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Study of Flexure Behavior of Beams Reinforced with Different Hybrid Percent of Glass and Carbon Bars

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Authors' contributions

This work was carried out in collaboration between all authors. Author MAO designed the study and wrote the protocol. Author HAA performed the statistical analysis, wrote the first draft of the manuscript and managed literature searches. Authors HAA, MAO and HMI managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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Case Study

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ABSTRACT

An experimental program has been conducted in order to investigate the flexural behavior of concrete beams reinforced with hybrid glass and carbon bars. A test series of fifteen simple beams containing different types of reinforcement (steel, glass and hybrid carbon & glass) bars had been conducted in this investigation. The parameters included in the experimental program are the reinforcement ratio, the carbon fiber volume fraction (CFVF) in the bar and the strength of concrete. The effect of hybrid bars reinforcement on the flexural response, cracking load, crack propagation, deflection, ultimate capacity, strain in the reinforcement bar at middle of the span and failure characteristics for the beams, is examined. Based on the experimental results, It was founded that the beams reinforced with hybrid bars behave linearly up to cracking load with high initial stiffness and linearly after cracking with great reduction in stiffness, As the carbon fiber volume faction increase the deflection of the beam at ultimate load decrease, Beams reinforced with hybrid bars 40% C and 50% C with medium strength concrete give higher ultimate load than that of the beam reinforced with steel at the same strength of concrete, but generally with less number of cracks.

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Keywords: Flexural behavior; hybrid bars; carbon fiber volume faction.

1. INTRODUCTION

Over the last few decades, research has been conducted in order to find a solution to the problem of corrosion in steel reinforced concrete. As a result, methods such as galvanization, the use of stainless steel bars, cathodic protection, epoxy coatings, concrete additives, etc., have been tried. Unfortunately, none of these methods has totally solved the corrosion problem. The outstanding characteristics of fiber reinforced polymer (FRP) suggest that these materials may be the solution to the problem of steel corrosion. These characteristics include high resistance to corrosion, high strength-to-weight ratio, and fatigue resistance [1].

Hybrid composites are more advanced composites as compared to conventional FRP composites. Hybrids can have more than one reinforcing phase and a single matrix phase or single reinforcing phase with multiple matrix phases or multiple reinforcing and multiple matrix phases. They have better flexibility as compared to other fiber reinforced composites. Normally it contains a high modulus fiber with low modulus fiber. The high-modulus fiber provides the stiffness and load bearing qualities, whereas the low-modulus fiber makes the composite more damage tolerant and keeps the material cost low [2]. The mechanical properties of a hybrid composite can be varied by changing volume ratio and stacking sequence of different plies.

Carbon fibers are becoming widely adopted in many sectors such as Transportation, sporting goods and civil engineering [3,4]. This is because "carbon-fiber composites weigh about one-fifth as much as steel, but can be comparable or better in terms of stiffness and strength depending on fiber grade and orientation" [5-7]. In addition, carbon fiber show good creep resistance and good compatibility with epoxy matrix. However, the main drawbacks of carbon fiber composites for industrial use are rather susceptible to stress concentration and impact damage due to the brittleness of carbon fiber [6-8]. The other major factor that is prohibiting the use of carbon fiber in common use is the high price [9-12]; to overcome both of these problems and to make carbon fiber more adaptable, hybridization is done. In the process a more ductile and low priced fiber is introduced in certain proportions to improve the mechanical properties, Glass fiber is a good candidate for the preparation of hybrid composites of this type. It has good toughness properties, low price and relatively good interfacial adhesion to the matrix [13-17]. In this study hybrid composites have been prepared with glass fiber and carbon fiber as reinforced materials and epoxy resin as matrix in a form of bars. Theoretically, the hybridization of brittle carbon fibers with ductile glass fibers improve the mechanical properties stated above.

