4th International Engineering Conference on Developments in Civil & Computer Engineering Applications 2018 (ISSN 2409-6997)

INVESTIGATING FLEXURAL STRENGTH OF BEAMS MADE WITH ENGINEERED CEMENTITIOUS COMPOSITE (ECC) UNDER STATIC AND REPEATED LOADING

Kawa O. Ameen[1], Bayar J.Al-Sulayvani[2], Diyar N. Al-Talabani[3]

[1&2] *Mosul University*
[3]*Cihan University-Erbil*
[1]*Kawa.civil@yahoo.com,* [2]*Diyarnasih90@gmail.com,* [3]*Diyar.nasih@cihanuniversity.edu.iq*

doi:10.23918/iec2018.05

ABSTRACT

The main purpose of this research is to investigate the flexural strength of reinforced ECC beams under static and repeated loading. Eighteen reinforced ECC beams with deferent fiber content and deferent steel ratio were constructed and tested by applying static and repeated loading. The experimental variables considered in this study include fiber content, steel ratio, and loading type (static or repeated). All beams were geometrically similar with the dimension of (120mm in width, 200mm in depth, and 1000mm in length) and the applied loads were subjected to the beams with two point loads and simply supported span. The experimental outputs divided into four parts: the first part concerned with the effect of fiber content on the load-deflection curves. The second part focused on the effect of steel ratio on the load-deflection curves. Furthermore, the third part studied the comparison between static and repeated loading. Eventually, the last part investigated the effect of fiber content and steel ratio on flexural toughness. In reinforced ECC, with increasing fiber content (for the same flexural reinforcement) the sample will increase its flexural strength. In general, to increase the ultimate flexural strength, the addition of steel ratio has much higher effect than increasing fiber content. Finally, for identical reinforced ECC beams, the flexural strength will be lower when applying repeated load other than static one.

Keywords: Engineered Cementitious Composite (ECC); Repeated Load; Flexural Strength; Flexural Toughness.

1. INTRODUCTION

In the past several decades, concrete with increasingly high compressive strength have been used for many structural applications. However, most of these materials remained brittle. In some cases, the brittleness as measured by brittleness number actually increases as the compressive strength goes up [1]. This poses potential danger and limitation of high strength concrete in structural fields. in the last several years, the University of Michigan has been investigating a composite material named Engineered Cementitious Composites (ECC). In many respects, this material has properties similar to medium to high strength concrete. Furthermore, the tensile strain capacity generally exceeds 1%. a number of investigations have been achieved on the applications of ECC in structural applications at the University of Michigan in the US, Kajima Corporation, University of Tokyo, and Building Research Institute, Tsukuba City in Japan. These studies involve the usage of ECC in shear elements subjected to cyclic loading, in beam-column connections, in shear wall retrofitting of reinforced concrete (R/C) buildings, in R/C beams as durable cover for re-bar corrosion control, and in general concrete structural repair [2].

The principal aims of this study are summarized as follows:

1. Investigating experimentally the effect of fiber volume fraction on the mechanical properties of the flexural beams.
2. Investigating practically the effect the steel ratio on the response of beam deflection.
3. Investigating experimentally the effectiveness of loading types on the flexural strength of reinforced ECC beams.

2. EXPERIMENTAL PROGRAM

The eighteen reinforced ECC beams were casted in the steel molds with 1000mm length, 120mm width, and 200mm height. Although ECC has excellent shear strength, extra shear reinforcement was added to make sure that the beams will fail by flexural first. All of the specimens were reinforced with compression reinforcement 2Ø8mm and the tensile reinforcements were 2Ø8mm, 3Ø8mm, and 4Ø8mm. The shear regions were reinforced with stirrups Ø6mm at 110mm, but the middle third part was unreinforced with stirrups. Figure (1) explained the internal details for one of the specimens. The reinforced beams were tested under two point load test.

