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Shear Strength of Fiber Reinforced Concrete

Prof. Dr. Laila Mahmoud Abdul-Hafez, Associate Prof. Yasser Rifat Tawfic,
Associate Prof. Osama Hammed, Eng. Ahmad Saudi Abdul-Zaher

Abstract

Shear strength of fiber reinforced concrete (FRC) has its prime importance in structural design. Concrete members like brackets, corbels and ledger beams may fail in direct shear. Such failure can be sudden and brittle. The presences of fibers positively affect 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 is precisely detected. Experimental investigation was carried out to study the shear transfer of un-cracked fibrous concrete. This study investigates the behavior of shear strength of FRC beams and the direct shear strength of FRC by testing push-off specimens. The experimental parameters were the type of fibers, the volume percentage of fibers, the concrete compressive strength and the presence of stirrups in beams. Test results showed that presence of fibers increases the concrete shear strength, reduces numbers and width of cracks and increases the stiffness and ductility. The use of steel fiber experienced more shear strength, ductility and stiffness than glass fiber.

Introduction

The brittle and catastrophic shear failure of concrete can be relieved by the addition of the fiber. Previous studies have shown that steel fibers can improve the shear performance of concrete [4-6-7-8-13]. The use of fibers as shear reinforcement decreases crack width and the control of concrete cracking. However, the results obtained are highly variable. This variability is due to the great diversity of mechanical properties of the FRC, specifically its tensile strength. Furthermore, most were developed for SFRC with up to 1 % in fiber content [2-3-9-10-11-14]. Fibers were used in concrete by Swamy et al. [12] to study their effect on shear transfer. Test results showed that inclusion of fibers increase the remaining shear transfer strength which was generally lower in light- weight concrete than in normal weight concrete. It was shown also that the shear transfer stiffness can be related to the crack width. Tan and Mansur [13] indicated that the inclusion of fibers significantly improves the strength and deformation characteristics of the concrete.

1- **Prof. Dr. Laila Mahmoud Abdul-Hafez** (Head of civil engineering department the prof. of reinforcement concrete structure at El-Minia university)
2- **Associate Prof. Yasser Rifat Tawfic** (Associate prof. of reinforcement concrete structure at El-Minia university)

3- **Associate Prof. Osama Hammed** (Associate prof. of project management at El-Minia university)
4- **Eng. Ahmad Saudi Abdul-Zaher** (Demonstrator of Higher Institute of Engineering and Technology in Minia)

Khaloo and Kim [5] 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. Aziz [1] studied the effect of steel fibers on the shear transfer of plain reinforced concrete specimens. The results showed that the lateral separation and stirrups strain decrease with the increase of fibers volume fraction and reinforcement parameter.

Experimental program

The experimental program was divided into two parts:

Part one includes 12 rectangular reinforced concrete beams have 12 cm width, 30 cm depth and 130 cm length show in figures (1) and (2) and table (1), were tested to evaluate the effect of addition of steel fiber or glass fiber with various content (0, 0.2, 0.4 and 0.6 %) by the volume of concrete with constant compressive strength 300 kg/cm^2 for two groups, first group presence of stirrups but second group without contain stirrups in the region of shear.

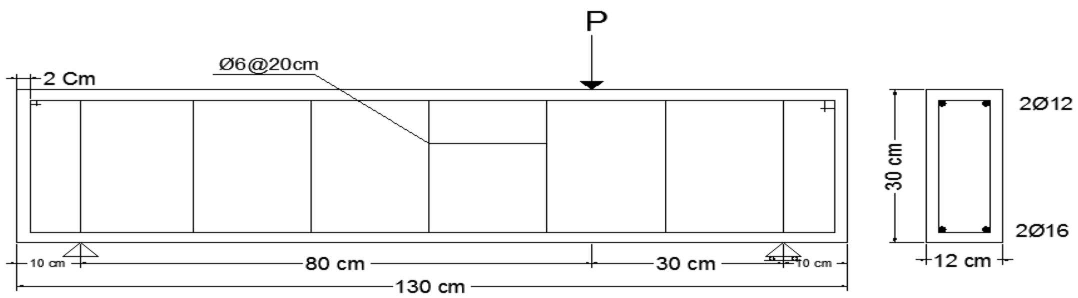


Figure (1) Details of First Group Tested Beams (A_1 to A_5)

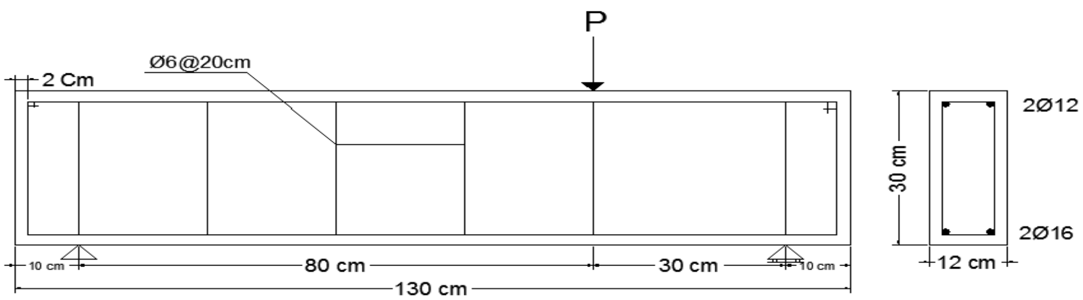
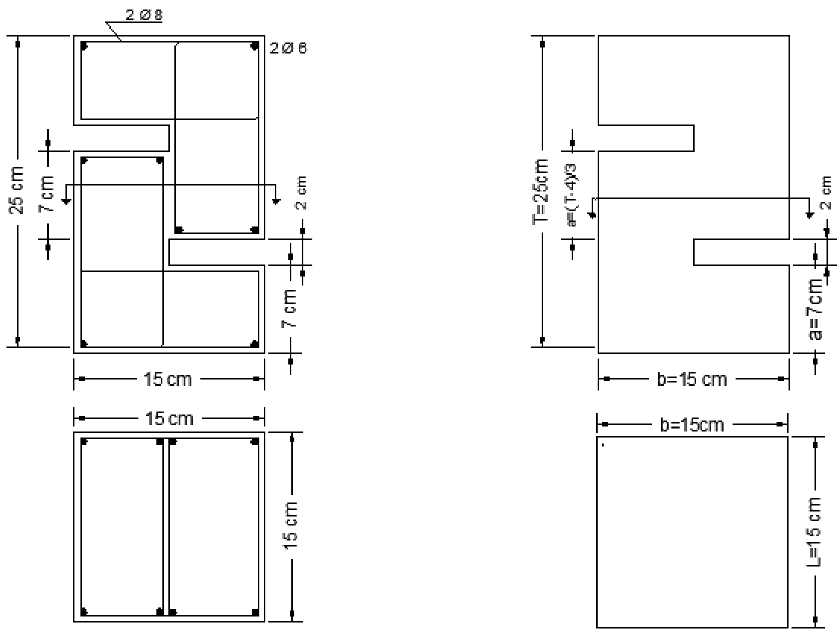


