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Improving of Impact Resistance of Concrete using Innovative Shapes of Steel Fibres

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Abstract- Concrete is often subjected to impact and other dynamic loads in service. These loads may occur due to blasts, traffic, and seismic activity. To enhance the impact resistance of concrete, many types of fibers can be used. In this research, two shapes of steel fibers are used: hook-ended shape (SF) and a new spiral shape (SSF). The innovative shape is introduced manually in fresh concrete with suitable vertical and horizontal alignment. The test program is designed to study the effect of SF, and SSF on the impact resistance of concrete and selected mechanical properties. The two shapes of steel fibers were added at the fraction volume of 0.5%, 1.0%, 2.0%, and 3.0%. The compressive strength of steel fibers reinforced concrete (SFRC) enhanced by 43.4% at 2.0% volume fraction relative to plain concrete. The compressive strength of spiral steel fibers reinforced concrete (SSFRC) enhanced by a 65% at 3.0% volume fraction relative to plain concrete. The splitting tensile strength and modulus of rupture of SFRC improved with increasing of fiber volume fraction recording 52.6% and 137.5% enhancement, respectively, at 2.0% volume fraction. The splitting tensile strength and modulus of rupture of interlocked spiral steel fibers (SSFRC*) improved with the increase in volume fraction up to 3.0%, recording 147% and 62.5% enhancement, respectively. Also, The toughness index of SFRC enhanced with the increase in the fraction up to 2.0%. The toughness indices I5, I10, and I20 registered values of 10.7, 20.5, and 35.1, respectively, at 2.0% fraction volume. The toughness index of SSFRC* enhanced with increasing the fraction volume up to 3.0%. The indices I5, I10, and I20 recorded values of 9.76, 18.78, and 35.8, respectively, at 3.0% fraction volume. The impact resistance of SFRC improved with the increase in the fiber content up to 2.0%, recording 33 times that of the impact resistance of plain concrete, at 2.0% fraction volume. The impact resistance of SSFRC* enhanced with the increase in the fiber volume fraction recording 116 times the impact resistance of plain concrete, at 3.0% fraction volume.

Keywords: Reinforced Concrete; Steel Fibers; Strengthening; Impact; Mechanical Properties.

I. INTRODUCTION

Resistance to impact loads is recognized today as one of the significant properties of concrete used for structural applications. It is well known that fiber-reinforced concrete generally has good fracture toughness and impact resistance compared to plain concrete [1]. This paper studies the impact resistance of plain concrete, SFRC, and SSFRC (vertical-horizontal-vertically interlocked spirals Figure 1. The impact resistance of concrete was determined using drop-weight falling from 30 cm height on 100x100x500 mm beams and the number of blows was recorded at failure [9]. Laboratory studies were carried out on concrete specimens (cubes, cylinders, beams), which are prepared by adding two shapes of steel fibers (Hooked ended with aspect ratio=50), and an innovative shape of steel fibers (spiral shape with diameter 2.5, 1.5 cm and variable length).

The two shapes of fibers have the same mechanical properties, and it was added by amount of (0.5, 1.0, 2.0, and 3.0 %) by volume. The experimental investigation is discussed in the next section showing the characteristics of materials used, design of mixes, tests on specimens, and equipments used. The main objectives of the present research focused on the evaluation of new shape of steel fibers (spiral shape) and studying the effect of using this new technique on the impact resistance of concrete by:

1. Controlling of the fibers content avoiding problem in workability and compaction (no balling or clumping), by introducing the SSF with suitable way and length, according to the dimensions of specimens.
2. Controlling of the orientation and alignment of fibers (vertical or horizontal). This means uniform distribution of fibers rather than random.
3. Enhancing the bond between fibers and the matrix by using spiral shape rather than hooked end ones, as shown in figure 1.
4. Enhancing the capacity of spiral fibers by interlocking them together in some cases. This means the change in failure mode by de-bonding (fractured) fiber rather than pulling-out.

