EXPERIMENTAL ANALYSIS OF R.C. BEAM STRENGTHENED WITH DISCRETE GLASS FIBER

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Abstract. *The usage of discrete glass fiber with concrete provides enhancement the ductility and deformability. This study aims at understanding and evaluating shear behavior of discrete glass fiber concrete beams. This paper presents an experimental investigation carried out on reinforced concrete beams with discrete glass fiber mixed randomly with concrete, with 150×150mm cross section. The studied parameters included stirrups spacing (50, 75, and 100 mm) and weight percent of discrete glass fiber (0.0%, 0.75%, and 1.5%). Experimental results indicated that the shear strength of beams was significantly enhanced. Although, the number of cracks increased as a result of using discrete fiber, they became finer. Moreover, the crack propagation and its modes may be changed by using discrete fiber. The discrete glass fiber increases ductility and prevents sudden failure due to shear.*

Key words: *Discrete glass fiber, Shear strength, Shear cracks.*

1. INTRODUCTION

Glass fiber reinforced concrete (GFRC) is cement based composite product that is reinforced with glass fibers. GFRC is a relatively new type of building material and it is being increasingly used in different countries. Adding glass fiber to concrete increases its durability and sturdiness. GFRC has many architectural applications. While the regular concrete is normally used at a fraction of the weight, GFRC can be used anywhere. Common applications in architecture make use of GFRC advantages such as: lightweight, high moisture resistance, high compressive strength; low maintenance, low thermal expansion and high fire resistance [1-14]. The problem of determining the shear strength of reinforced concrete beams has not been solved up to know. Thus, the shear strengths predicted by different current design codes for a particular beam section can vary by factors of more than 2. In contrast, the flexural strengths predicted by these same codes are unlikely to vary by more than 10%. For flexure, the plane sections hypothesis forms the

basis of a universally accepted, simple, rational theory for predicting flexural strength. In addition, simple experiments can be performed on reinforced concrete beams subjected to pure flexure and the clear results from such tests have been used to improve the theory. In shear, there is no agreed basis for a rational theory, and experiments cannot be conducted on reinforced concrete beams subjected to pure shear [Bentz, and et al. 2006].

While hundreds of tests have been undertaken on the shear in reinforced concrete beams, the test pools of fiber-reinforced specimens are few. Fewer still are tests of fiber reinforced concrete members where the fiber concrete is designed to carry the full shear capacity [Yoon-Keun and et al, 2002]. The theory of concrete plasticity provides a good basis for shear design of SFR-UHPC beams as the use of high quantities of ductile steel fibers in the concrete matrix leads to a relatively plastic response after cracking of the matrix with high tensile strengths maintained for large crack openings [[Yoon-Keun and et al, 2002].

The results shown that the nominal stress at shear cracking and the ultimate shear strength increased with increasing fiber volume, decreasing share span-depth ratio, and increasing concrete compressive strength. Moreover, as the fiber content increase, the failure mode changes from shear to flexure [Zararis, P. D, and et al, 2008].

The diagonal shear failure of reinforced concrete beams has long known to be a brittle type of failure. Therefore, a larger safety margin is provided by the capacity reduction factor in the codes. The present code formulas have been calibrated to provide adequate safety against the initiation of diagonal shear cracks. However, the crack initiation load is not proportional to the ultimate load. It can be much smaller, or only slightly, depending on the beam size and other factors. Therefore, the existing design formulas cannot be expected to provide a uniform safety margin against failure. Ideally, the design should insure proper safety margins against both of failure and crack initiation [Bazent, Z. P, and et al, 1991].

The primary purpose of inclusion of steel fibers in conventionally reinforced concrete is not for increasing strength. The strength can be increased more easily and economically by bar reinforcement placed along the direction of principal tensile stresses. The deficiencies of ordinary reinforced concrete in the form of micro-cracks, which cannot be corrected by bar reinforcement, can be remedied to a significant extent by fiber reinforcement. Addition of randomly oriented fiber in plain concrete helps to bridge and arrest the cracks formed in the brittle concrete under applied stresses, and enhances the ductility and energy absorption properties of the composite [Shah, R. H, and et al, 2004].