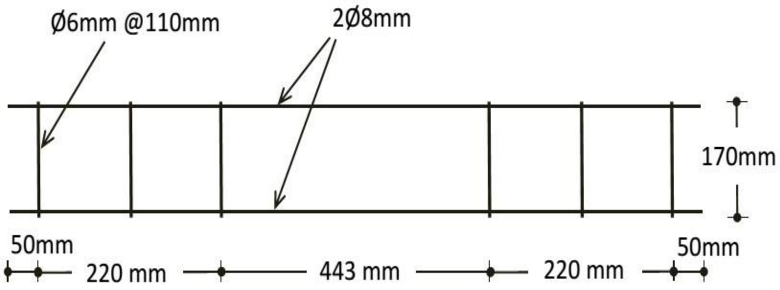


FIGURE 1. Reinforcement details of LS beams

The experimental works were divided into three parts: the first part studied the effect of flexural steel ratio, the second part studied the effect of fiber content, and, the last part studied the effect of load types.

Part I: the effect of flexural steel ratio

For this part, three flexural reinforcement ratio, ρ (ρ=As/bd), were used; namely, LS, MS, and HS. Each of specimen has ρ as 0.004911, 0.007367, and 0.009822, respectively. To represent this effect, eighteen samples were tested, each six sample with the same steel ratio.

Part II: the effect of fiber volume fraction

For this part, three fiber volume fraction were used; namely LF, MF, and HF, each of them were 0.75%, 1.5%, and 3% respectively. To study the effect of fiber volume fraction on the response of ECC beams, eighteen beams were tested each six had the same fiber content (first six samples had 6.76 kg/m3 of fiber, second six samples had 13.52 kg/m3 of fiber, and third six samples had 27.04 kg/m3 of fiber).

Part III: the effect of load type

The overall tested specimens were divided into two groups, the first nine samples were tested by applying static load until the failure, and another remained nine specimen tested using repeated loads.

3. CONSTITUENT MATERIAL PROPERTIES

3.1 . CEMENT

Ordinary Portland cement (Type I) of Kirkuk mark was used in casting all the beams and cylinders. Before using cement, it was kept in a dried place to avoid it from the atmospheric severe. The physical properties of the used cement is given in Table (1). The results are conformed to the Iraqi Standard Specification (IS-No.5, 1984) [3].

TABLE 1.

Physical properties of cement

Property		Result	Iraqi Specification Limits I.Q.S 5/1984
Fineness (residual on sieve		4	Not more than 10
Fineness (Blain), cm2/gr		3277	
Initial setting time, min.		12 7	Not less than 45
Final setting time, min		18	Not more than 600
Compressive strength (MPa)	3-day	3.39	Not less than 16
	7-day age	2.36	Not less than 24

3.2 .SILICA FUME

In the present study, MasterRoc MS 610 was used which was the trade name of the high quality silica fume powder for high performance concrete. The use of this type of silica fume was changed the porous structure of the concrete making it denser and more resistant to any type of external influence. The technical data was explained in Table (2).

TABLE 2.

Technical data of MasterRoc MS 610

Density	0.55-0.7 kg/l
Recommended	5-15% of the cement
Chloride Contend	<0.1
Colour	Gre
Form	Powd

3.3. FIBER

To obtain multiple and nearly spaced crack, the use of fiber was essential which was made the brittle property of the matrix to the ductile one. Polypropylene fibers of C080 FiberCem mark was used in preparing all samples. The physical and the mechanical properties were showed in Table (3).

TABLE 3.

Physical and mechanical properties of C080 FberCem

Length	12 mm
Density	3
Yield Point	35.52 MPa
Elongation at Yield	11%
Tensile Break	35.52 MPa
Elongation at Yield	400 %
Tensile Modulus	1.312 GPa
Physical state at 20oC	solid
Melting point	160-165 oC
colour	white opaque

3.4. SUPERPLASTICIZERS

The Flocrete SP90S was used as plasticizers which complies with ASTM C494 [4], Type B, D, and G, depending on the dose. The Flocrete SP90S can be used with all types of Portland cement and cement replacement materials and should be added to the concrete with the mixing water to attain optimum performance. Table (4) shows the technical data of Flocrete SP90S.

