



## SHEAR BEHAVIOR OF FIBER REINFORCED CONCRETE BEAMS

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### ABSTRACT

Shear strength of fiber reinforced concrete (FRC) has prime importance in structural design. Concrete members like brackets, corbels and ledger beams may fail in shear. Such failure can be sudden and brittle. The presence of fibers positively affects the behavior of concrete, as it increases the residual shear transfer and reduces the formation and extension of cracks. As many parameters affect it, shear strength of FRC could not be precisely detected. Experimental investigation was carried out to study the shear transfer of un-cracked fibrous concrete. The study investigates the shear strength of FRC beams. The experimental parameters were the type and the percentage of fibers volume fraction and the presence of stirrups in reinforced concrete beams. Test results showed that the presence of fibers resulted in higher values of shear strength, stiffness, ductility and controlled the concrete cracking behavior. Instead of glass fibers, the use of steel fibers improved overall shear behavior of concrete.

### 1. Introduction

The brittle and catastrophic shear failure of concrete can be relieved by the addition of fibers.

Previous studies have shown that steel fibers can improve the shear performance of concrete [5], [8], [9], [10], [15]. The use of fibers as shear reinforcement controls the concrete cracking and decreases crack width. However, the results obtained are highly variable [2], [4]. This variability is due to the great diversity of mechanical properties of the FRC, specifically its tensile strength [11], [12], [13], [16]. Swamy et al. [14] 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 [15] indicated that the inclusion of fibers significantly improves the strength and deformation characteristics of the concrete.

Khaloo and Kim [6] carried out an experimental investigation to assess the effect of concrete strength on the strength and ductility behavior of steel fiber reinforced concrete under direct shear. Test results showed that the enhancement in shear strength, toughness and ductility was more pronounced in high strength concrete than in lower strength concrete.

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Aziz [1] 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. Shah and Rangan [18] conducted uni-axial compression test on glass FRC specimens. The results showed that the increase in strength of 6% to 17% compressive strength, 18% to 47% split tensile strength, 22% to 63% flexural strength and 8% to 25% modulus of elasticity, respectively. Kim et al. [3] proposed a new type of fiber reinforced polymer (FRP) shear reinforcement as a substitute for steel stirrups. Plate-type FRP shear reinforcement has better constructability and easier fabrication than FRP stirrups. Also, plate shear reinforcement does not reduce the strength by concentrating stress in the bent portion. In an earlier paper, the types of FRP and shape of reinforcement did not significantly affect the shear strength. Based on previous research about high ductile fiber reinforced concrete (HDC) mechanical property [7], [17], it is proposed that the failure mode, deformation behavior, and shear capacity of steel-concrete composite beams would be improved by using HDC. The test results of six high ductile fiber reinforced concrete (HDC) beams were studied to investigate the influence of shear-span ratio and HDC mechanical property on the improvement of the shear failure mode and shear capacity of short beams.

The objective of this research was to investigate the effect of addition of steel or glass fiber on the shear behavior of RC beams with or without stirrups in the critical shear zone.

## 2. Layout of experimental work

The experimental program is to investigate the shear behavior of FRC beams. This includes 12 rectangular RC beams having 12 cm width, 30 cm depth and 130 cm length of span as shown in figures (1) and (2). The RC beams were tested to evaluate the effect of steel or glass fibers on the shear behavior of beams. The variables were the type of fibers (glass and steel), the volume fraction of fibers (0%, 0.2%, 0.4% and 0.6 %) and the presence of stirrups in the shear zone. All RC beams have  $325 \text{ kg/cm}^2$  compressive strength and table (1) summaries the details of the tested RC beams. To perform the tests, the beams were simply supported and subjected to three loading points (2 support points and 1 load point). These beams were tested up to failure under gradual increasing load in a Universal Test Machine. All beams were 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. All beams were casted and tested at the concrete and strength of material laboratory of Civil Engineering Department, Faculty of Engineering, El-Minia University.

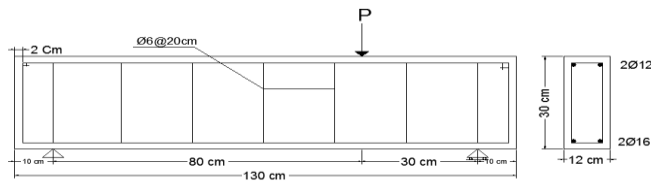


Fig. 1. Concrete dimensions and details of the internal reinforcement for beams ( $A_1$  to  $A_5$ )

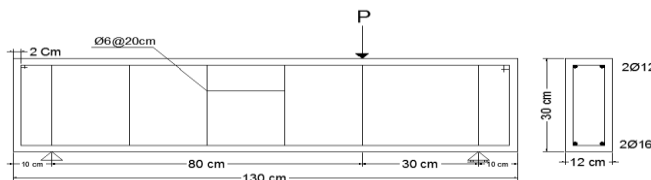


Fig. 2. Concrete dimensions and details of the internal reinforcement for beams ( $B_1$  to  $B_7$ )