Figure (2) Details of Second Group Tested Beams (B_1 to B_7)

Table (1) Details of Reinforced Concrete Beams

Group	No. of Beams	Dimension (cm)	Compressive strength F_{cu} (kg/cm^2)	Percentage of fiber V_f %	Length of fiber (mm)	Type of fiber
I	A 1	12*30*130	300	-----	----	No Fiber
	A 2			0.20	50	Steel fiber (Corrugated)
	A 3			0.60		
	A 4			0.20	12	Glass fiber
	A 5			0.60		
II	B 1			-----	----	No Fiber
	B 2			0.20	50	Steel fiber (Corrugated)
	B 3			0.40		
	B 4			0.60		
	B 5			0.20	12	Glass fiber
	B 6			0.40		
	B 7			0.60		

Part two includes 27 specimens 15x15x25 cm show in figure (3) and table (2), were tested to evaluate the effect of the inclusion of different content of steel fiber or glass fiber with various content (0, 0.2, 0.4, 0.6 and 0.8 %) by the volume of concrete with different compressive strength (200, 300 and 400 kg/cm^2).



a)Details of tested specimens b) Geometry of tested specimens

Figure (3) Details of Tested Specimens

Table (2) Details of Plain Concrete Specimens

Series	No. of specimens	Dimension B*L*T (cm)	F cu (kg/cm^2)	Percentage of fiber V_f %	Length of fiber (mm)	Type of Fiber
I	S1-1	15*15*25	200	-----	-----	No Fiber
	S1-2			0.20	25	Steel fiber (Corrugated)
	S1-3			0.40		
	S1-4			0.60		
	S1-5			0.80		
	S1-6			0.20	12	Glass fiber
	S1-7			0.40		
	S1-8			0.60		
	S1-9			0.80		
II	S2-1		300	-----	-----	No Fiber
	S2-2			0.20	25	Steel fiber (Corrugated)
	S2-3			0.40		
	S2-4			0.60		
	S2-5			0.80		
	S2-6			0.20	12	Glass fiber
	S2-7			0.40		
	S2-8			0.60		
	S2-9			0.80		
III	S3-1		400	-----	-----	No Fiber
	S3-2			0.20	25	Steel fiber (Corrugated)
	S3-3			0.40		
	S3-4			0.60		
	S3-5			0.80		
	S3-6			0.20	12	Glass fiber
	S3-7			0.40		
	S3-8			0.60		
	S3-9			0.80		

Material properties

The test specimens were cast using coarse aggregate, fine aggregate, cement, water, silica fume, super plasticizer and fibers.

Coarse aggregate: was gravel supplied from local quarries, have maximum size of gravel 20 mm used in this work, the specific gravity, volume weight, fineness modulus respectively were 2.5, 1.54 t/m^3 and 6.37.

Fine aggregate: was natural desert sand, clean and free from silt and clay. The surface texture of particles was smooth, the specific gravity, volume weight, fineness modulus respectively were 2.5, 1.7 t/m3 and 3.4.

Cement: was ordinary Portland cement, the fineness specific surface area was 3250 cm^2/g.

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

Silica fume: is used in concrete to improve its properties. It has been found that silica fume improves compressive strength, bond strength and reduces permeability.

Super plasticizer: improve the workability and compressive strength of concrete.

Fibers: used two types of fibers steel fiber and glass fiber, the properties of steel and glass fibers show in table (3).

Table (3) Properties of Fiber

Materials	Type	Density (t/m^3)	Young's modulus (t/cm^2)	Length (mm)	Thickness (mm)
Steel	Corrugated	7.85	2100	50	1
				25	
Glass	Straight	2.6	750	12	0.1

Mixture proportioning

Mix designs were prepared to produce strength of concrete 200, 300, 400 kg/cm^2 after 28 days. The details of the mix proportion by weight and the used materials are given in table (4).

Table (4) Concrete Mix Properties

Mix No.	F_{cu} kg/cm^2	Components materials						Percentage %		
		C kg/m^3	G kg/m^3	S kg/m^3	W liter/m^3	SP liter/m^3	SF kg/m^3	W/C	SF/C	SP/C
1	200	250	1280	690	112	0	0	44.80	0	0
2	300	400	1188	590	148	6.00	0	37.00	0	1.5
3	400	450	1188	590	155	6.75	45	34.44	10	1.5

C: Cement, **G:** Gravel, **S:** Sand**,** **W:** Water, **SF:** Silica fume, **SP:** Super plasticizer, **F_{cu}:** compressive strength at 28 days

Instrumentation and Test Procedure

Dial gauge to measured displacement and recorded at the bottom of the first part of specimens, also two rows of demec studs for measured strain of concrete specimens, were stuck around the vertical axis of specimens on one side of the specimens surface. These positions are shown in figure (7) for direct shear specimens. But beams measured deflection was recorded at the bottom surface at 30 cm of support, i.e; under the load. Five rows of demec studs around the vertical axis of beams on one side of the beam. For each beam one strain gauge was attached to the main steel under the load and one strain gauge was attached to the stirrups which located in the shear zone, as shown in figures (4) to (6). All direct shear specimens and beams were tested after 28 days the load reading started when the surface top of concrete contacted the upper jaw of the machine was considered. As the beginning of loading, the corresponding strains were also recorded. Afterwards, the applied load was increased gradually by 0.5 ton/time. At each increment the deflection and strain of concrete and steel were recorded.

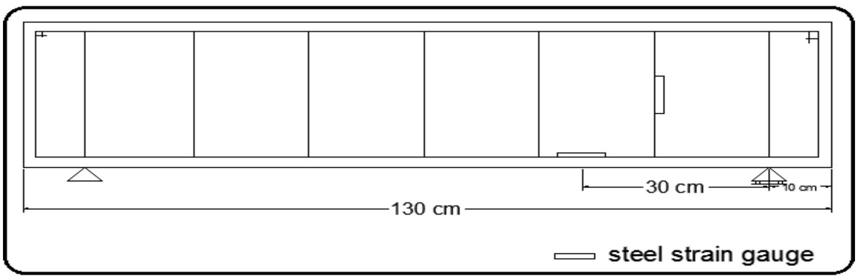


Figure (4) Location of Electrical Strain Gauge of Steel with from A_1 to A_5 Beams

