CRACKS CONTROL IN HIGH STRENGTH REINFORCED CONCRETE BEAMS USING STEEL FIBERS

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الملخص

تحدث التشققات في الخرسانة عندما يزيد إجهاد الشد المسلط عن سعة شد الخرسانة. أحد الخيارات المتاحة لتقليل التشققات في الخرسانة المسلحة هي بإضافة ألياف موزعه عشوائيا داخل جسم الخرسانة. في هذه الورقة تمت دراسة تأثير نسب مختلفة من ألياف الحديد (0.25، 0.5، 0.75 و1.0 %) معقوفه النهاية علي سلوك التشققات في الخرسانة عالية المقاومة. تم تجهيز واختبار عتبات خرسانيه مسلحة بطول 1000 مم ومساحة مقطع مستطيله 100 x 200 مم. تم دراسة عرض التشقق الأقصى، أول تشقق، عدد التشققات وعلاقة الحمل مع الهبوط وذلك لتخمين سلوك الانحناء للعتبات. بالإضافة إلى ذلك تم دراسة خواص الخرسانة الطرية والصلدة التالية: زمن في بي، الكثافة الرطبة، مقاومه الانضغاط ومقاومه الشد الانشطاري. نتائج الاختبارات تشير إلى أن عرض التشقق يقل بشكل مؤثر بزيادة ألياف الحديد. محتوي ألياف 1.0% نتج عنه انخفاض مقداره 75% في عرض التشقق الأقصى مقارنه بالخرسانة المرجعية (الخالية من الألياف). توضح النتائج أيضا بان العرض الأقصى للتشقق للخرسانة عالية المقاومة يمكن السيطرة عليه بإضافة نسب قليله من الألياف.

ABSTRACT

Cracking occurs in concrete when the tensile stress developed in the member exceeds the tensile capacity of the material. One of the available options to reduce cracks in reinforced concrete is by adding short randomly distributed fibers. In this paper, the effect of hooked-end steel fibers (0.25%, 0.5, 0.75, and 1.0%) on cracks behavior of high strength reinforced concrete was investigated. Reinforced concrete beams having span of 1000 mm and rectangular cross section of 100x200 mm were prepared and tested. Maximum crack width, first crack, cracks number, and load-deflection relations were investigated to evaluate the flexural behavior of beams. Fresh and hardened concrete properties such as Vibe time, wet density, compressive strength and splitting tensile strength were also investigated. The experimental results indicated that the crack width is significantly reduced with the addition of steel fibers. Fiber contents of 1.0% resulted in 75% reduction in maximum crack width compared to control concrete (without fiber). The results also showed that maximum crack width can be controlled for high strength concrete with the addition of even low fiber volume.

KEYWORDS: High Strength Concrete; Steel Fibers; Maximum Crack Width; Cracks Number; Compressive Strength; Splitting Tensile Strength.

INTRODUCTION

High-strength concrete (HSC) is defined as concretes having a compressive cylinder strength above the present existing limits in national codes (60 MPa, and up to 130 MPa), the practical upper limits for concretes with ordinary aggregates [1]. The crucial parameters to produce high strength concrete are high cement content, good feature and good graded aggregates, low water to cement ratios, and adequate compaction and curing [2]. The advantage of HSC structures is to reduce section sizes and consequently steel reinforcement and dead load. The cost of formwork for HSC elements is also reduced.

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 [3-5]. Fiber reinforced concrete 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” [6].

Many studies have been conducted to investigate the effect of steel fibers on concrete [7-15]. Marar et al., (2001) [7] reported that the addition of steel fibers to high strength concrete 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. Study by Tanoli et al., (2014) [15] showed that the compressive strength is slightly increased, but the increase is significant in tensile strength due to addition of steel fibers. In this experimental study, the cracks behavior of high-strength steel fiber-reinforced concrete (HSSFRC) 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 crack, cracks number, and load-deflection relations were investigated. Fresh and hardened concrete properties of high strength steel fiber reinforced concrete, such as splitting tension strength, compression strength, Vibe time 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.