2. EXPERIMENTAL WORK

2.1 Used Materials

The beams tested in this experimental program were cast of concrete made of local materials in Egypt .Cement was ordinary portland cement, fine and coarse aggregates were composed of siliceous sand and good dolomite clean from impurities and well graded. Normal mild steel used for stirrups and high grade steel for longitudinal bars were locally produced bars. Two concrete mixes proportions were designed and used for the beams to obtain normal strength concrete with 30 MPa and medium strength concrete with 60 Mpa to study the effect of concrete compressive strenght on the behavior of the beams reinforced with hybrid bars. Table 1 presentes the mix proportions by weight for 1 m^3 of concrete for normal and medium strenght concrete (M.S.C) respectively. The Hybrid bars consist of three row materials: Carbon Fiber (has areal weight 230 gm/m^2 and fabric width 500mm and density of 1.8 gm /cm^3), Glass Fiber (has aweight of 2.25 gm/m and density of 2.5gm/ cm^3) and the used Resin is polyester (ES 1319 having high self –extinguishing resin with medium viscosity and medium reactivity, the self – extinguishing properties of the resin are due to the change in the molecular composition And not to the halogenated additives. The use of polyester mixed with small portion of peroxide to accelerate the process of hardening under temperature. The polyester density is 1380 Kg/m^3). Fig. 1 shows the stress-strain curve of the raw materials (Carbon, Glass and steel). The rebars were manufactured using pultrusion method .The bars are manufactured in El-Asher men Ramadan Industrial city, 50 Km away from Cairo, Fig. 2 shows the steps of pultrusion method.

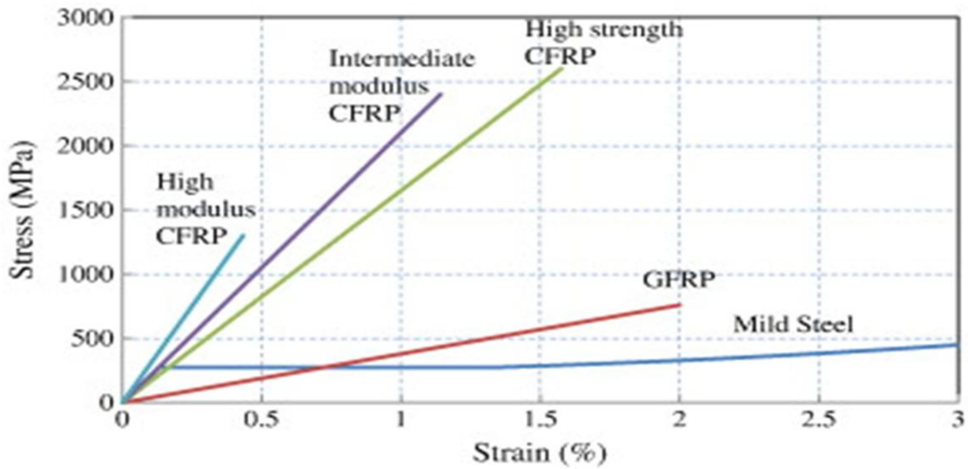


Fig. 1. Stress –strain curve of carbon, glass and steel

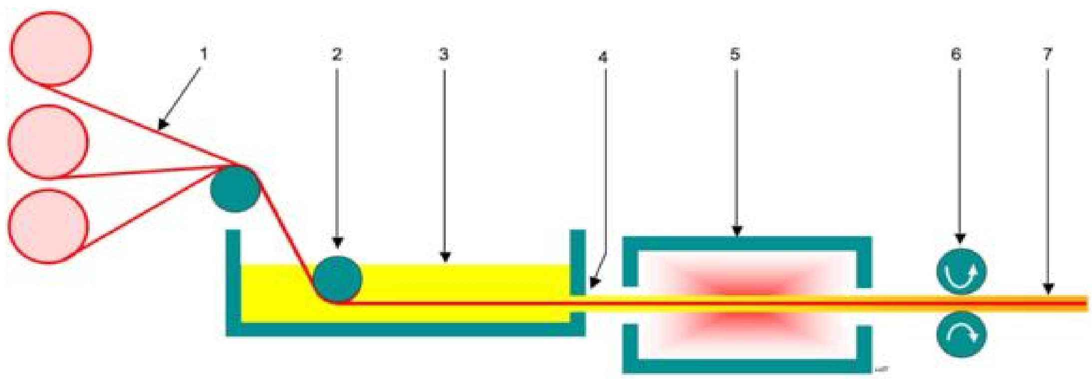


Fig. 2. Pultrusion method used in manufacturing hybrid bars

1 – Continuous roll of reinforced fibers or woven fiber mat
2 – Tension roller
3 – Resin Impregnator
4 – Resin soaked fiber
5 – Die and heat source
6 – Pull mechanism
7 – Finished hardened fiber reinforced polymer

Pultrusion is a continuous manufacturing process used to shape polymeric composite materials into parts with constant cross section. The reinforcement fibers, in the form of continuous strands (roving) or mats, are placed on creel racks; fibers are pulled through a guide plate and then impregnated passing by a resin bath. A water cooling channel is placed in the first part of the die, to prevent premature material solidification; the heat for material polymerization is provided by heating platens placed on the top and bottom surfaces of the die. Outside the die, the cured composite material is pulled by a continuous pulling system (caterpillar or reciprocating pullers) and then a travelling cut-off saw cuts the part into desired length. Table 2 shows the properties of hybrid bars used in beams.

