Flexural Cracking Behavior Of Steel Fiber Reinforced Concrete Beams

Ashraf Abdalkader, Omer Elzaroug, Farhat Abubaker

Abstract: Steel fibers are added to concrete due to its ability to improve the tensile strength and control propagation of cracks in reinforced concrete members. Steel fiber reinforced concrete is made of cement, fine, water and coarse aggregate in addition to steel fibers. In this experimental work, flexural cracking behavior of reinforced concrete beams contains different percentage of hooked-end steel fibers with length of 50 mm and equivalent diameter of 0.5 mm was studied. The beams were tested under third-point loading test at 28 days. First cracking load, maximum crack width, cracks number, and load-deflection relations were investigated to evaluate the flexural cracking behavior of concrete beams with 34 MPa target mean strength. Workability, wet density, compressive and splitting tensile strength were also investigated. The results showed that the flexural crack width is significantly reduced with the addition of steel fibers. Fiber contents of 1.0% resulted in 81% reduction in maximum crack width compared to control concrete (without fiber). The results also showed that the first cracking load and maximum load are increased with the addition of steel fibers.

Index Terms: Steel fibers, Normal strength concrete, Crack width, Compressive strength, Splitting tensile strength, First cracking load, Maximum load.

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1 INTRODUCTION

Flexural cracking occurs in concrete beams when the developed tensile stress exceeds the tensile capacity of the concrete. Steel fiber is added to concrete due to its ability to restrict the growth of cracks and thus changing the brittle mode of composite to a strong matrix with superior crack resistance, improved ductility and distinctive post-cracking behavior prior to breakdown [1],[2]. Fiber reinforced concrete (FRC) is defined as "concrete made with hydraulic cement, containing fine or fine and coarse aggregate and discontinuous discrete fibers that may also contain pozzolans and additives" [3]. The influence of the steel fibers on concrete properties has been considered by many researchers [4],[5],[6],[7],[8],[9],[10],[11],[12],[13],[14],[15]. Marar et al., [4] reported that the addition of steel fibers to improves resistance to impact and toughness characteristics of high strength concrete. Impact resistance of high strength concrete containing 2.0% fiber fraction increased by about 74 times compared to that of concrete without fiber. According to this study compression toughness was also increased due to the addition of steel fibers. Fatih et al.,[5] examined the addition of two different percentage of hooked steel fibres on toughness of concrete with two grades (20 and 30 MPa). Steel fibers with 60 mm in length and 0.75 mm in diameter were used in this research. The results showed an increase in the energy absorption of concrete grade 20 and 30 by 121% and 135%, respectively. Jodeiri et al.,[6] examined the effect of steel fibre on flexural capacity of reinforced concrete beam. The hooked-end steel fiber with length of 33 mm and diameter of 0.55 mm was used in this study. The results showed that the addition of steel fibres in concrete increases the first cracking load, ultimate load, stiffness and ductility of the concrete beams. Study by Tanoli et al.,[7] showed that the compressive strength is slightly increased, but the increase is significant in tensile strength due to addition of steel fibers. Jusoh et al.,[8] investigated the effect of steel and polypropylene fibers on flexural behavior of reinforced concrete beams. The total fiber volume fraction was fixed at 1.5% proportion of combined steel (75%) and polypropylene (25%) fibers. The hooked end steel fiber with 60 mm length and polypropylene fibers with 19 mm length were used in this study. The test results show improvement in flexural capacity of reinforced concrete beams. In this experimental study, the flexural cracking behavior of steel fiber-reinforced concrete was investigated. Concrete beams having rectangular cross section of 100x200 mm and 1000 mm span, 100x200 mm cylinders and 150 mm cubes were prepared and tested. Maximum crack width, first cracking load, cracks number, and load-deflection relations were investigated. Splitting tensile strength, compressive strength, workability and wet density were also studied. Four different volume percentages (0.25, 0.5, 0.75 and 1.0% by volume of concrete) of hooked end steel fibers were used.