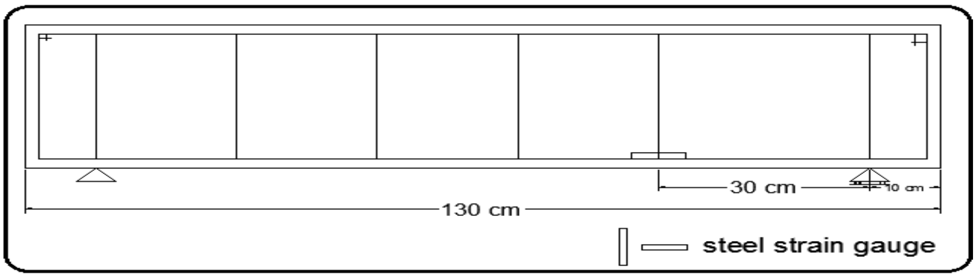


Figure (5) Location of Electrical Strain Gauge of Steel with from B_1 to B_7 Beams

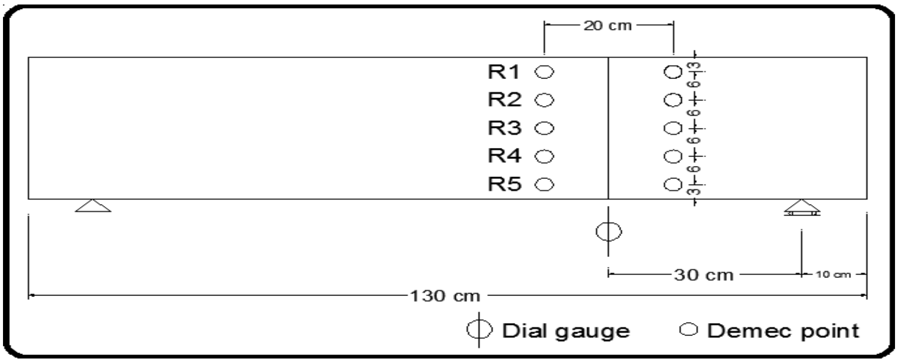


Figure (6) Location of Dial Gauge and Demec Points

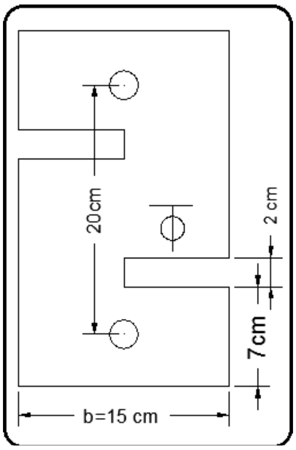


Figure (7) Location of Dial Gauge and Demec Points
for Direct Shear Specimens

Results and Discussion

The results included cracking load, ultimate load, strain of concrete, strain in tension steel, strain in stirrups and deflection, for beams and specimens, show in tables (5) and (6).

Cracking pattern and Ultimate Load

For beams ultimate and cracking load increases with the increase of the percentage of fibers, this due to the modulus of elasticity of concrete consequently the stiffness of the beams increases with the increase of the fiber content. Numbers of cracks are reduced in the region of shear when using fibers too. It can be seen that the cracks appeared on the surface of concrete when using glass fiber lower than steel fiber, it may be the effect of the length of fiber and the propagation the fibers, as show in figure (8) and table (5). **For specimens** ultimate load increases with increasing of the percentage of fibers only or increases the compressive strength only or both of them. The shear cracks appear near the upper and lower notch and with increasing loads the cracks were propagating toward the center of the specimens, as show in figure (9) and table (6).

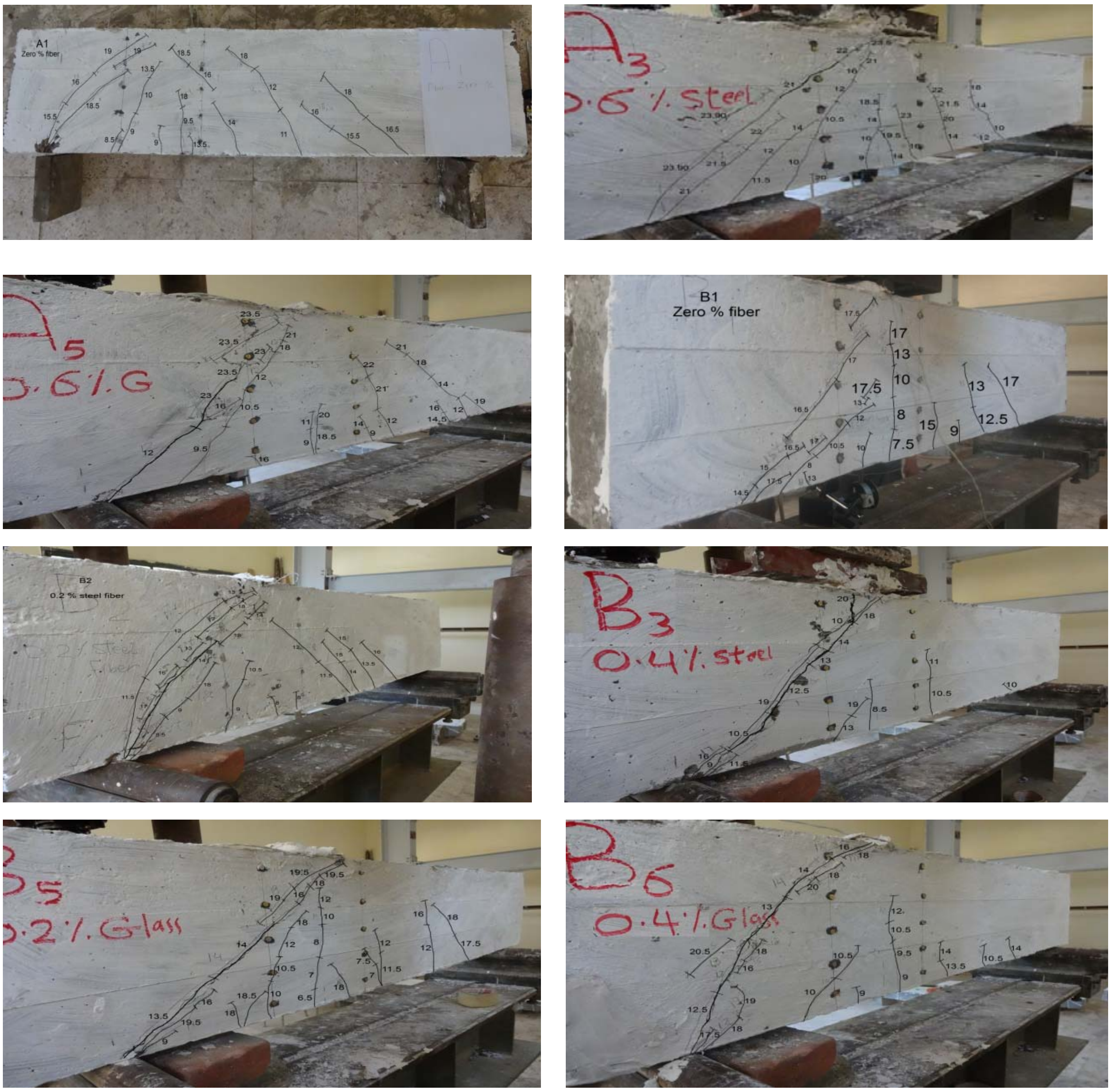


Figure (8) Crack Pattern and Shape of Failure of Beams

Figure (9) Crack Pattern and Shape of Failure of Specimens

Series	No. of Beams	V_f %	Type of fiber	F_{cu} kg/cm^2	P_{cr} ton	$P_{ult.}$ ton	$\frac{P_{cr}}{P_{ult.}}$	δ_u mm	ε_{ms}	ε_{ss}	ε_{cu}	$\frac{P_{cr}}{P_{cr(control)}}$	$\frac{P_{ult}}{P_{ult(control)}}$	$\frac{\delta_u}{\delta_{u(control)}}$	Mode of failure
I	A_1	0.0	No fiber	343.70	8.5	19	0.45	2.4	0.0018300	0.000305	-0.00143	1.00	1.00	1.00	Shear failure