2.2 Roughing Surface of Hybrid Bars

The bond between the Hybrid-bars and concrete is very important to make stronger structural element., there were several methods to increase the bond strength between the two surfaces which depends on the surface area of the bars, and depends also on the roughen of the surface which leads to increase the physical or mechanical interlock between concrete and Hybrid-bars. The product of Hybrid bars, had circular shape and a smooth surface, giving week bond strength to concrete. The process of roughness Using sand is one of several methods to increase the bond between hybrid bars and concrete.

Table 1. The mix proportions by weight for 1 m³ of concrete for normal and high strenght concrete

Mix proportions of normal strength concrete						
Volume (m^3)	**Water (liter)**	**Cement (kg)**	**Coarse aggregate (kg)**		**Fine aggregate (kg)**	
1	190	350	1400		600	
Mix proportions of medium strength concrete						
Volume (m^3)	**Water (liter)**	**Cement (kg)**	**Coarse aggregate (kg)**	**Fine aggregate (kg)**	**Silica fume (Kg)**	**Super plasticizer (liter)**
1	160	500	1050	677	55	11

Table 2. The properties of hybrid bars used in beams

	Number of yarns		**Fiber volume fraction %**		**Polyster**	**Effective area (mm^2)**		**Bond strenght (KN/m^2)***	**Modulus of elasticity (Gpa)**	**Tensile strength (Mpa) ***
Bar tybe	**Glass**	**Carbon**	**Glass**	**Carbon**		**Glass**	**Carbon**			
Glass fiber	53	-	60.76	0	Random dispertion	47.7	-		41.200	1300
Hybird (25%Carbon)	40	26	45.66	15.1		36	11.856	30	69.100	8000
Hybird (40%Carbon)	32	42	36.36	24.4		28.8	19.15	34	85.8400	7800
Hybird (50%Carbon)	27	52	30.35	30.35		24.3	23.712	37	97.000	7500

**Reference no. 16*

Table 3. The test specimens details

Group number	**Beam no.**	**Fcu. (N/mm²)**	**Steel %**	**Glass%**	**Carbon%**	**No.of bars**	**Percentage of reinforcement %**
Group (1)	B1	30	100	-	-	2Ø10	0.35
	B2	30	100	-	-	4 Ø10	0.70
	B3	60	100	-	-	2Ø10	0.35
Group (2)	B4	30	-	100	-	2Ø10	0.35
	B5	30	-	100	-	3Ø10	0.52
	B6	30	-	100	-	4Ø10	0.70
	B7	60	-	100	-	2Ø10	0.35
Group (3)	B8	30	-	75	25	2Ø10	0.35
	B9	30	-	75	25	3Ø10	0.52
	B10	30	-	75	25	4Ø10	0.70
	B11	60	-	75	25	2Ø10	0.35
Group (4)	B12	30	-	60	40	2Ø10	0.35
	B13	60	-	60	40	2Ø10	0.35
Group (5)	B14	30	-	50	50	2Ø10	0.35
	B15	60	-	50	50	2Ø10	0.35

2.3 Test Setup

The structural testing frame in the concrete testing laboratory of the faculty of Engineering at Mataria, Helwan University has been used for testing. The frame is mainly consisted of horizontal I–beam fixed to two vertical columns. The columns are rested on the floor. Two horizontal angles are used to support the measuring dial gauges. The specimens are simply supported on two I-beams where they are supported on the frame by welding to produce two line supports. The clear span between the two supports is 1500 mm; one hydraulic loading jack with a capacity of 500 KN is used at the mid span of the beam. A load cell with a capacity of 300 KN is placed underneath the loading jack. The load cell is connected to a digital display screen to read the applying loads. Vertical deflection was measured at the mid- span of the