TABLE 4.

Technical properties of Florcrete SP90S at 25 ºC

Density	1.17∓ 0.01 kg/l
Recommended Dosage	0.80-2.10 liters/100 kg of cementitious materials
Chloride Contend	Nil
Freezing point	≈ -2ºC
Color	Brown liquid

3.5. WATER

Ordinary clean tap water was used for casting and curing all beams and cylinders. The constituent materials (cement, silica fume, fibers, plasticizers, and water) used in this study was shown in Figure (2).

FIGURE 2. Constituent materials

3.6. STEEL REINFORCEMENT

Two types of steel reinforcement were used to reinforce the beam specimen one of them as flexural reinforcement and another as shear reinforcement. The flexural and shear reinforcement were deformed steel bars of size (8 mm in diameter) and (5.59 mm in diameter), respectively. Three specimens of each type were tested under tension according to ASTM A370-05 [5]. The yield stress and the ultimate strength and other experimental results will summarize in Table (5).

TABLE 5.

Reinforcement properties

Sample	Flexural			Shear		
Diameter (mm)	8			5.59		
Area (mm2)	50.26			24.54		
Ultimate load	803	767	739	689	575	559
Yield Stress (MPa)	712	671	639	675	557	527
	674 (average)			586 (average)		
Elongation (%)	10.11	10.17	9.07	4.10	4.36	4.10

4. SAMPLE PREPARATION

4.1. MIX PROPORTIONS

The mixture details for one cubic meter and mix proportion were shown in Table (6). This mixture had showed the unique properties of ECC [6].

TABLE 6.

Mix proportions

Parameters	Amount (kg/m3)	Fraction (%)
Cement	1339.75	1.00 by weight
Silica Fume	133.97	0.10 by weight
Plasticizers	26.79	0.02 by weight
Water	468.56	0.35 by weight
LF	6.76	0.75 by volume
MF	13.52	1.50 by volume
HF	27.04	3.00 by volume

4.2 .MIXING PROCESS

(a) Adding silica fume to cement.

(b) Mixing silica fume with cement.

(c) Weighing chemical admixture.

(d) Adding plasticizer to water.

FIGURE 3. Mixing procedures

The eighteen reinforced ECC beams were prepared using the following steps:

1. All quantities were weighed and packed in a dry container.
2. After measuring the weight of all mix constituents, silica fume was slowly added to the cement and mixed together.
3. Plasticizers were added to water and then they added to the mixture of cement and silica fume.
4. Mix became uniform by used rotated drill with three steel blade head.
5. After the mixed materials became uniform, the dispersed fibers were slowly added by hand to the matrix.

The mixing steps were clarified in Figure (3). The total mixing time ranged between 15 and 30 min, depending on the batch size and the amount of fiber used (fiber volume fraction). Note that the workability of the 3% fiber composites was not as good as that for the lower fiber volume fraction composites.

4.3. CASTING AND CURING

(a) Oiling inside the mold.

(b) Placing steel reinforcement.

(c) Putting ECC into the mold.

(d) Vibrating each layers of ECC.

(e) Symbolizing the samples.

(f) Curing all the samples.

FIGURE 4. Casting and curing steps

When the mix was ready, the casting and curing stages were begun by following the steps below:

1. Steel mold were treated with oil prior to putting the reinforcement cage to prevent adhesion with concrete after hardening of ECC. (Figure (4a)).

2. Placing the required steel reinforcement in the steel mold (Figure (4b)). The clear concrete cover of 20mm was maintained by using crushed tile to prevent the effective depth, d, from changing its quantity.

3. Concrete was poured in the steel molds, and it was compacted using electrical handle vibrator. The cylindrical and beams were filled with ECC into three equal layers. Each layer was vibrated for 30 seconds (Figure (4c) and (4d)).