In this study, the main focus is the performance and the efficiency of the discrete glass fiber concrete and their impact on the shear behavior of R.C beams. Moreover, a comparison between the shear efficiency of increasing traditional transverse reinforcement (stirrups) and using discrete glass fibers with stirrups.

2. EXPERIMENTAL WORK

Five R.C beams with rectangular cross-section, sized 150 mm (width) $\times$ 150 mm (height) x 900 mm length, Fig. 1, were manufactured. Two groups were considered [variable discrete glass fiber ratio by weight, and variable distance between the stirrups]. Details of these two groups are shown in Table 1. The target compressive strength of concrete measured from the average of three tested cubes ($150\times150\times150$ mm).

Loads were applied using a hydraulic jack of 550 kN capacity connected to a steel space frame. The four point symmetrical loading with distance 150 mm between the loading points was statically applied to all specimens. The shear span to depth ratio was being constant to all the tested beams. All specimens were tested up to failure under monotonic loading.
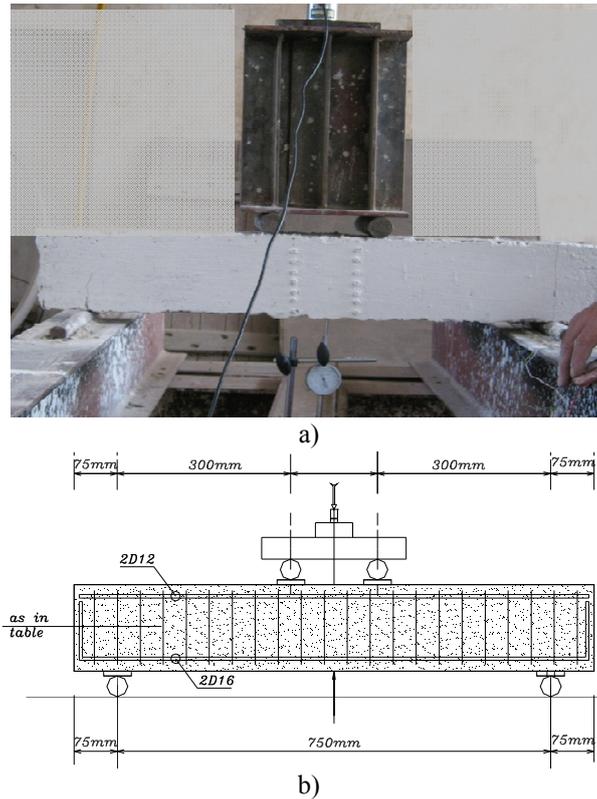

a)

b)

Fig. 1 (a) Test set-up and instrumentation, (b) Specimens RFT details

Table 1. Parameters studied

Group	Specimens	Fiber content	Stirrups	Main steel	Compression. St.
Group 1 (increase stirrups)	B – 15 – S	-------	D4@100mm	2D16mm	2D12mm
	B – 15 – S1	-------	D4@75mm	2D16mm	2D12mm
	B – 15 – S2	-------	D4@50mm	2D16mm	2D12mm
Group 2 (used fiber)	B – 15 – S	0.0%	D4@100mm	2D16mm	2D12mm
	B – 15 – G1	0.75%	D4@100mm	2D16mm	2D12mm
	B – 15 – G2	1.5%	D4@100mm	2D16mm	2D12mm

Concrete used to cast RC beams consisted of Portland cement and natural sand and gravel as aggregate. It was cleaned and free from organic material. Specimens were cured at about 95 percent relative humidity. Dry sand and cement were mixed mechanically, and then water was added and mixed thoroughly. Mixing operation was continued after adding water until a

uniform color was obtained. The mixing proportion of different materials was by weight of cement. The concrete was cast in the steel molds having a smooth surface and these surfaces were coated with oil before casting. The average of characteristic compressive strength without fiber is 23MPa and for fiber with ratio, 0.75% and 1.5% is 25MPa and 26Mpa respectively

The glass fiber with length 150mm had a young's modulus of 72 GPa, a shear modulus of 29.1 GPa, an ultimate tensile strength of 1600 MPa, and an ultimate tensile strain of 2.2% (based on the manufacturer).

