Shear Behaviour Enhancement of Reinforced Concrete Beams By Adding Different Types of Fibers

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Abstract - The present study investigate the influence of using different types of fiber together instead of using steel fibers only. Shear strength of fiber reinforced concrete beams (FRCB) was studied in this research project. Three types of fibers were examined: hooked-end steel fiber, glass fibers and polypropylene fibers. The experimental program included six beams with fixed length 2000mm and varied depth, which were divided into two groups A and B. The study investigates the shear strength of FRC beams. The experimental parameters were the type of fibers, effective depth and the presence of stirrups in reinforced concrete beams. The results showed that using steel fibers, glass fibers and polypropylene fibers together as well as steel fibers only increased the shear capacity of the beam specimens more than the beam reinforced with minimum shear reinforcement, reduced the induced deflections and strains and enhanced the load capacity. The result showed the effect of depth on FRC beams and the effect of using stirrups in the shear zone. We can concluded that using different fibers, instead of the use of steel fibers only improved overall shear behavior of concrete.

Key words- shear strength, experimental work, different fibers, load capacity.

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1. INTRODUCTION

Plain concrete processes a very low tensile strength, limited ductility, and little resistance to cracking. Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to brittle failure of the concrete. The brittle and catastrophic shear failure of concrete can be relieved by the addition of fibers such as steel fibers, glass fibers and Polypropylene Fibers. Using steel fibers to improving shear strength is expensive compare with glass fibers and polypropylene fibers. However, steel fibers more effective than glass and polypropylene fibers. Also, using steel fibers, glass fibers and polypropylene fibers gives the enhancement and reduction in cost.

2. LITERATURE REVIEW

Previous studies have shown that the fibers can improve the shear performance of concrete **[11]**, **[7]**, **[15]**, **[12]**, **[14]**, **[4]**, **[21]**. The use of fibers as shear reinforcement controls the concrete cracking and decreases crack width. However, the results obtained are highly variable **[6]**, **[8]**. This variability is due to the great diversity of mechanical properties of the FRC, specifically its tensile strength, **[18]**, **[19]**, **[21]**. **Swamy et al. [20]** conduct experimental tests to identify the behavior of shear strength of FRC. Test results showed that inclusion of fibers increase shear strength and reduce numbers and width of cracks. **Tan and Mansur [21]** indicated that the inclusion of fibers significantly improves the strength and deformation characteristics of the concrete. **Morsy et, al. [2]** shows that as fiber volumetric ratio (Vf) increased, the ultimate shear strength increased. Rate of increase in shear strength was almost constant with increasing Vf. **Mansur et, al. [13]** his results showed, that the critical a/d ratio required to induce a shear mode of failure decreases as the volume fraction of fibers is increased. **Arslan [9]** experimental results show that the use of steel fibers improved the shear strength and deformation capacity considerably. In the case of A2.5 series, the use of steel fibers in the amounts of 1.0% and 2.0% by volume increased the ultimate shear strength by 9% and 23%, respectively. It is to be noted that increasing the volume fraction of steel fibers from 1.0% to 2.0% for approximately the same concrete compressive strength (A2.5F1.0b and A2.5F2.0) increased the ultimate shear strength by 14%. In the case of A3.5 series, an increase in the ultimate shear strength due to the use of steel fibers in the amounts of 1.0%, 2.0% and 3.0% is 5%, 37% and 89%, respectively. **Sarita [16]** the test result showed that all the reinforced beam containing steel fiber showed the increase in first crack shear strength about 37.50%, 75.04%,117.55% in 40SFRC, 60SFRC, 80SFRC beams respectively than the beam without steel fiber(WSF). **Aziz [5]** studied the effect of steel fibers on the shear transfer of RC beams. The results showed that the stirrups strain decrease with increasing fibers volume fraction and reinforcement parameter. **[10]** the values of destructive forces and their increments compared to the values of the destructive forces for the reference beams (without fiber) were presented. By adding 80 and 120 kg/m3, the increase in destruction force volume was from 36.5% to 100.7% respectively. **Shoaib [1]** the normalized shear stress for SFRC specimens with h =1000 mm was only about 53% of that observed in specimens with h =308 mm, where h is the beam total depth. However, adding steel fibers into concrete enhanced the shear capacity considerably compared to the ACI 318-08 and CSA A23.3-04 predictions for non-fibrous RC members. Experimental results manifest that it is essential to consider the effect of shear span-to-effective depth ratio in predicting the shear strength of SFRC beams, as done by **[17]**, **[14]**, **[7]**. **Ata El-kareim, et al., [4]** this study aims to understand and evaluate shear behavior of discrete glass fiber concrete beams. The percentage of increased load reached to about 30% when the fiber ratio was increased to 1.5%. The failure of tested beams without glass fiber showed a brittle failure mode compared to specimens with glass fibers. **Karrar et. Al [11]** three types of fibers were examined: hooked-end steel fiber, crimped-steel fiber, and crimped-monofilament polypropylene fibers. The experimental program included five beam specimens. Maximum theatrical shear capacity for tested beams was 4.28, 6.7 and 7.6 kips for beam without shear reinforced, with minimum shear reinforced and with 1% monofilament-Crimped Polypropylene Fiber respectively. **Saeed Ahmed et. Al [15]** polypropylene fiber gives resistance to first crack but do not provide resistance if once the crack forms. After the first crack, the failure load is somewhat less than the control sample for minor ratios i.e. 0.20% to 0.40%, which indicates that no proper bridging action is developed in less percentage. However, when the percentage of fibers increases up to 0.60% there is an increase in failure load by a little percentage.