4. The upper surface of concrete was smoothly treated after casting was completed using hand trowel.

5. After casting, all reinforced ECC beam specimens and cylinders were covered with nylon for one day prior to demolding.
6. After 24 hours, the samples were demolded, symbolized, and placed in a water curing tank for 4 weeks (Figure (4e) and (4f)).
7. When curing time was completed, they were removed from water and prepared for testing. The specimens were painted by white emulsion before testing to better monitor the development of cracks.

5. DESCRIPTION OF TESTING MACHINE

During the experimental work many devices were used some of them used for applying loads another used for measuring purpose. A brief description for their capacities were mentioned below:

1. Three point testing machine: it has the capacity of

   3000 kN and used for testing ECC beams. By attaching sensor to the middle of reinforced ECC beams, deflections could be computed electrically.
2. Data collector: it has four channels each one connected to sensor with capacity of computing deflections and/or strains. With the manufacturer software, the load deflection curves data were obtained.
3. Hydraulic universal testing machine (UTM 4000): with capacity of 600 kN, it was used for reinforcement testing.

FIGURE 5. Testing machines

6. DESCRIPTION OF REPEATED LOADS

Concrete behavior subjected to repeated loads is different from the one subjected to static loads. Repeated loads caused crushing in some part of concrete because of loading and unloading process and also it were applied at low number of cycles and high intensity loading. the mechanism of applied repeated load is differ from static one. The ultimate static load (Pult) must be recorded first by testing one of the specimen. The first cycle should begin with 0.4Pult and increased 0.1Pult for every cycle until the failure of specimen. The use of 40 as the first applied load depend on the principle that the loads bellow that limit will not effect on the elastic behavior of the sample. Figure (6) shows the history of applied repeated loads.

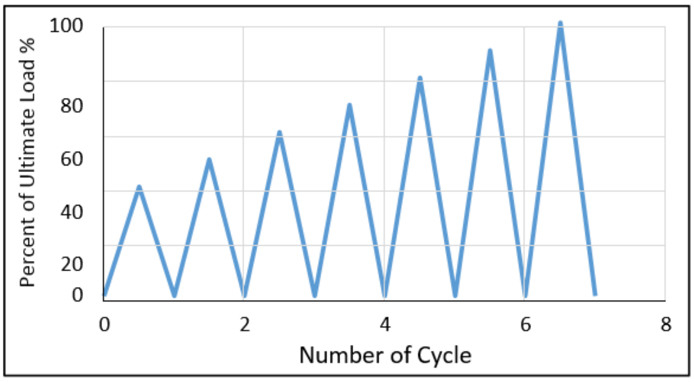


FIGURE 6. Mechanism of applying repeated load

7. LOAD-DEFLECTION CURVES (P- Δ)

Generally, the load-deflection curve defines behavior of tested sample during its loading stages. Many important parameters are depending on the shape of load-deflection curve such as toughness, stiffness, ductility, first cracking load and deflection, and so on. in this study, two types of load-deflection curves were plotted for applied static and repeated loading. Figure (7) to (9) or (13) to (15) showed the load-deflection curves for nine samples tested by applying static load .And, Figure (10) to (12) or (16) to (18) explained the applied load versus central deflection for remained nine samples which were tested by applying repeated load.