Digital Load cell of capacity 550kN with accuracy of 0.1kN was adopted to measure the applied load. The value of loads was recorded from the monitor connected to the load cell. The beams were tested using an incremental loading procedure. The vertical displacement of the beams was recorded using two electric dial gauges, one at the middle of beams and the other at distance equal to half of the beam depth from the support. The strains at mid-span section were measured by using damic points. Figure 1 shows the positions of the electrical strain gauges, dial gauges and damic points. During tests, the applied load was kept constant at each load stage for measuring and observing.

3. TESTED RESULTS AND ANALYSIS

All the beams failed in shear as it was expected. The values of ultimate shear, failure modes, and percentage of load increase based on the ultimate load of control beam are given in Table 2. As shown in this Table, the discrete glass fiber increased the ultimate capacity of RC beams. The percentage of increase reached to about 30 percent when the fiber ratio was increased to 1.5 percent. On the other side, the ultimate capacity of RC beams increased only by about 16 percent, when the distance of stirrups reduced to 50 mm. Consequently, the used of discrete glass fiber had a significant effect on the failure load with span to depth ratio equal 5, and shear span to depth ratio equal 2.0. In this framework the role of discrete glass fiber on the shear behavior of RC beams needs further experimental investigation and will be done in another article.

Table 2. The load failure of tested specimen

Specimens	Failure load (KN)	Increase ratio	Mode of failure
B – 15 - S	50	Control	Diagonal shear failure
B – 15 – S1	55	10%	Diagonal shear failure
B – 15 –S2	58	16%	Diagonal shear failure
B – 15 – G1	60	20%	Diagonal shear failure
B – 15 – G2	65	30%	Flexural shear failure

3.1. Crack Pattern and Mode of Failure

Crack pattern and failure mode for all beams with and without glass fiber are shown in Fig.2. All beams failed in shear failure. The failure load and failure mode are previously presented in Table 2. The failure of concrete without glass fiber showed a brittle failure behavior compared to specimens with glass fiber. The higher the stirrups number, the brisker failure of specimens. The crack pattern at failure was almost the same for the five specimens. In the shear, span one or two mayor cracks together with some secondary cracks formed. The mayor crack propagated from the support to the point of loading as

the load increased up to the beams failure. The crack patterns of the beams B-15-G1 and B-15-G2 were characterized by closer and thinner cracks than the beams B-15-S1, B-15-S2 and B-15-S3. Finally, it is found that the spread area of external crack increases to twice by increasing the percentage of cracks from 0.0% to 1.5%.
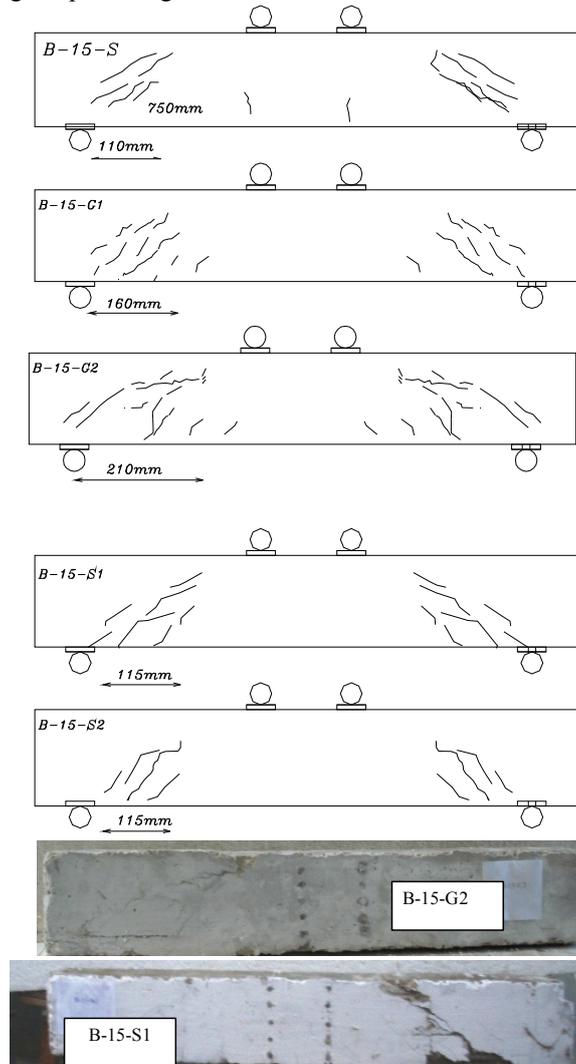

