IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 21, Issue 3, Ser. II (May - June 2019), PP 06-16
www.iosrjournals.org

Strengthening of RC Beams Exposed To Shear And Flexure Stresses by Different Methods

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Abstract:- *External steel (EX.steel), steel fiber reinforced concrete (SFRC) and carbon fiber reinforced polymer (CFRP) had been the most common Special methods for strengthening reinforced concrete structures recently. This paper presents experimental investigation for eight beams in two sets each one component of control beam and three beams strengthened by the three different methods without changing its dimensions. The beams were tested under four point loads. Ultimate loads, load-deflection curves, cracking and crushing patterns for strengthening beam had been compared with those of the RC beams without strengthening in shear and flexure stresses. The result showed that beams strengthened using CFRP had increased in load capacity about 24% and 27% in shear and flexure stresses receptivity, while the beams strengthened using SFRC were the lowest and did not achieve the aim of paper.*

Keywords: *-EX.steel, SFRC, CFRP, strengthen beam, load capacity*

Date of Submission: 30-04-2019 Date of acceptance: 14-05-2019

I. Introduction

Strengthening of reinforced concrete (RC) structures is commonly needed due to overloading, corrosion of the steel reinforcement, inadequate maintenance, change in use or in code of practice, and/or exposure to unfavorable conditions like earthquakes and blasts. In the past several decadesmany strengthening techniques have been usedto augment the members in their resistance strength.

Strengthening by external steel is widespread in the field application, laboratory investigation into the performance of this technique started in the 1960s. Since then, considerable experimental work has been reported on the performance of this strengthening technique when employed for strengthening of existing structural beams. However, only limited data has been published on the performance of beams when strengthened by external steel plate and steel angles. It has been reported that the overall response of the strengthened beams was significantly enhanced by using structural steel angles for partially confinement of RC beams [1]. The total capacity was increased compared to the control RC specimen, leading to higher shear and moment resistance in the strengthened specimen. Christopher M. Foley and Evan R. Buckhouse in 1998 used steel channels as an external reinforcing steel to strengthen beams for flexure [2]. They reported that overall, the design methodology proposed for the external reinforcing of existing beams is adequate. Both, strength of the member and stiffness are improved. One deficiency of the reinforced member is lack of ductility at failure. At ultimate load the deflection of strengthened beam reduces as the degree of strengthening increases and correspondingly the ductility of the composite beam reduces [3-4].Using steel plates as an external reinforcement with sound structural design, appropriate detailing, quality of materials and good workmanship will result in high flexure strength and good ductility [5-6]. The flexural strength of cracked beam may be enhanced by 1 to 17% and 70 to 94% depending upon the thickness of external steel plates and welding is a successful technique for attaching the external plates [7-8],while usingSFRCmix design helps to construct high quality concrete structure, improve concrete strength and crack control, effect of fiber distribution on concrete has been investigated[9]and according to current state-of-the-art the volume of addedfibres ranges from 0.5% to 2.5% and the most popular type of engineered steel fibres is the hooked one [10-11]. Addition of steel fiber increases the strength of concreteflexure and shear, the ultimate load andductility increase Compared to control beam[12-13-14],finally CFRPcomposite materials had been experienced a continuousincrease of use in structural strengthening and repairapplications around the worldin the last decade[15],CFRP strengthening provides additional flexural or shear reinforcement, the reliability for this material application depends on how well they are bonded and can transfer stress from the concrete component to CFRP laminate[16] when used carbon fiber sheets to strengthening shear or flexure for beams by different shapes,it wasfound to increase shear and flexure strength and some times change type of failure[17-18-19-20], thebehaviour of CFRP strengthened beams in shear was youngas compared with strengthened beams in flexural. There isno design guideline for optimizing and choosing thethickness of CFRP sheet/laminate for strengthening RCbeams. From the researches conducted on RC beams sections were strengthened in shearwith CFRP with 1, 2 and 3layers of CFRP[21].

