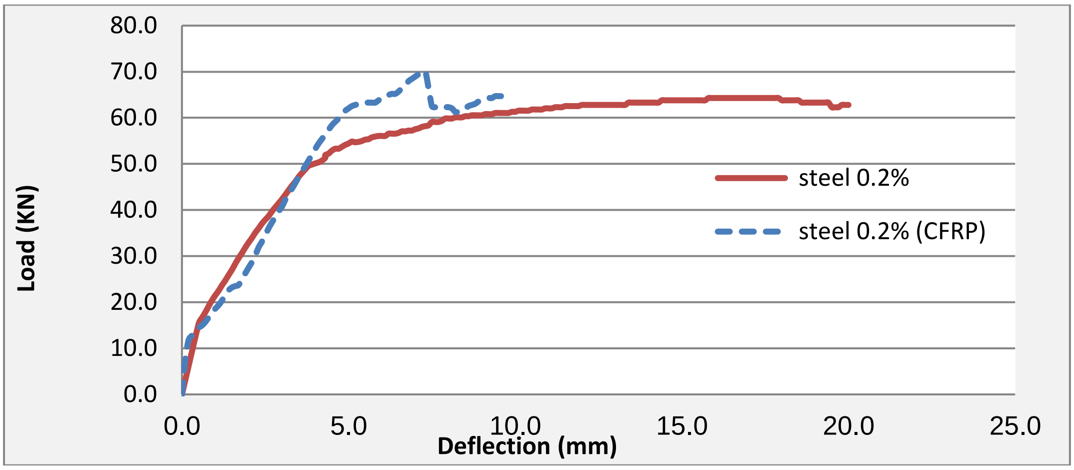

Figure (8) Load-deflection curve for steel 0.2 % and CFRP beam.

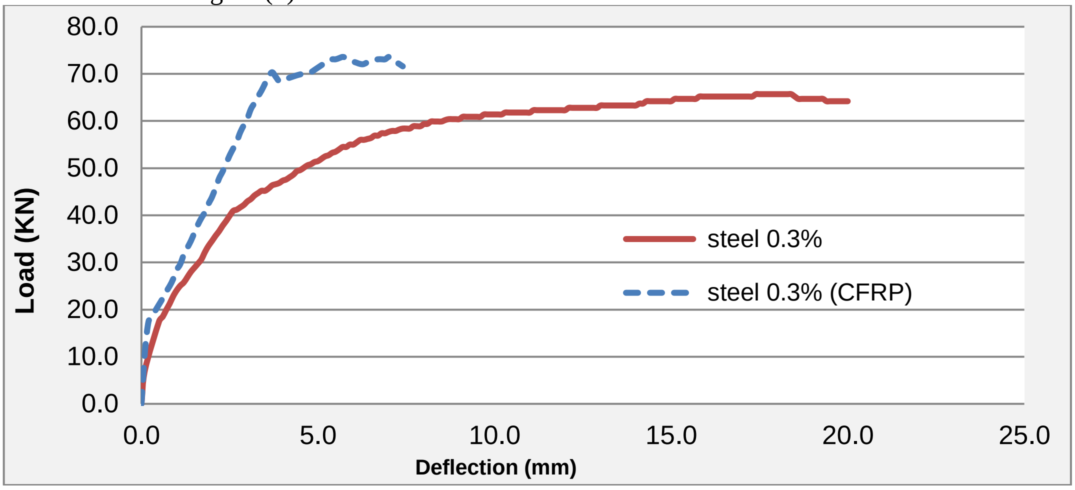

Figure (9) Load-deflection curve for steel 0.3 % and CFRP beam.