Fig. 2. The crack pattern and failure modes of the specimens

3.2. Mid-Span Strain and Steel Strain

Figure 3 shows the strain distributions at mid-span of all beams for different groups and different loads. It can be observed that strain increase rate of beam without glass fiber decreases after cracking load where diagonal cracks deformed. On the other hand, strain increase rate at mid-span for glass fiber concrete is almost constant. By comparing the strain distributions of the

beams with and without glass fiber, it can be noticed that the concrete with glass fiber behaves as a homogenous material as the strain in tension nearly equal to that at compression.

Figure 4 shows relationships between load and steel strains for the main longitudinal steel at mid-span and steel stirrups at distance equal to half the depth from the support, respectively. The cracking load decreases by using glass fiber as the steel strain gradually increased from 3.8 ton load until failure (B-15-G1) as shown in Fig.4a. Quite the opposite, stirrup strain of B-15-S and B-15-S2 have a sudden increase after crack load. Furthermore, Fig.4b shows that at the same load, steel stress at B-15-G2 is less than that of B-15-S2 that means that glass fiber contributes to tension stress at mid-span and in turn in shear zone.
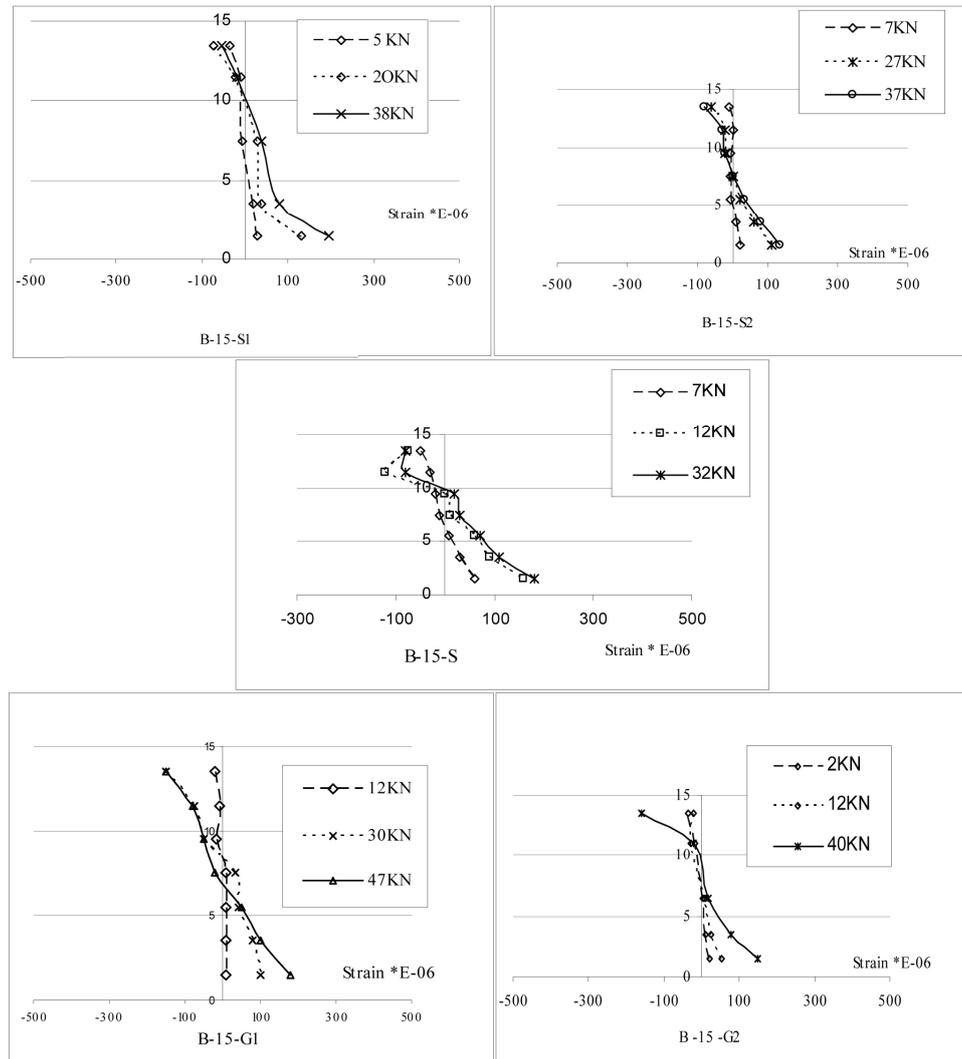

