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Flexural behavior of beams reinforced by GFRP bars with CFRP sheets immersed in epoxy as shear

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ABSTRACT

Corrosion in steel bars is considered a big problem because corrosion is mainly responsible of decrease virtual age of structures and many risks indicated by deterioration. In addition, corrosion increases the cost of maintenance, particularly structures exposed to harsh environmental condition. FRP bars (Fiber Reinforced Polymer) became an alternative material from traditional steel bars. FRP had properties made it used in civil engineering sectors which are lightweight, non-corrosive, non-conductive made it a preferred alternative from steel bars in aggressive environments. FRP bars don't have yield made it con not bind outside its linear behavior to make ties, because of the brittle behavior of FRP bars up to failure. So that, the new innovative manner by using CFRP sheets stirrups immerged by sikadur330 for produce beams can resist the harsh condition and purely reinforced with FRP in a new manner can provide stirrups in full different sizes and with lower cost. Twelve beams reinforced with GFRP bars in three different ratios of tension reinforcement (four beams for each ratio). Three control beams with steel stirrups: two beams were designed to fail in shear. Whilst, the residual nine beams with shear reinforcement made from CFRP sheets strips, immerged by sikadur330. The main variable were studied is the change in type and amount of secondary reinforcement and change in amount of primary reinforcement. The test was conduct under four point loading and in simply supported conditions. The result of tested beams illustrated that, beams had a higher percentage of tension reinforcement and shear reinforcement displayed an increasing in ultimate load about 38.1% from related control beam. While, an equivalent amount of shear reinforcement displayed an increasing in carrying load capacity up to 10%. In maximum ratio of CFRP sheets immerged by sikadur330 stirrups convert failure mode from shear to flexural indicated by crushing in cover of concrete. In addition, increased energy absorption, changed cracks orientation, increased energy absorption, decrease principal strain and increased concrete tensile.

1. Introduction

In past, a large amount of research were conducted about flexural and shear behavior on steel reinforcement concrete beams under static and impact loading **(Bentz, 2009; Hassan *et al.*, 2008; Saatci and Vecchio, 2009).** While, the corrosion of steel still the big challenge effect on structures age and decrease the structure ability to resist loads which was designed because of detrition. The Australian Water Industry spend annually huge amount of money about one billion dollars for maintenance according to (**Moore and Emerton, 2010)** because of the corrosion inherent problem. Corrosion in shear reinforcement had further risks because stirrups exposure to environment condition greater than longitudinal reinforcement because it near to cover than flexural reinforcement **(Fakharifar *et al.*, 2016)**. Furthermore, United Stat is spend about 22.6 billion dollars for bridge maintenance as predicted annually coast (**Koch *et al*, 2001)**. At last years, the temperature degree increase in atmosphere and ocean causes an increase in carbon dioxide emission which accelerated the process of corrosion, increase the corrosion cost and the structures life reduced particular in infrastructures and marine structures **(Goldston, 2016)**. To build structures can resist aggressive environment conditions and dominate corrosion in

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infrastructures which increase structures life and more economical to spare the cost of annually maintenance. Fiber reinforcement polymer (FRP) bars are certify material. FRP bars considered a credit material and a necessity for reinforced concrete for overcomes corrosion. FRP bars considered a composite consist of matrix which represent bonder strengthened with fibers. In further details, other formed of fibers currently used in application and projection so known as FRP sheet, used for externally strengthening in case of shrivel strength or corroded members **(Secer *et al.*, 2017)**. The major advantages of use FRP as a material of reinforcement is high tensile strength and non-corroded material which solved the inherent problem in steel reinforcement, in spite of FRP cost higher than steel at first but the reduction in cost of maintenance makes more economically than steel bars. In general, FRP materials separated according to type of fibers, the famous three types of FRP: CFRP (Carbon fiber reinforced polymer), GFRP (Glass fiber reinforced polymer) and AFRP (Aramid fiber reinforced polymer). The type of resin as common resin matrix is epoxy. In addition, FRP properties such as light weight about 1/6 to 1/4 from weight of steel, make it easy to handle and to reduce structure's weight. On disadvantage term of FRP, the linear elastic behavior without any warning up to failure causes risks because no plastic behavior before failure. So that, all member designed with FRP bars should be over reinforcement to show some plastic behavior before failure by crushing in concrete. Furthermore, suffered in serviceability conditions, deflection and deformability because the modulus of elasticity is lower than steel except CFRP had modulus of elasticity higher than steel.