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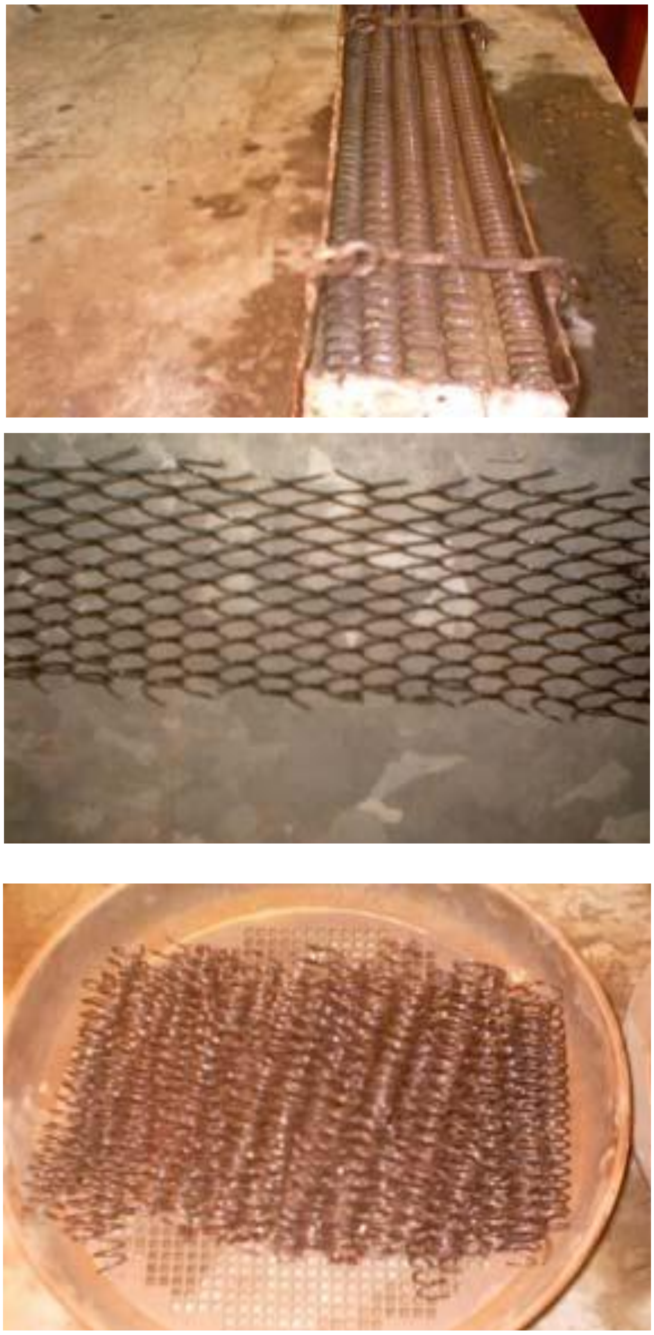

Figure 1. Introducing spiral fibers into fresh concrete specimens

II. EXPERIMENTAL PROGRAM

2.1 Materials Used

The fine aggregate used in the experimental program was of natural siliceous sand. Its characteristics satisfy the (E.C.P. 203/2007) [17], (E.S.S. 1109/2008) [18]. It was clean and nearly free from impurities with a specific gravity 2.6 t/m^3 and a modulus of fineness 2.7

The cement used was the Ordinary Portland cement, type produced by the Suez cement factory. Its chemical and physical characteristics satisfied the Egyptian Standard Specification (E.S.S. 4657-1/2009) [16].

The water used was the clean drinking fresh water free from impurities used for mixing and curing the R.C. beams tested according to the (E.C.P. 203/2007) [17].

Super plasticizer used was a high rang water reducer HRWR. It was used to improve the workability of the mix. The admixture used was produced by CMB GROUP under the commercial name of Addicrete BVF. It meets the requirements of ASTM C494 (type A and F) [19]. Super plasticizers of 400, 918, 918, 180, and 6 kg/m3 were used to make the plain concrete. The admixture is a brown liquid having a density of 1.18. The kg/litre at room temperature amount of HRWR was 1.0 % of the cement weight.

Steel fibers The hook-ended and spiral steel fibers were made of mild carbon steel. The hook-ended fibers have an average length of 50 mm, nominal diameter of 1.0 mm, and the aspect ratio of 50. The spiral fibers have a variable length according to dimensions of specimens. Its chemical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/2011) [20].

2.2 Preparations of Samples

In the production of concrete, the constituent materials were initially mixed without fibers [5]. The hooked-end fibers were then added in small amounts to avoid fiber balling and to produce concrete with uniform material consistency and good workability. The spiral steel fibers were placed manually in layers before and 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 fiber distribution. The mix was placed into a beam mold to cast a standard 100x100x500 concrete beams. Each layer was consolidated using a vibrating table. At the end of 24h after consolidating, the specimens were removed from the mold and cured in water at 230C for 28 days [8].

2.3 Test Methods

Impact is applied using a falling mass striking the concrete beam. The impact produces a load pulse on the beam and this pulse again results in strain and deflections of the beam [6]. The impact releases an amount of energy which is determined by the weight of the falling body and the falling height. The energy is calculated according to the following relation: E= Mass (Kg) x Height (m) x g (m/sec^2) In this study, impact resistance of SFRC is measured by a test using a 4.2 kg mass falling onto midpoint of (100x100x500 mm) beams from 0.3m height. The numbers of blows required for cracking of specimens are recorded. Also, using the innovative shape (spiral shape) the similar tests are experimented for vertical and horizontal alignment of spirals in the beam. In addition to testing SSFRC beams, special case by interlocking spiral fibers in vertical alignment is tested, and in this case the test continued until depending of spiral fibers.

III. RESULTS AND DISCUSSION

3.1 Compressive Strength

Table 1, shows the compressive strength test results on SFRC and SSFRC. Each strength test result was the average for 3 test specimens [4].

The compressive strength enhancement of SSFRC versus SFRC is shown in Fig.2. The cube compressive strength of plain concrete was 32.55 N/mm2 and an improvement for SFRC at each volume fraction was noticed. The improvement, (strength-enhancement) as shown in Table l and Fig.2, was 10.2 at 0.5% fraction volume, 29.2% at 1.0% fraction volume, and reduced to 18.3%, and 14.5% at 2.0%, and 3.0% fraction volume, respectively. The cylinder compressive strength of plain concrete was 28.1 N/mm2 and for SFRC, an improvement at each volume fraction shown in Table 1, and Figure 2.