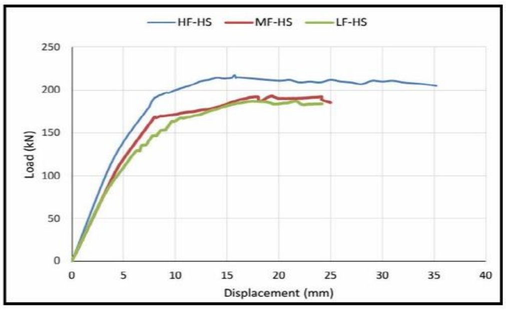


FIGURE 7. Load-deflection curves for HF-HS, MF-HS, and LF-HS with static load

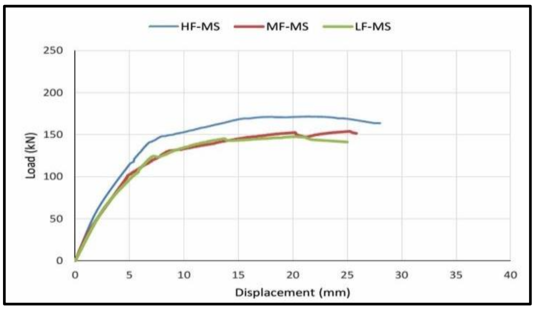


FIGURE 8. Load-deflection curves for HF-MS, MF-MS, and LF-MS with static load

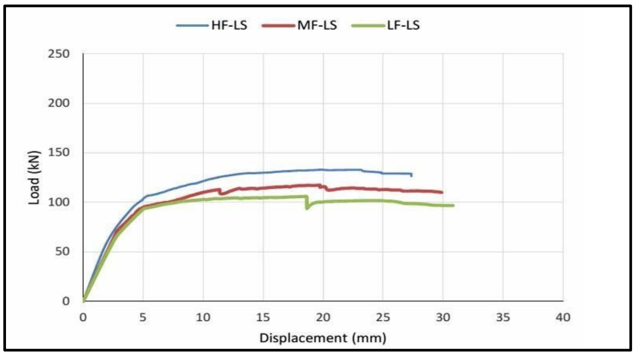


FIGURE 9. Load-deflection curves for HF-LS, MF-LS, and LF-LS with static load

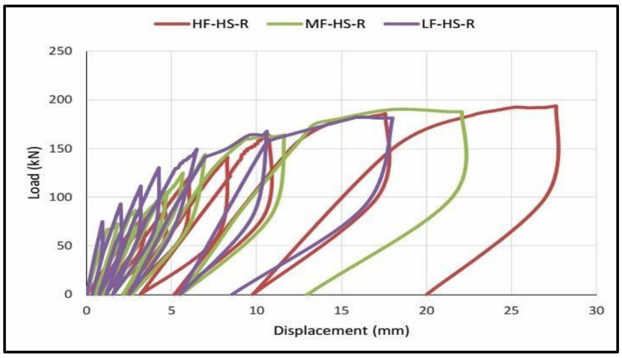
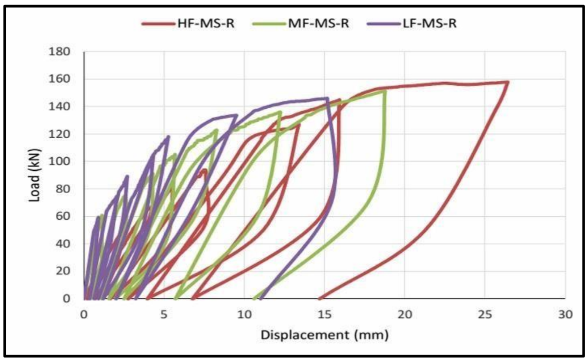


FIGURE 10. Load-deflection curves for HF-HS, MF-HS, and LF-HS with repeated load



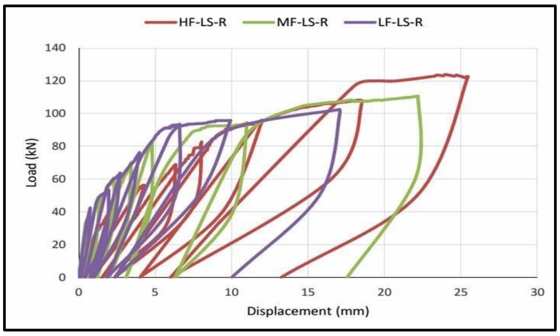
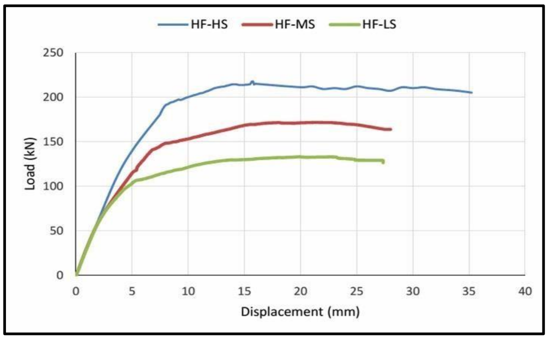