EXPERIMENTAL PROGRAM

Materials Properties

Cement

Ordinary Portland cement obtained from Alfataih Factory (Darna – LIBYA) complying with BS 12: 1996 [16] was used in this study. Table (1) shows the physical properties and chemical analysis of the cement used.

Table 1: Physical and chemical properties of cement

Chemical Composition	(%)	Physical properties	
SiO_2	20.95	Fineness-Blaine (cm^2/gr)	3093
CaO	63.2	Setting Time (minute) ;	
Al_2O_3	5.39	Initial	129
Fe_2O_3	3.03	Final	164
MgO	1.35	Specific weight	3.07
SO_3	2.40	Compressive strength (MPa) ;	
L.O.I.(Loss on Ignition)	2.60	3days	24.1
Alkalies	0.88	28days	44.8

Coarse aggregate

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). properties were measured in accordance with BS 812: Part 2: 1995 [17], BS 812: Part 110: 1990 [18] and BS 812: Part 112: 1990 [19].

Table 2: Physical and mechanical properties of coarse aggregate

Property of Aggregate	Type 1	Type 2
Apparent specific gravity	2.60	2.57
Absorption (%)	1.42	1.38
Impact value (% Fines)	20.0	
Crushing value (% Fines)	29.0	

Fine aggregate

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 [20].

Admixture

Super plasticizer (high range water reducing admixture) was used at a dosage of 2.0% by weight of cement to produce a high strength concrete.

Steel fiber

Hooked-end steel fiber with length of 50 mm and equivalent diameter of 1.0 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 (i.e. 19.63, 39.25, 58.88 and 78.5 kg/m^3).

Mixture Proportions and Mixing Procedure

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). 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 with super plasticizer (mixed together first) were added gradually in 15 seconds and the mixing continued for 2 minutes.

Table 3: Proportioning of concrete mixes (kg/m^3)

Mix	Cement	Super-plasticizer	Fiber volume	Water	Coarse Aggregate		Sand
					Type 1 10-20 mm	Type 2 5-10 mm	
HF-0	550	11	0	165	657	438	590
HF-0.25	550	11	19.63	165	657	438	590
HF-0.50	550	11	39.25	165	657	438	590
HF-0.75	550	11	58.88	165	657	438	590
HF-1.00	550	11	78.5	165	657	438	590

Therefore, the total mixing time was 3 minutes for each concrete mixture. Finally, 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.

Curing of test specimens

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 Figure (1) for 28 days at 20°C.

Figure 1: Concrete specimens in curing water tank

Experiments on Fresh Concrete

The workability of freshly mixed concrete was measured by using Vebe Consistometer according to BS1881: Part 104:1983 [21]. The fresh unit weight of concrete was measured in accordance with BS 1881: Part 107:1983 [22].

Compressive and Tensile Strength Tests

The size of standard cylinder mould used for splitting tensile strength was 100 mm diameter X 200 mm height and the test was carried out according to BS 1881: Part 117: 1983 [23]. For compressive strength, the test was performed on 150 mm cube according to BS 1881: Part 116:1983 [24]. For each test, three specimens were tested at 28 days of water curing.

Testing Procedure

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 Figure (2).

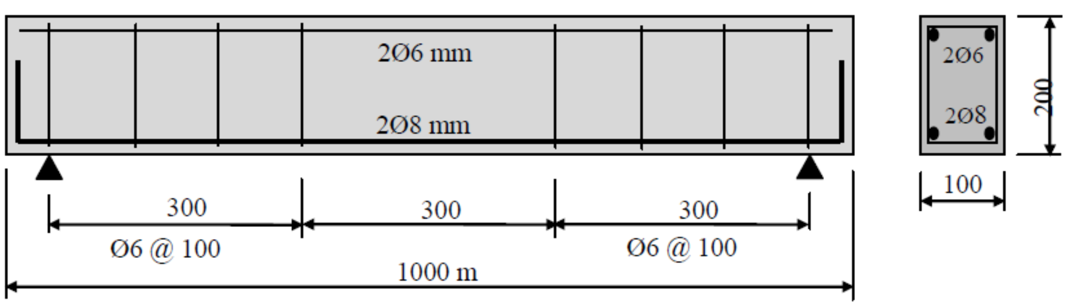

Figure 2: Details of tested beam

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 Figure (3). 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.