At last years, a lot of researches were carried out to check the validity of use FRP as reinforcement. **(Alsayed, 1998)** experimentally investigated under four point loading the flexural behavior of twelve beams. These beams were divided into four groups according to the materials properties with concrete compressive strength vary from 31 MPa to 41 MPa. Group A represent controlled spacemen contain three beams reinforced with steel bars designed to fail by steel yielding. While, groups B, C and D reinforced with GFRP (Glass Fiber Reinforced Polymer) bars and designed to be over reinforcement and to carry the same flexural capacity of group A. The result showed that load-deflection calculated from "Building Code Requirements for Reinforced Concrete and Commentary" ACI (1995) compared with experimental test errors upshots to 70%. For decrease this error parentage, Alsayed (1998) proposed different cases of FRP reinforcement govern different mode of failure and different scenarios. Experimental results gave indicated view that FRP reinforcement consider good alternative material reinforcement. Load-deflection behavior of FRP beams showed bi-linear response until failure govern by crushing in concrete which consider ductile failure. In the other hand, reference beams as prospective fail by yielding steel at first, followed concrete crushing. (**Kaszubska *et al.*, 2017)** studied the effect of the change in percentage of longitudinal reinforcement and their distribution in the height of beams (multi-layer of longitudinal reinforcement) in enhancement shear strength and showed the change in crack pattern. Beams have been designed without stirrups to demonstrate the difference in one and two layer of longitudinal reinforcement in shear strength . Test were conducted under three point loading. Test results proved that using two layers of longitudinal reinforcement with a ratio of 1.8% gave increase in shear resistance up to 28% and a more extensive crack pattern than that for one layer of longitudinal reinforcement. Also, Number of cracks depend on number of bars for the same ratio of longitudinal reinforcement as well as number of layers. Angle of shear failure in all beams ranged from 35^o to 50^o. While **(Shehata *et al*, 2000)** investigated ten reinforced concrete T-beams under four point loading. All beams designed to fail with shear, eight beams with tension reinforcement of steel bars and two beams reinforced with CFRP strands as tension reinforcement. Four beams reinforced with CFRP stirrups, four beams with GFRP stirrups, one beam with steel stirrups and the lasts beam without shear reinforcement. The main variables were the type of tension reinforcement, stirrups spacing and the materials properties. Test result showed all beams failed in shear before rupture in FRP or yield steel in tension reinforcement. For eight beams with FRP stirrups, six beams failed by shear observed by FRP stirrups rupture, while the remain two beams failed by crushing in concrete at the shear span zone. The main objective from this research is to produce new method for design shear reinforcement by using CFRP sheets to overcome the problem of corrosion. In addition, produce stirrups from CFRP sheets at the jobsite to produce structures can resist aggressive environment.

2. Experimental Program

2.1. Materials

2.1.1Cement

Ordinary Portland cement was used in the present study, which produced by Al-Mass factory in north of Iraq, which corresponding to the Iraq specification (IQS NO, 1984). The physical properties are present in Table (1) and chemical analysis for cement are provided in Table (2) were compared with related specification.

Table 1 Physical properties of cement

Type of test	Property	Iraqi specification limit I.Q.S 5/1984
Initial setting time (minutes)	194 min	No less than 45 min
Final setting time (minutes)	245 min	Not more than 600 min
Fineness (cm2/g) by Blaine method	2600	Not less than 2500
Compressive strength at 3 days in MPa	16	Not less than 15
Compressive strength at 7 days (MPa)	28	Not less than 23

Table 2 chemical analysis of cement

Oxides	Percentage by weight	Limitation of Iraqi specification IQS 5/1984
Cao	66.26	-----
Fe2O3	3.73	-----
SiO2	19.11	-----
Al2O3	6.42	-----
MgO	1.45	Not more than 5%
SO3	1.85	Not more than 2.5%
Lime saturation factor	0.91	0.66-1.02
Loss on ignition	2.2	Not more than 4%
Insoluble residue	0.96	Not more than 1.5%
The main components		
C3A	2.9	Less than 3.5%
C2S	8.52	-----
C3S	61.8	-----
C4AF	7.07	-----

2.1.2 Sand

Round and smooth surface sand used in concrete with fineness modulus of 2.65 from Al-Hassow in Anbar as provided by Table (3). This sand was identical to Iraqi specifications (NO.45-1984) with percentage of clay less than 2% less than 3% which the percentage specified by Iraqi specifications.