3. METHODOLOGY

Experimental work- The aim of the experimental program is to investigate the shear behavior of FRC beams with different types of fibers. This experimental program includes six rectangular RC beams having fixed length of 2000 mm, fixed width of 150mm and varied depth of 250mm and 350mm respectively and divided into two groups (A) and (B) as shown in table(1) and figure 1 through figure 3 to achieve the objectives of the research project. The FRC beams were tested to evaluate the effect of using different fibers (steel, glass and polypropylene) instead of steel fibers only on the shear behavior of beams. The variable parameters were the type of fibers (steel, glass and polypropylene) or steel fibers only, size of beams and the presence of stirrups in the shear zone. All beams was made without any stirrups along the shear span to investigate the effect of fibers on the RC beam without web reinforcement except beam (BB0) was made with 6 mm diameter mild steel M.S stirrups without any fibers as a reference beam and beam (BB1) was made with 6 mm diameter mild steel M.S stirrups with 1.5% steel fibers, the stirrups were arranged with 200 mm space in order to investigate presence of stirrups in the shear zone, the remaining beams were reinforced by four stirrups of 6 mm in diameter at beam-ends to avoid bearing failure and at the two point loads. All beams were simply supported and tested under static two point loading, the applied loads and support reactions were transmitted to the tested beam by 300×100×10 mm steel plates. These beams were tested up to failure under gradual increasing load in a Universal Test Machine and tested after 28 days. A dial gauge was fixed at the bottom of beams to measure the deflection under the load application, also an extensometer and strain indicator were used to measure strain of concrete and strain of reinforcement, respectively.

Table (1): Variable parameters and Properties of the tested beams.

Series	Beam	d (mm)	SF %	GF %	PF %	Stirrup	/d ratio
A	AB1	250	1.50%	-	-	-	1.9
	AB2	250	0.75%	0.50%	0.25%	-	1.9
B	BB0	350	-	-	-	stirrup	1.9
	BB1	350	1.50%	-	-	stirrup	1.9
	BB2	350	1.50%	-	-	-	1.9
	BB3	350	0.75%	0.50%	0.25%	-	1.9

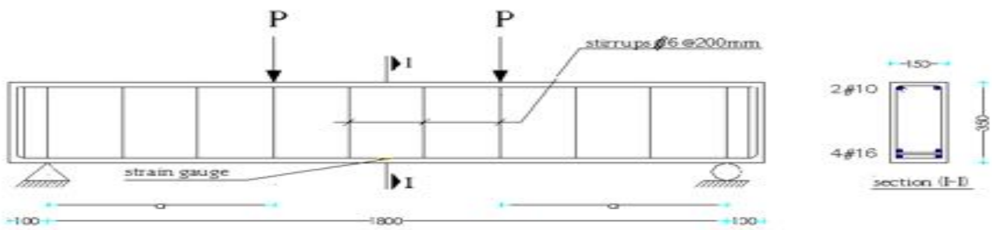


Figure 1: Details of reinforcement and position of loads for control beam BB0 (Dimensions in mm).

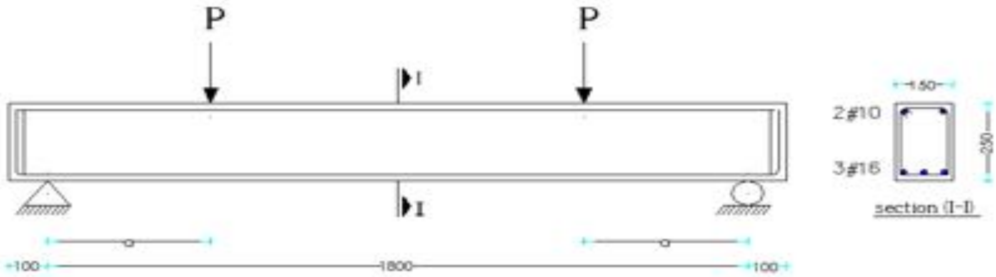


Figure 2: Details of beams in group A (Dimensions in mm).

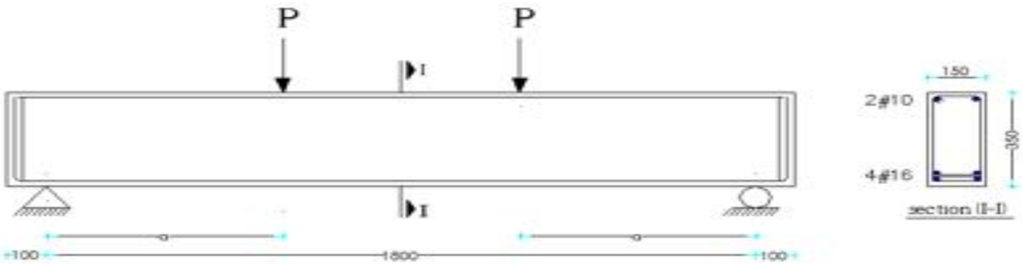


Figure 3: Details of beams in group B (Dimensions in mm).