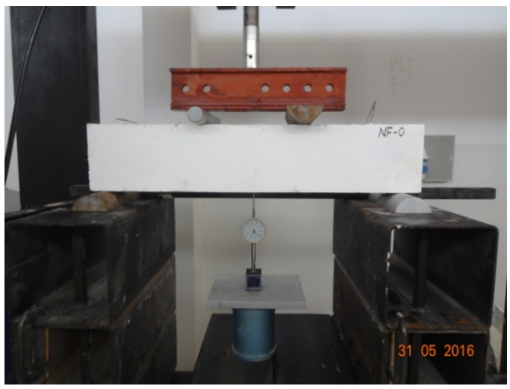

Figure 3: Test set-up arrangement

RESULTS AND DISCUSSIONS

Fresh Mix Properties

The results of Vebe time and wet density tests are given in Figures (4 and 5), respectively. Generally and as Figure 4 shown, the Vebe time increases with the addition of steel fiber. Therefore, workability decreases with increasing fiber volume fraction. This is because increasing the amount of fibers in the mix causes better resistance against compaction. The highest Vebe time is obtained in mix HF-1.0 with fiber volume fraction of 1.0%. This increase in Vebe time is 8.6 times bigger compared to control concrete (HF-0). From Figure (5), it can also be seen that increasing the fiber volume percentage led to increase the wet density of fresh concrete slightly for all mixes. The highest wet density is 2410 kg/m^3, and obtained in mix HF-1.0 with fiber volume fraction of 1.0%.

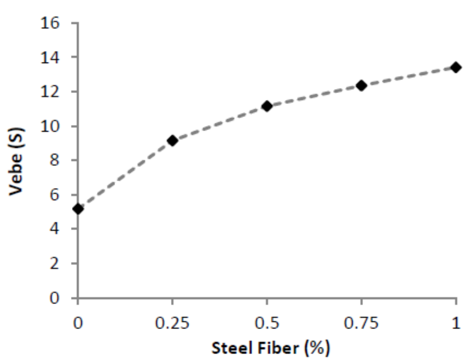

Figure 4: Effect of fiber volume on Vebe time

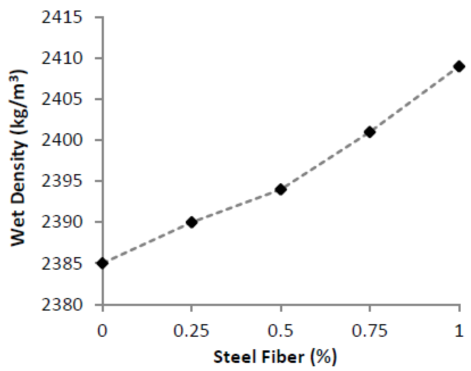

Figure 5: Effect of fiber volume on wet density

Compressive Strength

Figure (6) shows the effect of fiber fraction on compressive strength. In compression to plain concrete (HF-0), a slight increase in compressive strength with the addition of steel fiber is observed. It can be seen from the graph, an increase in compressive strength by about 3.4% is observed with the addition of 1.0% fiber volume compared to control concrete (HF-0). According to study done by Yazıcı et al. [9], the use of steel fiber in concrete increases the compressive strength of concrete by about 4-19%. On the other hand, a reduction in compressive strength with the addition of steel fibers was observed by others [10]. This difference could be the results of several factors such as material properties, test methods and water to cement ratio.