**Table 1.**

Data of the tested beams

Group	No. of Beams	Compressive strength $F_{cu}$ (kg/cm <sup>2</sup> )	Percentage of fiber $V_f$ %	Length of fiber (mm)	Aspect ratio ( $L_f/d_f$ )	Type of fiber
<b>First group with presence of stirrups in the critical shear zone</b>						
I	A 1	343.70	0.00	----	0	No Fiber
	A 2	348.98	0.20	50	50	Steel fiber (Corrugated)
	A 3	358.46	0.60			
	A 4	347.20	0.20	12	120	Glass fiber
	A 5	352.92	0.60			
<b>Second group without stirrups in the critical shear zone</b>						
II	B 1	343.70	0.00	----	0	No Fiber
	B 2	348.98	0.20	50	50	Steel fiber (Corrugated)
	B 3	353.16	0.40			
	B 4	358.46	0.60			
	B 5	347.20	0.20	12	120	Glass fiber
	B 6	350.58	0.40			
	B 7	352.92	0.60			

### 3. Material properties

Test specimens were cast using coarse aggregate, fine aggregate, cement, water, super plasticizer and fibers. The physical properties of the material used in the mix are as follows:

- 1- Coarse aggregate:** Gravel supplied from local quarries, have maximum nominal size of 20 mm was used to cast all specimens. The specific gravity, volume weight, fineness modulus were 2.5, 1.54 t/m<sup>3</sup> and 6.37, respectively.
- 2- Fine aggregate:** The fine aggregate was natural desert sand, clean and free from silt and clay. The specific gravity, volume weight, fineness modulus were 2.5, 1.7 t/m<sup>3</sup> and 3.4, respectively.
- 3- Cement:** Ordinary Portland cement was used. The specific gravity and fineness specific surface area were 3.15 and 3250 cm<sup>2</sup>/g, respectively.
- 4- Water:** Drinking water was used for mixing and curing of concrete.
- 5- Super plasticizer:** Super plasticizer improves the workability and compressive strength of concrete.
- 6- Fibers:** Steel and glass fibers were used in test specimens, the properties of steel and glass fibers are shown in table (2).

**Table 2.**

Properties of fiber

Materials	Type	Density (t/m <sup>3</sup> )	Young's modulus (t/cm <sup>2</sup> )	Tensile strength (kg/cm <sup>2</sup> )	Length (mm)	Thickness (mm)
Steel	Corrugated	7.85	2100	8500	50	1
					25	
Glass	Straight	2.6	750	2500	12	0.1

### 4. Mixture proportioning

Concrete mix was designed to give compressive strength (325 kg/cm<sup>2</sup>) after 28 days. Table (3) lists weight of the materials used in the mix.

**Table 3.**

Weights of the materials used in the mix

Components materials					W/C	SP/C
C kg/m <sup>3</sup>	G kg/m <sup>3</sup>	S kg/m <sup>3</sup>	W liter/m <sup>3</sup>	SP liter/m <sup>3</sup>		
350	1188	590	165	3.5	0.47	0.01

**C:** Cement, **G:** Gravel, **S:** Sand, **W:** Water, **SP:** Super plasticizer.

## 5. Results and Discussion

Test results of cracking and ultimate load, concrete strain, steel strain and deflection for RC beams were recorded and listed in table (4).

### 5.1. Cracking patterns and modes of failure

Figure (3) shows the patterns of cracks and modes of failure for the RC tested beams. In general, all RC tested beams failed due to shear. On loading the control beam A<sub>1</sub> (reinforced with stirrups in the shear zone and has no fibers); flexural crack initiated under point of load application. As the applied load increases, more flexural cracks were formed and propagated upward and were followed by the initiation of an inclined crack. 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 RC beams. The presence of low fiber volume fraction (up to 0.2%) showed no clear difference in the patterns of cracks and modes of failure when compared to the control beam. As the percentage of volume fraction of steel or glass fibers increases (up to 0.6 %) for beams A<sub>3</sub> and A<sub>5</sub>, higher values of first shear cracking loads were detected and the cracks were spaced more closely. It is found that with the increase of the fiber volume fraction results in higher values of the concrete tensile strength and modulus of elasticity, and consequently the stiffness of the RC beams increased. Alternate to the control beam (first group) A<sub>1</sub>, the failure of the control beam B<sub>1</sub> (without reinforced stirrups in the shear zone and has no fibers, second group) was sudden and brittle. The main reason of the sudden and brittle type of failure of beam B<sub>1</sub> was due to the removal of the shear reinforcement from the critical shear zone. The general trend of failure and patterns of cracks for beams (B<sub>2</sub>, B<sub>5</sub>) has low percentage of fiber up to 0.2% were similar to that of the control beam B<sub>1</sub>, however slightly higher number of cracks were observed. Increasing the value of percentage of steel or glass fibers (up to 0.6 %) resulted in higher value of first cracking load as well as higher numbers of cracks. Compared to the control beam B<sub>1</sub>, the presence of fibers has obviously positively affected the ductility of beams (B<sub>3</sub>, B<sub>4</sub>, B<sub>6</sub> and B<sub>7</sub>). The comparisons between the beams in group I and group II showed that the presence of stirrups 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.