Materials-Test specimens were cast using coarse aggregate, fine aggregate, cement, water, super plasticizer and fibers. The properties of the constituent materials are given below:

1- Aggregate: Both the Coarse aggregate (gravel) and fine aggregate (sand) were natural. Coarse aggregate have maximum nominal size of 20 mm was used to cast all specimens, fine aggregate was clean and free from silt and clay. Physical and chemical properties of the used sand and gravel are listed in Table (2)

Table (2): Physical and chemical properties of the used aggregates.

property	sand	Gravel 1	Gravel 2
Volume weight in loose state (t/m3)	1.57	1.523	1.457
Volume weight in compacted state (t/m3)	1.705	1.65	1.52
Specific gravity	2.50	2.56	2.70
% Absorption	1.0	0.67	0.51
% Fine Materials	2.0	0.5	0.15
% Crushing Value	-	6.0	4.0
% Loss of wear	-	-	27.0
Fineness Modulus	2.71	7.21	6.06
% Chloride ions	0.041	0.018	0.032
% Sulphate ions	0.38	0.170	0.095
PH	8.78	8.50	8.50

2- Cement: Ordinary Portland cement with grade of 42.5 N was used. The specific gravity and fineness specific surface area were 3.15 and 3250 cm2 /g, respectively.

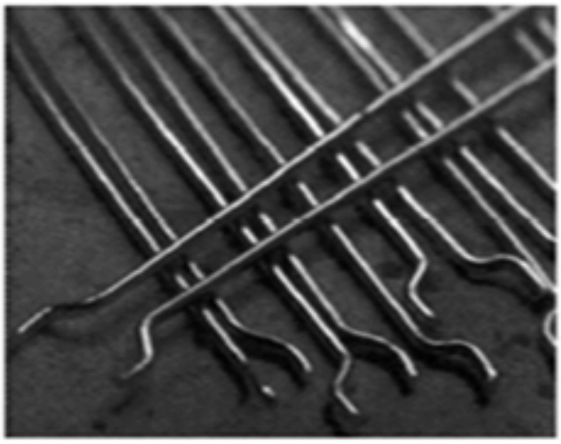
3- Water: Drinking water was used for mixing and curing of concrete.

4- Super plasticizer: Super plasticizer improves the workability and compressive strength of concrete.

5- Fibers: Three types of fiber were used in test specimens (steel, glass and propylene) figure 4. The properties of fibers are shown in table (3).

Table (3). Properties of fiber

Materials	Type	Density (t/m^3)	Young' s modulus (t/cm^2)	Tensile strength (kg/cm^2)	Length (mm)	Thickness (mm)	Aspect ratio
Steel	Hocked end	7.85	2100	6500	35	0.7	50
Glass	Straight	2.6	750	2500	24	0.14	170
propylene	Straight	0.91	-	-	24	0.2	120



(a)

(b)

(c)

Figure 4 (a, b, c): steel fibers, glass fibers and polypropylene fibers respectively.

4. Mixture proportioning

Concrete mix was designed to give compressive strength (450 kg/cm2) after 28 days. Table (4) lists weight of the materials used in the mix.

Table 4. Weights of the materials used in the mix

Components materials					W/C	SP/C
C kg/m3	G kg/m3	S kg/m3	W liter/m3	SP kg/m3		
470	1179	635	160	14.1	0.33	0.03

5. Test set-up and Procedure

Testing Beams Test specimens were instrumented to measure the applied load, mid-span deflection, strains of concrete and strains of longitudinal reinforcement at the critical sections. A linear variable displacement transducer (LVDT) for measuring deflection was mounted at the bottom side of the midspan for each specimen. Two electrical resistance strain gauges mounted on the concrete and longitudinal reinforcement were used to measure the concrete and steel strains up to failure. Load was applied using a hydraulic jack of 60 ton capacity in compression. The jack was equipped with a calibrated load cell of ± 75 kg capacity to measure the applied load. The load was applied at two points of the tested beam, transmitted from the load cell to the tested beam through a steel I.B and two steel plate 300×100×10 mm. Roller assembly was utilized at one reaction point to create a well-defined roller-supported condition for the tested beam. The other support was more rigid support to prevent horizontal deformation as a hinge-support as shown. Hinge and roller support plates were 300×230×30 mm. Steel bearing plates 300×100×10 mm were placed at the interface between the beam and the supporting assemblies. Figure 5 shows the details of the test setup. The test was continued after the ultimate load in order to evaluate the post peak behavior of the tested beams. During testing, the general deformational behavior was tracked. The development of cracks was marked along the sides of the specimens. At each load stage, the electrical strain gauges, load cells and (LVDT) voltages were fed into the data acquisition system. The voltage excitations were read, transformed and stored as micro strains, force, and displacement by means of a computer program that runs under the Lab View software. Data obtained from these gauges were later used to estimate the cracking and the ultimate loads of the test specimens.