2 EXPERIMENTAL WORK

2.1 Properties of Materials

Ordinary Portland cement obtained from Alfataih Factory (Darna – LIBYA) complying with BS 12: 1996 was used in this study. Table 1 shows the physical properties and chemical analysis of the cement used. Crushed limestone aggregates were used and designated as type 1 and 2 with maximum sizes of 20 and 10 mm, respectively. Some of the physical and mechanical properties of the aggregates used in this investigation are given in Table 2. Natural sand with an apparent specific gravity of 2.63 and absorption of 0.4% was used. Aggregates were used as all-in aggregate with the standard limitations of BS 882:1992. Hooked-end steel fiber with length of 50 mm and equivalent diameter of 0.5 mm was used in the study. Four different steel fiber percentages were added to concrete at 0.25, 0.5, 0.75 and 1.0%, by volume of concrete.

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Table 1. *PROPERTIES OF CEMENT*

Chemical Composition (%)		Physical properties	
SiO_2	20.95	Fineness-Blaine	3093
CaO	63.2	Setting Time (minute) ;	
$Al_2 O_3$	5.39	Initial	129
$Fe_2 O_3$	3.03	Final	164
MgO	1.35	Specific weight	3.07
SO_3	2.40	Compressive strength	
L.O.I.(Loss on	2.60	3days	24.1
Alkalies	0.88	28days	44.8

Table 2. *PROPERTIES OF COARSE AGGREGATE*

	Apparent Specific Gravity	Absorption (%)	Impact Value (% Fines)	Crushing Value (% Fines)
Type 1 1	2.60	1.42	20.0	29.0
Type 2 2	2.57	1.38		

2.2 Mix Proportions

Mix design proportioning was performed by using weight-batching method and was designed in accordance with the Building Research Establishment (British method). Proportioning of concrete mixtures is shown in Table 3.

Table 3. *PROPORTIONING OF CONCRETE MIXES (KG/M^3)*

Mix Type	Cement	Fiber volume	Water	Coarse Aggregate		Sand
				Type 1	Type 2	
N-0	300	0	195	733	489	658
NF-0.25	300	19.63	195	733	489	658
NF-0.50	300	39.25	195	733	489	658
NF-0.75	300	58.88	195	733	489	658
NF-1.00	300	78.5	195	733	489	658

2.3 Mixing Procedure

All mixtures were mixed in a laboratory pan mixer with a capacity of 56 liters. The mix ingredients placed in the mixer was in the following order; dry aggregates and cement were mixed in the mixer for 30 seconds. Then, steel fibers were added for 30 seconds and water were added gradually in 15 seconds and the mixing continued for 2 minutes. Therefore, the total mixing time was 3 minutes for each concrete mixture. In order to avoid balling and interlocking between fibers, the fibers were added in small quantities during the mixing process. After mixing, the molds were filled with the five different types of concrete and properly compacted by means of a vibrating table. The top surface was leveled and finished by trowel.

2.4 Curing Procedure

After casting, the specimens were covered with polyethylene sheet and left for 24 hours in the mould at 20±2°C (laboratory temperature). After 24 hours, specimens were removed from the mould and kept in water curing for 28 days at 20°C.

3 Experiments on Fresh and Hardened Concrete

The workability of freshly mixed concrete was measured by using slum test according to BS1881: Part 102:1983. The fresh unit weight of concrete was measured in accordance with BS 1881: Part 107:1983. The size of standard cylinder mould used for splitting tensile strength was 100 mm diameter x 200 mm height and for compressive strength the test was performed on 150 mm cube according to BS 1881:Part 116:1983. For each test three specimens were tested at 28 days.

4 TESTING PROCEDURE FOR FLEXURAL CRACKING BEHAVIOR

Five reinforced concrete beams having rectangular cross section of 100X200 mm and span of 1000 mm were prepared and casted. The concrete specimen was supported on a roller bearing at one end and on a hinged bearing at other end. The distance between the two supports was kept at 900 mm for all specimens. All beams have longitudinal bottom steel reinforcement of 2Ø8 in addition to longitudinal top steel reinforcement of 2Ø6 and four stirrups of Ø6 mm @ 100 mm distributed at a distance of 300 mm from both ends. After 28 days of water curing, the concrete beams were left for 15 minutes at laboratory temperature (20±2°C), then white painted and marked prior to being tested. Each test specimen was subjected to increasing load increments at the rate of 2 kN per minute, until failure. The applied loads were measured using a load cell attached to the hydraulic jack. After each load increment, the crack pattern was marked and the surface crack width and spacing were measured. Specimens were instrumented with Dial-gage at mid span to monitor the vertical deflection (Fig. 1). All measurements were regularly recorded at 5 minute intervals. A magnifier lens and a hand-held microscope were used to detect the manifestation of first crack and crack width measurements, respectively.