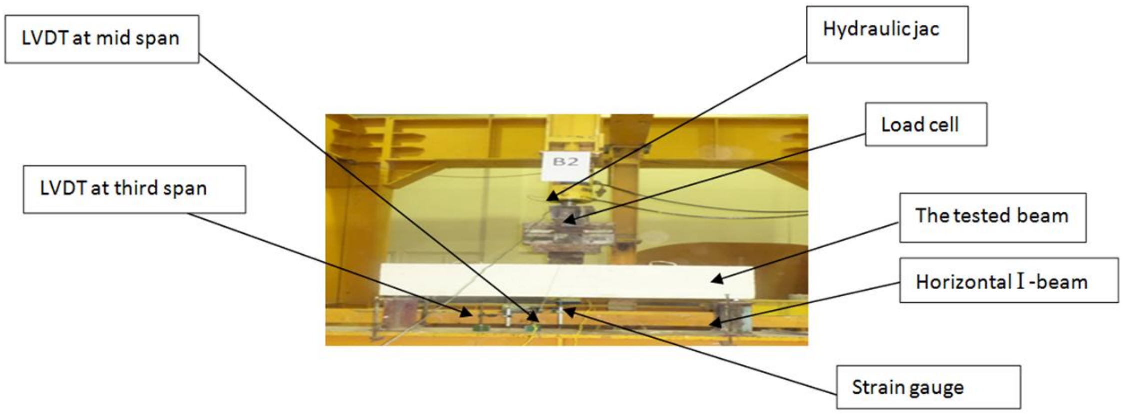


Fig. 3. The test setup and loading system

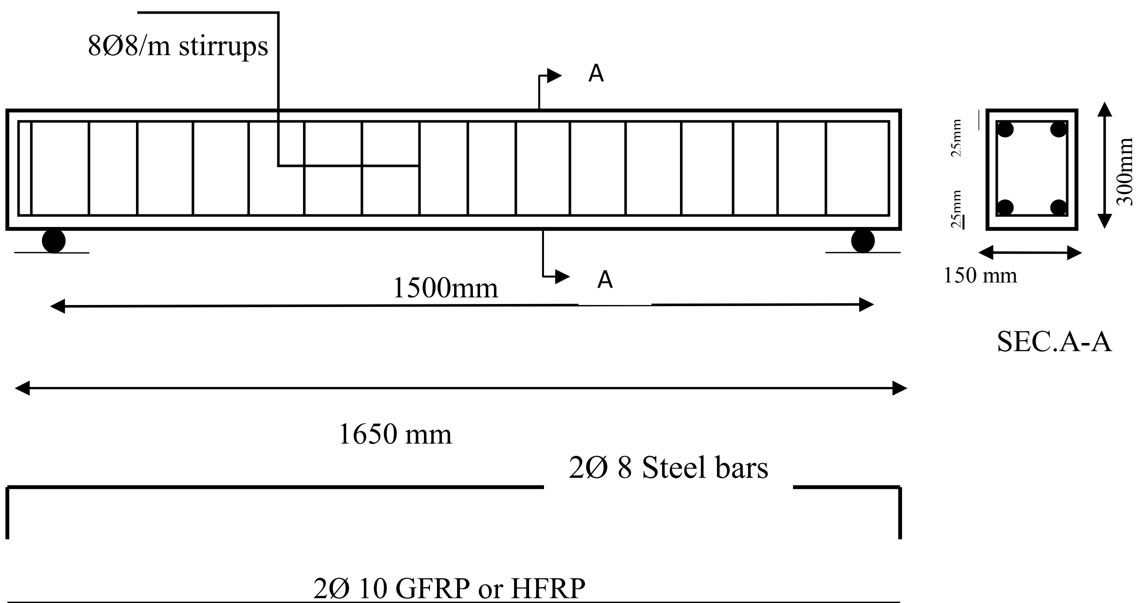


Fig. 4. Concrete cross section and the span of all the beams

beams and at the third of the beam by linear variable differential transducer (LVDT). The data acquisition system used to record the deflection measurment underneath the bottom of the beam at mid and third of the span A three- point load is used for testing beams, the test setup and loading system are shown in Fig. 3 above.

2.4 Test Specimens

The experimental programe consistes of 15 beams divided into 5 groups as listed in Table 3. All beams has the same rectangular cross section with dimensions of 150 mm×300 mm with length of 1650 mm, the member sizes have been chosen to be suitable for the equipment in laboratory. The clear span of the tested beams was fixed at 1500 mm. Fig. 4 above shows the concrete cross section and the span of all the beams.