Table (5) Experimental Test Results of Beams

	A_2	0.2	Steel	348.98	10	22.6	0.44	2.85	0.0022300	0.001733	-0.00173	1.18	1.19	1.19	
	A_3	0.6		358.46	10.5	23.9	0.44	3.1	---------	0.001830	-0.00198	1.24	1.26	1.29	
	A_4	0.2	Glass	347.20	9	19.8	0.45	2.75	0.0018300	0.001870	-0.00145	1.06	1.04	1.15	
	A_5	0.6		352.92	9.5	23.5	0.40	3.26	0.0022200	0.002150	-0.00158	1.12	1.24	1.36	
II	B_1	0.0	No fiber	343.70	8	17.5	0.46	2.2	0.0013220	0	-0.00120	1.00	1.00	1.00	
	B_2	0.2	Steel	348.98	8.5	19.5	0.44	2.6	0.0020400	0	-0.00150	1.06	1.03	1.18	
	B_3	0.4		353.16	9	20.5	0.44	2.71	0.0020900	0	0.00165	1.13	1.17	1.23	
	B_4	0.6		358.46	9.5	23	0.41	2.88	0.0021200	0	-0.00180	1.19	1.31	1.31	
	B_5	0.2	Glass	347.20	9	18	0.50	2.54	0.0014230	0	-0.00130	1.13	1.03	1.15	
	B_6	0.4		350.58	10	20	0.50	2.63	0.0020000	0	-0.00155	1.25	1.14	1.20	
	B_7	0.6		352.92	10.5	21.5	0.49	2.73	0.0020500	0	-0.00172	1.31	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, **δu:** max. deflection, **ε_{ms}**: max. strain in tension steel, **ε_{ss}**: max. strain in stirrups**,** **ε_{cu}**: max. strain of concrete in compression, **A_1:** control beam at first group, **B_1:** control beam at second group.

Series	No. of specimens	V_f %	Type of fiber	F_{cu}	P_{cr}	$P_{ult.}$	$\frac{P_{cr}}{}$	δ_u	ε_{cu}	$\frac{P_{cr}}{P_{cr(control)}}$	$\frac{P_{ult}}{P_{ult(control)}}$	$\frac{\delta_u}{\delta_{u(control)}}$	Mode of

Table (6) Experimental Test Results of Specimens

				kg/cm^2	ton	ton		mm					
I	S1-1	0.0	No fiber	194.81	0.9	3.70	0.24	1.80	-0.00158	1.00	1.00	1.00	Pure shear failure
	S1-2	0.2	Steel	205.93	1.2	4.40	0.27	2.00	-0.00166	1.33	1.19	1.11	
	S1-3	0.4		217.78	1.5	4.90	0.31	2.10	-0.00179	1.67	1.32	1.17	
	S1-4	0.6		229.63	1.7	5.40	0.31	2.15	-0.00185	1.89	1.46	1.19	
	S1-5	0.8		240.74	2.0	6.60	0.30	2.18	-0.00195	2.22	1.78	1.21	
	S1-6	0.2	Glass	200.74	1.0	3.80	0.26	1.95	-0.00168	1.11	1.03	1.08	
	S1-7	0.4		207.41	1.3	4.15	0.31	1.98	-0.00170	1.44	1.12	1.10	
	S1-8	0.6		216.30	1.5	4.90	0.31	2.00	-0.00185	1.67	1.32	1.11	
	S1-9	0.8		228.15	1.7	5.35	0.32	2.05	-0.00196	1.89	1.45	1.14	
II	S2-1	0.0	No fiber	343.70	1.2	4.60	0.26	2.20	-0.00169	1.00	1.00	1.22	
	S2-2	0.2	Steel	349.63	1.5	5.10	0.29	2.30	-0.00178	1.25	1.11	1.28	
	S2-3	0.4		354.07	2.0	5.80	0.34	2.50	-0.00189	1.67	1.26	1.39	
	S2-4	0.6		358.52	2.3	6.90	0.33	2.80	-0.00192	1.92	1.50	1.56	
	S2-5	0.8		367.41	2.8	7.50	0.37	3.00	-0.00206	2.33	1.63	1.67	
	S2-6	0.2	Glass	346.67	1.3	4.90	0.27	2.22	-0.00174	1.08	1.07	1.23	
	S2-7	0.4		351.11	1.5	5.20	0.29	2.25	-0.00178	1.25	1.13	1.25	
	S2-8	0.6		352.59	1.8	6.30	0.29	2.56	-0.00183	1.50	1.37	1.42	
	S2-9	0.8		357.04	2.1	6.90	0.30	2.52	-0.00196	1.75	1.50	1.40	
III	S3-1	0.0	No fiber	374.81	1.5	5.00	0.30	2.70	-0.00198	1.00	1.00	1.00	
	S3-2	0.2	Steel	379.26	1.9	5.70	0.33	2.90	-0.00213	1.27	1.14	1.07	
	S3-3	0.4		383.70	2.4	6.50	0.37	3.10	-0.00222	1.60	1.30	1.15	
	S3-4	0.6		389.63	3.0	8.18	0.37	3.28	-0.00235	2.00	1.64	1.21	
	S3-5	0.8		397.04	3.3	8.60	0.38	3.35	-0.00244	2.20	1.72	1.24	
	S3-6	0.2	Glass	377.78	1.6	5.50	0.29	2.75	-0.00204	1.07	1.10	1.02	
	S3-7	0.4		380.74	2.0	5.80	0.34	2.75	-0.00210	1.33	1.16	1.02	
	S3-8	0.6		383.70	2.5	7.20	0.35	3.02	-0.00217	1.67	1.44	1.12	
	S3-9	0.8		388.15	3.0	8.00	0.38	3.08	-0.00231	2.00	1.60	1.14	

V_f: fiber volume content, **F_{cu}**: average compressive strength of specimens, **P_{cr}**: first crack load, **$P_{ult.}$**.: ultimate load, **δu:** max. deflection.

