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# Influence of Steel Fiber on the Shear Strength of a Concrete Beam

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**Abstract**

The shear failure in a concrete beam is a brittle type of failure. The addition of steel fibers in a plain concrete mix helps to bridge and restrict the cracks formed in the brittle concrete under applied loads, and enhances the ductility of the concrete. In this research an attempt was made to investigate the behavior and the ultimate shear strength of hooked end steel fiber reinforced concrete beams without traditional shear reinforcement. Four simply-supported reinforced concrete beams with a shear span-to-depth ratio of about 3.0 were tested under two-point loading up to failure. Steel fibers volumetric fractions that used were 0.0, 0.5, 0.75 and 1.0%. Test results indicated that using 1.0% volume fraction of hooked steel fiber led to exclude shear failure and enhanced the use of steel fibers as shear reinforcement in concrete beams. The results also showed that a concrete beam with hooked steel fiber provided higher post-flexural-cracking stiffness, an increase in the shear capacity and energy absorption and an increase in the maximum concrete and steel reinforcement strains.

*Keywords:* Concrete Beam; Shear Failure; Shear Strength; Steel Fiber; Volume Fraction.

## 1. Introduction

The prediction of the shear behavior and ultimate shear strength in a steel fiber reinforced concrete (SFRC) beam involves various factors and is complicated. The main parameters involved are the fiber content, fiber geometry, fiber aspect ratio, fiber tensile strength, longitudinal reinforcement ratio shear span-to-effective depth ratio and cement composite properties.

The effects of the shear span-to-effective depth ratio on shear behavior of SFRC beams have been extensively studied by various researchers. To distinguish between short and slender beams, Batson et al. (1972) [1] suggested a critical value for the shear span-to-effective depth ratio of 3.0 for SFRC beams.

Test results indicate that the fibers have significant influence on the mode of failure and ultimate shear strength of a longitudinally reinforced concrete beam [2]. Addition of fibers increased the beam stiffness and ductility, depending upon the shear-span/depth ratio and transformed the mode of failure into a more ductile one [3]. Also, the addition reduced the beam deformations substantially at all load levels, controlled dowel and shear cracking, reduced spalling in the cover, helped to preserve the ductility and overall integrity of the structural member and increased the ultimate shear strength [4].

Steel fiber reinforced high-strength concrete beams effectively resist abrupt shear failure. Such beams exhibit higher cracking loads and energy-absorption capabilities than comparable high-strength concrete beams without fibers [5].

The addition of steel fibers consistently decreased crack spacing and sizes, increased deformation capacity and changed a brittle mode to a ductile one [6]. The addition of fibers in concrete provide an effective crack arresting mechanism and can serve as an energy dissipation methodology in neutralizing seismic forces during earth quakes [7].

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The direct shear tests indicated that steel fibers are effective in increasing shear strength of concrete, and the fibers caused a decrease in shear crack width and they were able to modify the failure form, from shear to bending [8].

The normalized shear stress at failure for SFRC members was observed to decrease with an increase in the overall height. This indicates that a size effect in shear exists for SFRC members similar to well-known size effects in RC members without transverse reinforcement and without fibers [9].

Addition of fibers to conventionally reinforced beams increases the fatigue life and decreases the crack width under fatigue loading [10]. The cracking shear stress is directly proportional to fiber content and inversely proportional to shear span to depth ratio [11].

The fact that the use of steel fibers improves the ultimate shear strength, diagonal cracking strength and ductility significantly was justified by Arslan et al. (2017) [12]. The fibers appeared to be effective in delaying the formation of cracks and in arresting initial growth of the crack [13].

Yoo and Yang (2018) [14] presented an investigation on the effectiveness of using a percentage of steel fiber and minimum amount of shear reinforcement on the shear behavior of various sized reinforced high-strength reinforced concrete beams.

Based on their experimental work results, Morsy and El-Raki (2018) [15] concluded that the addition of 0.75% steel fiber content in the SFRC beams without shear stirrups is sufficient to achieve the ultimate shear resistance that is the same as the conventional reinforced concrete member with steel stirrups.

Test results indicated that the minimum shear reinforcement of high strength concrete beams was effectively eliminated by adding only a small amount of steel fibres ($\geq$ 0.25 vol%). This amount was much smaller than the minimum requirement by ACI 318 code [16].