3. ANALYSIS OF THE TEST RESULTS

The behavior of test specimens is investigated for the studied parameters. The parameters are: the percentage of reinforcement, the compressive strength of concrete material and carbon fiber volume fraction of bars.

Table 4. The effects of different parameters in the study on the behavior of the beams

Parameter's effect on the behavior of the tested beams	Crack pattern	Cracking load	Ultimate load	Deflection at ultimate load
CFVF	The cracks are found to be wide and there is less number of cracks. The increasing in CFVF from 0% to 50% decreases the number of cracks, increase the crack width and the spacing between cracks nearly the same. It was found that the crack pattern and mode of failure were not affected widely with the change of carbon fiber volume fraction from 25% C to 50%C	It was obvious that the beams reinforced with steel give higher cracking and ultimate loads. Beams reinforced with glass bars and beams reinforced with hybrid (25.0% C) bars nearly give the same cracking load, when the carbon fiber volume fraction increased, the cracking load decrease	Beams reinforced with glass bars and beams reinforced with hybrid (25.0% C) bars nearly have the same ultimate load, As the carbon fiber volume faction increases the ultimate load of the beam increased by 12.4% when the carbon fiber volume fraction increased from 25.0% to 40% and increased by 19.9% when the carbon fiber volume fraction increased from 25.0% 50.0%.	It was noticed that when the carbon fiber volume fraction of carbon increases in the bar the deflection decrease. The beam (B14) which reinforced with hybrid bars (50.0% C) gives the lowest deflection in all beams at ultimate load.
Increasing in Reinforcement ratio	It was notice that in beams reinforced with glass bars the cracks increased with the increase of reinforcement ratio, the crack width decrease and the spacing between cracks decrease, also in beams reinforced with hybrid bars (25.0% C) the number of cracks increased while there are a few cracks in the reinforcement ratios 0.35% and 0.52% and 0.70%. (2 or 3 main cracks only)	It was obvious that the beams reinforced with steel the cracking load increased by 32.2% when the reinforcement ration is doubled. Beams reinforced with glass the cracking load increased when the reinforcement ratio increased and also the beams reinforced with hybrid bars (25.0% C) the cracking load increased by 6.0% when the reinforcement ratio increased from 0.35% to 0.52% and increased by 53.4% when the reinforcement ratio increased from 0.35% to 0.72%.	It was obvious that the beams reinforced with steel the ultimate load increased by 85.0% when the reinforcement ration is doubled. Beams reinforced with glass the ultimate load increased by 28% when the reinforcement ratio increased from 0.35% to 0.52% and increased by 54.0% when the reinforcement ratio increased from 0.35% to 0.72%. But for beams reinforced with hybrid bars (25.0% C) the ultimate load increased by 21.0% when the reinforcement ratio increased from0.35% to 0.52% and increased by 27.0% when the reinforcement ratio increased from 0.35% to 0.72%.	the deflections of the beams reinforced with hybrid bars (25.0 % C) increased, when the reinforcement ratio of the beams increased. While the deflection profile of the beams shows that there is a break at the third middle of the beams reinforced with Hybrid bars (25.0% C), which indicate that the values of the deflection are not express a real dutility for the beams and also that break indicate the imperfect bond between the hybrid bars and concrete. It is obvious that the deflections of the beams reinforced with glass increased when the reinforcement ratio increased

Parameter's effect on the behavior of the tested beams	Crack pattern	Cracking load	Ultimate load	Deflection at ultimate load
Concrete strength	The effect of compressive strength of concrete are not slightly in beams reinforced with hybrid fiber reinforced polymer (HFRP) bars with fiber volume fraction of 25.0% C however, the beams reinforced with hybrid bars with fiber volume fraction of 40.0% and 50.0% C the cracks increased when the strength of concrete increased, this is due to increasing in bond characteristics between the bars with higher CFVF and the concrete with higher strength	It is obvious that in beams reinforced with hybrid (50.0% C) the cracking load nearly the same in both normal and medium strength concrete. While in beams reinforced with glass and hybrid (25.0% and 40.0% C) with M.S.C, the cracking load increased by 44.0%, 41.0% and 39.5.0% of the cracking load of that beams with N.S.C respectively	It was obvious that the beams reinforced with steel give higher ultimate load when the concrete is medium strength concrete (increased by 9.0% of the load of N.S.C). Beams reinforced with- glass bars and beams reinforced with hybrid (25.0% C) bars-nearly give the same load in both normal strength and medium strength concrete but in the beams reinforced with hybrid bars (40.0% and 50.0% C) the ultimate load increased by 39.0% and 33.0% (of the ultimate load in N.S.C) respectively, when the concrete is medium strength and also they give a higher load than that in beams reinforced with steel of about 9% for beams reinforced with hybrid 40.0% C and about 12.0% for beams reinforced with hybrid 50.0% C.	It was noticed that the beam with M.S.C give higher deflection than that beam with N.S.C but this high measure of deflection is due to a break at the middle third of the beam. also in 25%C in beams reinforced with hybrid bars (40.0% C), the M.S.C gives lower deflection than that beam with N.S.C while both beams gives lower deflection than that beam reinforced with steel bars beams reinforced with Hybrid bars (50.0% C). It is obvious that the beam with M.S.C gives higher deflection than the beam with N.S.C, while both beams gives lower deflection than the beam reinforced with steel bars

