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# Introducing a New shape of Steel Fibres and Studying its Effect on the Mechanical Properties of Concrete.

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## ABSTRACT

The marked brittleness with low tensile strength of plain concrete can be overcome by the addition of steel fibres (SF). This paper investigates the mechanical properties of steel fibre reinforced concrete (SFRC) and spiral steel fibre reinforced concrete (SSFRC). The properties included compressive and splitting tensile strength, modulus of rupture, and toughness index. The steel fibres were hook-ended shape with aspect ratio *(l/d=50)*. The introduced shape was spiral steel fibres (SSF) with diameter of spiral=1.5 cm. The two shapes of steel fibres were added at the volume fraction of 0.5%, 1.0%,2.0%, and 3.0%. All the mechanica1 properties of SFRC enhanced up to 2.0% volume fraction of fibers, whereas the mechanical properties of SSFRC enhanced up to 3.0% volume fraction. The compressive strength of SFRC and SSFRC enhanced by 43.4% and 65% respectively relative to plain concrete. The splitting tensile strength of SFRC and SSFRC enhanced by 52.6% and 147% respectively relative to plain concrete. The modulus of rupture of SFRC and SSPRC enhanced by 137.5%, and 62.5% respectively relative to plain concrete. The toughness index of SPRC improved with increasing the fraction up to 2.0%. The indices $I_5$, $I_{10}$, and $I_{20}$ registered values of 10.7, 20.5, and 35.1 at 2.0% fraction. The toughness index of SSFRC improved with increasing the fraction up to 3.0%. The indices $I_5$, $I_{10}$, and $I_{20}$ registered values of 9.76, 18.78, and 35.8, respectively, at 3.0% volume fraction.

## I. INTRODUCTION

Adding fibers to fresh concrete is a common way to improve the mechanical properties of concrete. The fibers improve the crack resisting properties and provide concrete with greater tensile stresses, ductility an~ high impact resistance. Using .these techniques the structural capacity can be improved to resist heavier explosions or dynamic loading.

This investigation concern with steel fibres using two shapes of steel fibres (hooked-end shape , spiral shape SSF). The new shape of steel fibres is intended to be used in: a) controlling of fibres content without problem in workability, by introducing the SSF with suitab1e way and length, according to dimensions Of specimens b) controlling of the orientation of fibres and alignment his allows a uniform distribution of fibres rather than random c) enhancing the bond between fibres and matrix d) enhancing the capacity of materials by interlocking the spirals together. This study

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demonstrated that the use of SSF in concrete can greatly enhance the compressive, splitting, flexural strength, and flexural toughness of concrete at the age of 28 days.

## 2. EXPERIMENTAL PROGRAM

### 2.1. *Material*

Type I cement, sand with a fineness modulus of 2.29, and crushed rock of 6.3 maximum sizes were used. Super plasticizers based on naphthalene formaldehyde condensate were used as workability agents to ensure the desired strength without increasing the water-cement ratio. The cement, sand, crushed rock, water, and super plasticizers of 400, 918, 918, 180, 6 kg/m3 were used to make the plain concrete. The V-B time ranged from 9s to 22s. The hooked-end and spiral steel fibres were made of mild carbon steel. The hooked-end fibres have an average length of 50 mm, nominal diameter of 1.0 mm, and the aspect ratio of 50. The spiral fibres have a variable length according to dimensions of specimens with diameter of spiral of 15 mm.

### 2.2. Preparations of samples

In the production of concrete, the constituent materials were initially mixed without fibres. The hooked-end fibres were then added in small amounts to avoid fibre balling and to produce concrete with uniform material consistency and good workability. The spiral steel fibres were placed manually by layers during the casting of fresh concrete. Mixing time was prolonged from 3 minutes for the conventional mixture to 5 minutes for the SFRC to ensure a homogeneous fibre distribution. Each layer was compacted using a vibrating table. At the end of 24 h after compaction, the specimens were de-molded and cured in water at 23° C for 28 days before performing the required test.

### 2.3. Test methods

The compressive strength test was performed on standard cubes and standard cylinders, according to ASTM C192 and BS 1881; part 110. The cubes and cylinders were loaded, in a testing machine, under load control, at the rate of 0.3 MPa/s until failure.

The splitting tensile test, cylinders were tested according to the ASTM C496 test for splitting tensile strength of cylindrical concrete specimens. In the test, load applications were continuous, and shock less and at a constant rate of 900 kPa/min until specimen failure.

The flexural strength (modulus of rupture, MOR) test was conducted, according to the ASTM C1018 test for flexural toughness and first-crack strength of fibre-reinforced concrete. The testing machine applied the load in a manner to increase the deflection at a constant rate; and the load-deflection relationship was recorded.