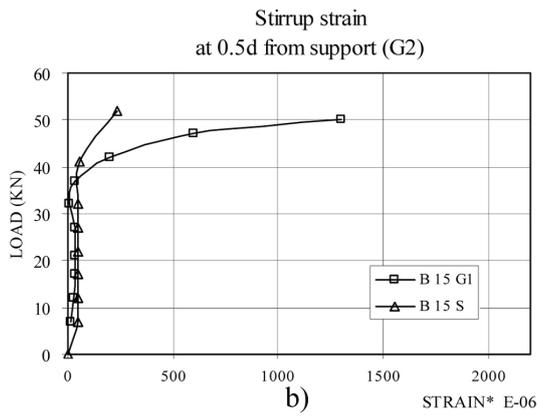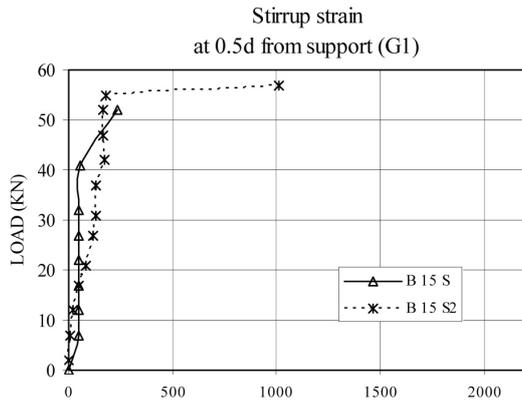**Fig. 3**. The strain for beam at the mid-span

Strain at the mid-span
fom long. RFT

a)

Stirrup strain
at 0.5d from support (G1)

Stirrup strain
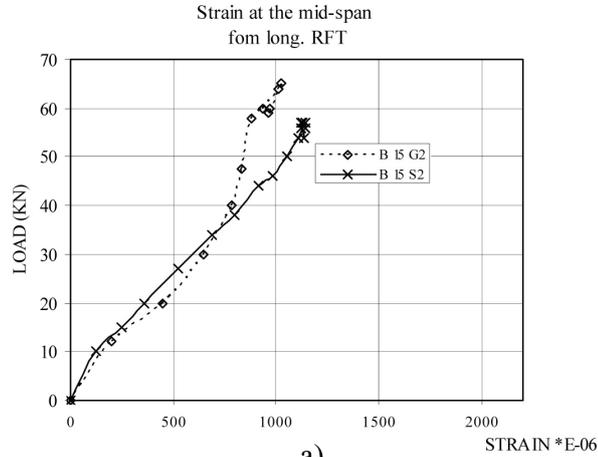at 0.5d from support (G2)

b)

Fig. 4. The strain for steel stirrup and longitudinal tension steel RFT
a) Tension steel bar   b) Steel stirrup for G1, G2