Table 3 Sieve analysis for sand

NO	Sieve size in mm	Cumulative passing %	Limit of Iraqi specifications NO.45-1984
1	10	100	100
2	4.75	93	100-90
3	2.36	71	95-60
4	1.18	52	70-30
5	0.6	30	34-15
6	0.3	13	20-5
7	0.15	3	10-0

2.1.3 Coarse Aggregate

Refined crushed coarse aggregate were used in mix of concrete with a maximum size of aggregate 10 mm and with nearly rounded shape. Table (4) provided the coarse aggregate sieve analysis and Iraqi specifications with grading (5-10) mm.

Table 4 Grading for coarse aggregate

Sieve size in mm	Limit of Iraqi specifications NO.45-1984	Cumulative passing %
14	100	100
10	100-90	100
7	90-50	60
5	0-10	0

2.1.4 Water

Ordinary water valid to drink is use in concrete mixtures and curing.

2.1.5 GFRP bars

GFRP bars with warped and sand coated manufacturing surface to provide good bond between concrete and GFRP bars were used as primary reinforcement with diameter 12.61 mm. Figure (1) show the stress-strain diagram for GFRP bar which conduct at Ministry of Science and Technology corresponding to ASTM D 7205/7205M specification.

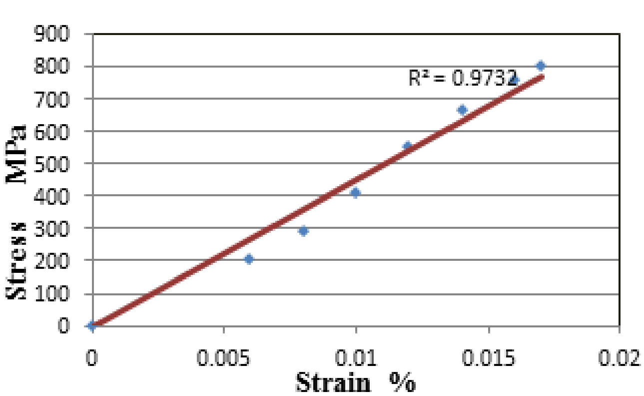

Figure 1 Stress-Strain diagram for tested GFRP bars

2.1.6 Steel Reinforcement

Smooth steel bars with a diameter of 6 mm were used as secondary reinforcement in reference beams (stirrups) which tested according to ASTM A615(2003). The test conducted in laboratory at the university of Anbar the in department of Civil Engineering, the result of test is shown in Table (5).

Table 5 Details of steel bars tensile test

Samples	Yield stress MPa	Average Yield stress MPa	Ultimate Stress MPa	Average Ultimate stress MPa
Sample 1	380	382	451	458
Sample 2	384		465	

2.1.7 CFRP sheets immersed by sikadur330 tensile strength

SikaWarped-300C immerged by sikadur300 were used as stirrups instead of steel stirrups to check the validity of use CFRP sheets as stirrups. The test was achieved at Ministry of Science and Technology according to ASTM D3039 to calculate tensile strength and test outcome were available at Table (6).

Table 6 Test results of CFRP sheets immerged sikadur330

Samples	**Yield stress MPa**	**Average Yield stress MPa**	**Ultimate stress MPa**	**Average Ultimate stress MPa**
1	380	382	451	458
2	384		465	

2.2 Reinforcement details

To study shear and flexural behavior in a precisely manner and try to find percentage of shear reinforcement which convert failure from shear to flexural, all beams designed overly reinforcement to fail with crushing in concrete cover having some ductility before failure. Three ratios 0.005, 0.01 and 0.015 of longitudinal reinforcement with four beams for each ratio reinforced with GFRP bars as tension reinforcement and different types and amount of stirrups.

Three beams as reference with steel reinforcement and designed to fail by shear (for longitudinal reinforcement 0.01 and 0.015) and flexural (for 0.005 longitudinal reinforcement) are shown in Figure (2). The other nine beams (three beams for each ratio of longitudinal reinforcement) reinforced by CFRP sheets stirrups immerged by sikadur330 with different configurations.

For each ratio had shear reinforcement by one layer CFRP sheets with spacing 140 mm, two layer CFRP sheets with spacing 140 mm and the last beam with two layers of CFRP sheets and spacing 90 mm as shown in Figure (3). Table (7) provided the further details for all beams.