3.1 Crack Patterns and Failure Character

By studying the crack patterns and failure character for beams B1, B4, B8,) B12 and B14 which are shown in Fig. 5, it was found that the cracks in beam (B1) - reinforced with steel bars – are distributed along the beam with a large number of cracks. the crack pattern of beam (B4)-reinforced with glass fiber rebars – are distributed in the middle third of the beam with an opened crack on the right side of the beam, while (B8, B12 and B14)-reinforced with hybrid bars-have less number of cracks (2 or 3 cracks) and they have wider cracks than that in beams reinforced with steel and glass fiber rebars. The failure character of the tested beams are flexural due to bar rapture especially in beams reinforced with hybrid bars 25% C and no shear failure was observed.

3.2 Load-deflection Relationship

Fig. 6 shows the load-deflection curves for different tested beams. The load–deflection curves of beams reinforced with steel bars shows traditional behavior for reinforced concrete beams. The curve is almost linear at first stage of loading till the cracking load and then the curve softens. After that the deflection increases substantially with increase in deflection till failure. On the other hand, all beams reinforced with FRP-bars show different behavior than for steel reinforced beams. For beams reinforced with glass bars and those reinforced with HFRP bars the load-deflection curves showed a bilinear behavior. The first part was nearly a straight line till the cracking load. The second part of the curve is also linear from the point of cracked load to the point of failure load and the stiffness of the beam starts to decrease and the beam deflection increased rapidly with the same load increment.

3.3 Cracked and Ultimate Load

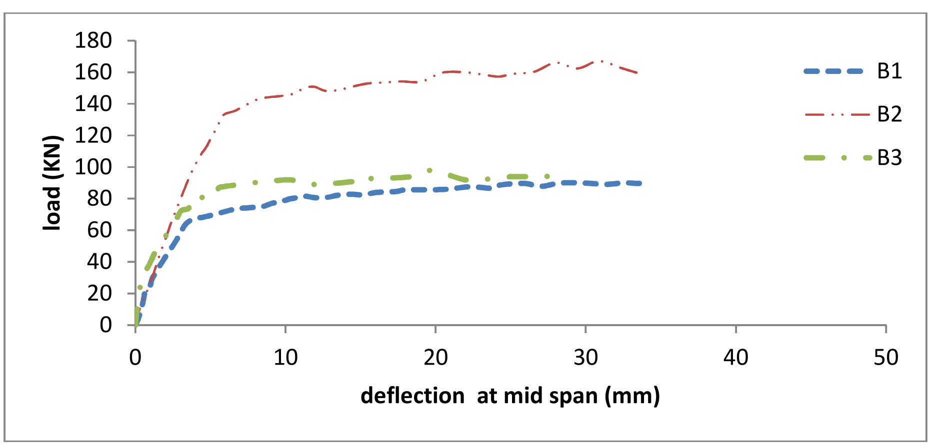
The cracked load is determined as the load of the first appearance of a crack on the beam when it loaded while the ultimate load is determine as the maximum load for the beam during the test, Table 4 show the effects of different parameters in the study on the behavior of the beams at cracked, ultimate loads, deflections and crack pattern, Tables 5 and 6 shows the enhancement in ultimate load with respect to the reference beam that reinforced with steel bars at the two concrete mix , 30 MPa and 60 MPa respectively. Values of ultimate and cracking loads and its corresponding deflections for all tested beams are shown in Table 7.