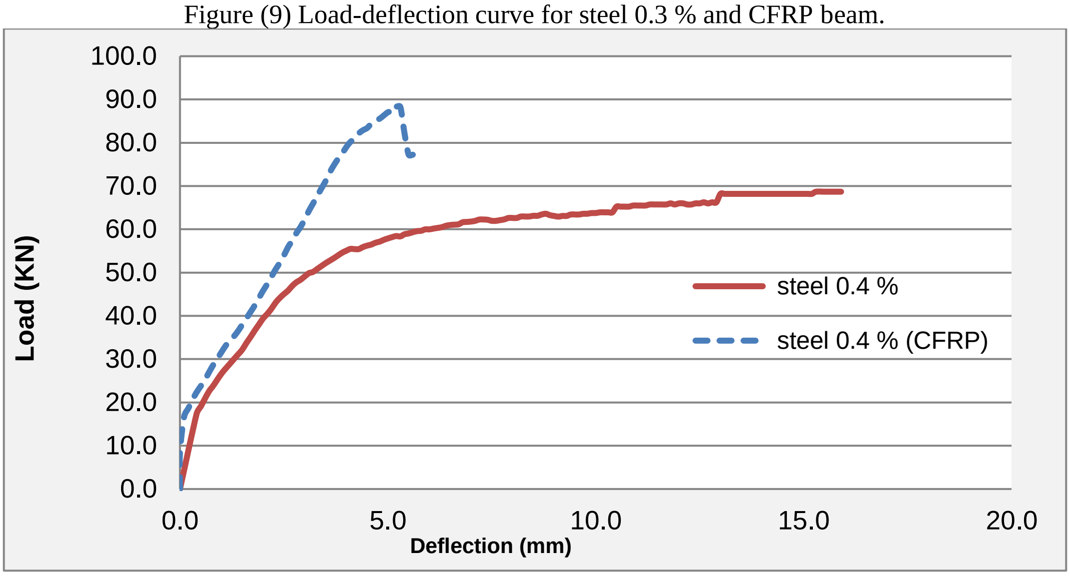

Figure (10) Load-deflection curve for steel 0.4 % and CFRP beam .

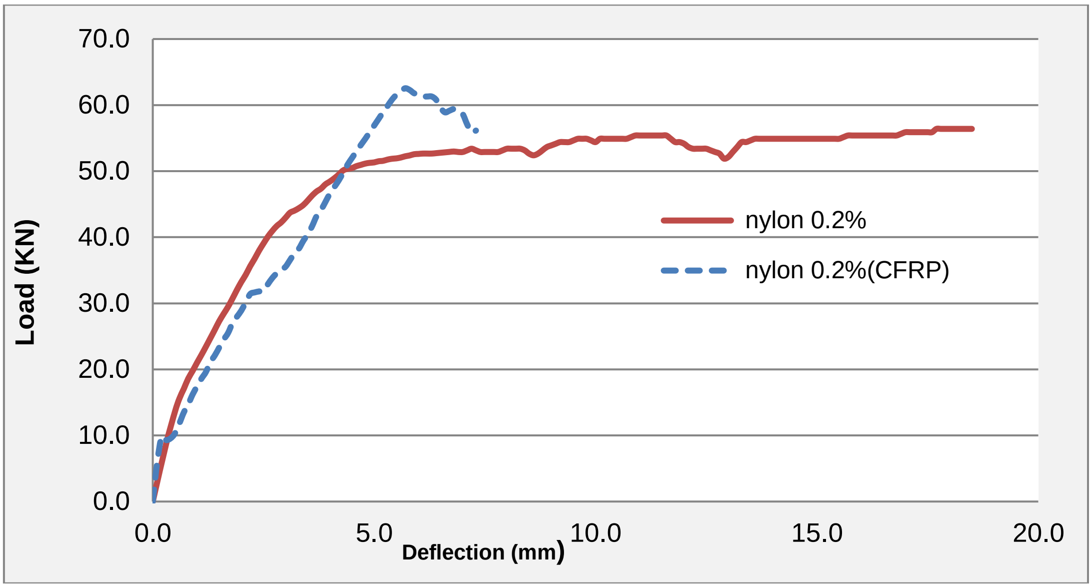

Figure (11) Load-deflection curve for nylon 0.2 % and CFRP beam .

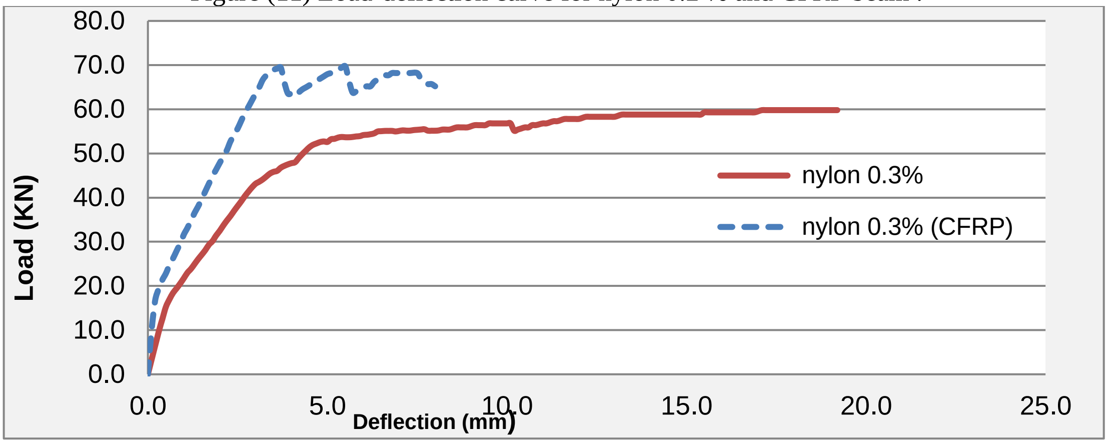

Figure (12) Load-deflection curve for nylon 0.3 % and CFRP beam.