FIGURE 11. Load-deflection curves for HF-MS, MF-MS, and LF-MS with repeated load

FIGURE 12. Load-deflection curves for HF-LS, MF-LS, and LF-LS with repeated load



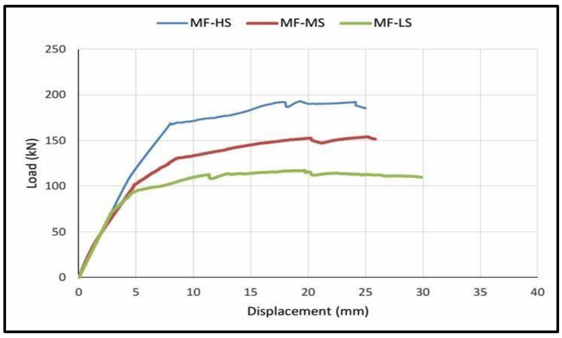
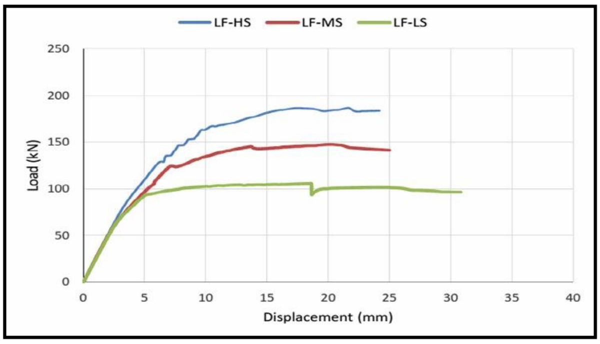