## 3. RESULTS AND DISCUSSIONS

Table (1) shows the compressive strength test results on SFRC and SSFRC. Table (2) shows the tensile strength test results on SFRC, SSFRC, and SSFRC. Each strength test result was the average for 3 test specimens. The compressive strength, splitting tensile strength, and modulus of rupture of SPRC improved to different extents in response to fibre volume fractions up to 2.0%. Using SSf the above properties improved up to 3.0% volume fractions.

### 3.1. Compressive strength

The compressive strength development of SFRC versus plain concrete is siven in Fig. 1, declaring that the cube compressive strength of plain concrete was 32.55 N/ mm2 and using SFRC provided an improvement at each volume fraction. The improvement, as shown in Table land fig. 2, was 10.2%, 29.2%, 18.3%, 14.5% for fractions 0.5%, 1%, 2%, 3% The cylinder compressive strength of plain concrete was 28.1 N/mm2 and using SFRC provided improvement at each volume fraction as shown in Table 1, Fig. 3, and Fig. 4.

The compressive strength development of SSFRC versus plain concrete is siven in Fig. 1, declaring that the cube compressive strength of plain concrete was 32.55 N/ mm2 and using SSFRC provided an improvement at each volume fraction. The improvement, as shown in Table 1, was 10.2 at 0.5% fraction, 27.7% at 1.0% volume fraction, 35.8% at 2.0% volume fraction, and 47.4% at 3.0% volume fraction. The cylinder compressive strength of plain concrete was 28.1 N/mm$^2$ and using SSFRC provided an improvement at each volume fraction as shown in Table (1), Fig.3 & Fig.4 .

Table (1) Compressive strength test results and strength-enhancement for SFRC and SSFRC

| Fibre Volume Fraction (%) | Cube compressive strength | | | | Cylinder compressive strength | | | |
|---|---|---|---|---|---|---|---|---|
| | SFRC* | | SSFRC** | | SFRC*** | | SSFRC**** | |
| | Measured N/mm$^2$ | strength-Enhancement (%) | Measured N/mm$^2$ | strength-enhancement (%) | Measured N/mm$^2$ | strength-enhancement | Measured N/mm$^2$ | strength-enhancement (%) |
| 0 | 32.55 | - | 32.55 | - | 28.1 | - | 28.1 | - |
| 0.5 | 35.88 | 10.2 | 35.87 | 10.2 | 32.4 | 15.3 | 32.5 | 15.6 |
| 1.0 | 42.07 | 29.2 | 41.56 | 27.7 | 37.5 | 33.4 | 37 | 31.6 |
| 2.0 | 38.5 | 18.3 | 44.2 | 35.8 | 33.5 | 19.2 | 39.5 | 40.5 |
| 3.0 | 36.4 | 14.5 | 48 | 47.4 | 32.6 | 16 | 43.8 | 55.8 |

3.2. Splitting tensile strength

The development of splitting tensile strength of SFRC at various volume fractions is shown in Fig. 2; compared to plain concrete, the strength of SFRC improved with increasing the volume fraction up to 2.0%. Prom the strength-enhancement as shown in Table 2, the improvement ranged from 16.7% at 0.5% volume fraction and up to 49% at 2.0% volume fraction, but reduced to 38% at 3.0% volume fraction.

The development of splitting tensile strength of SSFRC at various volume fractions is shown in Fig. 2; compared to plain concrete, the strength of SSFRC improved with increasing the volume fraction up to 3.0%. From the strength-enhancement shown in Table 2, it is latenesling to note that the improvement ranged from 25.2% at 0.5% volume fraction and up to 85.5% at 3.0% fraction.

Table (2) Tensile strength test results and strength-enhancement on SFRC and SSFRC

| Fibre Volume Fraction (%) | Splitting tensile strength | | | | Flexural tensile strength (MOR) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SFRC | | S.SFRC | | SFRC | | SSFRC(H) | | SSFRC* | |
| | Measured $N/mm^2$ | strength-Enhancement (%) | Measured $N/mm^2$ | strength-enhancement (%) | Measured $N/mm^2$ | strength-enhancement (%) | Measured $N/mm^2$ | strength-enhancement (%) | Measured $N/mm^2$ | strength-enhancement (%) |
| 0 | 3.1 | - | 3.1 | - | 3.2 | - | 3.2 | - | 3.2 | - |
| 0.5 | 3.62 | 16.7 | 3.88 | 25.2 | 3.6 | 12.5 | 3.27 | 2.2 | 3.4 | 6.25 |
| 1.0 | 4.43 | 43 | 4.56 | 47 | 5.6 | 75 | 3.43 | 7.2 | 3.48 | 8.75 |
| 2.0 | 4.62 | 49 | 5.08 | 64 | 7.6 | 137.5 | 3.45 | 8 | 4.4 | 37.5 |
| 3.0 | 4.28 | 38 | 5.75 | 85.5 | 6.2 | 93.7 | 3.46 | 8.1 | 5.2 | 62.5 |