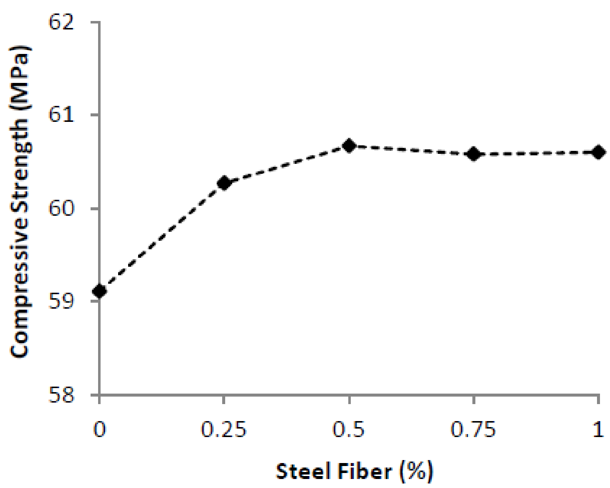

Figure 6: Effect of fiber on compressive strength

Splitting Tensile Strength

The effect of fiber fraction on splitting tensile strength is shown in Figure (7). Increasing fiber volume fraction lead to increase splitting tensile strength compared to plain concrete (HF-0), as Figure (7) demonstrates. The maximum increase in concrete splitting tensile strength is about 66% with fiber volume percentage of 1.0%. Similar results were obtained by other researchers [7 and 10]. 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.

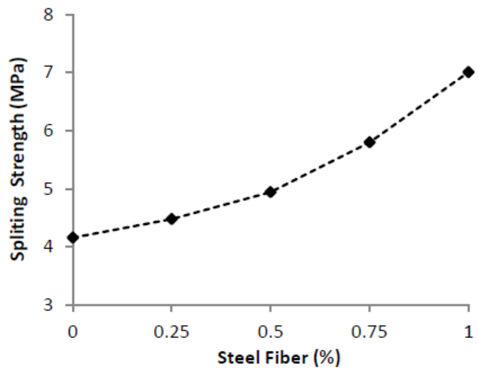

Figure 7: Effect of fiber on splitting strength

Cracks Behavior of HSSFRC

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 (8). 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 (HF-0). This increase is remained constant at about 7% for all mixes.

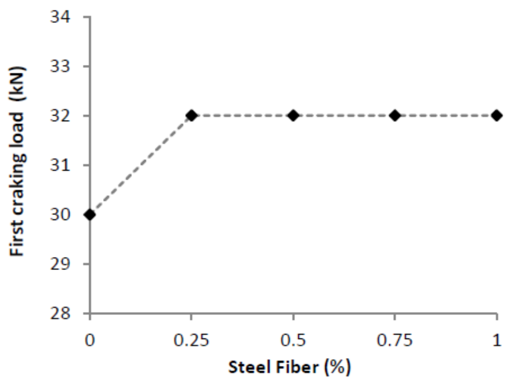

Figure 8: Effect of fiber on first crack load

Maximum crack width

The crack patterns were very similar in all beam specimens, the first crack occurred at different load levels 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 midspan 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 (9) shows the crack patterns of tested beam.

Figure (10) illustrates results of maximum crack widths which were measured at the same load level (72 kN). It can be seen from Figure (10) that the addition of steel fiber causes a significant decrease in maximum crack width of high strength concrete compared to control concrete beam (HF-0). When 1.0% fiber fraction was added, the maximum crack width was reduced by about 75%, compared to control beam. This is due to the enhancement in the bond of concrete component when steel fiber present in the matrix.