Ananthi et al. (2018) [17] concluded that 1% of crimped steel fibers of aspect ratio (50) is the best type of steel fibers for replacing transverse stirrups in high strength concrete beams when analyzed with the steel fibers and hooked ends.

ACI Committee 318 [18] permits to use SFRC for shear resistance when it contains at least 0.76% volume fraction of deformed steel fibers (60 kg per cubic meter of concrete).

The effect of adding different ratios of steel fiber on the ultimate shear strength of a concrete beam without stirrups need to be studied in details. In this work, an experimental attempt will be done to study the using of hooked steel fiber to increase the shear strength of a reinforced concrete beam made without stirrups and explore the use of steel fiber as minimum shear reinforcement in concrete beams.

The experimental work consisted of testing to failure of simply supported SFRC beams designed to fail in shear under monotonically increasing loads in a four-points loading configuration. The performance of the SFRC beams was benchmarked against the behavior of the control beam.

## 2. Experimental Work

### 2.1. Material Properties

All the materials, which have been used in the tests, were confirmed to the authorized specifications and standards. Ordinary Portland cement (Type I) of Al-mass mark was used in casting all the specimens. Cement properties were conformed to the Iraqi Specifications limits (I.O.S. 5/1984) [19]. The grading of the aggregate was conformed to the requirements of Iraqi Specification (I.O.S. 45/1984) [20], Zone 2 for sand and 10 mm maximum aggregate size for gravel. Hooked end steel fibers of length equals 50 mm and diameter equals 1.05 mm (steel fiber aspect ratio = 47.6) were used throughout the experimental work. Steel fibers have nominal ultimate tensile strength of 1100 MPa [21], while reinforcing steel of grade 550 MPa [22] was used as tensile reinforcement.

### 2.2. Concrete Mix Design

In this work, the concrete mix was prepared using ordinary Portland cement Type-I, sand and crushed gravel of 10 mm maximum aggregate size. Three trial different mixes were used, and correction was applied to mix proportions until the following proportion by weight of 1:1.56:2.44 with water – cement ratio equals to 0.42 was found to be sufficient to achieve the required strength of 40 MPa. The compressive strength of the concrete was determined from standards cubes (150 × 150 × 150 mm) taken from the concrete mix.

## 3. Test Setup

Four SFRC beams have been cast and tested up to failure throughout this research work. All the beams have a rectangular cross – section with dimensions of 150 mm width, 200 mm overall depth and with overall length of 2000 mm with an effective depth of 177 mm. The clear cover of concrete that used was 15 mm, for both the bottom and top reinforcement bars. All the beams were reinforced with 2-ϕ16 mm bars in the longitudinal direction in the bottom and pend at the both ends upward to work as a hocked end, and to support only three closed stirrups in the transverse direction with ϕ10 mm bars at each end of beam, to avoid any potential local failure near the supports. Figure 1 shows geometrical details of the beams and steel reinforcement. To inspect the effects of the addition of steel fibers on the shear behavior of a RC beam, four ratios of steel fibers volumetric fractions (0, 0.5, 0.75 and 1.0%) were used. Table 1 shows beams steel fiber contents.

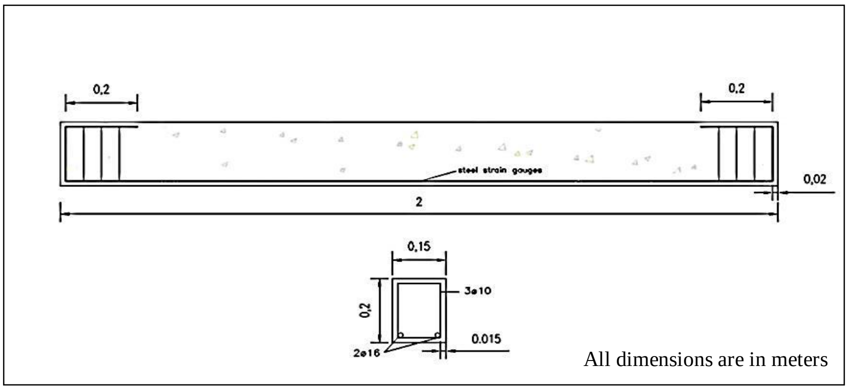



**Figure 1. Beam details**

**Table 1. Tested beams details**

| Beam | Steel fiber (%) | Ultimate load (kN) | Failure type |
|---|---|---|---|
| B01-SF0-SH | 0.00 | 92.5 | Shear |
| B02-SF0.5-SH | 0.50 | 130 | Shear |
| B03-SF0.75-SH | 0.75 | 140 | Shear |
| B04-SF1-SH | 1.00 | 155 | Flexure |