Control Specimens - A Tinius Olsen Compression testing machine with capacity of 150 tons was used to carry out compression tests on 150x150x150 mm cubes as shown in Figures 6.

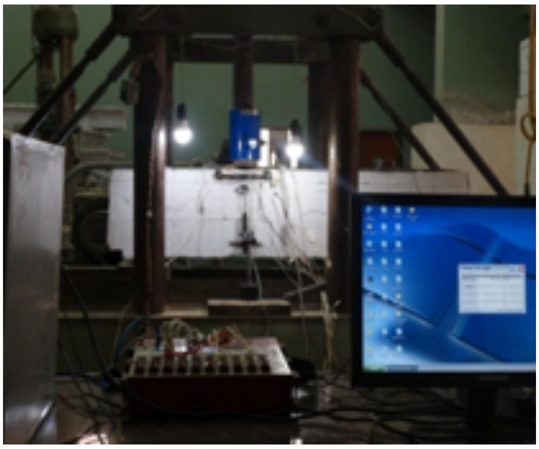


Figure 5: Test setup of the tested beams.

Figure 6: Testing the control specimens.

6. Results and Discussion

The behavior of the tested beams is discussed in terms of the cracking pattern, the measured deflections and strains, the cracking load, ultimate shear capacity and mode of failure for the tested beams. The summary of the test results for the tested beams are presented. Also, the maximum deflection (δ_{max}) is measured below the middle point at the ultimate load. The cracking behavior, diagonal cracking and ultimate loads, modes of failure, deflections and measured strains are presented as follows:

6.1. Cracking behavior and mode of failure

The crack patterns and modes of failure for the FRC beams are shown in figure (7). In general, all tested specimens were designed to fail in shear and this presumption was investigated for all tested FRC beams. For all specimens, the first crack development, crack propagation, and plane of failure were remarked during the test. The crack development approximately followed a similar pattern in all of the tested specimens. For beam (BB0) whose Control beam with stirrups but without any fibers, the cracking pattern is shown in Figure (7). The failure of this beam was denoted as a diagonal – tension failure. By increasing the load, the control beam BB0 (reinforced with stirrups in the shear zone and has no fibers); shear crack initiated under point of load application. This crack is diagonal shear crack, which was widen by increasing load. Failure was occurred at load of 18.500 tons.

For (BB1) whose beam had a steel fibers ratio of 1.50% and stirrups as shown before, the cracking pattern is shown in Figure (7). The first cracks were formed within the shear-span. The critical diagonal crack was formed independently from the middle of the beam section in the shear-span as a web-shear crack. Failure was occurred by losing bond between steel bars and concrete at load higher than the failure load of beam BB0. On loading the tested beam BB2 (reinforced with 1.5% volume fraction of steel fibers only in the shear zone); shear crack initiated in the shear zone. As the applied load increases, the inclined crack was extended upward and downward and more diagonal tension cracks were formed in the region of maximum shear zone leading to the failure of the FRC beams. The same percentage of volumetric ratio 1.5% but using different fibers (0.75% steel fibers, 0.5% glass fibers and 0.25% polypropylene fibers) in the tested beam BB3 showed no clear difference in the patterns of cracks and modes of failure when compared to the tested beam BB2 as mentioned above. The failure of beams BB2 and BB3 more ductile when compared to the control beam.

For beams (AB1, AB2) in group A, using 1.5% volume fraction of steel fibers only in the shear zone in beams AB1 compartion with using different fibers (0.75% steel fibers, 0.5% glass fibers and 0.25% polypropylene fibers) in the tested beam AB2 in group A, showed no clear difference in the patterns of cracks and modes of failure. Compared to the control beam BB0, the presence of fibers has obviously positively affected the ductility.

The comparisons between the beams (AB1, AB2) and (BB2, BB3) in group A and B, showed that the presence of using different fibers (0.75% steel fibers, 0.5% glass fibers and 0.25% polypropylene fibers) in the shear zone minimizes the occurrence of the sudden and brittle type of the shear failure and improves the general behavior of the RC tested beams as same as using steel fibers only.