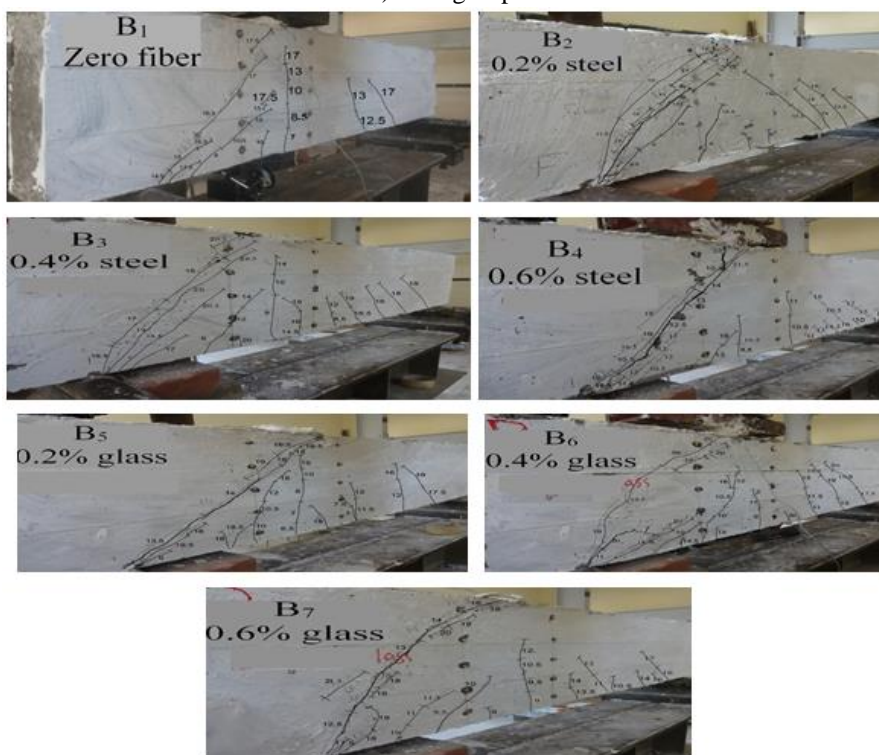
### 5.2. Shear cracking load

The first shear cracking load (FSCL) is the load at which the first diagonal crack was initiated in the critical shear zone. Figure (4) and table (4) show the first shear cracking load for all RC tested beams. Compared to the control beam A<sub>1</sub>, beams (A<sub>2</sub>, A<sub>3</sub>, A<sub>4</sub> and A<sub>5</sub>) (have stirrups in the critical shear zone) showed higher values of FSCL with the enhancement ranged from 5.88% to 23.53%. The presence of 0.2% steel fibers for beam A<sub>2</sub> and the presence of 0.6% steel fiber for beam A<sub>3</sub> resulted in 17.65 % and 23.53% increase for the

values of the FSCL, respectively. However, the presence of 0.2% and 0.6% of glass fiber for beams  $A_4$  and  $A_5$  led to an enhancement 5.88% and 11.76%, respectively. The use of steel fibers, showed higher values of the shear cracking loads than the use of glass fibers, because the steel fibers have higher values of modulus of elasticity and tensile strength.



a) First group beams



b) Second group beams

Fig. 3. Patterns of cracks and shapes of failure for beams

The presence of steel or glass fibers for the beams in the second group (have no stirrups in the critical shear zone) showed 6.25% to 31.25% increase for the value of the FSCL when compared to control beam B<sub>1</sub>. The presence of 0.2%, 0.4% and 0.6% of steel fibers for beams B<sub>2</sub>, B<sub>3</sub> and B<sub>4</sub> resulted in 12.5%, 25% and 31.25% increase for the values of the FSCL, respectively. However, the presence of 0.2%, 0.4% and 0.6% of glass fiber for beams B<sub>5</sub>, B<sub>6</sub> and B<sub>7</sub> led to 6.25%, 12.50% and 18.75% increase for the values of the FSCL, respectively.

Compared to the control beam, the presence of fiber showed higher enhancement for the values of the FSCL particularly for beams with no stirrups in the critical shear zone when compared to those having stirrups in the critical shear zone. This may be attributed to the high shear capacity of beams provided with stirrups.