All beams have been tested using the test system shown in Figure 2. In the testing, all the beams were simply supported and loaded by two loads placed symmetrically between the supports. Ideally, no shear forces were applied between the two loading points. Steel plates were installed to transfer the applied force from the two steel rods to the top surface of the beam, to avoid local stress concentration. The vertical load was measured using a 50 ton capacity compression-tension load cell. A mechanical dial gauge was set beneath mid-span of the beam, to measure beam deflections during testing. To observe if the steel reinforcement yielded, strain gauges were fixed on the reinforcing bars near the mid-span of each casted beam. Also at the mid-span, two concrete strain gauges have been fixed on the side surface of each beam at 13 mm from the top and bottom surfaces.

Deflections were imposed by increasing the applied load in small increments. The applied load, the beam deflection at mid-span, concrete strains and steel reinforcement strain were recorded continuously until failure.

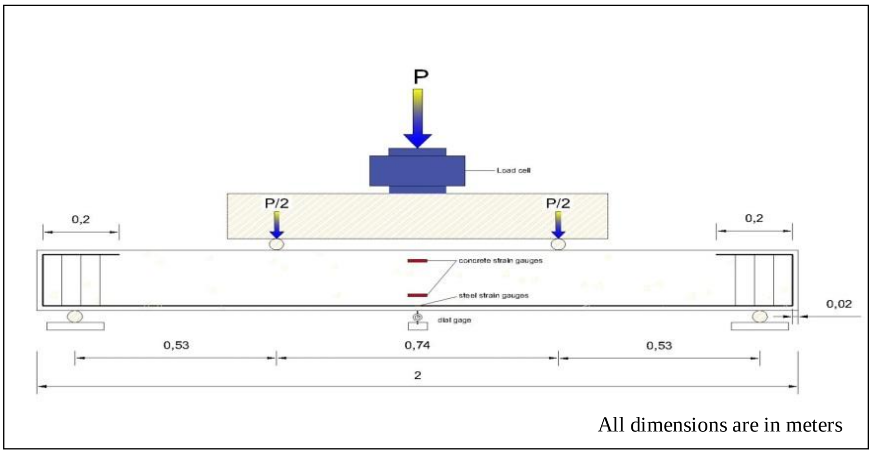



**Figure 2. Tested beam details and positions of strain gauges in beam**

All beams have been tested using a steel frame in University of Baghdad Structural Engineering Laboratory. This frame (Figure 3) was used for a wide range of tests by adding suitable instruments such as supports, manual jack and other required accessories for tests. Figure 4 shows one of the casted beams under shear test.

**Figure 3. The test frame**

**Figure 4. Beam under shear test**

## 4. Test results

### 4.1. Deflections for Test Specimens

Deflection was measured at mid-span section of the tested beam subjected to two point loads. The deflection in all tested beams was monitored and recorded during the whole range of loading up to failure and plotted as load – mid-span deflection curves. Figure 5 shows the mid-span deflection variations of the four beams due to applied load for comparison purposes. The addition of a volume fraction of hooked steel fiber as shear reinforcement imparts ductility and substantially increases the shear strength of a concrete beam, but leaves the deflection at certain load almost without change.