Deflection

Being the deflection of concrete considered as one of the main parameters. Figures (10) and (11) shows the relationship between the deflection and the applied load for all beams and first group of specimens and tables (5) and (6) summarized the experimental results of all tested specimens. The curves show the effect of increasing of fibers content on the deflection of the tested specimens, at the same load the deflection decreases with the increase of the percentage of fibers however the increasing of the fibers content is accompanied by increasing of the maximum deflection subsequently the ductility of the tested specimens. In general one can conclude that the increase of the modulus of elasticity of concrete consequently the stiffness of the beams increases with the increase of the percentage of fibers. It resembles with the findings of the other experimentally work. The maximum deflection and the stiffness when using glass fiber lower than the steel fiber, may be due to the different effect of the modulus of elasticity or tensile strength of fibers, i.e; the effect of fibers can be seen the ultimate load clearly in all tested specimens curves and have modified from behavior of beams to stiffness and more ductility.

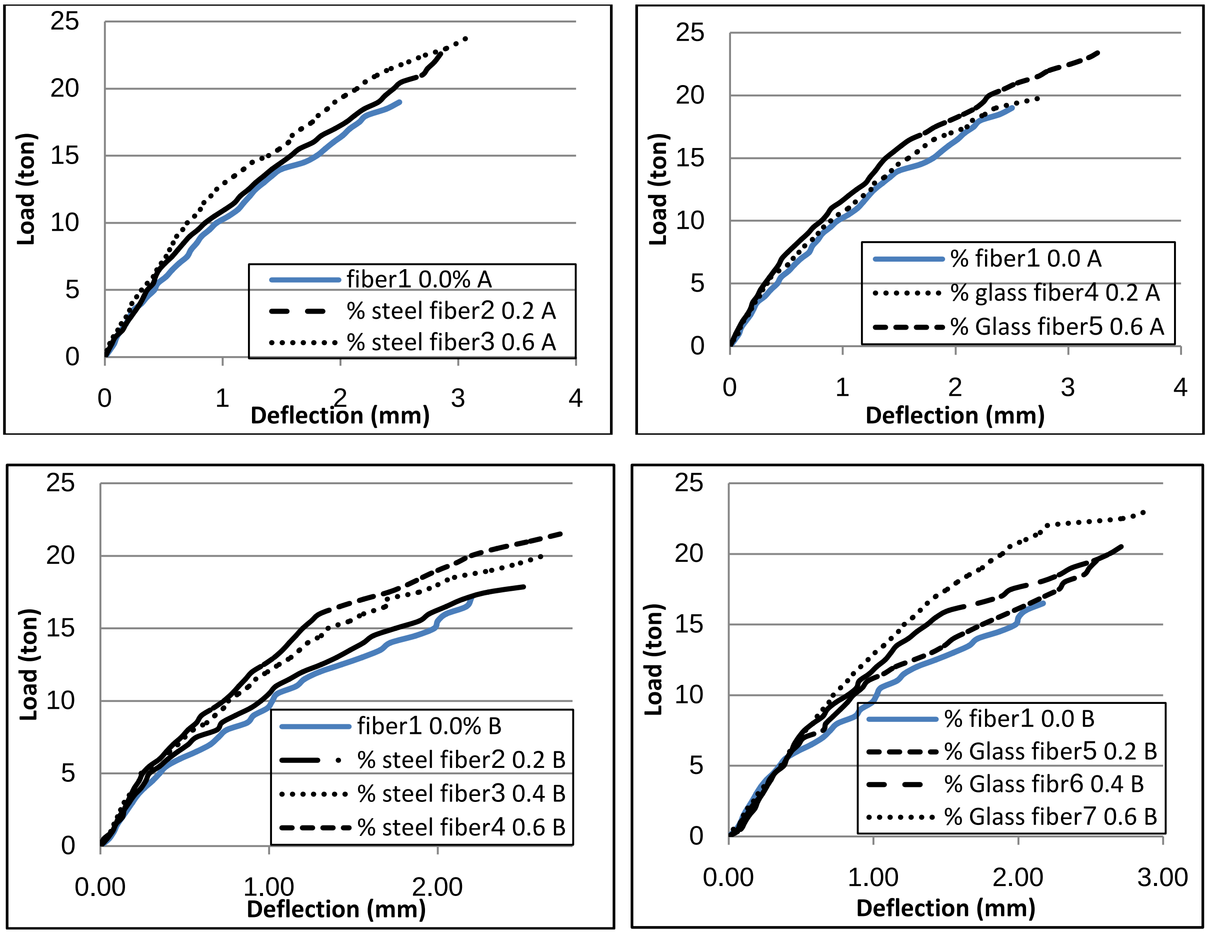


Figure (10) Load-Deflection Curves for Tested Beams

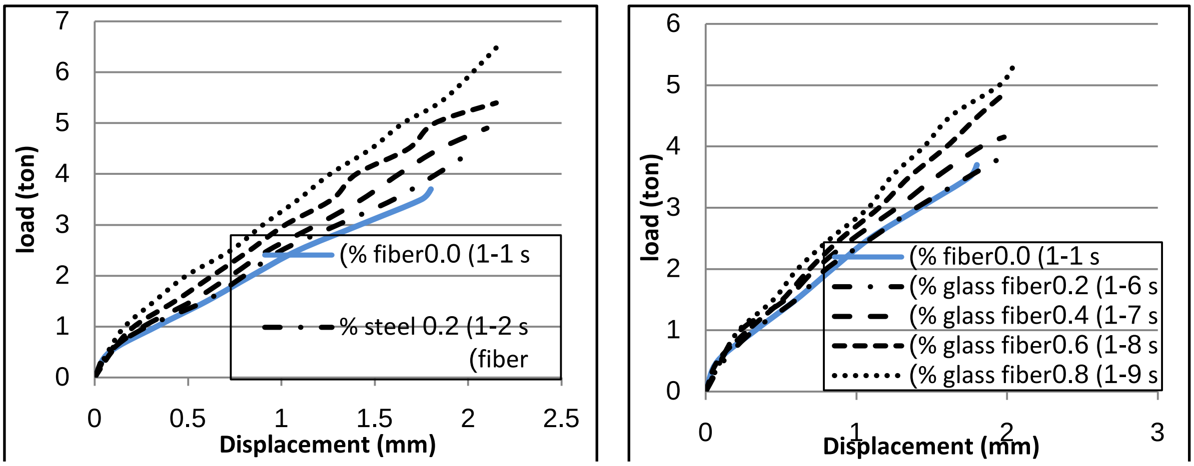


Figure (11) Load- Displacement Curves for first group Specimens

Concrete Strain

Tables (5) and (6) summarized the experimental results of the all tested specimens. Figures (12) and (13) show the load – concrete compressive strain for all beams and first group of specimens. It can be observed that for a certain applied load, the compressive concrete strain decreases as the percentage of fibers increases at the same applied load. Also for a specified compressive concrete strain, the carrying load capacity for beams increases as the percentage of steel or glass fibers increases. One can include the general trend of load-compressive concrete strain is the same of load-deflection. The maximum compressive concrete strain increases with increasing of the percentage of fibers content. i.e; fibers at ultimate stages have more strain capacity.