II. Test Materials

The following materials had beenselected and tested according tothe Egyptian specifications and standards; the materials used in this study are as follow:

- **Cement** is (CEM I, 52.5N) product by the suez cement factory. Its chemical andphysical characteristics satisfy the requirements of the Egyptian Standard Specifications (E.S.S. 4756-1/2009) [22].
- **Fine aggregate** used in the experimental program is natural siliceous sand. Its characteristics satisfy the requirements of the Egyptian Code of Practice (E.S.S. 1109/2010) [23]. Its physical properties are shown in Table 1. Its grading is shown in Table 2.
- **Coarse aggregate** used is Crushed dolomite , has maximum size 25mm. Its characteristics satisfy the requirements of the Egyptian Code of Practice (E.S.S. 1109/2010) [23]. Its physical properties are shown in Table 3. Its grading is shown in Table 4.
- **Water** Mixing of drinkable clean water, fresh and free from impurities is used for mixing processes of the tested samples according to the (E.C.P. 203/2007)[24].
- **Reinforced stee**l bars high strength steel (steel 52) of (12-10) mm diameter are used as reinforcement in RC beam, (steel 48) of (8-6) mm diameter used as stirrups, (steel 60) steel plate thick 2mm used as strengthened. It meets the requirements of (E.S.S. 262/2011) [25].
- **Addibond 65**is a versatile adhesive with a wide range of applications. It is latex dispersion admixture based on styrene butadiene rubber and is used for improving the properties of cement mortar and concrete, specifically with regards to bond strength to different building materials, and impermeability to water.with meets the requirements of the American Standard (ASTM C631) [26] and the technical specifications of the plant CMBI 2012.Properties for Addibond 65used (as provided by the manufacturer) shown in Table 5.
- **Steel Fibers** had a length (L_f) of 50 mm and a diameter (D_f) of 1 mm. Hence, their aspect ratio was 50. The tensile strength of the fiber was found to be 1225 MPa. Fiber used having hooked-ends. The requirements of the American Standard (ASTM A 820/A 820M-04) [27].
- **Carbon Fiber** manufactured by NCC chemical company were used for flexural and shear strengthening. The mechanical properties of the used CFRP sheets and its epoxy used (as provided by the manufacturer).shown in Table 6.

Concrete Mix was designed to be 30 N/mm2 after 28 days by using (absolute volume method) and according to the requirements Egyptian standard specifications by conducting trial mixes and making suitable adjustments in the mix proportion for good slump and requisite strength, by using cubic of dimention (150 x 150 x 150) and tested after 7and 28 days, the following mix proportion has finally been arrived at as shown in Table 7. The six cubes were casted to ensure from value of the concrete strength and slump. The result of strength value of the concrete after 7 days was 25.5 N/mm2 , 28 days was 31.7 N/mm2 and the slump In concrete was 125 mm.

Table(1) Physical and mechanical properties of the sand used

Property	Value
Specific gravity	2.58
Volume weight (t/m3)	1.73
% Absorption	0.78
%Void ratio	33.8
Fineness modulus	2.72

Table(3) Physical and mechanical properties of the dolomite used

Property	Value
Specific gravity	2.62
Volume weight (t/m3)	1.84
% Absorption	0.74
%Void ratio	31
Fineness modulus	6.48

Table(2) Grading of the sand used according to(E.S.S. 1109/2010)

Sieve size (mm)	4.75	2.36	1.18	0.61	0.31
%Passing used sand	100	94	81	52	5
%Passing (E.S.S. 1109/2010)	95 - 100	80 - 100	75 - 100	55 - 100	5 - 70

Table(4) Grading of the dolomiteused according to(E.S.S. 1109/2010)

Sieve size (mm)	25	19	12.5	9.5
%Passing used sand	100	97	50	5
%Passing (E.S.S. 1109/2010)	100	90 - 100	20 - 55	0 - 10

Table(5) Mechanical properties for Addibond 65used (as provided by the manufacturer)

Material	Density	Solid content	colour
Addibond 65	1.02±0.02kg/L	47±3%	white

Table(6) Mechanical properties for CFRP sheet and its adhesive used (as provided by the manufacturer)

Material	Ultimate tensile strength MPa	Ultimate strain %	Elastic modulus MPa	Compressive strength MPa
CFRP Sheet	4000	2%	240,000	--
Adhesive	45	--	10,000	60

Table(7) Concete mix proportion, kg/m3.

CEMENT (kg/m^3)	Water ($Liter/m^3$)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)
350	120	1200	800

III. Test Specimens

A total two sets of experiments having four concrete beams in each set with cross section 100 * 200 mm, total length 2000mm and effective span 1800mm. The first set to flexure resistance and second to Shear resistance , in each set one control beam and three beams strengthened by EX.steel, SFRC and CFRP.The control beams for flexure set was designed to fail in flexure, while control beams for shear set was designed to fail in shear. Fig(1) and Table (8) illustrates the reinforcement of beams, shape and strengthening method.The beams was tested under the effect of 4 points loading by compression machine, using The electric concrete strain gauge is 60mm long and is of a type(PL-60-11-1L) and A dial gauge was used to measure the defflection in beams. Fig(2) and Fig(3)illustrates locations ofstrain gauge,points loading and dial gauge.