Table 5. The enhancement in ultimate load in case of N.S.C

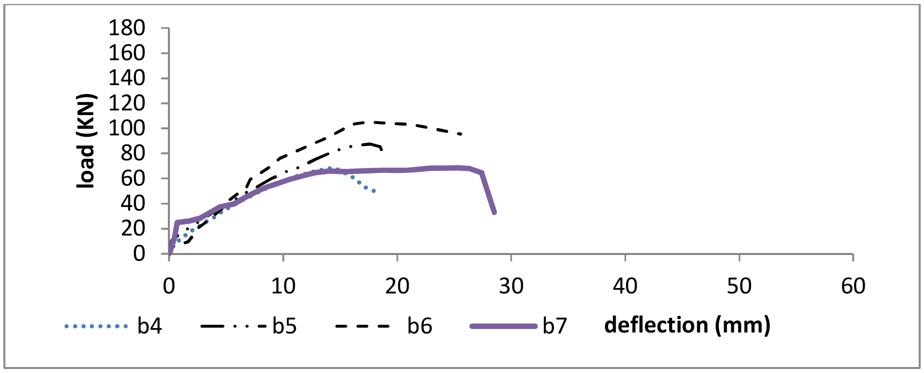
Type of reinforcement	pu	Enhancement in ultimate load
Steel	90.15	1
Glass	68	0.75
25% C	68.7	0.76
40% C	77.2	0.86
50% C	82.4	0.91

Table 6. The enhancement in ultimate load in case of M.S.C

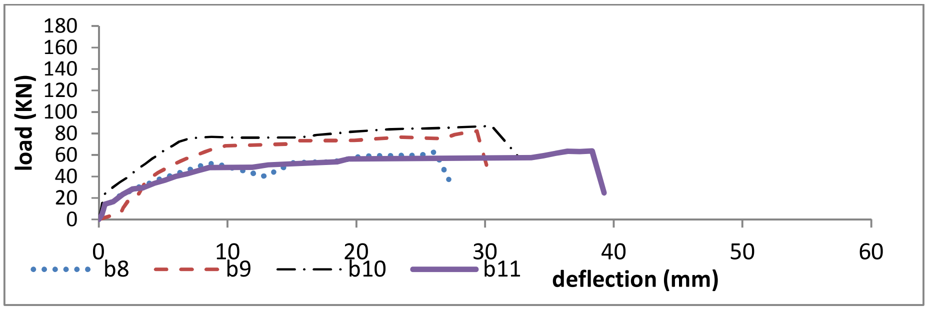
Type of reinforcement	pu	Enhancement in ultimate load
Steel	98	1
Glass	68	0.69
25% C	67	0.68
40% C	107	1.09
50% C	110	1.12



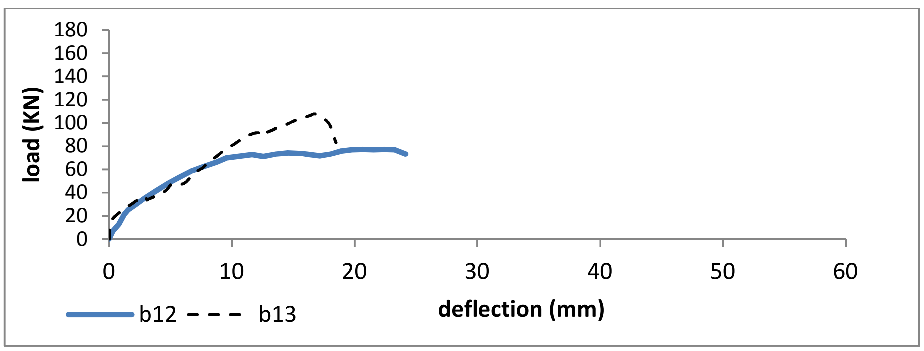
A. Load-deflection curves for beams reinforced with steel bars (reference) G1