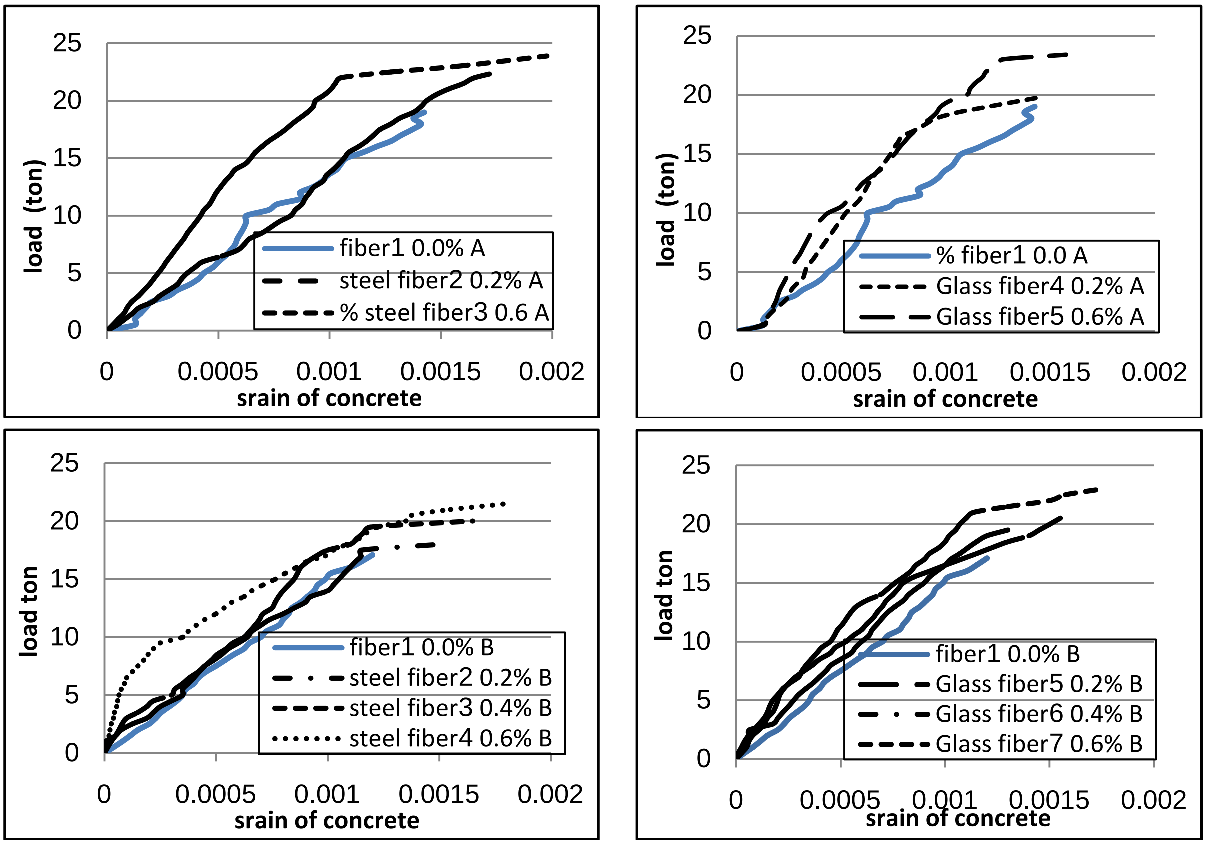


Figure (12) Load-Concrete Strain Curves in Compression for Beams

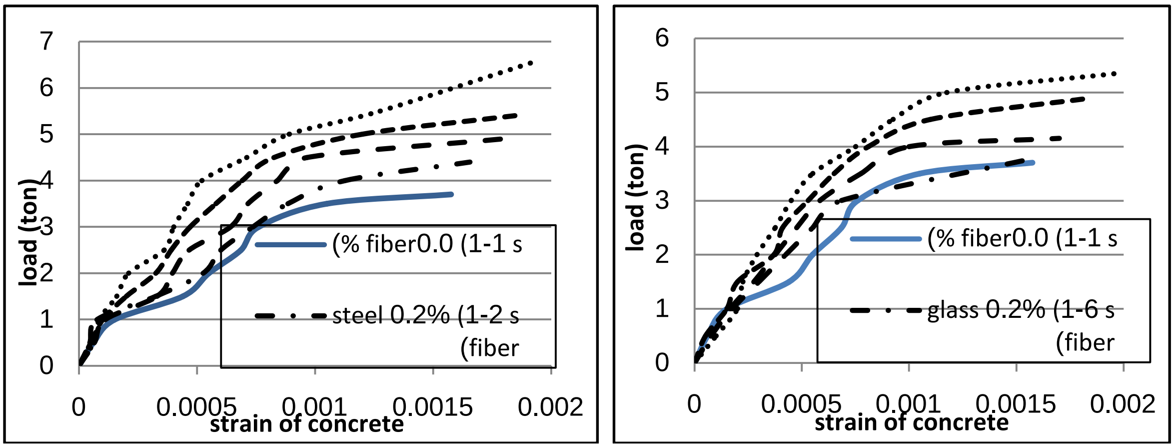


Figure (13) Load-Concrete Strain Curves for Specimens

Tension Steel Strain

Electrical strain gauges were used for measuring the longitudinal strains in tension steel bars for all tested beams. Figure (14) show the relation between the applied load and the corresponding strain in the longitudinal tensile reinforcement for beams. The experimental measured values of the maximum tension steel strains of the tested beams are summarized in table (5). General increasing the percentage of steel or glass fibers decreases the strain in the main steel for the same load, however the maximum main steel strain increases with increasing of the percentage of fibers this due to the increase of the load carrying capacity of the beams.