Table(8)details of rienforcement for test specimens and strengthening method

	Beam code	Upper Reinforcement	lower Reinforcement	Stirrups	Strengthening method
Flexure set	**BF0**	2 Ø 8	2 Ø 10	1 Ø 6 /150mm	control beam
	BF1				Beam strengthened by using mix concrete with 1%Steel fiber by weight in flexure area
	BF2				Beam strengthened by welding 2 steel angle (20*2) in flexure area
	BF3				Beam strengthened by using adhesive carbon fiber U-shape in flexure area
shear set	**BS0**	2 Ø 10	2 Ø 12	——	control beam
	BS1				Beam strengthened by using mix concrete with 1%Steel fiber by weight in shear area
	BS2				Beam strengthened by welding U steel plate (10*2) each 250mm in shear area
	BS3				Beam strengthened by using adhesive carbon fiber U-shape in shear area

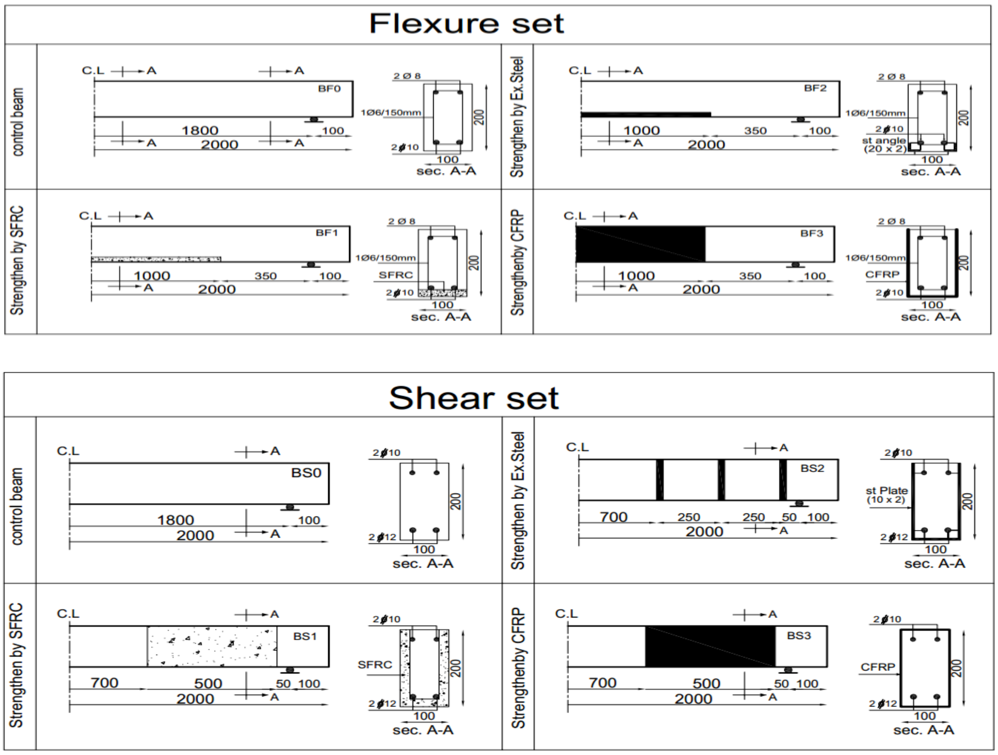
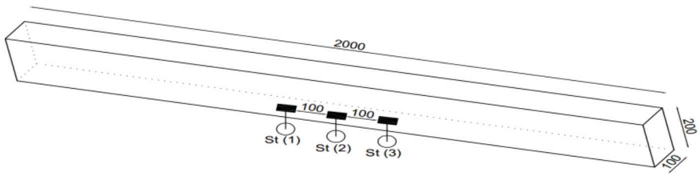
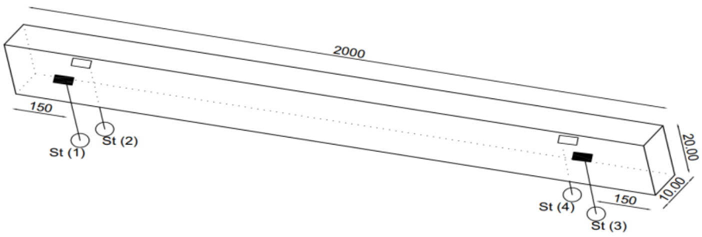