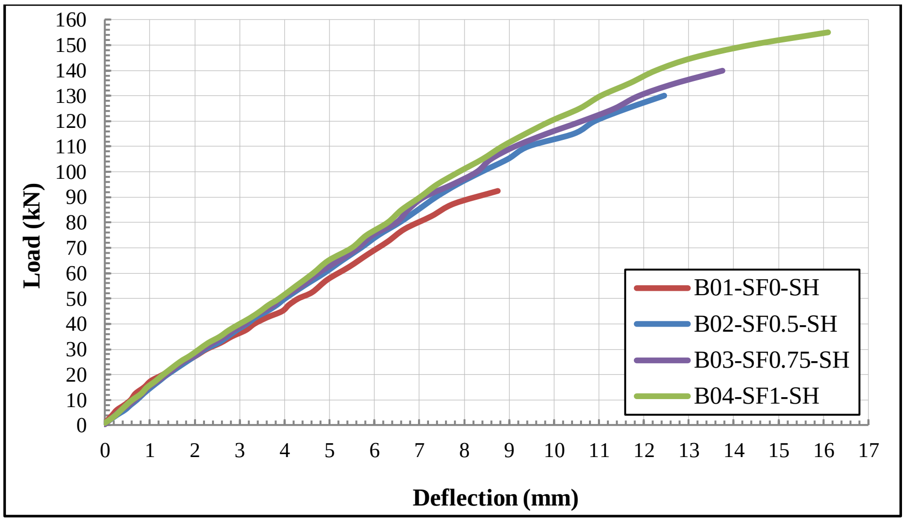



**Figure 5. Load – deflection diagram for tested beams under shear force**

It can be seen that there is a noticeable increase in the shear capacity and energy absorption up to 1.0% volumetric fraction of fibers. The details of percentage increases in the ultimate load and percentage decreases in the mid-span deflection at certain load (80 kN) for the tested beams are stated in Table 2.

**Table 2. Effect of increasing steel fiber ratio on ultimate loads and mid-span deflections**

| Beam | Steel fiber (%) | Ultimate load (kN) | Increasing in ultimate load (%) | Mid-span deflection (mm) | Decreasing in mid- span deflection (%) |
|---|---|---|---|---|---|
| B01-SF0-SH | 0.00 | 92.5 | ----- | 6.98 | ----- |
| B02-SF0.5-SH | 0.50 | 130 | 40.54 | 6.57 | 5.81 |
| B03-SF0.75-SH | 0.75 | 140 | 51.35 | 6.49 | 6.95 |
| B04-SF1-SH | 1.00 | 155 | 67.56 | 6.30 | 9.68 |

From the load – deflection variations obtained, it is obvious that, for all the four tested beams, the load deflection relation is linear up to about 70% of the ultimate load, after that a nonlinear relationship with gradually reducing slope was observed up to shear failure.. The maximum deflection in SFRC beams is found to be increased with the increase in the fiber content, which infers that steel fiber addition in a beam improves the ductility.

The addition of hooked steel fibers reduced the mid-span deflection at certain load (80 kN) in the tested beams due to providing an increase in flexural stiffness of SFRC beam.

The randomly distributed discontinuous steel fibers role as bridges across the cracks that develop through loading and provide some post-cracking ductility. So, the steel fibers work to increase the ultimate strain that could be reached leading to increase the peak load and providing increase in the toughness of the concrete.

### 4.2. Mode of Failure

Two different modes of failure were observed in the tests. The first mode is the diagonal splitting failure, which is happened in beams B01-SF0-SH, B02-SF0.5-SH and B03-SF0.75-SH. Flexural cracks were first formed at the bottom face (tension zone) of the tested beam in the central region of the beam, where the maximum moment occurred. As the applied load increased, these cracks were widened, increased in number and spread upward and toward the support. When the applied load was adequate to cause a diagonal tensile stress greater than that of concrete tensile strength, small cracks began to form at the line drawn from the support toward the applied load. At ultimate load, these cracks joined together forming a diagonal crack start from the bottom of beam near the support and then developed towards the applied load followed by a shear failure of the beam.