- First group

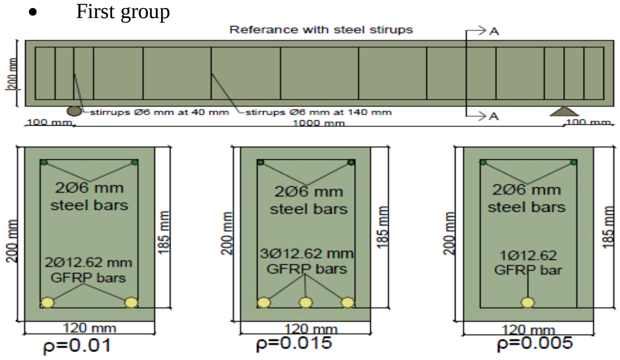

Figure 2 (a) and (b) Reinforcement details and beam dimension for first group (b) Cross section A__A

- Second group (beams with CFRP sheets immerged by sikadur330 stirrups)

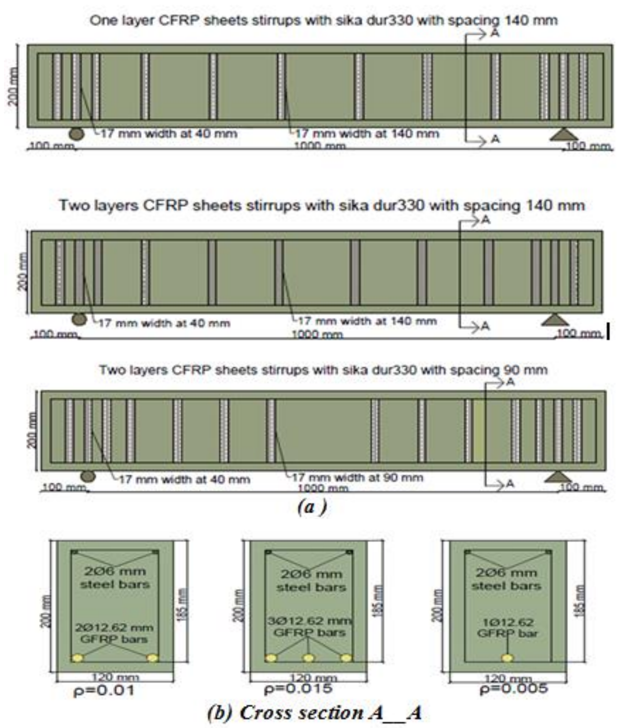

Figure 3(a) and (b) Beam dimension and reinforcement details for second groups

The casting was conducted with concrete compressive strength 36.41 MPa at 28 days. The reinforcement details started by making strips with 17 mm width and 620 mm length from CFRP sheets. After that, this strip immerged by sikadur330 as shown in Figure (4) and placed to longitudinal reinforcement in the form of stirrups by supporting it by string at longitudinal reinforcement as shown in Figure with overlap length 120 mm as shown in Figure (5).

Table 7 Description of beams

Specimen name	Maim Long. Reinf.	Type of tie reinforcement	Number of layers	Spacing between stirrups
Reference beams with steel shear reinforcement				
1B-S-140	ρ=0.005	Steel	------------	140 mm
2B-S-140	ρ=0.01	Steel	------------	140 mm
3B-S-140	ρ=0.015	Steel	------------	140 mm
Nine beams with shear reinforcement made of CFRP sheets with sikadur330				
1B-F-1L.E-140	ρ=0.005	CFRP with sikadur330	One layer	140 mm
1B-F-2L.E-140	ρ=0.005	CFRP with sikadur330	Two layers	140mm
1B-F-2L.E-90	ρ=0.005	CFRP with sikadur330	Two layers	90 mm
2B-F-1L.E-140	ρ=0.01	CFRP with sikadur330	One layer	140 mm
2B-F-2L.E-140	ρ=0.01	CFRP with sikadur330	Two layers	140 mm
2B-F-2L.E-90	ρ=0.01	CFRP with sikadur330	Two layers	90 mm
3B-F-1L.E-140	ρ=0.015	CFRP with sikadur330	One layer	140 mm
3B-F-2L.E-140	ρ=0.015	CFRP with sikadur330	Two layers	140 mm
3B-F-2L.E-90	ρ=0.015	CFRP with sikadur330	Two layers	90 mm

Figure 4 The steps of preparing stirrups with CFRP sheets

Figure 5 Beams reinforced with CFRP sheets immerged by sikadur330

3. Load Deflection Response

3.1 Load deflection curve for reference beams with different longitudinal reinforcement

Figure (6) shows the load deflection scheme for three controlled beams at mid-span. A bi-linear response scheme for 1B-S-140 beams load-deflection. Furthermore, suffered more deflection corresponding to lower bending stiffness which provided by longitudinal reinforcement. A crush point made beam suffered further deflection produced a bi-linear scheme. While, 2B-S-140 and 3B-S-140 showed a linear response governed by shear failure before crushing in concrete cover. That failure related to insufficient shear reinforcement. 3B-S-140 showed a more stiffer than 2B-S-140 because have higher bending stiffness than 2B-S-140. Bending stiffness is related directly to longitudinal reinforcement.
Equations and formulae should be typed in Mathtype, and numbered consecutively on the right hand side of the page. They should also be separated from the surrounding text by one space.