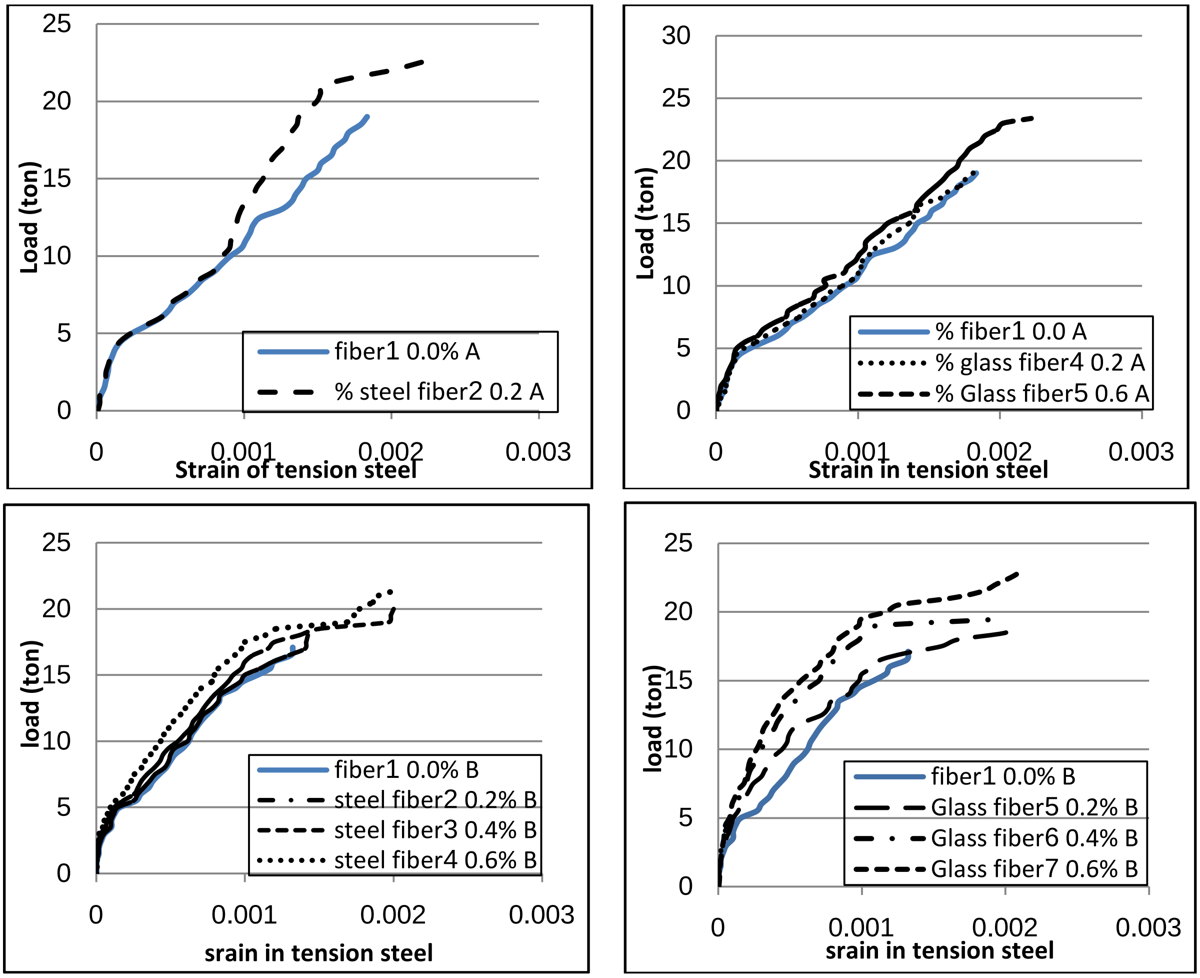
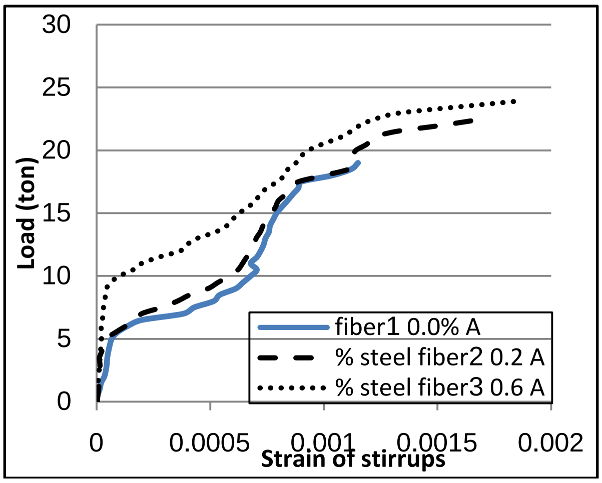


Figure (14) Load-Tension Steel Strain Curves for Beams

Stirrups Steel Strain

Electrical strain gauges were used for measuring the strains in stirrups steel bars for first tested beams group only. Figure (15) show the relation between the applied load and the corresponding strain in the stirrups for beams. The experimental measured values of the maximum stirrups strains of the tested beams are summarized in table (5). In beams A_4 and A_5 may be the device of strain indicator or strain gauge separated during the procedure tested experimentally. General increasing the percentage of steel or glass fibers decrease the strain of the stirrups for the same load. Due to the presence of fibers on concrete, the tensile strength of concrete increases and carrying some tension before transfer to the stirrups. The presence of fibers increases the load capacity of all beams, so can be seen clearly at the ultimate load and strain of stirrups.



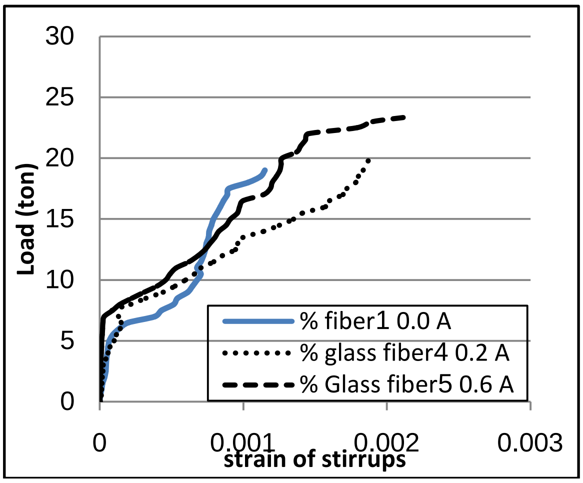


Figure (15) Load-Stirrups Strain Curves for Beams

Effect of fiber to shear Strength

Being the shear strength of concrete is considered an important parameter of this study. Figure (16) show the relationship between the percentage of fibers and the shear strength for specimens. The curves show the effect of increasing of steel or glass fibers content on the shear strength of specimens. Shear strength increase with increasing the percentage of fiber at the same compressive strength. Also the values of shear strength with the use of steel fiber greater than glass fiber at the same compressive strength, due to the modulus of elasticity of fibers. For all tested, the fibers have improved the shear strength of specimens and increases the modulus of elasticity of concrete subsequently give more ductile and stiffness.