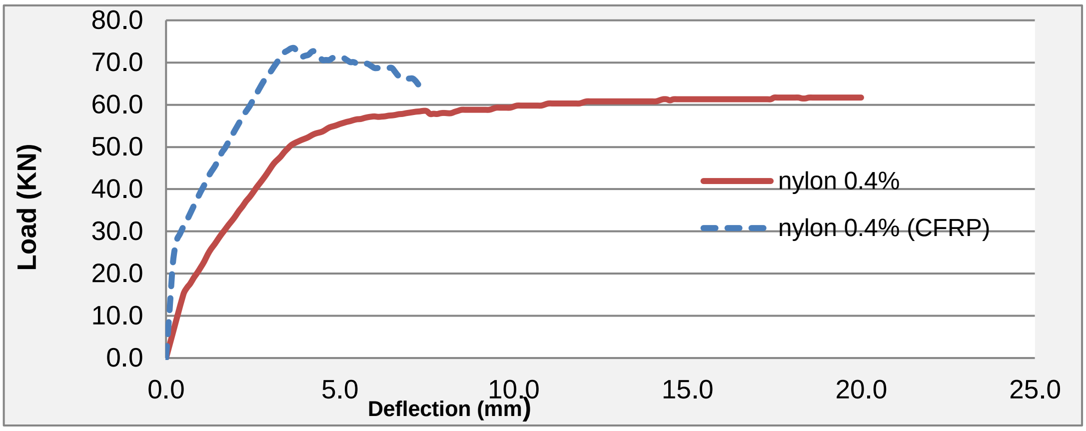

Figure (13) Load-deflection curve for nylon 0.4 % and CFRP beam.

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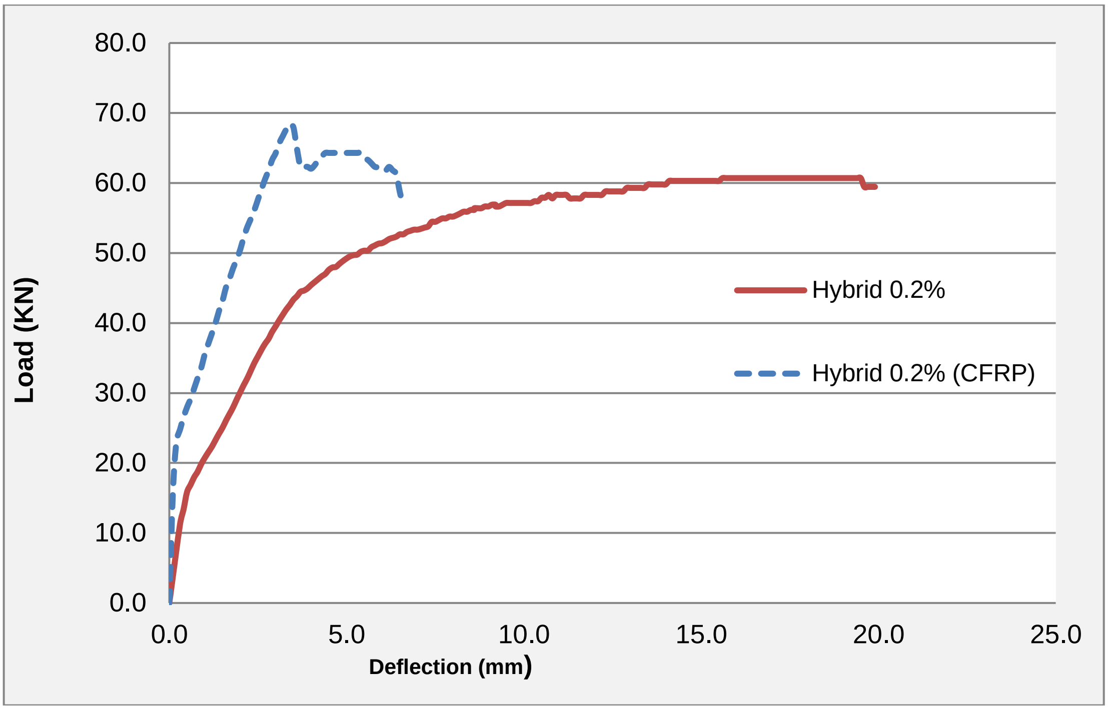

Figure (14) Load-deflection curve for hybrid 0.2 % and CFRP beam .