For beam BB1 in group B, showed that the presence of using fibers by 1.5% and stirrups together in the shear zone lead to higher ductility and stiffness

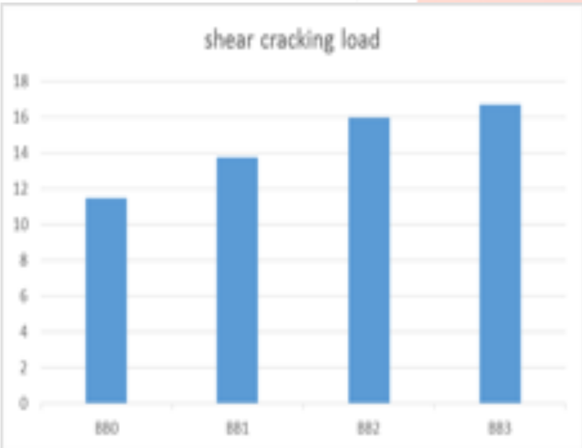
(a): Group A

(b): Group B

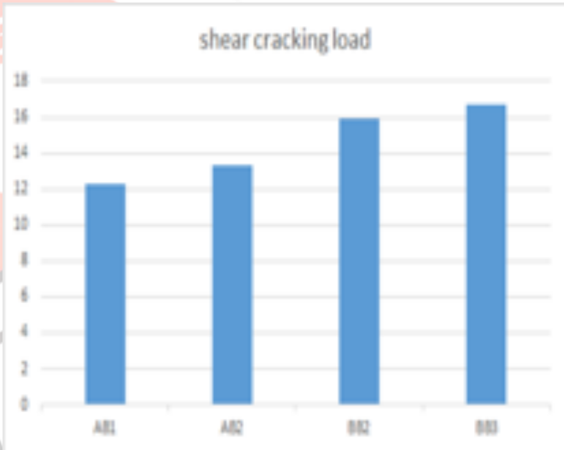
Figure (7): The crack patterns and modes of failure for the FRC beams

6.2. Shear cracking load

The first shear cracking load (FSCL) is the load at which the first diagonal crack was initiated in the critical shear zone. Figure (8) show the first shear cracking load for all the tested beams. Compared to the control beam BB0, beam BB1 (have 1.5% steel fibers and stirrups in the critical shear zone) and beam BB2 (have 1.5% steel fibers only in the critical shear zone) showed higher values of FSCL with the enhancement of 54.56% and 19.35% respectively. The presence of steel, glass and polypropylene fibers for the beams BB3 in the second group (have no stirrups in the critical shear zone) showed 45.22% increase for the value of the FSCL when compared to control beam BB0. Using steel fibers, glass fibers and polypropylene fibers together by 1.5% volumetric ratio in beams (AB2 and BB3) instead of using 1.5% steel fibers only in beams (AB1 and BB2) resulted in increasing first shear cracking load for beams (AB2 and BB3) by 8.57% and 7.12% comparison between (AB1,BB2) respectively. The using of steel fibers, glass fibers and polypropylene fibers together, showed higher values of the shear cracking loads than using of minimum stirrups as the same of using steel fibers only.



Effect of 1.5% fibers



Effect of replacing 1.5% steel fibers by (0.75% steel, 0.5% glass and 0.25% polypropylene)

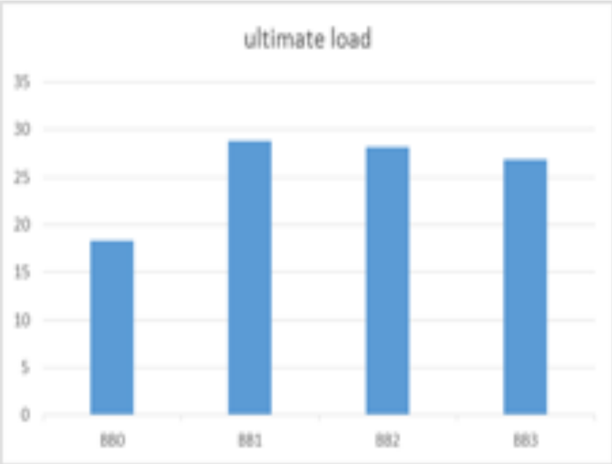
Figure (8): Shear cracking load

6.3. Ultimate load

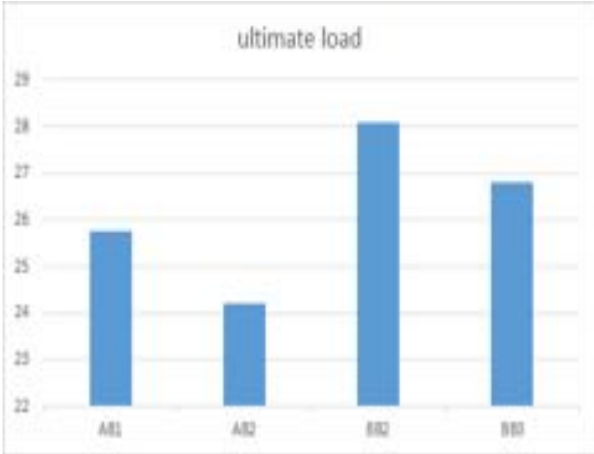
Figure (9) show that the presence of fibers led to increasing the value of the ultimate loads. Beams (BB1) (have stirrups and steel fibers by 1.5%) showed increase the value of the ultimate load by 57.57% when compared to the control beam BB0. The presence of 1.5% steel fibers for beams BB2 and 1.5% (steel, glass and polypropylene) for beam BB3 resulted in increase the values of the ultimate load by 52.13% and 46.05 %, respectively when compared to the control beam BB0. Compared to using 1.5% steel fibers only in beams (AB1 and BB2),the presence of steel fibers, glass fibers and polypropylene fibers together by 1.5% volumetric ratio resulted in decreasing the values of the ultimate load for beams (AB2 and BB3) by 0.53% and 0.061% respectively.