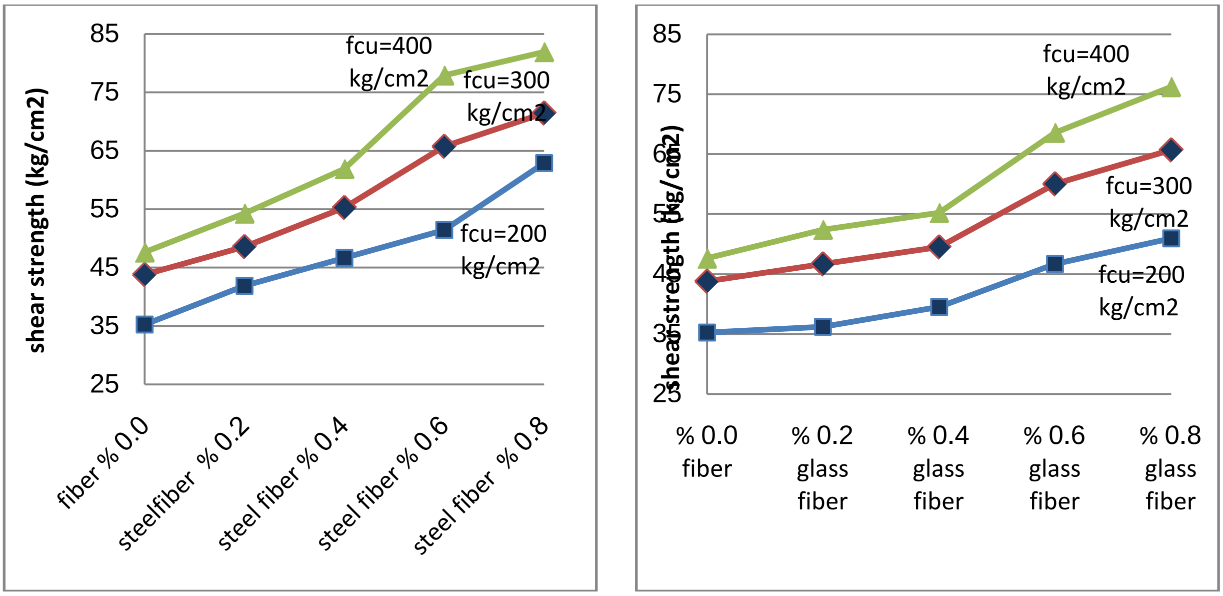
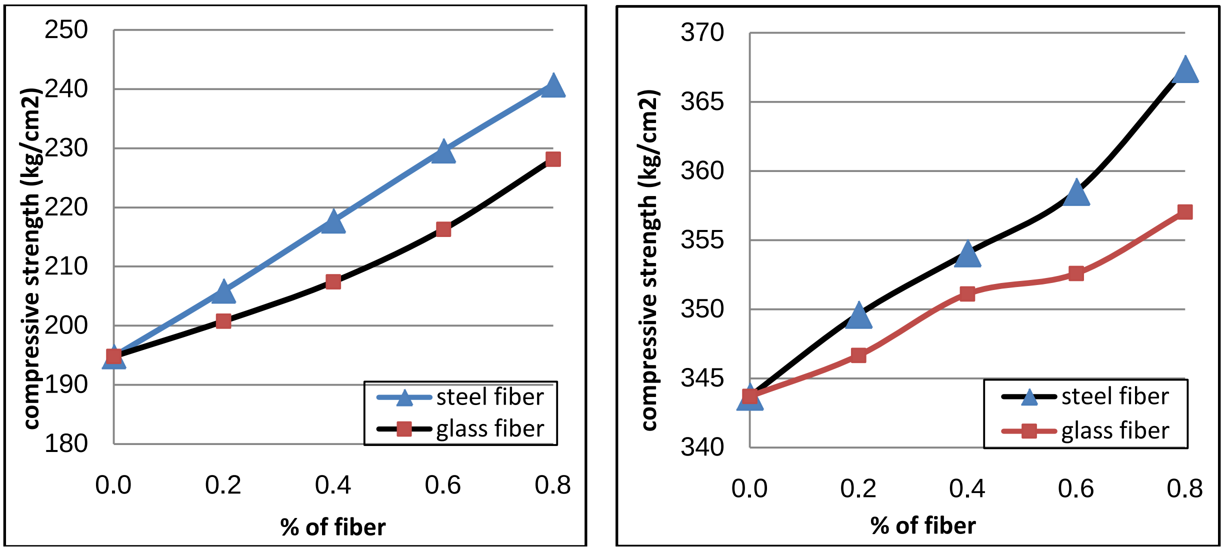


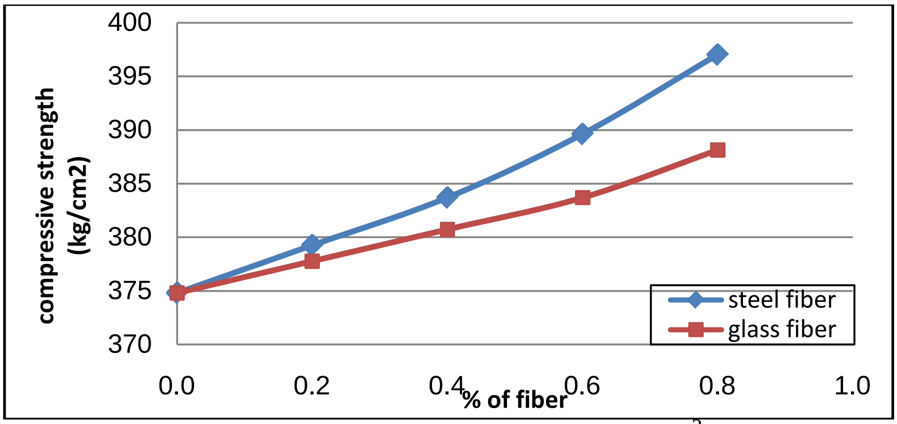
Figure (16) Shear Strength-Percentage of Fibers

Effect of fiber to compressive Strength

Tested three cubes 15x15x15 cm of cube each percentage and each type of fibers and take the average of this cubes. Increasing compressive strength for increases the percentage of fibers, the use of steel fibers give high compressive strength of fiber glass due to the modulus of elasticity of steel fiber higher than glass fiber. Figure (17) show relation between compressive strength and percentage and type of fibers.



a) at compressive strength= 200 kg/cm^2 b) at compressive strength= 300 kg/cm^2



c) at compressive strength= 400 kg/cm^2

Figure (17) Compressive Strength-Percentage of Fibers

Conclusions:

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

1- The study reveals that by incorporating steel or glass fibers in reinforced concrete beams is potentially important and practical construction method, as fiber concrete beams and specimens exhibit substantial increase in their ultimate load as well as in the load at first cracks, enhanced deformation characteristics at all stages of loading up to failure, as well as improving their shear.

2- The first shear cracking strength, the ultimate shear strength and the compressive strength of concrete increases with increasing of the percentage of fibers, because the increase of modulus of elasticity of concrete.

3- The maximum deflection of the all beams and specimens increases with the increase in percentage fibers and compressive strength subsequently the deflection decrease at the same load too. This is primarily because of concrete becomes more ductile and hence it fails after long deformation.

4- The presence of fibers reduces numbers and width of cracks.

5- The influence of glass fibers on shear strength, stiffness and ductility of concrete beams less than steel fiber, due to the reduction of modulus of elasticity.

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