FIGURE 13. Load-deflection curves for HF-HS, HF-MS, and HF-LS with static load

FIGURE 14. Load-deflection curves for MF-HS, MF-MS, and MF-LS with static load



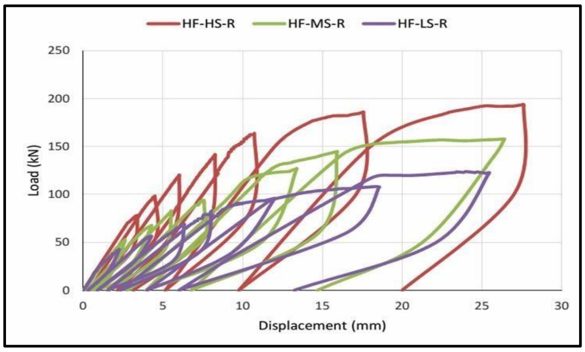


FIGURE 15. Load-deflection curves for LF-HS, LF-MS, and LF-LS with static load

FIGURE 16. Load-deflection curves for HF-HS, HF-MS, and HF-LS with repeated load

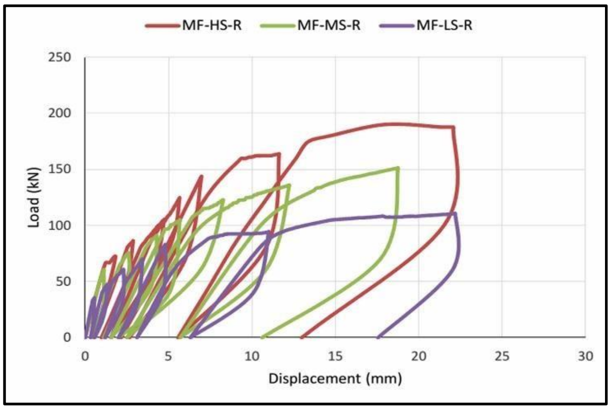


FIGURE 17. Load-deflection curves for MF-HS, MF-MS, and MF-LS with repeated load

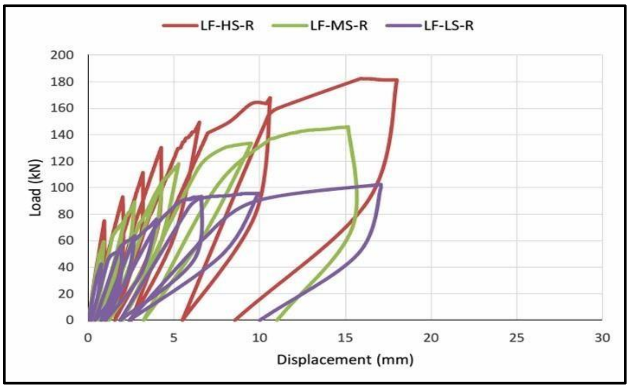


FIGURE 18. Load-deflection curves for LF-HS, LF-MS, and LF-LS with repeated load

7.1. EFFECT OF FIBER VOLUME FRACTION ON P-Δ

Figure (7) to (9) showed the effect of fiber content on load-deflection curve for each steel ratio by applying static load and Figure (10) to (12) explained the same effect but with applying repeated loading. Figure (7) showed the effect of fiber content for HS beams. It was showed that with increasing fiber content from 0.75% to 1.5% and 3%, the ultimate strength was increased by 3.16% and 14.05%, respectively.
Also, Figure (8) explained the effect of fiber content for MS beams. It was stated that with increasing fiber content from 0.75% to 1.5% and 3%, the ultimate strength was increased by 4.09% and 13.87%, respectively. Finally, Figure (9) clarify the effect of fiber content for LS beams. It was explained that with increasing fiber content from 0.75% to 1.5% and 3%, the ultimate strength was increased by 9.68% and 20.34%, respectively.

7.2. EFFECT OF STEEL RATIO ON P-Δ

The effect of steel ratio on load-deflection curves was indicated in Figure (13), (14), and (15) for applied static loading and Figure (16), (17), and (18) for applied repeated load. Figure (13) was used to show the effect of steel ratio on load-deflection curves for HF beams. It was clear that with increasing steel ratio from 0.004911 to 0.007367 and 0.009823, the ultimate strength was increased to 22.51% and 38.89%, respectively. and, Figure (14) was used to explain the effect of steel ratio on load-deflection curves for HF beams. It was showed that with increasing steel ratio from 0.004911 to 0.007367 and 0.009823, the ultimate strength was increased by 23.89% and 39.27%, respectively. also, Figure (15) was used to state the effect of steel ratio on load-deflection curves for HF beams.it was clear that with increasing steel ratio from 0.004911 to 0.007367 and 0.009823, the ultimate strength was increased to 28.33% and 43.36%, respectively.

7.3. COMPARISON BETWEEN STATIC AND REPEATED LOADING

Usually the load types affect the final results of tested sample. For identical beams, the strength will be lower when applying repeated load other than static one due to the effect of fatigue during loading and unloading processes.

Figure (19) showed the load deflection curves for two beams having the same properties, LF-LS, one of them tested under static load and the other with repeated load.

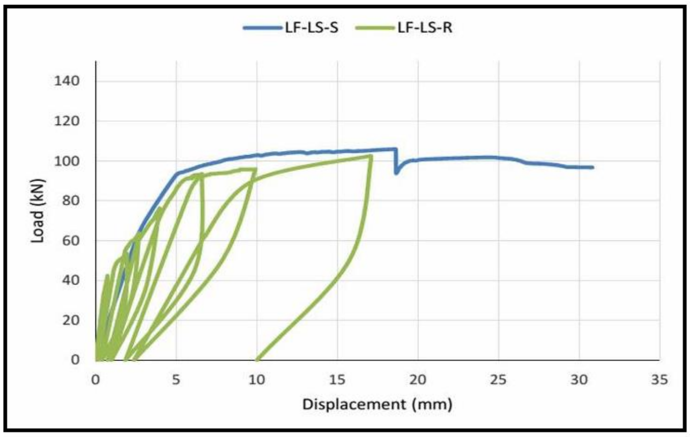


FIGURE 19. Effect of load type on load-deflection curve for LF-LS beam

Table (8) illustrated the results of all eighteen samples from which it can be concluded that the percent of decreasing strength had significant effect with steel ratio compared to fiber effect. The results showed that HF-HS beams had maximum percent of difference between ultimate static load and ultimate repeated load (12.4%), however, LF-MS showed the minimum value (1.1%).