Fig.(1) Long section and cross section for test specimens (all dimention in mm)



locations of concrete strain gauges for flexure set



locations of concrete strain gaugesfor shear set

Fig.(2)sketch illustrates locations of concrete strain gauges

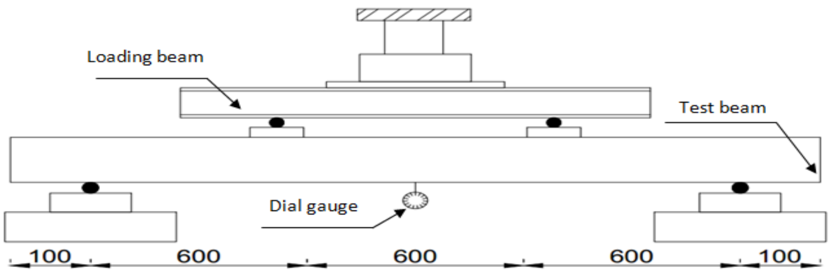


Fig.(3)sketch illustrates locations of points loading and dial gauge (All dimensions in millimeter)

IV. Preparingstrengthen Specimens

The strengthening by using (SFRC) was performed as follows: a groove shape was made for the beam in strengthening zone as shown in fig.(4), preparations the concrete mixture according to the components plus 1% SF from concrete volumeandaddiaddibond 65 with consumption 30 - 40 kg/m2 as shown in fig.(5), and casting new concrete mixture in strengthening zones as shown in fig.(6), while strengthening by using EX.steel(Plate and angles) was performed as follows: welding two angles steel (20*2) for beam strenthening in flexure zone as shown in fig.(7) and welding U-steel plate (10*2) each 250mm for beam strenthening in shear zone as shown in fig.(8) then casing beam, finally strengthening by using (CFRP) was performed as follows: preparing and Cleaning the surface, Painting the beams with primer to make the surface more suitable after about 20 hours as shown in fig.(9), Two components of epoxy are mixed according to recommendations on epoxy data sheet, applied the epoxy on the surface of the beam and CFRP sheets is installed over the concrete surface in the strengthening zones as shown in fig.(10).

Fig.(4) Preparation a groove in strengthening zones

Fig.(5) Concrete mixture with 1%steel fiber

Fig.(6) Casting new concrete mixture in strengthening zones

Fig.(7) Welding steel angle in flexure zone**Fig.(8)**Welding steel plate in flexureg zone