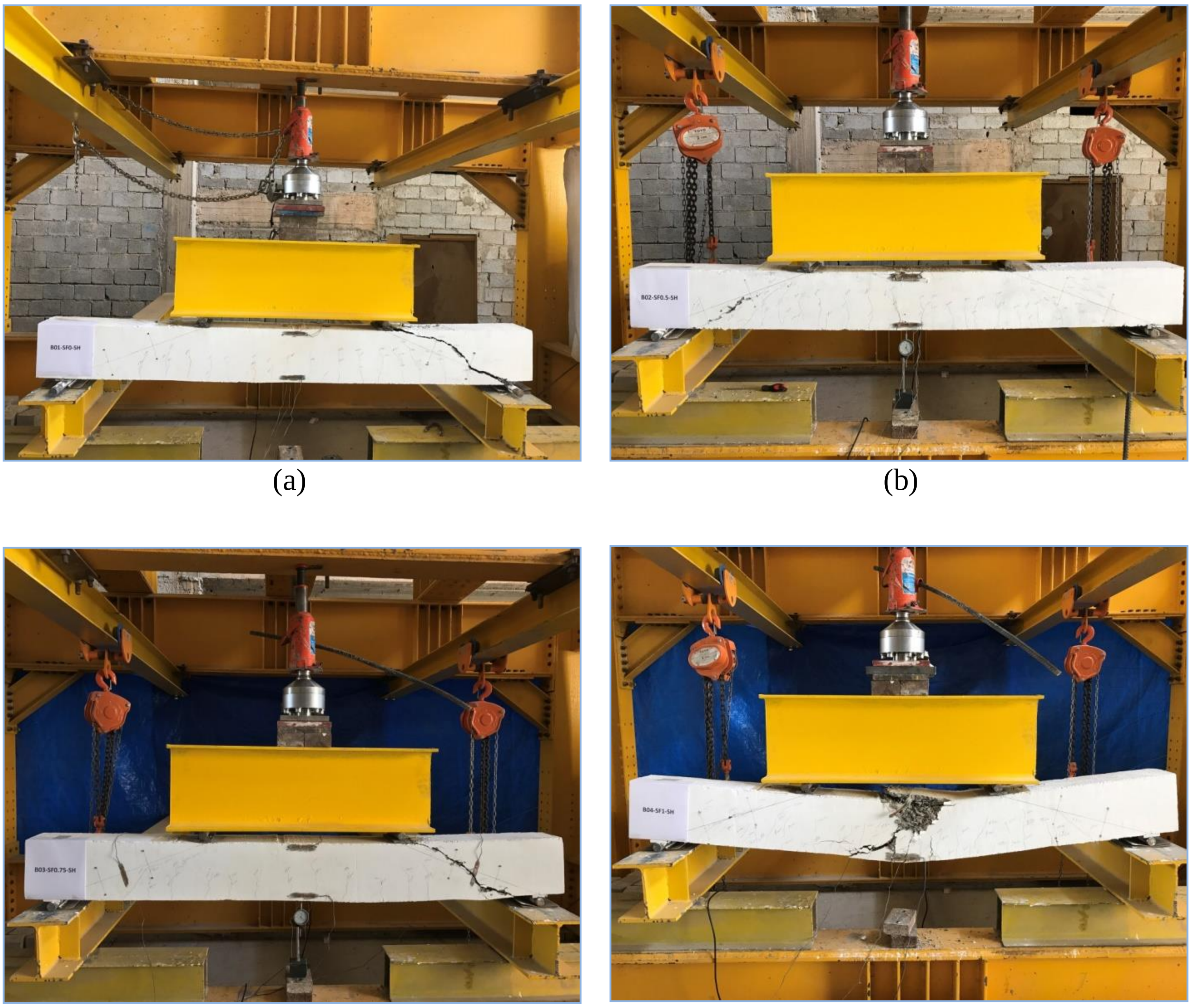
The second mode is the flexure failure, which is happened in beam B04-SF1-SH. Flexural cracks start from the bottom face of the tested beam at mid-span and developed, with the increasing in the applied load, toward the top surface of the beam (the compression zone) until the beam failed by secondary compression failure. In this beam, due to presence 1.0 % steel fiber, the mode of failure transduced from shear failure as happened in the previous beams to flexure failure (yielding of main reinforcement followed by crushing of concrete).

Table 3 summarizes the first flexural and diagonal cracks and mode of failure for all tested beams. It can be notice that the increasing in volume fraction of the steel fibers leads to delay appearance of the first cracks for both flexure and diagonal cracks and it was observed that flexure cracks were appeared before diagonal cracks.