### 3.3. Modulus of rupture (Mor)

The (MOR) for SSFRC(H) was improved slightly with increasing the volume fraction by 2.2% , 7.2% , 8% and 8.1% for fibre content 0.5%,1.0%, 2.0%, and 3.0%, respectively (figures 4.19,4.20). This can be attributed to expanding the spirals after cracking in mid span of beam, without high effect of fibres to resist the tensile stress at first crack similes is plain concrete.

The (MOR) for SSFRC (interlocking spiral) improved with increasing the volume fraction by 6.25% , 8.75% to 37.5% , 62.5% and fibre content 0.5, 1.0, 2.0, and 3.0%, respectively (figures 4.19, 4.20), due to the absence of voids, balling, and clumping in spiral fibres.

### 3.4. Flexural toughness

Flexural toughness is the energy absorbed in deflecting abeam a specified amount, being the area under a load-deflection (P-d) curve for the 100x 1 00x500 mm fibrous beam tested in third-point bending. toughness Index I for SFRC, SSFRC, and SSFRC reflects the improvement in flexural toughness over the non-reinforced concrete, being the flexural toughness at a specified deflection divided by that at the first-crack deflection (δ) of non fibre- reinforced concrete. The indices widely estimated indexes are 15 at 38, /10 at 5.58, and ho at 10.58 [δ] .All the three indices reached unity, assuming that the non fibre-reinforced matrix is elastic- brittle. Such results are illustrated in Table 3. For SFRC the toughness indices increased with increasing volume fraction of fibres up to 2.0%. The 15, /10, and ho values were 10.7,20.5, and 35.1, respectively, at volume fraction of 2.0%. But the values decreased to 8.6, 14.54, and 22.19 with volume fraction 3.0%, For SSFRC*(interlocking) the toughness indices increased with increasing volume fraction of fibres up to 3.0%. The $I_5$, $I_{10}$, and $I_{20}$ values were 9.76, 18.78, and 35.8, respectively, at the fibre volume fraction of 3.0% .

Table 3 Flexural toughness index at various fibre volume fractions for SFRC and SSFRC*

| Fibre Volume Fraction (%) | SFRC toughness index | | | SSFRC*(interlocking) toughness index | | |
|---|---|---|---|---|---|---|
| | $I_5$ | $I_{10}$ | $I_{20}$ | $I_5$ | $I_{10}$ | $I_{20}$ |
| 0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0.5 | 5.61 | 8.16 | 10.35 | 5.2 | 10.18 | 19 |
| 1.0 | 8.41 | 15.8 | 23.9 | 5.32 | 10.92 | 22.5 |
| 2.0 | 10.7 | 20.5 | 35.1 | 6.7 | 14.42 | 30.2 |
| 3.0 | 8.6 | 14.54 | 22.19 | 9.76 | 18.78 | 35.8 |

$$I_5 = \frac{\text{Toughens at } 3\delta \text{ for any concrete}}{\text{Toughens at } \delta \text{ for non fibre – reinforced concrete}}$$

- similarly $I_{10}$ & $I_{20}$
- How Come $I_5 = 1$, $I_{10} = 1$, $I_{20} = 1$ } for non Fibre Come