The efficiency of using fibers to increase the shear capacity was found to be high for beams having no stirrups in the critical shear zone. However, using of stirrups and fibers resulted in higher values of ultimate loads.

The presence of fibers and increasing the depth of the FRC beams resulted in increasing the values of the ultimate load when comparing (AB1 by BB2 and (AB2 and BB3).



Effect of 1.5% fibers



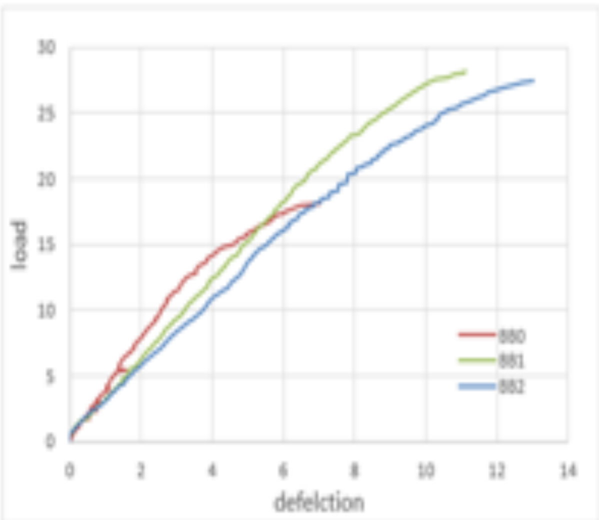
Effect of replacing 1.5% steel fibers by (0.75% steel, 0.5% glass and 0.25% polypropylene)

Figure (9): Ultimate load

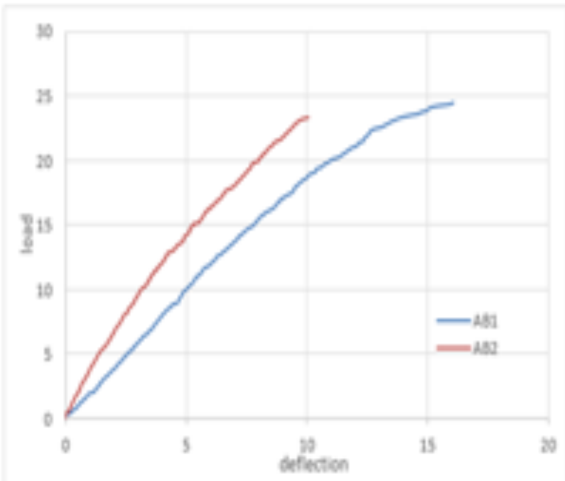
6.4. Deflection

The load-deflection relationship for the tested beams is presented in figure (10) and the maximum values of deflection are measured. The curves show that the beams exhibit three stages: the first stage which is the un-cracking stage. This stage starts from zero loading till the first cracking load. The behavior in this stage is characterized by the un-cracked behavior where the maximum tensile stress is less than the concrete tensile strength. The second stage which is the post- cracking stage begins with the first shear cracking. After cracking, lower values of stiffness were detected. The third stage, which is the post-serviceability stage, beams behaved with significantly reduced stiffness till the failure compared with the previous stage.

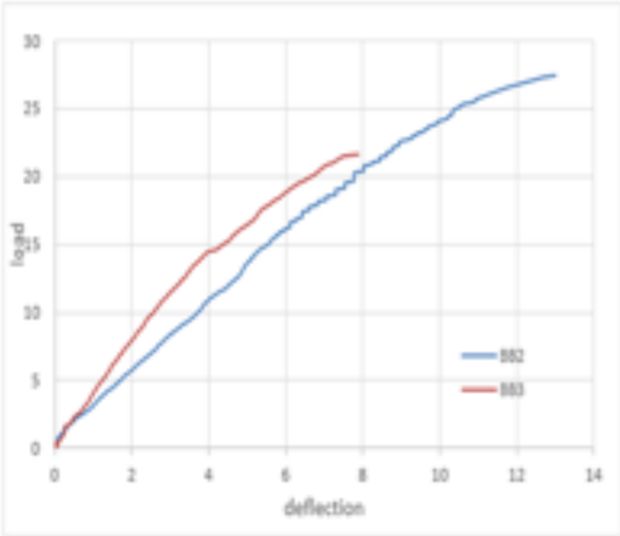
As shown in figure (10) for beams having 1.5% steel fibers only and 1.5% different fibers volume fraction at a certain load, the values of the deflection was found to be reduced compared to the control beam BB0. This may be attributed to the increase of the stiffness, the value of the modulus of elasticity and the tensile strength of the concrete due to the presence of fibers. However, the presence of different fibers by 1.5% volume fraction showed no clear difference in the deflection curve when compared to the using 1.5% steel fibers only. At failure load; the presence of fibers resulted in increase the values of the maximum deflection with percentage of 70.0% to 26.71 % for steel fibers and different fibers respectively. Because the presence of fibers resulted in higher values of ultimate load as well as higher values of the maximum deflection figure (10).