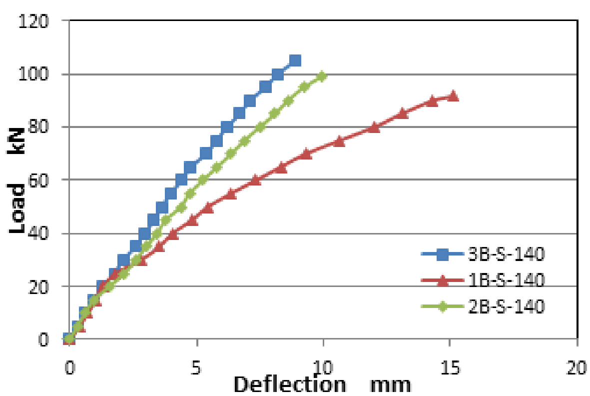

Figure 6 Load-deflection response scheme for control beams

3.2 Beams reinforced by different ratios CFRP sheets immersed by sikadur330 and constant main reinforcement

Figures (7-9) showed the effect of change in shear reinforcement on load-deflection scheme at mid span with constant longitudinal main reinforcement. Stiffness differ from each beams corresponding to shear reinforcement at constant tension reinforcement. At first, start description with beam had longitudinal reinforcement □= 0.01. 2B-F-1L.E-140 and 2B-F-2L.E-140 undergo more deflection with load increasing than 2B-F-2L.E-90 as shown in Figure (7). This response resulted confinement provided by stirrups made concrete can carry additional load before total failure and braced diagonal tension which caused shear failure. Regardless of longitudinal reinforcement, the type of failure is directly related to spacing and area of shear reinforcement. While, CFRP sheets stirrups undergone lower strain if decrease spacing and as a total result decrease deflection because of the strain in CFRP sheets stirrups held deflection and these interpretations was purely showed in beam like 2B-F-2L.E-140. The same interpretations are valid for beams with longitudinal reinforcement □= 0.015 as shown in Figure (8). While, beams with longitudinal reinforcement □= 0.005 failed by flexural and without any obvious difference in stiffness (simple effect) because the failure was governed by crushing in concrete cover resulted from was a sufficient amount of shear reinforcement prevent shear failure as shown in Figure (9) .

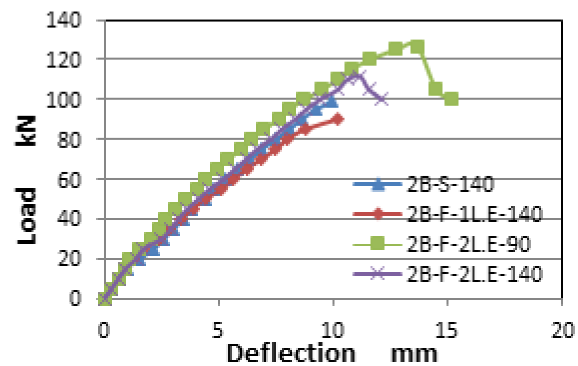

Figure 7 Load- deflection relation for beams with different amount of shear reinforcement with ρ=0.01

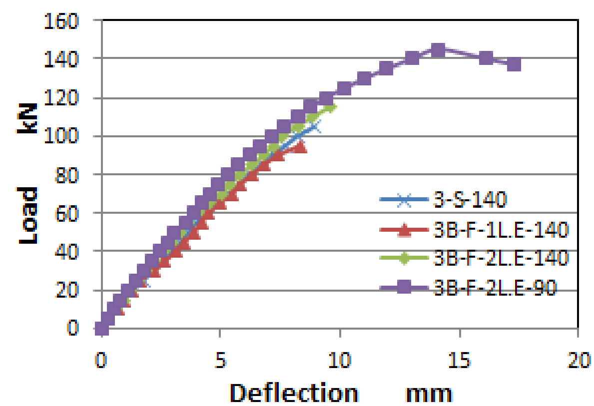

Figure 8 Load- deflection relation for beams with different amount of shear reinforcement with ρ=0.015