3.3. Load Deflection Curves

Figure 5 shows the relationship between the applied load and mid-span deflection for different stirrup distance (group 1) and different glass fiber ratio (group 2), respectively. While increase ratio of glass fiber enhances the stiffness of beams as shown in Fig. 5b, increasing number of stirrups nearly has no effect on the stiffness. Moreover, it is clear that the increase of glass fiber ratio increases the ultimate deflection as shown in Fig. 5b and in turn increases shear ductility of beams. On the other side, increase of the number of stirrups leads to reduction of the ultimate deflection of RC beams as shown in Fig. 5a, and brittle failure occurs.
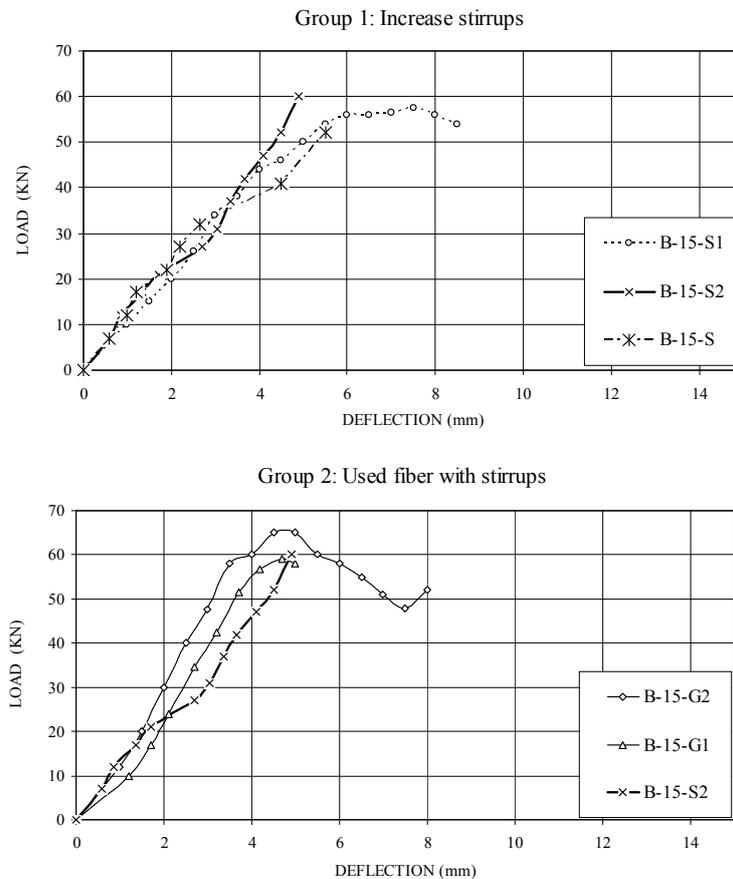

Fig. 5. Load deflection curves of tested specimens

4. THE EFFECT OF SPAN TO DEPTH RATIO

By comparing the test results in this study and test results with the same material properties and test setup, the depth was changed from 150mm to 300mm. The relation between the failure load and fiber content with different span to depth ratio was shown in

the Figures 6 and 7. The failure loads and the ratio between failure load with L/d = 2.5 to L/d=4 is as shown in Table 3.
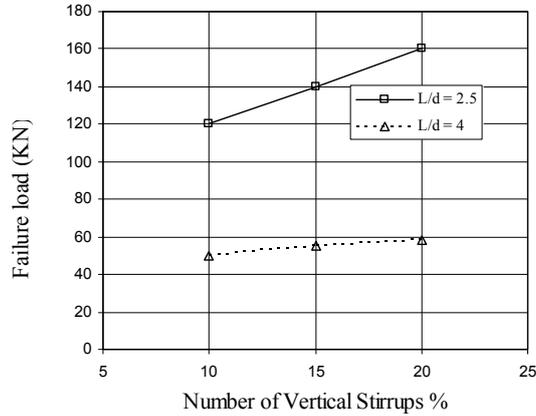

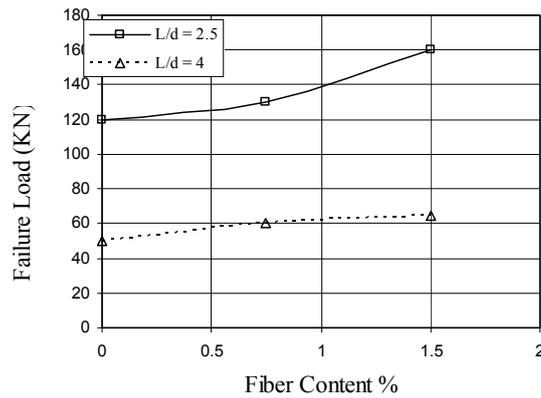**Fig. 6**. The relation between fiber contents and failure loads