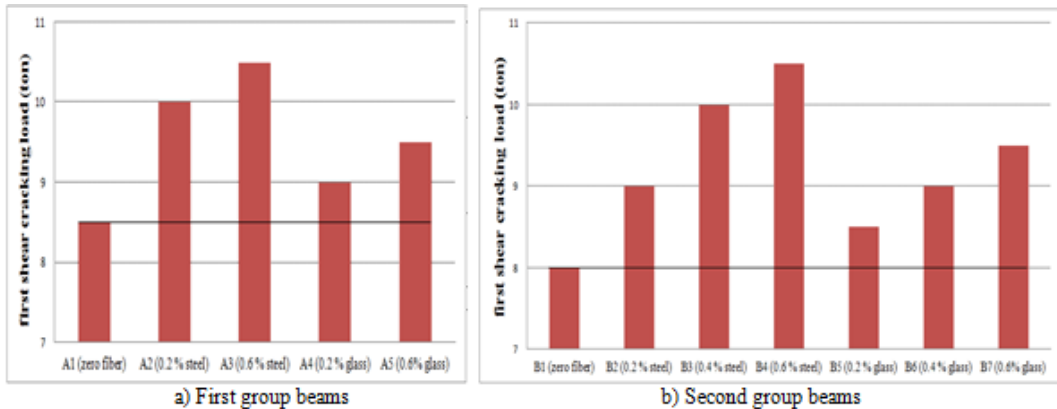


Fig. 4. First shear cracking load for beams

### 5.3. Ultimate load

Figure (5) and table (4) show that the presence of fibers led to enhancement for the value of the ultimate loads particularly for beams of highest fiber volume fraction. Beams (A<sub>2</sub>, A<sub>3</sub>, A<sub>4</sub> and A<sub>5</sub>) (have stirrups in the critical shear zone) showed about 4.21% to 25.79% increase for the value of the ultimate load when compared to the control beam A<sub>1</sub>. The presence of 0.2% and 0.6% steel fibers for beams A<sub>2</sub> and A<sub>3</sub> resulted in 18.95% and 25.79% increase for the values of the ultimate load, respectively. However, the presence of 0.2% and 0.6% glass fibers for beams A<sub>4</sub> and A<sub>5</sub> led to the increase of the percentage of the value of the ultimate load to 4.21% and 18.42%, respectively. The values of the ultimate load by using steel is higher than the values of the ultimate load by using glass fibers, because the steel fibers have higher values of modulus of elasticity and tensile strength.

Beams in the second group (have fiber and have no stirrups in the critical shear zone) showed higher values of the ultimate load with percentage ranged from 2.86% to 28.57% when compared to the control beam B<sub>1</sub>. The presence of 0.2%, 0.4% and 0.6% steel fibers for beams B<sub>2</sub>, B<sub>3</sub> and B<sub>4</sub> resulted in 11.43%, 17.14% and 28.57% increase for the values of the ultimate loads, respectively. However, the presence of 0.2%, 0.4% and 0.6% of glass fiber for beams B<sub>5</sub>, B<sub>6</sub> and B<sub>7</sub> led to 2.86%, 14.29% and 22.86% increase for the value of the ultimate load, 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.

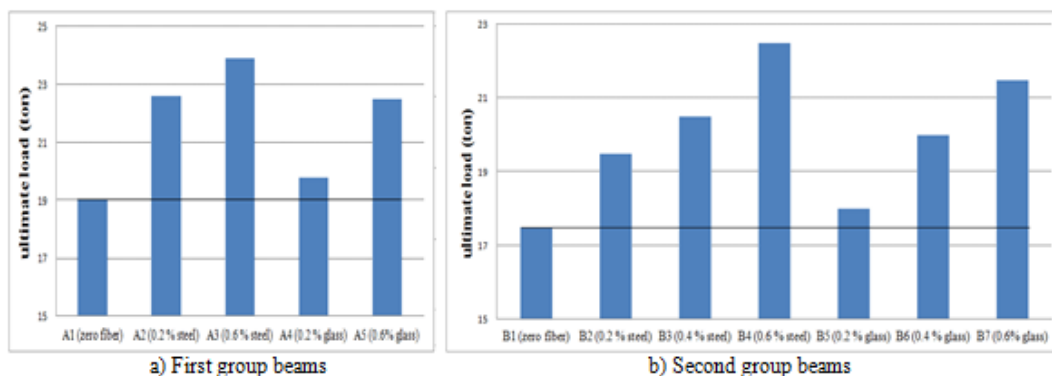


Fig. 5. Ultimate load for beams

Table 4.