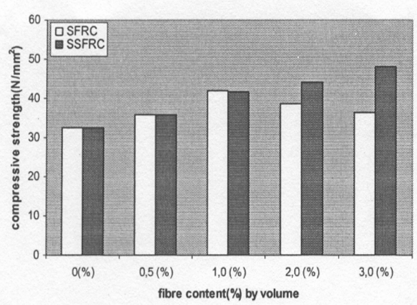


Fig. 1 Relation between cubes compressive And fibre content% by volume

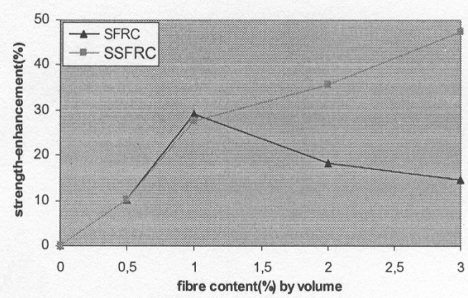


fig. 2 Relation between strength-enhancement% And fibre content% by volume

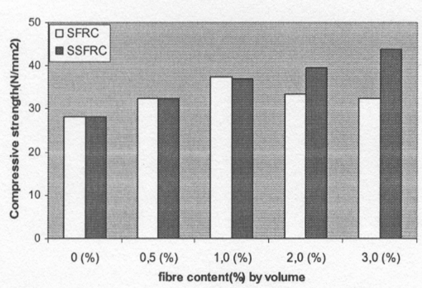


Fig. 3 Relation between cylinder compressive and fibre content% by volume

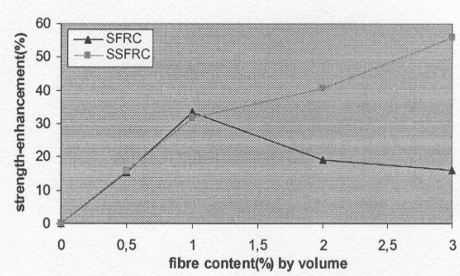


Fig. 4 Relation between strength–enhancement% and fibre content% by volume

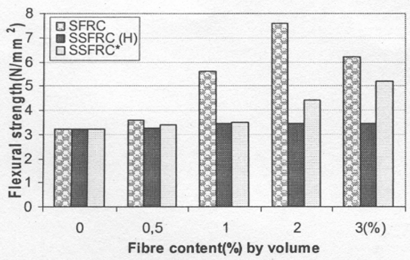


Fig. 7 Relation between flexural strength and fibre content% by volume

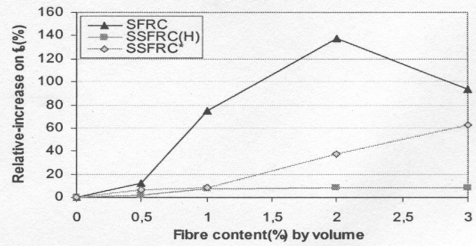


Fig.8 Relation between strength-enhancement% and fibre content% by volume

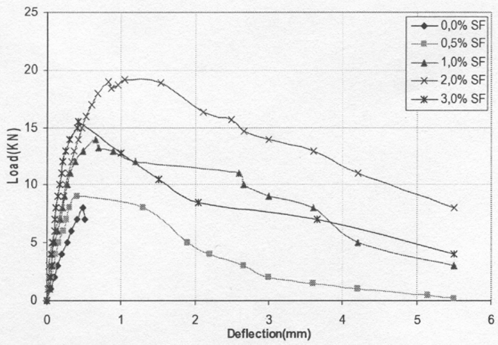


Fig. 9 Load-deflection curve from flections tests (various content of SF)

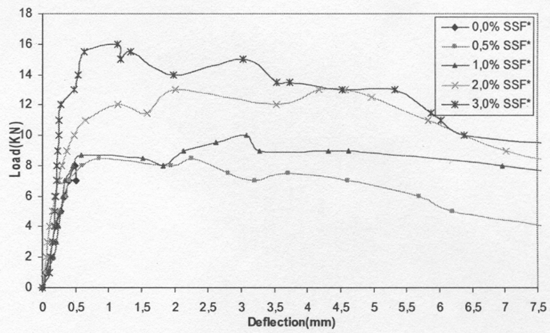


Fig. 10 Load-deflection curve from flections tests (various content of SSF*)

## 4. CONCLUSIONS

1. The compressive strength of plain concrete improved with the addition of steel fibres up to 2.0% by volume, but decreased at 3.0% fraction. The enhancement in compressive strength has reached 34%.
2. Using spiral steel fibres enables us to increase (the fibres content up to 3.0% by volume, with higher improvement of the compressive strength. The maximum enhancement reached 55.8% at 3.0% fraction.
3. The splitting tensile strength of concrete improved with increasing steel fibres up to 2.0% fraction, but decreased at 3.0% fraction. The maximum enhancement reached 49% at 2.0% fraction. Using spiral steel fibres more improvement with increasing the fibres content up to 3.0% fraction. The maximum enhancement obtained was 85.5% at 3.0% fraction.
4. The addition of SF to plain concrete increases the modulus of rupture up to 138% at 2.0% volume fraction. But using SSF in different orientations with and without interlocking the spirals, little and different enhancement in values of modulus of rupture was obtained , Using, SSF (H), and SSF the enhancement reached to 8.0%, and 63%, respectively at 3.0% volume fraction.
5. The ASTM toughness indices $I_5$,$I_{10}$, and $I_{20}$ increased as SF content increased up to 2.0%, but they decreased at 3.0% volume fraction compared to 2.0% volume fraction. The enhancement in toughness indices was 10.7, 20.5, and 35.1, respectively. Using SSF* the toughness indices increased as SSF content increased up to 3.0% volume fraction and the enhancement was 9.76, 18.78, and 35.8, respectively.

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