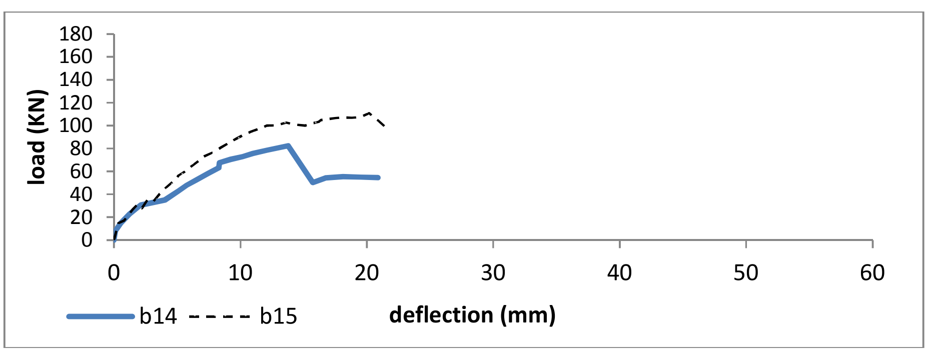
B. Load-deflection curves (GFRP) G2



C. Load-deflection curves (HFRP) (25%C) G3



D. Load-deflection curves (HFRP-40%C) G



E. Load-deflection curves (HFRP-50%C) G5

Fig. 5. The load-deflection curves for different beams

Fig. 6. Crack patterns of the tested beams

Table 7. The values of ultimate and cracking loads and its corresponding deflections for all tested beams

Beam no.	Concrete type	Pcr (KN)	Δcr (mm)	Pu (KN)	Δu (mm)	Max. deflection (mm)
B1(2Ø10-steel)	Normal	24.2	0.95	90.15	29.23	37.3
B2(4Ø10-steel)	Normal	32	1.195	167	30.87	33.7
B3(2Ø10-steel)	Medium	36	0.66	98	19.72	28.5
B4(2Ø10-glass)	Normal	17	1.763	68	14.4	18.6
B5(3Ø10-glass)	Normal	16	1.023	87	17.65	18.73
B6(4Ø10-glass)	Normal	20.1	0.89	105	18.8	20.32
B7(2Ø10-glass)	Medium	24	0.705	68	25.24	28.5
B8(2Ø10-25%(	Normal	16.3	1.04	68.7	26.14	27.3
B9(3Ø10-25%)	Normal	17.29	0.78	82.5	21.6	23.3
B10(4Ø10-25%)	Normal	25	0.533	87	30.5	32.6
B11(2Ø10-25%)	Medium	16.5	0.87	67	38.3	39.2
B12(2Ø10-40%)	Normal	12.9	0.81	77.2	20.6	24.16
B13(2Ø10-40%)	Medium	18	0.31	107	16.9	18.5
B14(2Ø10-50%)	Normal	14.9	0.52	82.4	13.78	20.89
B15(2Ø10-50%)	Medium	17.2	0.35	110	20.17	21.5

3.4 Reinforcement Strains

The beams reinforced with high tensile steel reinforcement showed a typical load- strain relationship, while the beams reinforced with HFRP-bars showed different load strain. By studying the values of the strains reinforcement. It is obvious that the glass and hybrid bars aren't work with their full capacity.

4. CONCLUSIONS

Based on the experimental results and its discussion in this study the following conclusions can be drawn:

1. Generally the increasing of carbon volume fraction in the bars increases significantly the modulus of elasticity of hybrid rebars.
2. Generally beams reinforced with hybrid bars behave linearly up to cracking with high initial stiffness and linearly after cracking with greatly reduced in stiffness.
3. There are a less number of cracks in the beams reinforced with hybrid bars comparing to those reinforced with steel or with glass bars and the cracks width are more wider than those beams reinforced with steel and glass bars.
4. The increasing in carbon fiber volume fraction from 25% C to 50% C is not affected widely on crack pattern and mode of failure. Only the crack width decrease by increase the carbon volume fraction.
5. As the carbon fiber volume faction increases, the ultimate load of the beam increased and the deflection of the beam decrease. The beam reinforced with hybrid bars (50% C) give the lowest deflection of all beams at ultimate load
6. For beams with medium strength concrete, the beams reinforced with hybrid (40% C and 50% C)bars have higher capacity load than those reinforced with steel bars by 9% and 12% respectively, while the deflection in beams with hybrid bars are lower than that beams reinforced with steel bars.
7. As the carbon fiber volume fraction increase, the energy absorption capacity of the beams increase up to CFVF 40% but decreased when the CFVF is 50%, this is due to sudden failure of beam reinforced with hybrid bars 50% C.

5. RECOMMENDATIONS

- Using a braidtrusion method (a process by combining pultrusion and braiding) is necessary for producing high quality hybrid bars [18].
- Change the resin type while manufacturing of the hybrid bars. (Such as epoxy).
- Improve the roughness of the bars surface to increase the bond between concrete and hybrid bars.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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