TABLE 8.

Maximum static and repeated loads

Sample	Ultimate Static Load (kN)	Ultimate Repeated Load (kN)	Percent Difference (%)
HF-HS	217.67	193.73	12.4
HF-MS	171.65	157.93	8.7
HF-LS	133.02	123.98	7.3
MF-HS	193.18	190.30	1.5
MF-MS	154.14	151.43	1.8
MF-LS	117.32	110.68	6.0
LF-HS	187.08	182.58	2.5
LF-MS	147.84	146.18	1.1
LF-LS	105.96	102.64	3.2

8. CONCLUSIONS

Depending on the experimental results, the study comes up with the following conclusions:

1. For HS beams, it was showed that with increasing fiber content from 0.75% to 1.5% and 3%, the ultimate strength was increased by 3.16% and 14.05%, respectively.

2. For MS beams, it was concluded that with increasing fiber content from 0.75% to 1.5% and 3%, the ultimate strength was increased by 4.09% and 13.87%, respectively.

3. For LS beams, it was explained that with increasing fiber content from 0.75% to 1.5% and 3%, the ultimate strength was increased by 9.68% and 20.34%, respectively.

4. To increase the ultimate strength, the addition of steel ratio has much higher effect than increasing fiber content.
5. For identical beams, the strength will be lower when applying repeated load other than static one due to the effect of fatigue in the times of loading and unloading processes. The results showed that HF-HS beams had maximum percent of variation between ultimate static load and ultimate repeated load (12.4%), however, LF-MS showed the minimum value (1.1%).
6. With specific fiber content the specimens with high steel ratio had the highest toughness, the specimens with medium steel ratio showed intermediate toughness, and the specimens with the minimum steel ratio showed the lowest toughness.

ACKNOWLEDGEMENTS

Many thanks to Bakhtiar A. Muheiddin for his supporting in my study and research and I ask Allah to put his pure soul in paradise.

REFERENCES

[1] Hillerborg, A., "Analysis of one single crack in fracture mechanics of concrete", edited by F.H. Wittmann, Elsevier Science Publishers B.V., Amsterdam, 1983, pp. 223-249.

[2] Victor C. Li, "Engineered cementitious composite for structural applications", ASCE J, Materials in Civil Engineering, Vol. 10, No. 2, 1998, pp. 66-69.

[3] Iraqi Specification No.05, "Portland cement", Baghdad, Iraq, 1984, (In Arabic).

[4] ASTM C494/C 494M-99a, "Standard Specification for Chemical Admixtures for Concrete", Annual Book of ASTM Standards, pp. 9.

[5] ASTM A 370-03a, "Standard test methods and definitions for mechanical testing of steel products", Annual Book of ASTM Standards, pp. 49.

[6] Salahuddin Qudah, Mohamed Maalej, "Application of engineered cementitious composites (ECC) in interior beam–column connections for enhanced seismic resistance", Engineering Structures, Vol. 69, 2014, pp. 234-245.

[7] ASTM C1018-97, "Standard test method for flexural toughness and first-crack strength of fiber-reinforced concrete (using beam with third-point loading)", Annual Book of ASTM Standards, pp. 8.

[8] JSCE-SF4, "Method of tests for flexural strength and flexural toughness of steel-fiber-reinforced concrete", Concr Libr JSCE, Japan Soc of Civ Eng, Tokyo, Vol. 3, 1984, pp. 58-61.