**Table 3. Summary of first cracking loads and mode of failure for all four tested beams**

| Beam | Steel fiber (%) | First flexural crack | | First diagonal crack | | Mode of failure |
|---|---|---|---|---|---|---|
| | | Load (kN) | Increasing (%) | Load (kN) | Increasing (%) | |
| B01-SF0-SH | 0.00 | 25 | ----- | 82.5 | ----- | diagonal splitting |
| B02-SF0.5-SH | 0.50 | 27.5 | 10 | 85 | 3 | diagonal splitting |
| B03-SF0.75-SH | 0.75 | 27.5 | 10 | 85 | 3 | diagonal splitting |
| B04-SF1-SH | 1.00 | 27.5 | 10 | 90 | 9 | flexure |

Figure 6 shows the cracks pattern at failure for the four tested beams.



(a) (b) (c) (d)

**Figure 6. Crack pattern at failure for the four beams (a) beam (B01-SF0-SH) (b) beam (B02-SF0.5-SH) (c) beam (B03-SF0.75-SH) (d) beam (B04-SF1-SH)**

## 4.3. Concrete Strain

The normal strains of the SFRC beams were measured at each loading stage using electrical strain gauges. Figure 2 indicates the positions of these gauges. Figure 7 illustrates top and bottom concrete strains across mid span sections for all four beams. The concrete strains seem to be rational and steel fibers have little effects on the strain values especially on the maximum strain that had been reached. This increase in the maximum strain was due to the composite effect of the steel fibers with the concrete producing a new material, which can sustain more loads.

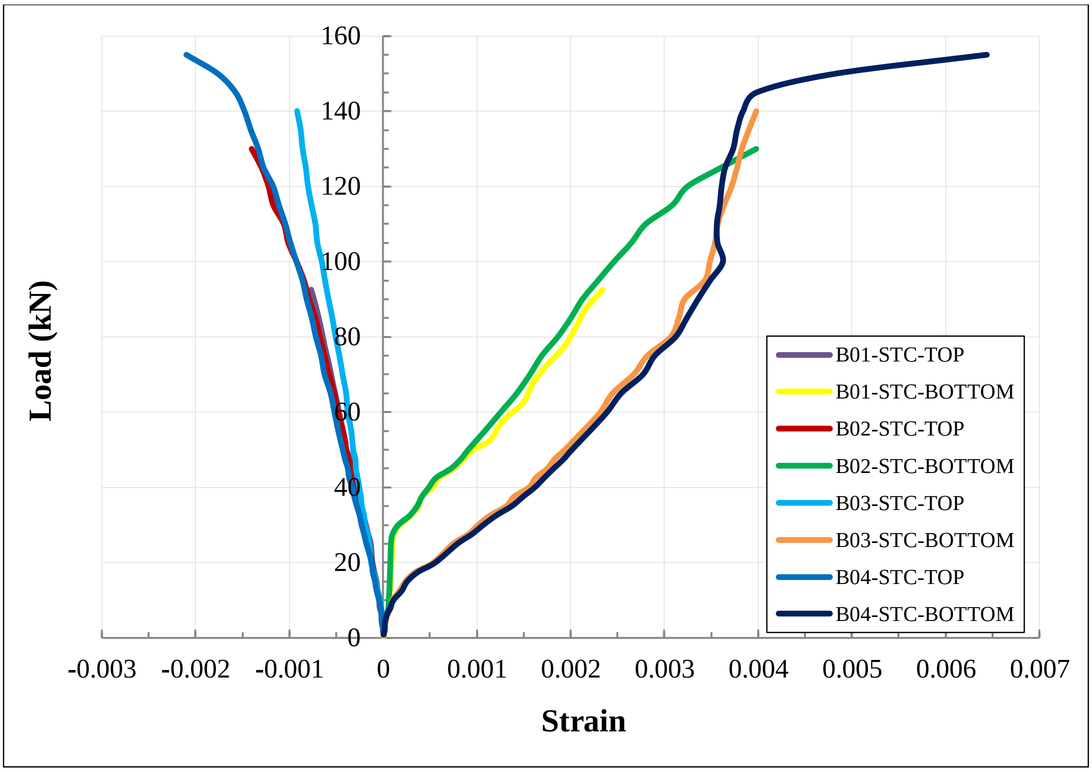



**Figure 7. Concrete strain across mid span sections for all four beams**

## 4.4. Steel Reinforcement Strain

Only one strain gage was instilled on the mid span of the main steel reinforcement for each casted beam. The strain introduced in the steel reinforcement at each stage of loading was recorded until the failure of the beams. Figure 8 illustrates the fully behavior of load-strain in steel reinforcement bar for all four tested beams. It can be noticed that the steel reinforcement strains did not vary with adding steel fibers, but the maximum strain has been increased clearly. It is obviously that the steel reinforcement in beams B02-SF0.5-SH and B03-SF0.75-SH and B04-SF1-SH have been yielded (yielding strain equals 0.00275).