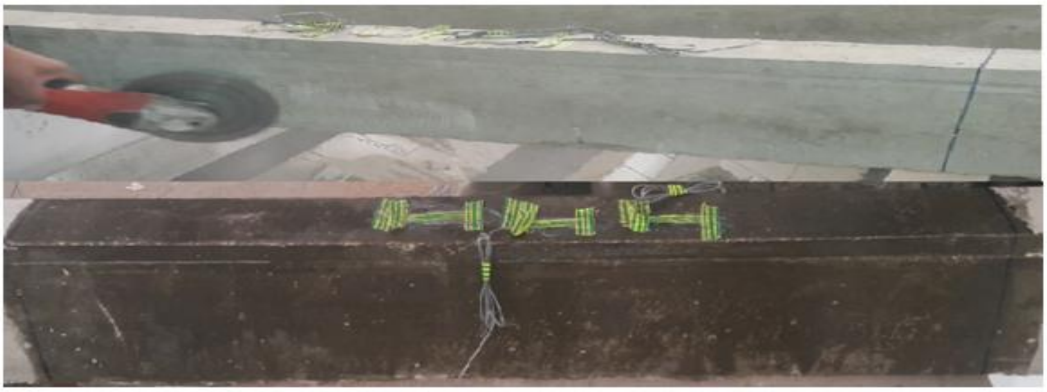


Fig.(9) Smoothing the surface and painting the primer

Fig.(10) Placing carbon fiber in strengthening zones

V. Results and Discussion

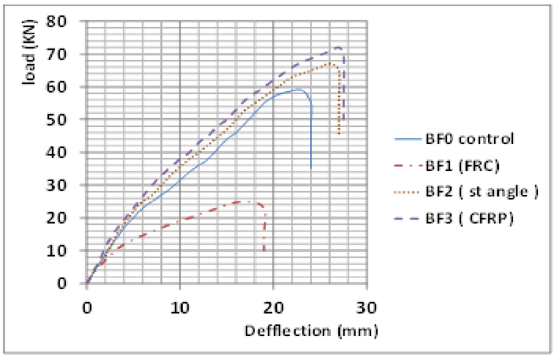
The beams were tested under four point up to failure. The deflection was measured at the bottom of middle span of the beam. Also the strain was measured by adding the strain gauge on strengthening area. the failure modes and the crack patterns occurred for all tested beams had been studied. Table (9) show the cracking, ultimate load (Pcr, Pu), the corresponding deflection at middle span values of tested beams (Δcr, Δu), and failure type . Pu-C is the ultimate load of a control beam, Pu-Str is the ultimate load of strengthened beams, and the ratio Pu-Str / Pu-C is calculated to assess the efficacy of the strengthening method in term of the increased load carrying capacity. Δu-cis the ultimate deflection of a control beam. Δu-str is the ultimate deflection of strengthened beams, andthe deformation capacity was evaluated as the ratio Δu-str / Δu-C.

Table(9) The value of crack and ultimate load , deflection and failure tupe.

Beam	**BF0**	**BF1**	**BF2**	**BF3**	**BS0**	**BS1**	**BS2**	**BS3**
P_{cr} (KN)	23	12	27	37	22	10	25	27
Δ_{cr} (mm)	6	3	8	10	8	4	9	9
P_u (KN)	59	25	67	72	50	37	56	62
Δ_u (mm)	23	19	26	28	20	19	24	27
$P_{u\text{-}Str}$ / $P_{u\text{-}C}$	1	0.74	1.14	1.22	1	.74	1.12	1.24
$\Delta_{u\text{-}str}$ / $\Delta_{u\text{-}C}$	1	0.83	1.13	1.21	1	0.95	1.20	1.35
Failure type	flexure	flexure	shear	shear	shear	shear	shear	shear

5.1Load–deflection curves

The deflection (mm) measured vs load (KN).Fig.(11)shows the load- deflection curves for beams exposed to flexure stress,while fig.(12)shows the load- deflection curves for beams exposed to shear stress. It is observed that use of CFRP allowed more deflection before failure in addition to increasing in the load capacity. The deflection at failure of RC beams strengthened in flexure approximately increased by 13%, and 21% for BF2, and BF3 respectively, decreased by 17% for BF1 than the control beam BF0, In addition, the load capacity for strengthened beams BF2, and BF3 increased by 14%, and 22% respectively, BF1 decreased by 26% than the control beam BF0, while beams strengthened in shear approximately increased by 20%, and 35% for BS2, and BS3 respectively, decreased by 5% for BS1 than the control beam BS0, In addition, the load capacity for strengthened beams BS2, and BS3 increased by 12%, and 24% respectively, BS1 decreased by 26% than the control beam BF0. Also the ductility values for the strengthened beams are less than the control beam. For the initial stiffness, it is observed that all the strengthened beams have approximately the same initial stiffness than the control beam.



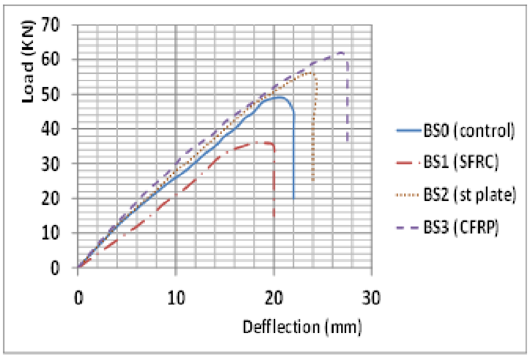
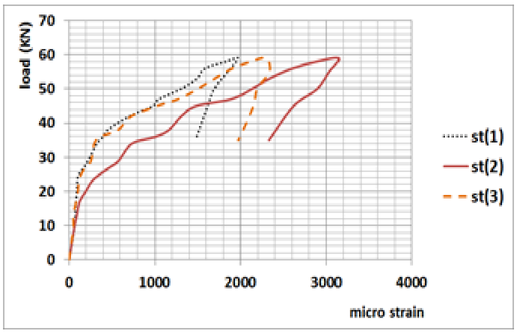


Fig.(11)load-deflection curves for flexure tested beams**Fig.(12)**load-deflection curves for shear tested beams

5.2Load-Strain curves

The strain (mm/m) measured vs load(KN).From fig.(13) tofig.(16)shows the load-strain curves for beams exposed to flexure stress, while from fig.(17) to fig.(20)for beams exposed to shear stress.It was observed that the beam strengthened with CFRP then EX.steel had more strain value than the control beam for beams exposed to flexure , while the beam strengthened with EX.steel then CFRP had more strain value than the control beam for beams exposed to shear stress.