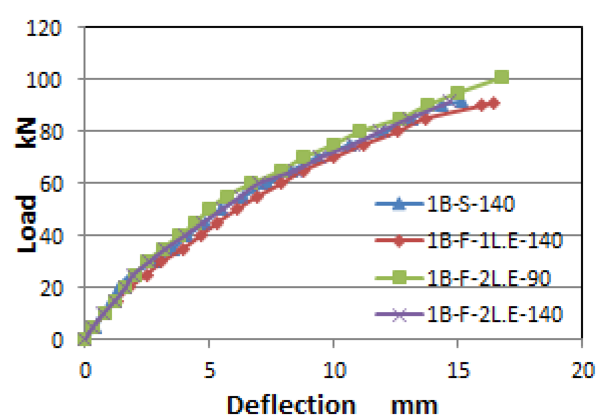

Figure 9 Load- deflection relation for beams with different amount of shear reinforcement with ρ=0.005

4. Load-tension strain

Figure (10) shows the load-micro tension strain curves at the level of GFRP bars for beams with CFRP sheets immerged by sikadur330. The strain was calculated by uniaxial 30 mm strain sensor produced by TML. From Figure (10), strain in concrete at the level of GFRP bars is directly affected by the type and amount of shear reinforcement. It can be observed that; strain increase if shear reinforcement increase or decreasing in amount of flexural reinforcement. As a reference point, strain in controlled beams used to calculate the effect of change in type of reinforcement and amount of shear reinforcement. The tension concrete strain at failure stage in controls beams 1B-S-140, 2B-S-140 and 3B-S-140 was 1820, 1666 and 982 micro strain respectively.

From the same Figure, by support amount of flexural reinforcement, it is obvious that for all beams in first groups (beams with CFRP immerged by sikadur330 stirrups) strain increase with shear reinforcement increase because the confinement provided by stirrups prevent shear failure and reduce cracks made concrete can carry compressive strain at shear span. Cracks at shear span causes compression strain at tension zone causing some negative recorded readings. 3B-F-2L.E-90 beam strain was increased to 28119 micro strain, while beam 2B-F-2L.E-90 suffered strain about 10380 micro strain. Furthermore, beam 1B-F-2L.E-90 beam strain were 2240 micro strain.

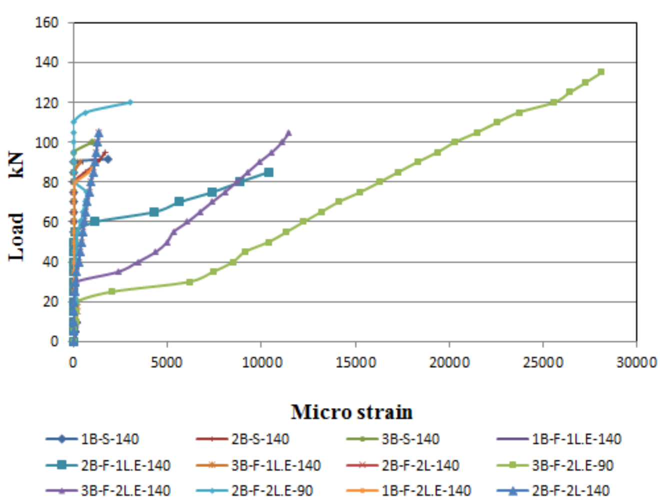

Figure 10 Load-micro strain scheme at the level of GFRP bar for beams had stirrups CFRP sheets

5. Validity of ACI440-IR-15 and CSA(2012) Concrete Shear Strength for New Alternative Ways

Table (8) provided the load required to failure in case of shear or flexure by use ACI440-1R-15 and CSA (2012) for calculating load at the failure stage for referenced beams were calculated at appendix B. In further details, the two design codes showed excellent agreement between experimental and predicted load specially with beams failed by shear failure.

Table 8 Experimental and calculated results for control beams

Beam	Experimental failure load Pu in kN	ACI 2015 Pn in kN	CSA 2012 Pn in kN	(Pn)ACI/Pu	(Pn)CSA/Pu
1B-S-140	91.7	84	87	0.916	0.95
2B-S-140	98.8	99	96.72	1	0.98
3B-S-140	105	106	105.364	1	1

For other nine beams, calculated by new alternative equation for two codes and compared with experimental results as provided in Table (9). This equation used for calculating the load required to failure. Beams with CFRP immerged by sikadur330 sheets stirrups showed good agreement between experimental and predicted load provided by new way and concrete shear strength provided by these codes and compression study showed that proposed equation is over estimated load.