Fig. 7. The relation between the number of stirrups per meters and failure load

Table 3. Comparing between failure loads for span to depth ratio 2.5 and 4

Specimens	Failure load (KN)			Strength (Q/bd) MPa		
	PL/d = 2.5	PL/d = 4.0	Ratio	V L/d = 2.5	V L/d = 4.0	Ratio
B – 30 – S	120.0	40.0	3.00	1.34	0.9	1.5
B – 30 – G1	130.0	60.0	2.17	1.45	1.34	1.08
B – 30 – G2	160.0	65.0	2.46	1.78	1.44	1.23
B – 30 – S1	140.0	55.0	2.55	1.56	1.22	1.27
B – 30 – S2	175.0	58.0	3.00	1.95	1.28	1.51

In general, by change ratio of L/d from 4.00 to 2.5 the failure load increased about 3 times. Moreover, by using discrete glass fiber with ratio 0.75% and 1.5% the load increased by about 2.17 and 2.46, respectively. From this, it is concluded that by increasing the depth the efficiency of discrete fiber reduced. In addition, by increasing the number of stirrups from 10, to 15, and to 20 the load increased by about 3, 2.55, 3 times. From this it is concluded that the efficiency of using discrete glass fiber on the failure loads can be considered as efficient as that of vertical steel. However, by comparing between the crack patterns and modes of failure it is found that the behavior is better when discrete glass fiber was used than when vertical stirrups were used. Where in the span to depth ratio 4, the failure mode changed from shear failure to flexure shear failure. And the number of cracks in specimens of span to depth ratio 2.5 is increased at the bottom of beams near to support. The cracking load is decreased by increasing failure load. By comparing between the strength for span to depth ratio 2.5 and 4 it found that, the shear strength in L/D=2.5 is more than that in L/D=4.0. The ratio between shear strength for L/D =2.5 to L/D =4 in the case of used fiber is less than that in the case of increased vertical stirrups

From studding the effect of span to depth ratio on the shear failure and using discrete glass fiber it was found that, by increasing span to depth ratio the efficiency of used discrete glass fiber increased.

5. CONCLUSIONS

This study presents the results of an experimental investigation of shear behavior of RC beams using glass fiber concrete with different ratio. The following conclusions can be drawn:

- This study presents the results of an experimental investigation of shear behavior of RC beams using glass fiber concrete with different ratio. The following conclusions can be drawn:-
- the usage of glass fiber in addition to stirrups increases the failure load and the efficiency of glass fiber equal to or more than that of increasing number of stirrups to the double.
- The failure behavior becomes more ductile by using discrete glass fiber compared to the control beams. On the other hand, the number of cracks increases and the width of cracks decreases.
- The discrete glass fiber share of both longitudinal steel bars and vertical stirrups as element resistance tensile strength after cracking.???
- The strut width of the compression zone increases by increasing the percentages of glass fiber.

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EKSPERIMENTALNA ANALIZA AB GREDA OJAČANIH DISKRETNIM STAKLENIM VLAKNIMA

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Korišćenje diskretnih staklenih vlakana u betonu obezbeđuje poboljšanje duktilnosti i deformabilnosti. Ova studija ima za cilj razumevanje i evaluaciju ponašanja betonskih grednih nosača sa staklenim vlaknima kod smicana. Rad daje eksperimentalno ispitivanje izvršeno na armirano betonskim gredama sa diskretnim staklenim vlaknima nasumično pomešanim sa betonom sa dimenzijama preseka 150x150mm. U studiji su uzengije bile razmaknute (50, 75 i 100 mm) a udeo težine staklenih vlakana je bio (0.0%, 0.75%, i 1.5%). Eksperimentalni rezultati su pokazali da je otpor na smicanje greda bio značajno povećan. Iako se broj prslina uvećao usled korišćenja diskretnih vlakana, one su postale manje. Šta više, širenje prslina i modusi širenja se mogu menjati korišćenjem diskretnih vlakana. Diskretna staklena vlakna povećavaju duktilnost i sprečavaju iznenadni lom usled smicanja.

Ključne reči: *Diskretna staklena vlakna, otpor na smicanje, smičuće prsline*