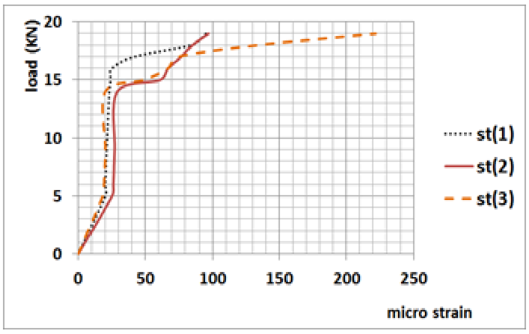
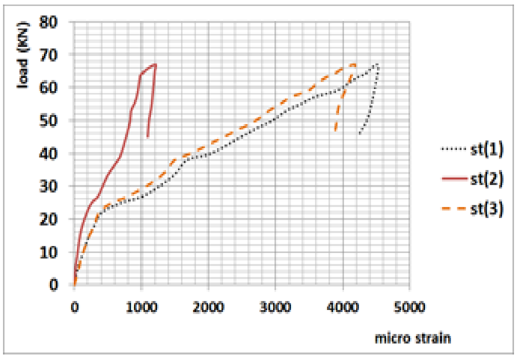


Fig.(13) Load - strain curves for beam (BF0)**Fig.(14)**Load - strain curves for beam (BF1)



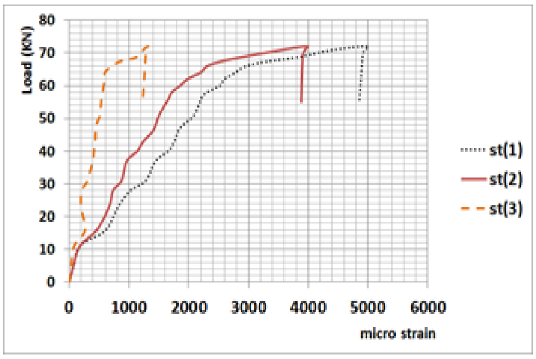


Fig.(15) Load - strain curves for beam (BF2) **Fig.(16)**Load - strain curves for beam (BF3)

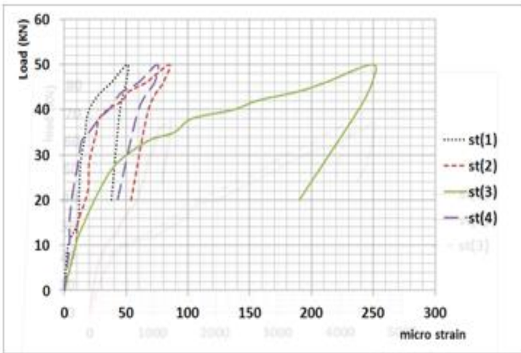


Fig.(17) Load - strain curves for beam (BS0)

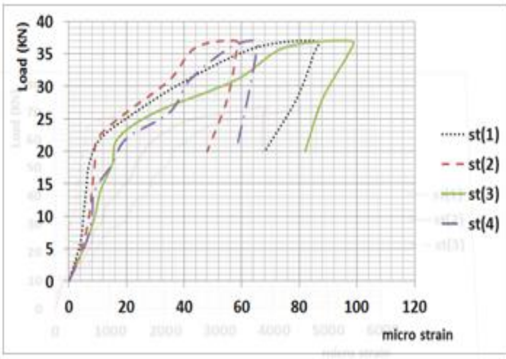


Fig.(18) Load - strain curves for beam (BS1)

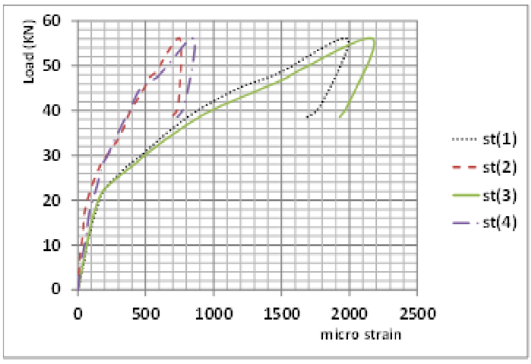


Fig.(19) Load - strain curves for beam (BS2)