Table 9 Validity of the proposed equation into ACI and CSA compared with experimental study

Beam	Experimental failure load Pu in kN	ACI 2015 Pn in kN	CSA 2012 Pn in kN	(Pn)ACI/Pu	(Pn)CSA/Pu
1B-F-1L.E-140	91.1	84	87	1.08	1.047
1B-F-2L.E-140	91.5	84	87	1.09	1.05
1B-F-2L.E-90	100.9	84	87	1.2	1.16
2B-F-1L.E-140	90	97	95.8	0.93	0.94
2B-F-2L.E-140	111.6	110.5	109.35	1.009	1.02
2B-F-2L.E-90	127	112	114	1.13	1.11
3B-F-1L.E-140	95	106	103	0.89	0.922
3B-F-2L.E-140	115	118	116	0.975	0.992
3B-F-2L.E-90	145	132	135	1.098	1.07
Average				1.045	1.035
Standard divergence				0.10	0.076412
Variance				0.01	0.00583

6. Crack Patterns and Mode of Failures

The innovative way to make stirrups showed good validity by converting mode of failure from shear to flexural and good convergence between modified predicted equation. While loading the beams, first crack was initiated between two point loading at the bottom surface in all beams. When the load increase, further cracks were developed and the old cracks have been growing and turn to move upwards and its width was increased. Overall, crack width and crack pattern was mainly select the failure mode if shear or flexural which corresponding to amount of shear reinforcement. In further details: Control beams 3B-S-140 and 2B-S-140 was failed by yielding the steel stirrups followed rapture in stirrups at 180 mm from support (shear span). Sudden failure indicated by quick cracks development at shear and growth in their widths as shown in Figures (11) and (12). While, 1B-S-140 beam was failed by crushing concrete at cover indicated by flexural behavior of failure explained by widening cracks in the area between two point load as shown in Figure (13).

The beams 1B-F-2L.E-140, 1B-F-2L.E-90 and 1B-F-1L.E-140 was failed by crushing at the concrete cover enhanced by extensive cracks and first crack showed more widening at bending span as illustrated in Figures (14, 15, and 16).

Beams 2B-F-2L.E-140 and 2B-F-1L.E-140 failed in shear indicated by the rupture in CFRP sheets stirrups immerged with sikadur330 and developed an extensive cracks in shear span lead to shear failure. In addition, shear cracks orientations ware held by angle ranged from 40 to 50 from the longitudinal axis as shown in Figures (17 and 18). Whilst , beam 2B-F-2L.E-90 was failed in flexural explained by crushing at cover of concrete and showed further cracks which distributed along beam span as shown in Figure (19).

Beams 3B-F-1L.E-140 and 3B-F-2L.E-140 failed in shear indicated by the rupture in CFRP sheets stirrups immerged with sikadur330 and developed an extensive cracks in shear span lead to shear failure. In addition, shear cracks orientations were held by angle ranged from 40 to 50 from the longitudinal axis as shown in Figures (20 and 21). whilst , beam 2B-F-2L.E-90 was failed in flexural explained by crushing at cover of concrete and showed further cracks which distributed along beam span as shown in Figure (22).