Fig. 1. *TEST SET-UP ARRANGEMENT FOR BEAMS*

5 RESULTS AND DISCUSSIONS

5.1 Fresh and Hardened Concrete Properties

The results of concrete properties are given in Table 4. As the table shows, the slump decreases with the addition of steel fiber, and thus workability decreases with increasing the steel fibers. This is because increasing the amount of fibers in the mix causes better resistance against compaction. The lowest slump is obtained in mix NF-1.0 with fiber volume fraction of 1.0%. The reduction in slump is about 4 times lower compared to control concrete (NF-0). It can also be seen from the table, increasing the fiber volume percentage causes a slight increase in the wet density of fresh concrete for all mixes. The highest wet density is 2395 kg/m3 obtained in mix NF-1.0 with fiber volume fraction of 1.0%. In compression to control concrete (NF-0), a slight increase in compressive strength with the addition of steel fiber is observed. It can be seen from the Table, an increase by about 3% in compressive strength is observed with the addition of 1.0% fiber volume compared to control concrete (NF-0). The effect of fiber fraction on splitting tensile strength is also shown in Table 4. Increasing fiber volume fraction lead to increase the splitting tensile strength compared to control concrete (NF-0), as shown in Table 4. The maximum increase in concrete splitting tensile strength is about 103% by adding 1.0% steel fiber. The increase in the ultimate splitting tensile strength when adding steel fibers could be related to the improvement in the bond of concrete component and thus the resultant arresting growth of cracks.

Table 4. *FRESH AND HARDENED CONCRETE PROPERTIES*

Mix	Fresh properties		Hardened Properties	
	Slump	Wet density	Compressive strength	Splitting strength
	mm	Kg/m³	MPa	MPa
NF-0	65	2375	34	2.8
NF-0.25	60	2377	34	2.9
NF-0.5	50	2382	34	3.2
NF-0.75	30	2387	35	4.1
NF-1.0	15	2395	35	5.7

5.3 First Crack Load

The first cracking load was the load where the first signs of cracking occur on the side of the test specimen. Loads at first cracking from the experimental results are illustrated in Figure 2. It can be seen from the figure that the strength at the first crack is increased with the addition of steel fiber compared to control concrete beam (NF-0). Beam (NF-1.0) containing 1.0% steel fiber showed an increase by 45% compared to NF-0. This could be related to the improvement in the bond of concrete component due to steel fibers and thus the resultant arresting growth of cracks.

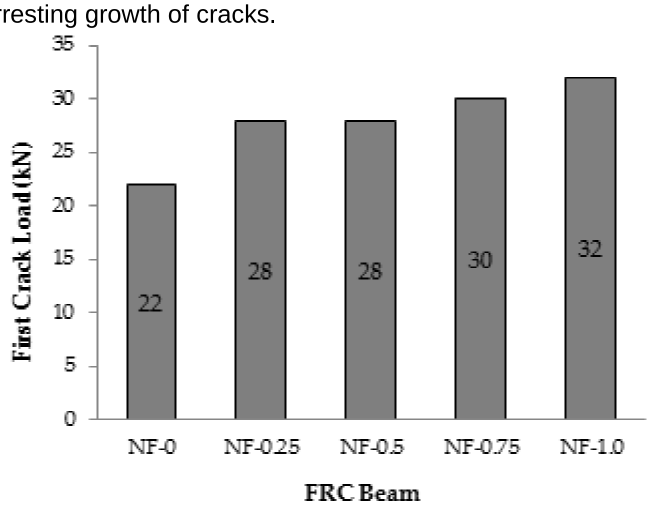

Fig. 2. *First crack load of FRC beams.*

5.4 Cracks Patterns

The crack patterns were very similar in all beam specimens, the first crack occurred at different load levels (Fig. 2) within the constant moment zone. Flexural cracking consisting of vertical cracks perpendicular to the direction of the principal tensile stress occurred early at mid-span. As the load increased, the vertical flexural cracks spread horizontally from the mid-span to the support. Cracking outside the constant moment zone (shear span of 300 mm on each side) started similarly to the flexural cracking. At a higher load, additional cracks started to form throughout the length of the specimen, propagating upward. Prior to failure, compressive cracks started to occur at the top surface of the concrete beams. Figure 3 shows the crack patterns of tested beams.