Experimental Test Results of Beams

Series	No. of Beams	$V_f$ %	Type of fiber	$P_{cr}$	$P_{ult.}$	$\frac{P_{cr.}}{P_{ult.}}$	$\delta_u$	$\frac{P_{cr.}}{P_{cr(control.)}}$	$\frac{P_{ult.}}{P_{ult(control.)}}$	$\frac{\delta_u}{\delta_u(control.)}$	Mode of failure	
				ton	ton							mm
<b>first group with stirrups in shear zone</b>												
I	A <sub>1</sub>	0.0	No fiber	8.5	19	0.45	2.4	1.00	1.00	1.00	Shear failure	
	A <sub>2</sub>	0.2	Steel	10	22.6	0.44	2.85	1.18	1.19	1.19		
	A <sub>3</sub>	0.6		10.5	23.9	0.44	3.26	1.24	1.26	1.36		
	A <sub>4</sub>	0.2	Glass	9	19.8	0.45	2.75	1.06	1.04	1.15		
	A <sub>5</sub>	0.6		9.5	22.5	0.42	3.10	1.12	1.18	1.29		
<b>Second group without stirrups in shear zone</b>												
II	B <sub>1</sub>	0.0	No fiber	8	17.5	0.46	2.2	1.00	1.00	1.00		
	B <sub>2</sub>	0.2	Steel	9	19.5	0.46	2.6	1.13	1.11	1.18		
	B <sub>3</sub>	0.4		10	20.5	0.49	2.71	1.25	1.17	1.23		
	B <sub>4</sub>	0.6		10.5	22.5	0.47	2.88	1.31	1.29	1.31		
	B <sub>5</sub>	0.2	Glass	8.5	18	0.47	2.44	1.06	1.03	1.11		
	B <sub>6</sub>	0.4		9	20	0.45	2.63	1.13	1.14	1.20		
	B <sub>7</sub>	0.6		9.5	21.5	0.44	2.73	1.19	1.23	1.24		

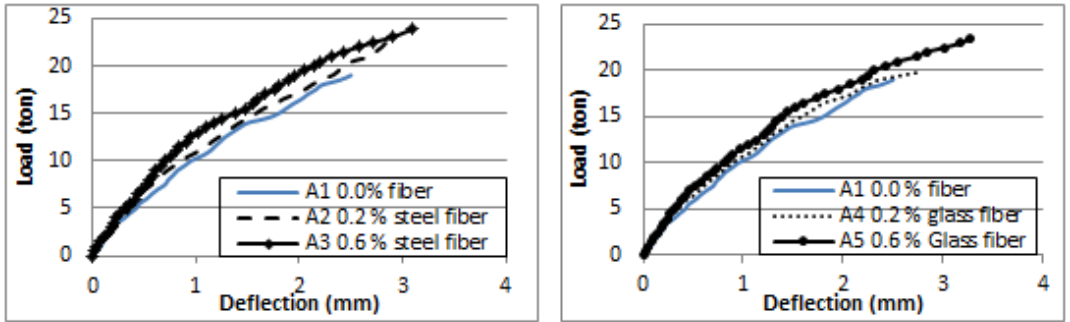
$V_f$ : fiber volume content,  $F_{cu}$ : average compressive strength of beams,  $P_{cr}$ : first crack load,  $P_{ult.}$ : ultimate load,  $\delta_u$ : max. Deflection,  $A_1$ : control beam at first group,  $B_1$ : control beam at second group.

#### 5.4. Deflection

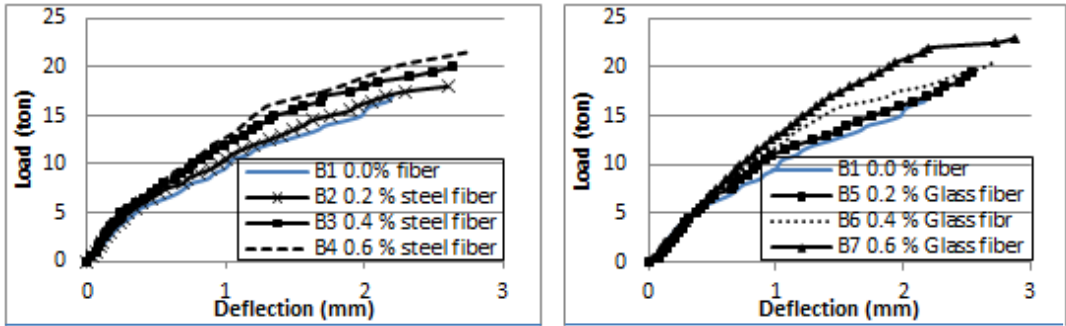
The load-deflection relationship for all RC tested beams is presented in figure (6) and the maximum values of deflection are tabulated in table (4). The curves show that the beams exhibit three stages: the first stage which is the un-cracking stage. This stage starts from zero loading till the first flexural cracking load. The behavior in this stage is characterized by the un-cracked behavior where the maximum tensile stress is less than the concrete flexural tensile strength. The second stage which is the post-cracking stage begins with the first flexural 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.