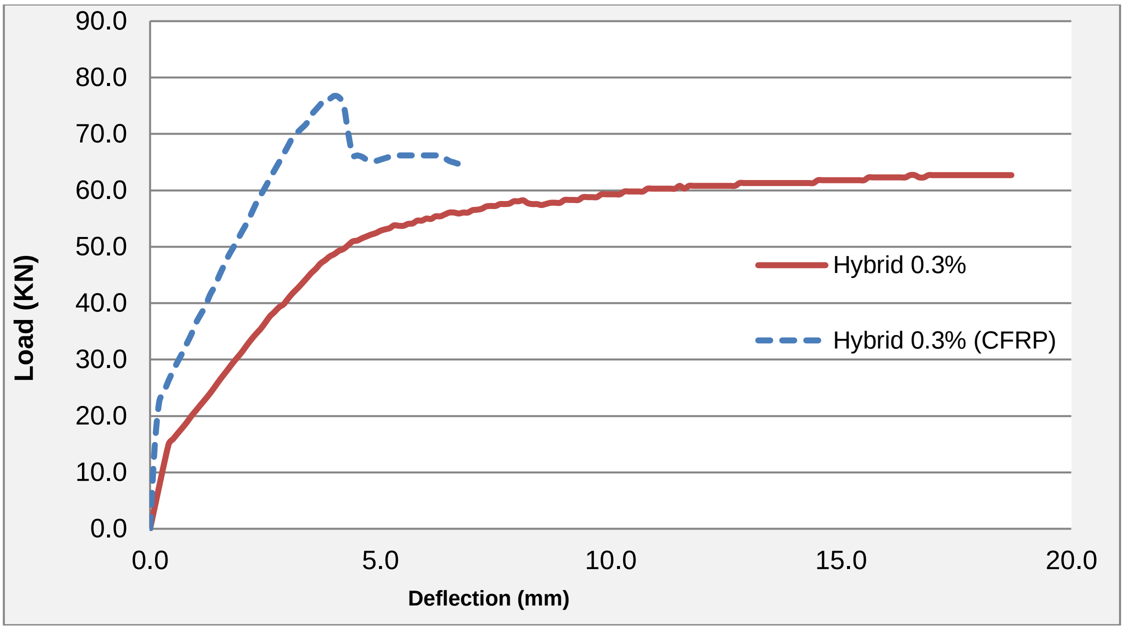

Figure (15) Load-deflection curve for hybrid 0.3 % and CFRP beam .

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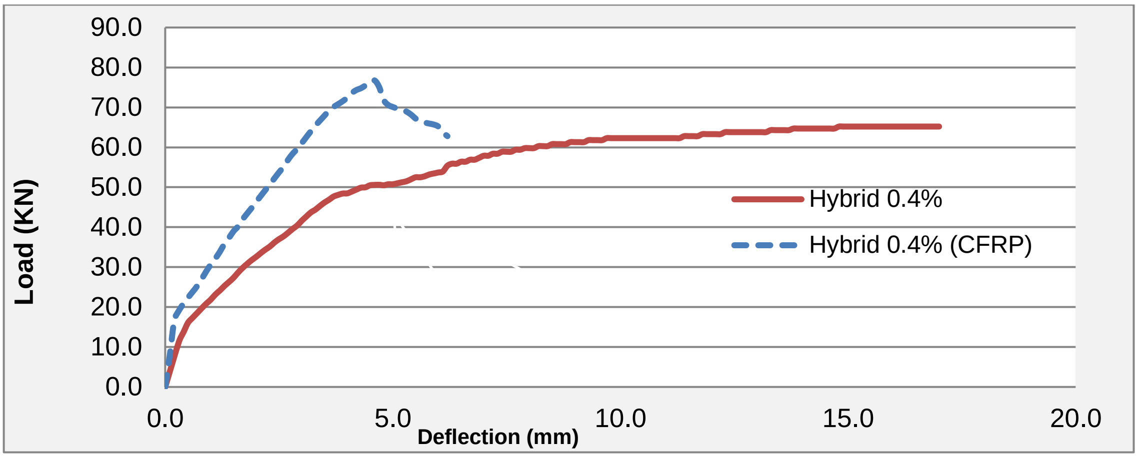

Figure (16) Load-deflection curve for hybrid 0.4 % and CFRP beam.

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