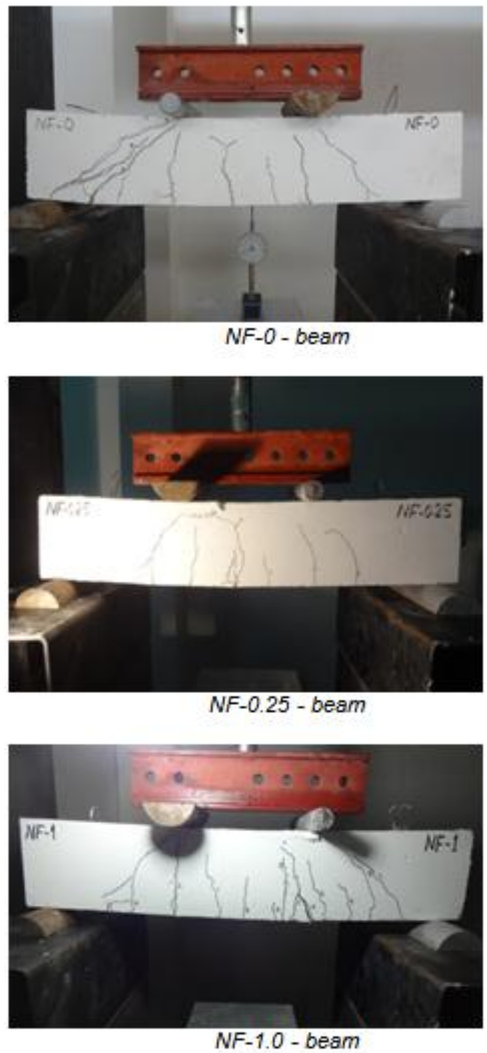

Fig. 3. *Cracks patterns of FRC beams.*

5.5 Maximum Crack Width

Figure 4 shows the results of maximum crack widths of FRC beams which were measured at the same load level (72 kN). It can be seen from Figure 4 that the addition of steel fiber causes a significant decrease in maximum crack width in FRC beams compared to control concrete beam (NF-0). When 1.0% fiber fraction was added, the maximum crack width was reduced by about 81%, compared to NF-0. This is due to the enhancement in the bond of concrete component when steel fiber present in the matrix (Figure 5).

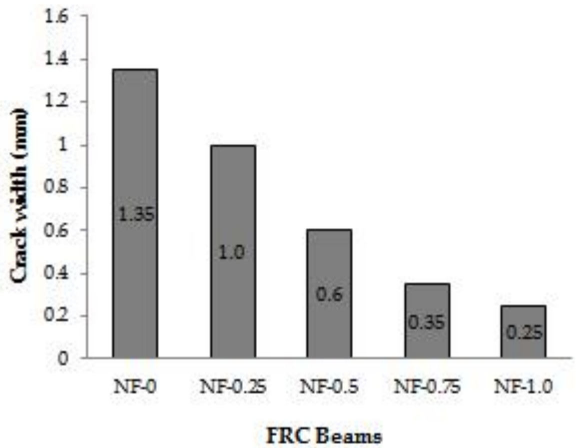

Fig. 4. Maximum crack width of FRC beams.

Fig. 5. Tested FRC beams.

5.6 Cracks Number

Figure 6 shows that the addition of steel fibers causes increase in cracks number. The number of cracks increased by two times when 1.0% fiber was added. It is noted that the increase in cracks number followed by redaction in cracks width (Fig. 4).