For beams having 0.4% and 0.6% fiber volume fraction at a certain load, the values of the deflection was found to be reduced. 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 low fiber volume fraction (0.2%) showed no clear difference in the deflection curve when compared to the control beam. At failure load; the presence of fibers resulted in increase the values of the maximum deflection with percentage ranged from 10.76% to 29.17 %. Because the presence of fibers resulted in higher values of ultimate load as well as higher values of the maximum deflection.



a) First group beams



b) Second group beams

**Fig. 6.** Load-deflection curves for tested beams

5.5. Ductility

Figure (7) shows the values of the ductility for all tested beams. The ductility can either be represented in terms of the ratio of maximum deflection to the yield deflection; both measured at under point load, or in terms of the stain energy consumed by the beams during the test measured as the area under the load deflection curve. Since the flexure mode of failure has been secured for all specimens to allow for shear mode of failure, it is found more appropriate to use the second measure of ductility. Beams (A<sub>2</sub>, A<sub>3</sub>, A<sub>4</sub> and A<sub>5</sub>) (have stirrups in the critical shear zone) showed about 25.96% to 76.86% percentage of increase for the values of the ductility when compared to the control beam A<sub>1</sub>. The presence of 0.2% and 0.6% steel fibers for beams A<sub>2</sub> and A<sub>3</sub> resulted in 36.32% and 76.86% increase for the values of the ductility, respectively. However, the presence of



0.2% and 0.6% glass fibers for beams A<sub>4</sub> and A<sub>5</sub> led to the increase of the value of the ductility by 25.96% and 57.46 %, respectively.

Beams in the second group (have fiber and have no stirrups in the critical shear zone) showed higher values of the ductility with percentage ranged from 26.52% to 78.42% when compared to the control beam B<sub>1</sub>. The presence of 0.2%, 0.4% and 0.6% steel fibers for beams B<sub>2</sub>, B<sub>3</sub> and B<sub>4</sub> resulted in 39.44%, 59.11% and 78.42% increase for the values of the ductility respectively. However, the presence of 0.2%, 0.4% and 0.6% of glass fiber for beams B<sub>5</sub>, B<sub>6</sub> and B<sub>7</sub> led to 26.52%, 54.75% and 77.32 % increase for the value of the ductility respectively. The presence of steel fibers resulted in higher value of ductility than the use of glass fibers, because the steel fibers have higher values of tensile strength and modulus of elasticity.

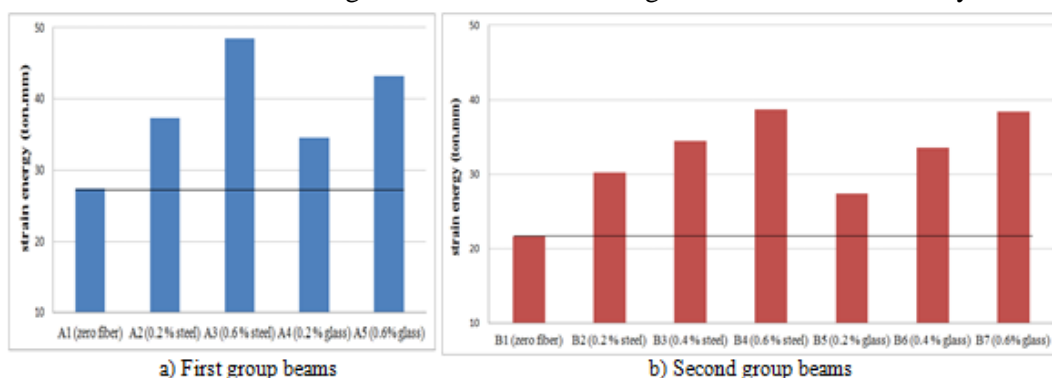


Fig. 7. Ductility measured for all beams

### 5.6. Stirrups strain

Electrical strain gauges were used to measure the strains induced at the center of stirrups. Figure (8) shows the relation between the applied load and the corresponding strain in the stirrups for the tested beams in group (1). The presence of steel or glass fibers led to decrease the value of the stirrup strain at a certain load. It also increases the load carrying capacity of beams and consequently increases the values of the maximum stirrups strain. The values of the maximum stirrups strain approximately equal to the value of the yield strain of stirrups.