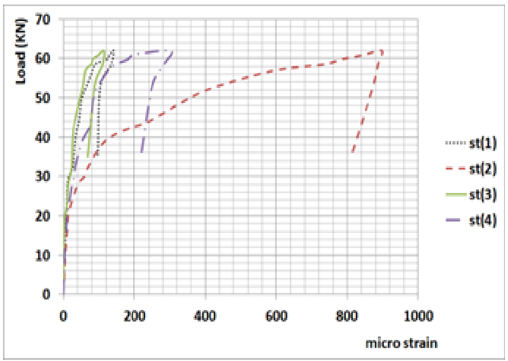


Fig.(12) Load - strain curves for beam (BS3)

5.3Crack pattern and failures modes

From fig.(21) to fig.(24) shows the failure modes and the crack patterns occurred for tested beams exposed to flexure stresses. It is observed that BF0 and BF1 failed by flexure mode, while BF2 and BF3 failed by shear mode. On the othe hand from fig.(25) to fig.(28) shows the failure modes and the crack patterns occurred for tested beams exposed to shear stresses. It is observed that BS0,BS1, BS2 and BS3 failed by Shear mode.

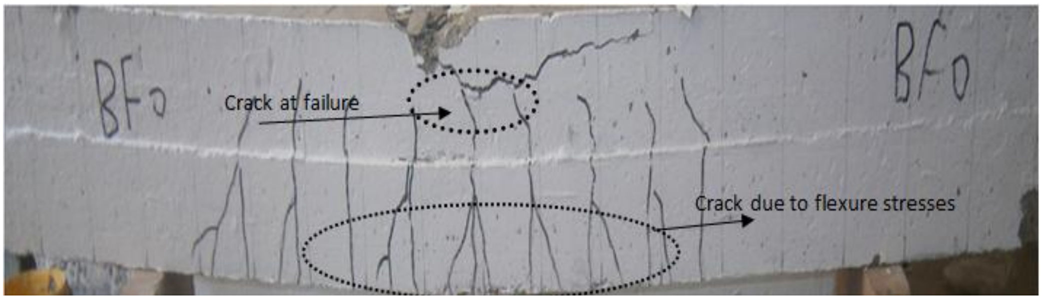


Fig.(21) Crack pattern after failure – BF0

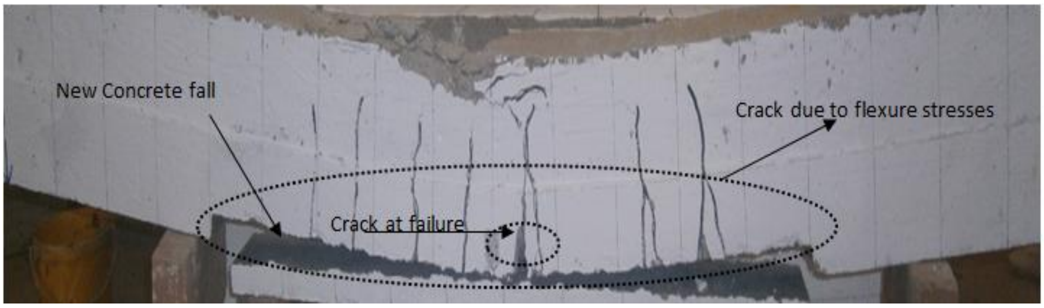


Fig.(22) Crack pattern after failure – BF1

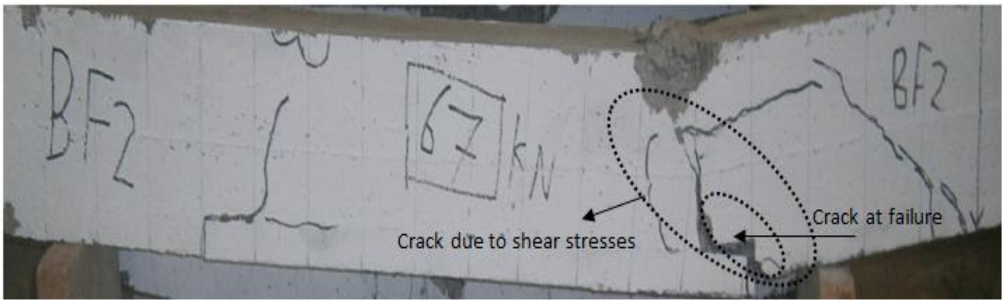


Fig.(23) Crack pattern after failure – BF2

Fig.(24) Crack pattern after failure – BF3

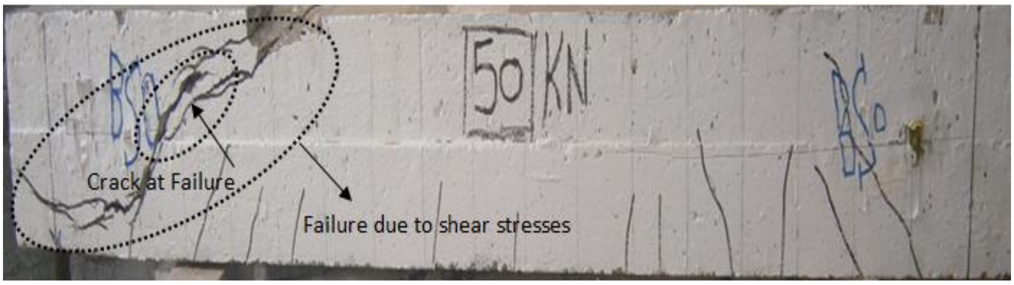


Fig.(25) Crack pattern after failure – BS0

Fig.(26) Crack pattern after failure – BS1

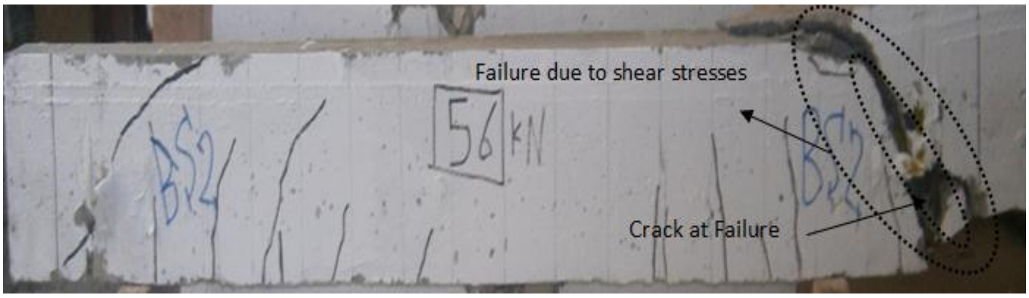


Fig.(27) Crack pattern after failure – BS2

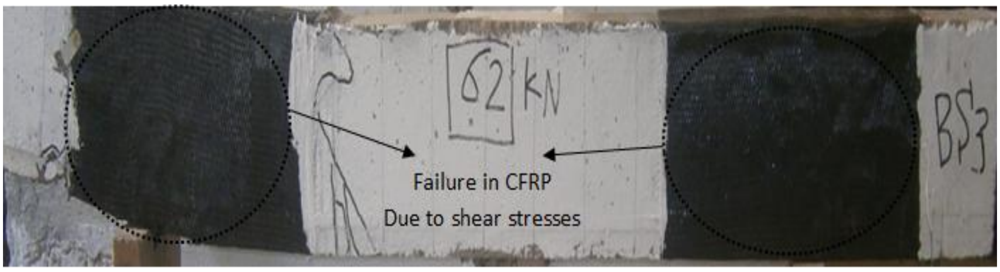


Fig.(28) Crack pattern after failure – BS3

VI. Conclusions

In this paper, the effect of strengthening RC beams by different methods without changing its dimensions has been investigatedexperimentally. Based on the results, the following conclusions can be drawn:

1. Using of SFRP in strengthening beams allowed more deflection before failure in addition to increasing in the load capacity then using of EX.steel.
2. The beams strengthened by CFRP increased load capacity by 24% in shear and 22% in flexure, and The deflection at failure approximately increased by 35% in shear and 21% in flexure than the control beam.
3. The beams strengthened by EX.steel increased load capacity by 12% in shear and 14% in flexure and the deflection at failure approximately increased by 20% in shear and 13% in flexure than the control beam.
4. the beams strengthened by CFRP increased load capacity by 11% in shear and 7% in flexure, whilethe deflection at failure approximately increased by 13% in shear and 8% in flexure than Beams strengthened by EX.steel.
5. The strengthening beams have approximately the same initial stiffness than the control beam, while ductility for strengthened beams are less than the control beam. .
6. The beams which strengthened by CFRP, and EX.steel had more strain value than the control beams in flexure and shear sets.
7. The failure modes for control beam BF0 was flexural failure, when strengthened by CFRP and EX.steel the failure was changed to shear .
8. Strengthening by using SFRC did not achieve the aim of the search.

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IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)is UGC approved Journal with Sl. No. 5019, Journal no. 49102.

Kamal G.Sharobim. "Strengthening Of Rc Beams Exposed To Shear AndFlexure Stresses By Different Methods" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)21.3 (2019): 06-16.