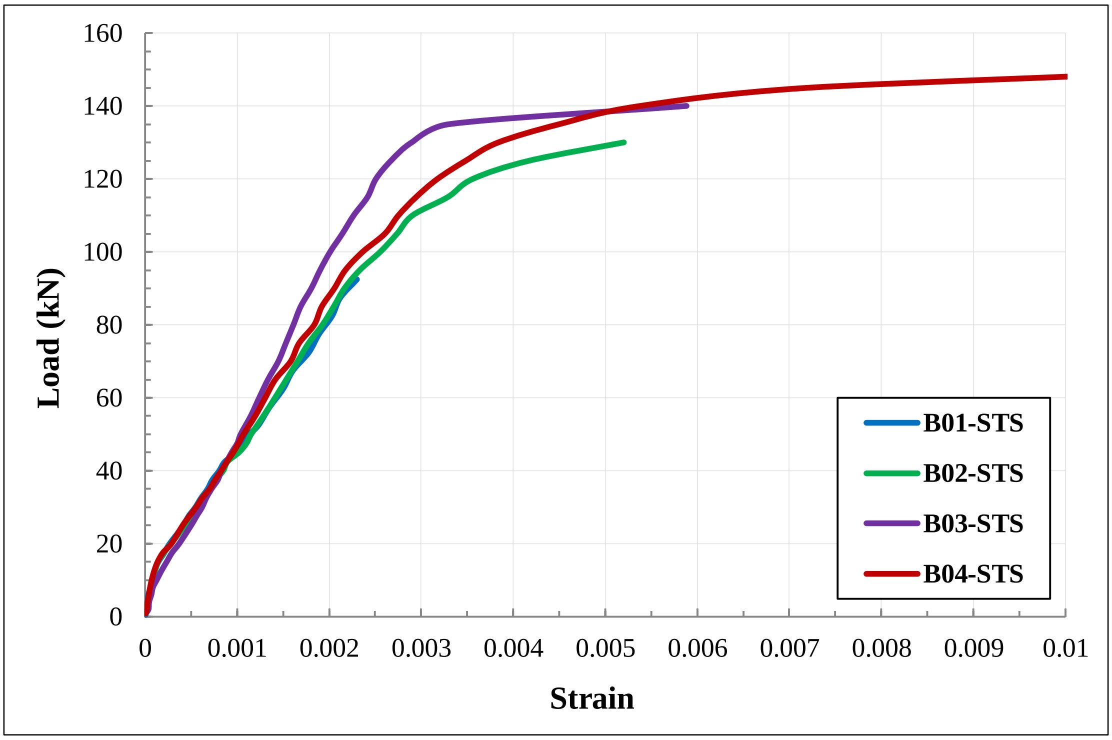



**Figure 8. Steel reinforcement strain across mid-span section for all four beams**

The addition of steel fibers was efficiently constrained cracks propagation and generated higher number of and more spread initial flexural cracks than ordinary concrete. Also, a noticeable higher post-flexural-cracking stiffness was gotten due to the enhanced tension stiffening in the SFRC beams. The randomly distributed discontinuous steel fibers act as bridges across the cracks and provide perceptible post cracking ductility.

## 5. Conclusions

The main conclusions, which can be extracted from the experimental test of SFRC beams exposed to shear force, are:

- Under shear force test the addition of steel fibers to RC beams improved their ultimate shear strength up to 67.56% when compared with the control beam.
- For specimens exposed to shear force, using steel fiber decrees the maximum mid-span deflection of SFRC beams up to 15.42% related to the control beam.
- The mode of failure of a SFRC beam transfers from shear failure to flexure failure due to adding 1.0% volume fraction of steel fiber. That gives a great indication of the role of steel fiber to enhancement shear strength of beams.

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