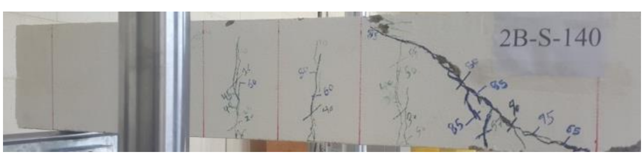

Figure 11 Cracks patterns of beam 2B-S-140

Figure 12 Cracks patterns of beam 3B-S-140

Figure 13 Cracks patterns of beam 1B-S-140

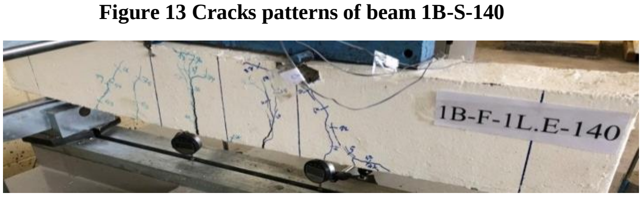

Figure 14 Cracks patterns of beam 1B-F-1L.E-140

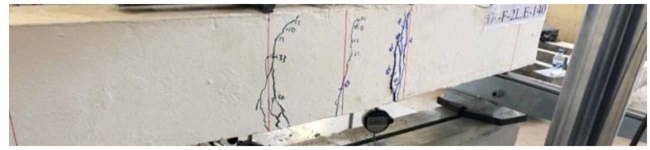

Figure 15 Cracks patterns of beam 1B-F-2L.E-140

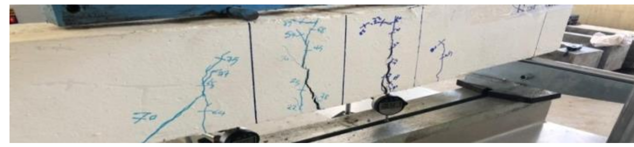

Figure 16 Cracks patterns of beam 1B-F-2L.E-90

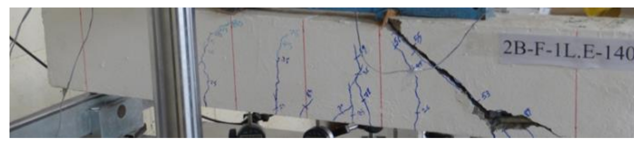

Figure 17 Cracks pattern of beam 2B-F-1L.E-140

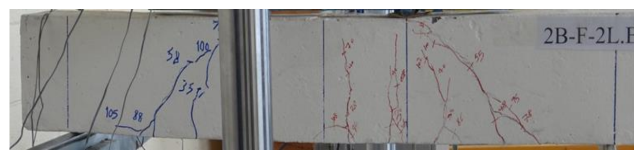

Figure 18 Cracks patterns of beam 2B-F-2L.E-140

Figure 19 Cracks patterns of beam 2B-F-2L.E-90

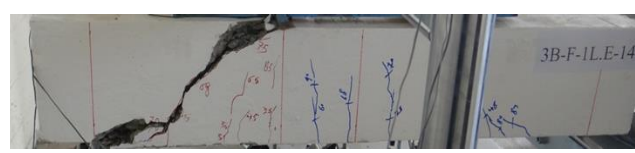

Figure 20 Cracks pattern of beam 3B-F-1L.E-140

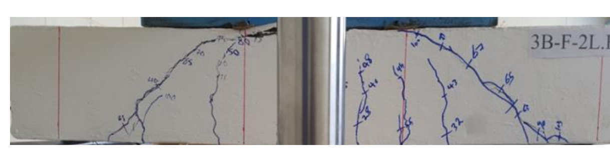

Figure *21 Cracks patterns of beam 2B-F-2L.E-140*

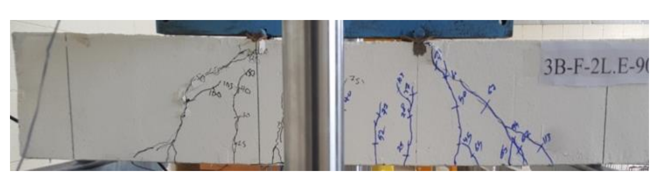

Figure 21 Cracks patterns of beam 3B-F-2L.E-90

7. Conclusion

Alternative new way for designed ties reinforcement to overcome the inherent problem in steel bars which is corrosion and try to produce infrastructures with further durability particularly bridges and marine structures. FRP bars were used for forty years ago for reinforcement and FRP sheets were used for strengthening at these time.

1. Experimentally tested beams result showed that beams with a longitudinal ratio of reinforcement (□f =0.1 and □f = 0.015) and with maximum amount of shear reinforcement by CFRP sheets immerged by sikadur330 provided the preferred performance. This response was changed the failure mode from shear (rupture in CFRP stirrups or steel stirrups for control beams) to flexural failure, which more ductile mode of failure provided by crushing in concrete cover. While, beams with ratio of primary reinforcement (□f = 0.005) failed by flexural failure of all four beams included control related beams.
2. In ultimate carrying load capacity, different ratios of longitudinal reinforcement and maximum amount of shear reinforcement showed an increasing by about 9%, 28% and 38% for beams 1B-F-2L.E-90, 2B-F-2L.E-90 and 3B-F-2L.E-90 respectively compared with each related reference beam.
3. The equivalent ratio of shear reinforcement showed some increase in carrying load capacity. For new beams (beams with CFRP sheets immerged by sikadur330) increased by 0.5%, 13% and 20% for beams 1B-F-2L.E-140, 2B-F-2L.E-140 and 3B-F-2L.E-140 respectively as compared with controls beams.
4. Experimental results showed load-deflection scheme stiffness is directly corresponding to the amount of flexural reinforcement firstly and amount, spacing and type of shear reinforcement secondly.
5. Regardless of the ratio of flexural reinforcement, beams with equivalent shear reinforcement and steel stirrups suffered principal strain $\varepsilon 1$ greater than the maximum amount of shear reinforcement. While, beams with maximum amount of shear reinforcement suffered concrete tensile greater than the other amounts of shear reinforcement.
6. The maximum amount of shear reinforcement changed the failure mode from shear to flexural for beams 2B-F-2L.E-90 and 3B-F-2L.E-90. While, beam 1B-F-2L.E-90 changed failure mode from flexural to pure bending.

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