Figure 9: Crack pattern

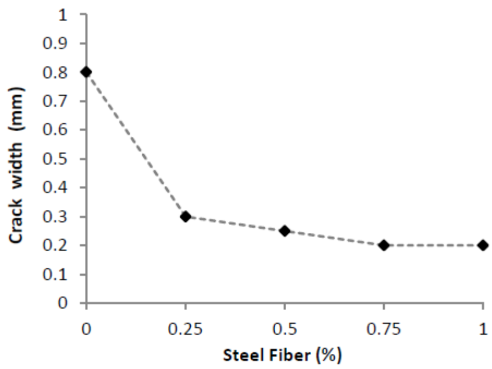

Figure 10: Maximum crack width of HSSFRC

Cracks number

Figure (11) shows that there is a general increase in the number of cracks by steel fiber addition. The addition of 1% fiber volume caused an increase in the number of cracks by about 38% compared to control concrete beam (without fiber). It is generally noted that the increase in cracks number followed by redaction in cracks width Figure (10). This Phenomenon is recommended in the design of the reinforced concrete structures.

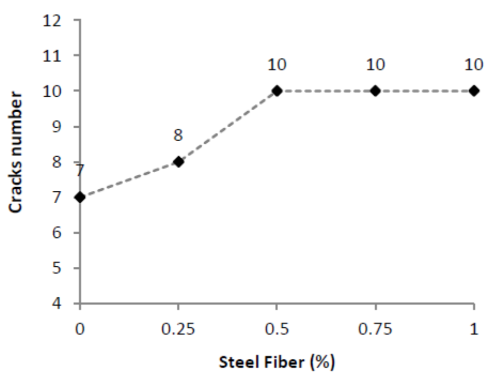

Figure 11: Effect of fiber on cracks number

Load – deflection curves up to ultimate load

The load-deflection curves for HSC beam specimens containing different volume fraction of steel fibers are plotted in Figure (12). In the linear region, the results have similar trends to the test specimens up to 30 kN. When the beam specimens start to crack, test beams become less stiff, as is evident in the figure. It can be seen from Figure (12) that all beams showed linear increase in the secondary linear region up to the load before reaching its maximum load. However, the FRC beams have higher values of ultimate load, and their values are increased as fiber fraction increased in the mix. This is more evident in beam (HF-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 [5].

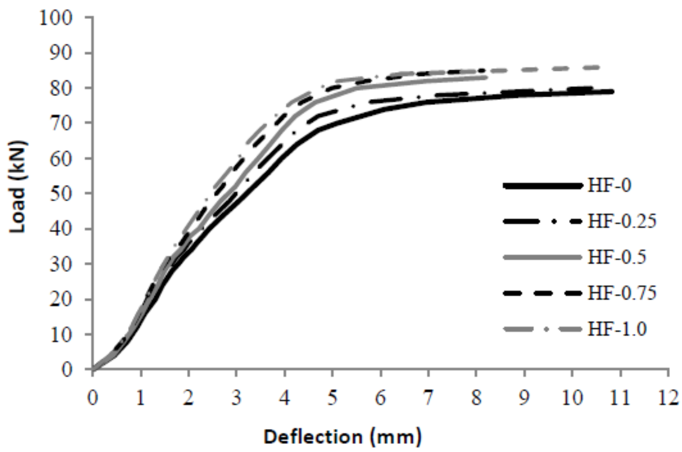

Figure 12: Effect of fiber on load-deflection relations

CONCLUSIONS

The present experimental results indicate that the addition of steel fibers has a positive impact on cracks behavior of high strength reinforced concrete beams. The following findings can be drawn from the obtained results:

a) The compressive strength of high strength concrete is slightly improved with the addition of steel fiber. However, splitting tensile strength shows clear improvement. The splitting tensile strength varied from 4.95 to 8.8 Mpa when 0.25% and 1.0 fiber volume is added to concrete, respectively. This can be attributed to arresting cracks by the addition of steel fiber.
b) The maximum crack width of high strength concrete is significantly reduced with the addition of steel fiber. The addition of 1.0% led to about 75 % reduction in maximum crack width compared to control concrete (without fiber). The results also indicate that maximum crack width can be controlled for high strength concrete at even low fiber volume (0.25%).
c) The experimental results show that the addition of steel fibers enhances the load-deflection relationship and ultimate load for HSC beams.

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