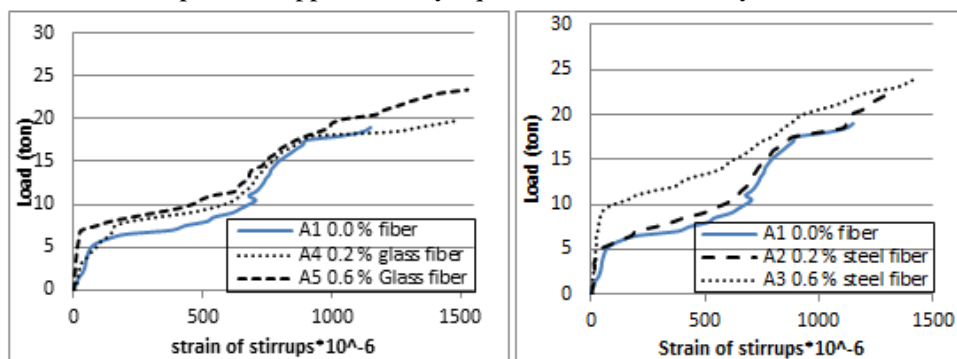
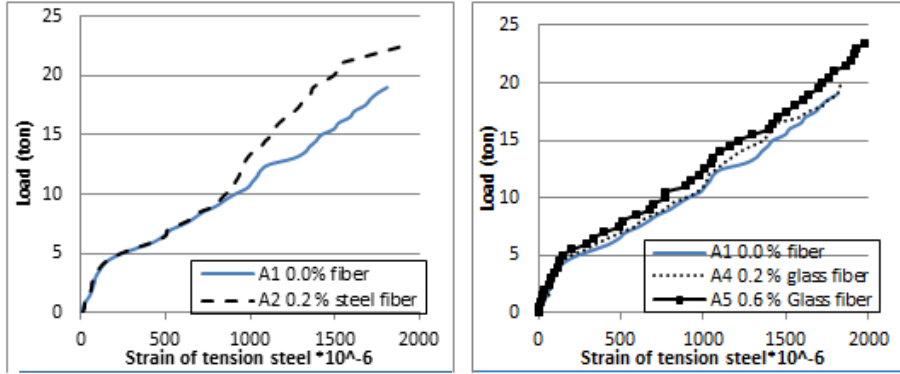


Fig. 8. Load-stirrups strain curves for beams

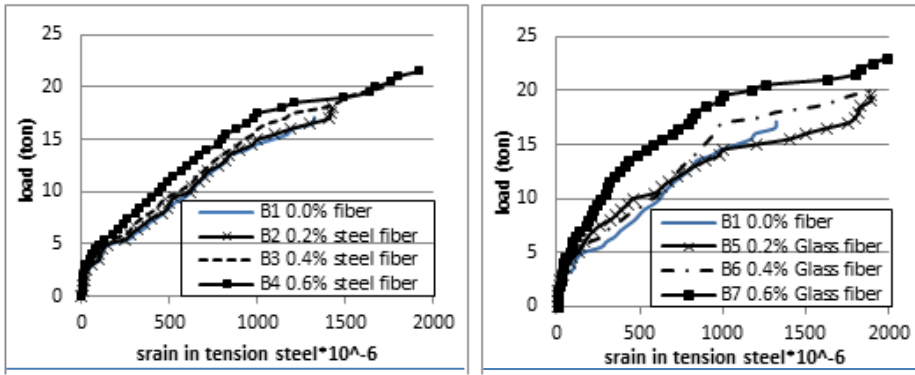
### 5.7. Strain in main steel

Figure (9) 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. Unfortunately, the strain gauge for beam A<sub>3</sub> was

damaged. 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 steel or glass fibers decreases the value of steel strain at a certain load. 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.



a) First group beams



b) Second group beams

**Fig. 9.** Load-tension steel strain curves for beams

5.8. Concrete strain

Figure (10) 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. At a certain load, the increase of the percentage of fibers led to decrease the concrete strain. Due to the presence of fiber, concrete absorbs more energy, and as a result the values of both modulus of elasticity and tensile strength of concrete increases. At failure load, the value of the maximum concrete strain increases with increasing the percentage of steel or glass fiber. The values of the maximum strain of concrete for all beams were less than 0.002.