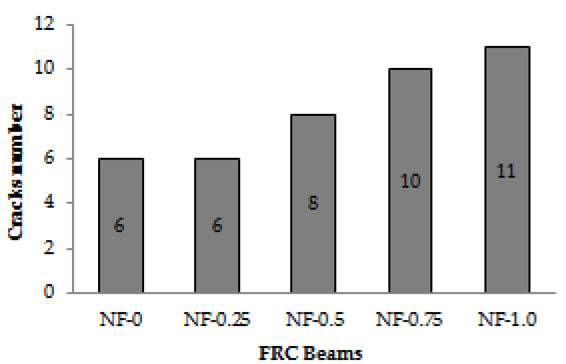

Fig. 6. Cracks number in FRC beams.

5.7 Load – Deflection Curves up to Ultimate Load

The load-deflection curves for FRC beams and control beam are shown in Figure 7. It can be seen from Figure 7 that all beams showed linear increase up to (60 to 70 kN) before reaching its maximum load. However, the FRC beams have higher values of ultimate load (Fig. 8), and their values are increased as fiber fraction increased in the mix. This is more evident in beam (NF-1.0) having 1.0% steel fibers which showed relatively largest toughness (area under curve). The short discrete fibers delay the propagation of micro-cracks, due to the fact that fibers bridge these cracks and restrain their widening, thus improve the post-peak ductility and energy absorption capacity [4].

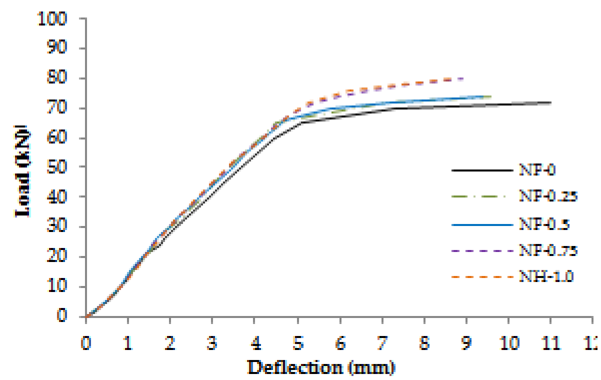

Fig. 7. Effect of steel fiber on load-deflection relations.

5.8 Maximum Flexural Load

The results of maximum flexural load are given in Figure 8. It can be noted from the figure that the gained maximum flexural load is improved with the addition of steel fiber. The addition of 1% steel fiber led to increase by about 11% in flexural load.

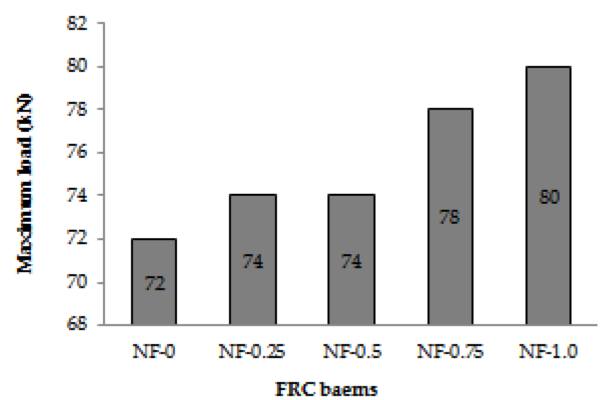

Fig. 8. Maximum flexural load of FRC Beams.

6 Conclusions

- The addition of steel fiber caused a slight increase in wet density, and clear reduction in slump, which is related to the improvement in compaction resistance.
- Compressive strength does not show a clear improvement due to the addition of steel fiber, but significantly enhances the splitting tensile strength. This may be related to arresting cracks by the addition of steel fiber.

- Maximum crack width of FRC beams is clearly reduced. The addition of 1.0% resulted in about 81 % reduction in maximum crack width compared to concrete beam without fiber. The addition of low steel fiber fraction is also found to be effective in controlling maximum crack width.
- The number of cracks increased by two times when 1.0% fiber was added. It is noted that the increase in cracks number followed by redaction in cracks width.
- The experimental results show that the addition of steel fibers enhances the load-deflection relationship and ultimate load for FRC beams.

ACKNOWLEDGMENT

The authors would like to thank civil engineering laboratory staff, Mr. SALAH BADER and Mr. MOHAMAD ABDALWAHAB for their helps throughout the experimental part of this study.

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