Load-deflection relationships for beams (BB0), (BB1) and (BB2).



Load-deflection relationships for beams (AB1) and (AB2).



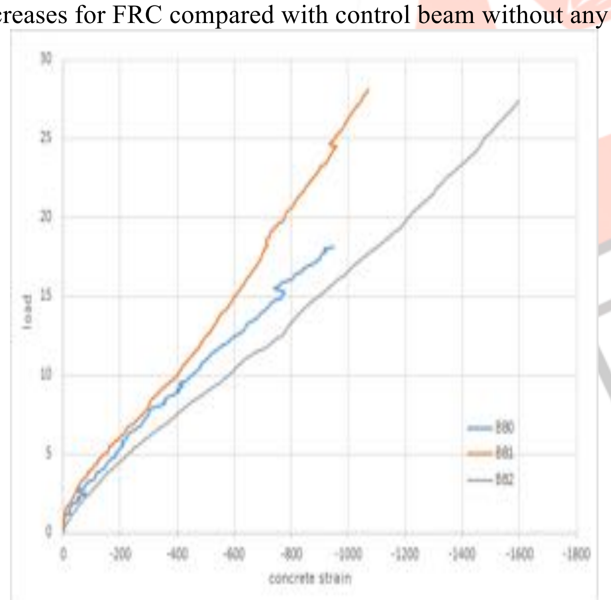
Load-deflection relationships for beams (BB2) and (BB3).

Figure (10): Load-deflection relationships for beams.

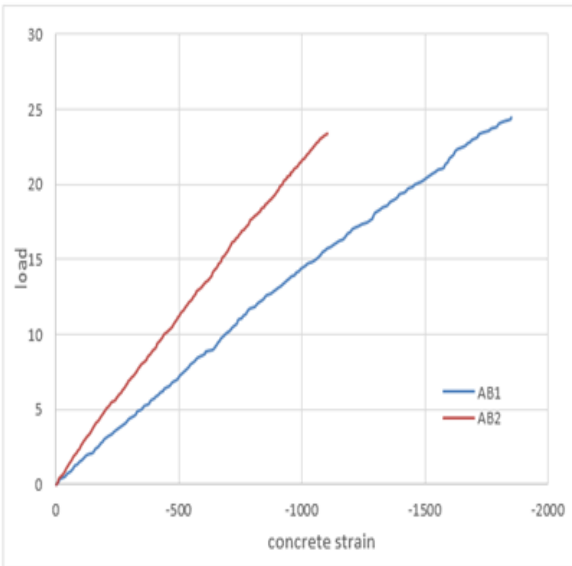
6.5. Concrete strain

Figure (11) shows the loads – concrete compressive strain relationship. The values of concrete strain were measured by using the extensometer. The general behavior is similar to the overall behavior of the load-deflection curves. The using of fibers and stirrups together led to decrease the concrete strain, but the use of fibers only led to increase the concrete strain.

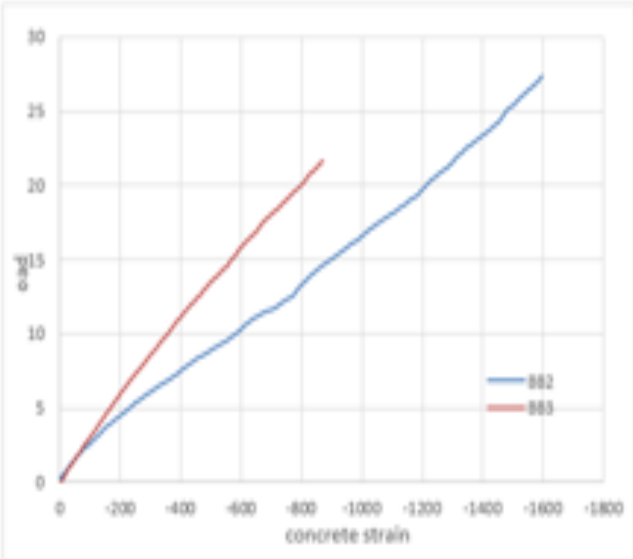
At a certain load, the use of different fibers led to decrease the concrete strain compared to the use of steel fibers only. Due to the technique of using steel fibers only or different fibers, concrete absorbs more energy, and as a result, the values of both modulus of elasticity and tensile strength of concrete were increased. At failure load, the value of the maximum concrete strain increases for FRC compared with control beam without any fibers.



Load – concrete compressive strain curve fore beams BB0, BB1 and BB2.



Load – concrete compressive strain curve fore beams AB1 and AB2.