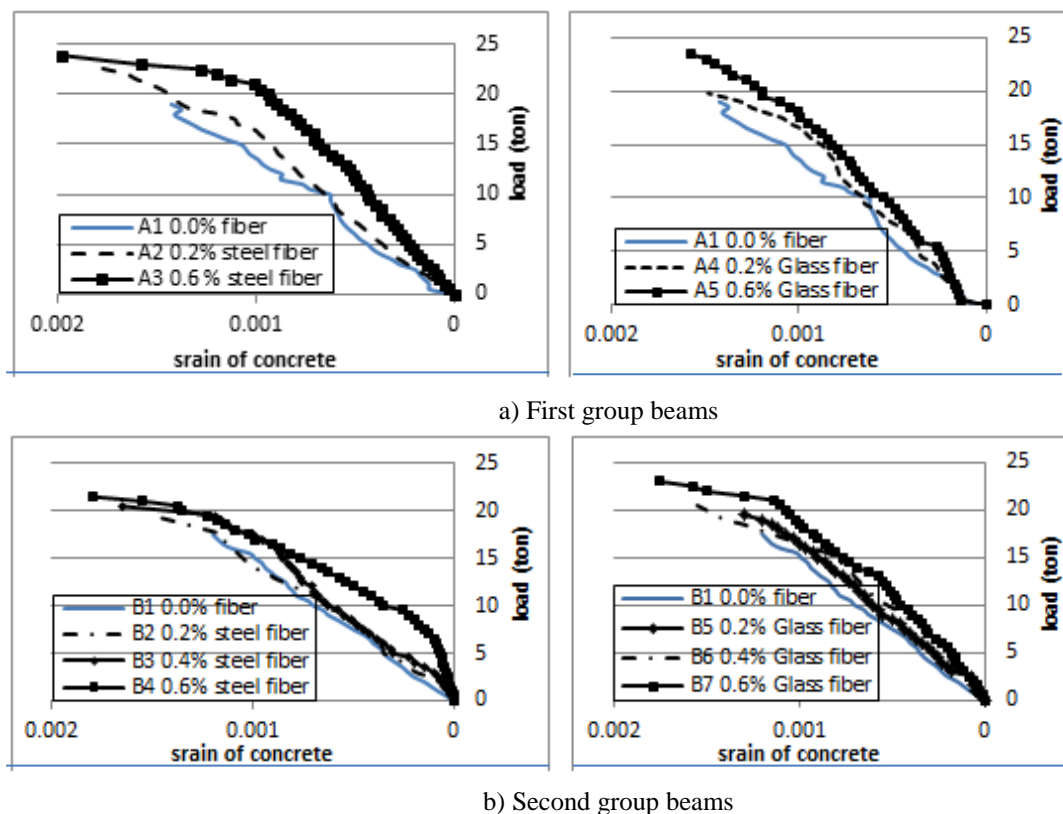


Fig. 10. Load-concrete strain curves in compression for beams

## 6. Conclusions

Gist of this research has been presented in this paper with a view to understand the role of fibers on the shear strength of concrete. Based on the study presented in this paper, the study has revealed the following conclusions:

- 1- The shear cracking load and the ultimate load increase with increasing of the percentage of fibers, because the fibers increase the tensile strength of concrete.
- 2- The presence of 0.2% and 0.6 % steel fibers resulted in 12.5 % and 31.25% increase for the values of the first shear cracking load, respectively. However, they led to 11.43% and 28.57% increase for the values of the ultimate load, respectively.
- 3- The presence of 0.2% and 0.6% glass fibers led to the increase of the percentage of the value of the first shear cracking load to 5.88% and 18.75%, respectively. As well as, led to 2.86% and 22.86% increase for the values of the ultimate load, respectively.
- 4- The addition of fibers not only improved the ultimate load capacity of the tested specimens, but also increased the stiffness and hence reduced the deflection at the same load. This improvement is more pronounced in case of beams reinforced with fibers and stirrups.
- 5- The values of the maximum deflection increase with the increase of percentage of fibers. This is primarily because concrete becomes more ductile and hence it fails after deformation.
- 6- The presence of stirrups in the shear zone minimizes the dangerous of the sudden and brittle type of the shear failure. Also, the presence of fiber and stirrups led to increase the value of ductility due to the fact that fibers increase the tensile strength of concrete.

- 7- The influence of steel fibers on shear strength, stiffness and ductility of concrete beams is higher than the influence of the glass fiber, because the steel fibers have higher value of the modulus of elasticity and tensile strength.

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## سلوك القص للكمرات المسلحة بالألياف

### الملخص بالعربي

مقاومة القص للخرسانة المسلحة بالألياف لها أهمية قصوي في التصميم الإنشائي. قد يحدث انهيار قص للأعضاء الخرسانية مثل الكمرات الخرسانية الطرفية والأقواس ويكون هذا الإنهيار مفاجئ وقصيف. ووجد أن احتواء الألياف يؤثر ايجاباً علي السلوك العام لها. كما أنها تزيد من نقل قوة القص المتبقية و تقلل من تكوين واتساع الشروخ. ويوجد الكثير من العوامل المؤثرة علي مقاومة القص للخرسانة المسلحة بالألياف. لذلك تم عمل دراسة معملية لتحقيق نقل قوي القص من خلال الخرسانة المسلحة بالألياف. وتناول هذا البحث دراسة سلوك مقاومة القص للكمرات المسلحة بالألياف. والمتغيرات التي تم دراستها معملياً هي نوع ونسبة الألياف وذلك من خلال وجود وعدم وجود كانات في منطقة القص الحرجه. وأوضحت النتائج المعملية أن إحتواء الألياف أدت إلي زيادة قيم مقاومة القص والجساءة والمطولية والتحكم في الشروخ. كما وجد أن استخدام الألياف الفولاذية تحسن من سلوك القص للخرسانة بدلاً من استخدام الألياف الزجاجية.