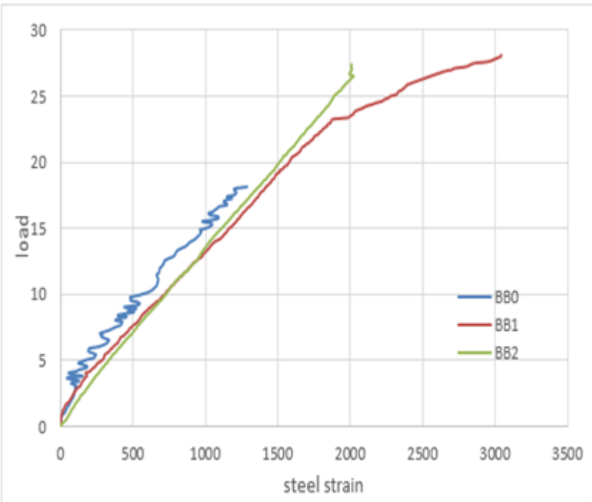


Load – concrete compressive strain curve fore beams BB2 and BB3.
Figure (11): Load-concrete compressive strain relationships.

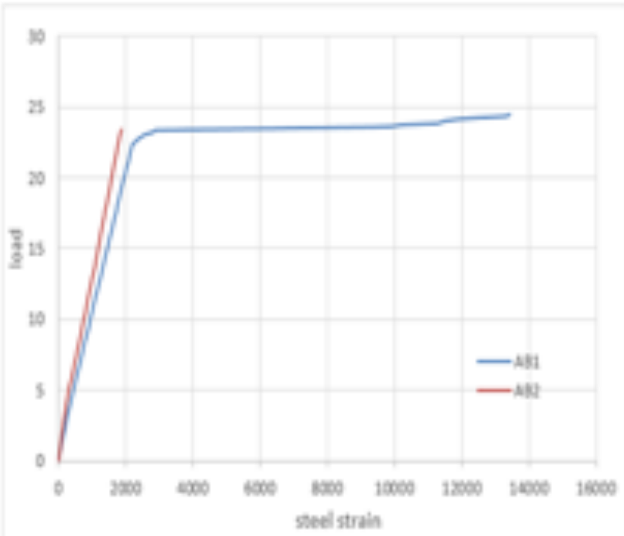
6.6. Strain in main steel

Figure (17) shows the relation between the applied load and the strain of the tensile reinforcement for the tested beams. Electrical strain gauges were used for measuring the strains in main steel bars under the load. Before cracking, small values of the steel strain have been recorded due to the fact that the concrete carries the tensile stress. After cracking, the value of the steel strain started to increase until the failure.

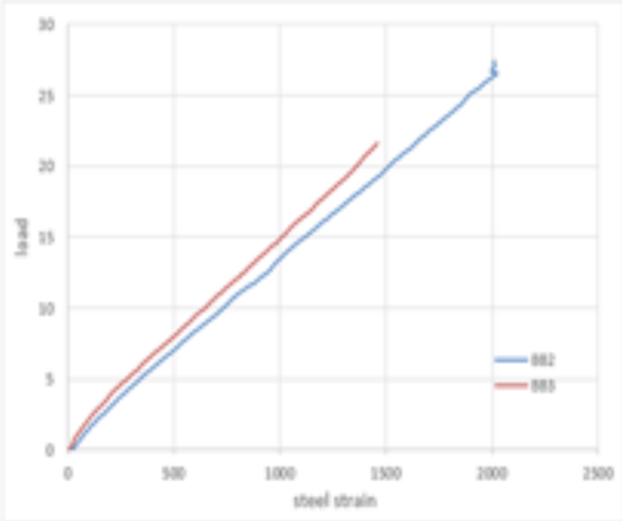
The presence of fibers increase the value of steel strain. At a certain load, the use of different fibers led to decrease the concrete strain compared to the use of steel fibers only in beams (AB1, AB2) and (BB2, BB3). However, increasing the load carrying capacity of beams consequently increases the values of the maximum steel strain. The values of the maximum steel strain for all beams are found to be close to the value of strain at yield.



Load – steel strain curve fore beams BB0, BB1 and BB2.



Load – steel strain curve fore beams AB1 and AB2.



Load – steel strain curve fore beams BB2 and BB3.

Figure (12): Load-steel strain relationships.

7. Conclusions

Based on the study presented in this paper, the study has revealed the following conclusions:

1. Using 1.5% volume fraction of steel fibers resulted in increasing the shear cracking load and the ultimate load by 38.69% and 54.22% respectively, increasing the stiffness, decreasing the deflection at the same load and increasing the maximum measured deflection, because the fibers increase the tensile strength of concrete.
2. Using steel fibers in addition to using stirrups in the shear zone of RC beams led to increasing the ultimate load more than RC beams without fibers and more than RC beams with fibers only.
3. Using different fibers (0.75% steel, 0.5% glass and 0.25% polypropylene) resulted in increasing the shear cracking load and the ultimate load by 45.21% and 44.95% respectively comparing with control beam.
4. Replacing 1.5% steel fibers by (0.75% steel, 0.5% glass and 0.25% polypropylene) led to improving shear behavior of FRC beams as well as steel fibers only, the cracking load increase, the ultimate load slightly decrease, maximum deflection decrease, concrete compressive strain decrease and steel strain decrease comparing with SFRC beams.
5. Increasing the size of FRC beams led to increasing the shear cracking load and the ultimate load, as well as decreasing the maximum deflection and increasing the stiffness of the beams. The mode of failure was not ductile and the crack propagation was less than the small one.

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