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

Fiber volume fraction (%)	cube compressive strength				cylinder compressive strength			
	SFRC		SSFRC		SFRC		SSFRC	
	measured N/ mm²	strength-enchancement (%)	measured N/ mm²	strength-enchancement (%)	measured N/ mm²	strength-enchancement (%)	measured N/ mm²	strength-enchancement (%)
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	42.07	29.2	41.56	27.7	37.5	33.5	37	31.6
2	38.5	18.3	44.2	35.8	33.5	19.2	39.5	40.5
3	36.4	14.5	48	47.4	32.6	16	43.8	55.8

$$Strength-enhancement\ \% = \left(\frac{Fiber\ concrete\ -\ plain\ concrete}{Plain\ concrete}\right)100$$

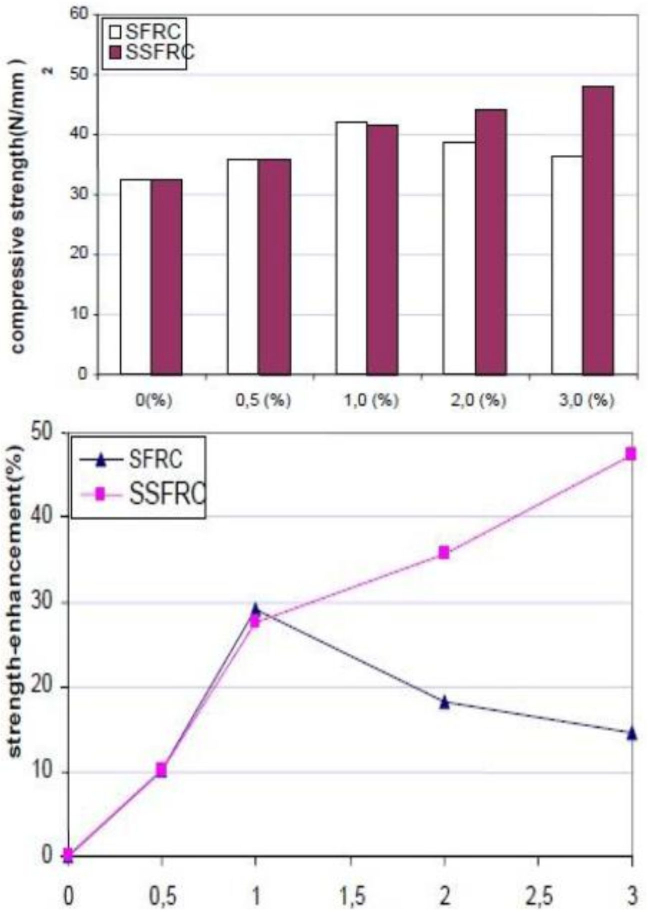

Figure 2. Relation between compressive strength–enhancement% and fiber content% by volume

The compressive strength enhancement of SSFRC versus plain concrete is shown in Table 1. The cube compressive strength of plain concrete was 32.55 N/ mm2 and an enhancement for SSFRC at each volume fraction was noticed. The improvement, as the strength-enhancement is shown in Table 1, was 10.2 at 0.5% fraction volume, 27.7% at 1.0% fraction volume, 35.8% at 2.0% fraction volume, and 47.4% at 3.0% fraction volume. The cylinder compressive strength of plain concrete was 28.1 N/mm2 and for SSFRC, an improvement at each volume fraction is shown in Table 1, and Figure 2.

3.2 Splitting Tensile Strength

The enhancement in splitting tensile strength of SFRC at various volume fractions relative to plain concrete is shown in Table 2. The strength of SFRC improved with increasing the volume fraction up to 2.0%. The improvement started from 16.7% at 0.5% fraction volume and extended to 49% at 2.0% fraction volume, but reduced to 38% at 3.0% fraction volume. However, the optimum limit could be considered at 2% volume fraction. The development of splitting tensile strength of SSFRC at various volume fractions is shown in Table. 2. Compared to plain concrete, the strength of SSFRC improved with increasing the volume fraction up to 3.0%. From the results of strength enhancement in Table 2, the improvement started from 25.2% at 0.5% fraction volume and extended to 85.5% at 3.0% fraction volume [9].

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

Fibre volume fraction (%)	SFRC			SSFRC* (interlocking)		
	toughness index			toughness index		
	I5	I10	I 20	I 5	I 10	I 20
0	1	1	1	1	1	1
0.5	5.61	8.16	10.35	5.2	10.18	19
1	8.41	15.8	23.9	5.32	10.92	22.5
2	10.7	20.5	35.1	6.7	14.42	30.2
3	8.6	14.54	22.19	9.76	18.78	35.8

3.3 Modulus of Rupture (MOR)

The MOR for SFRC at various volume fractions is shown in Table. 2. Also, the strength-enhancement is illustrated in Table 2 indicating that the MOR values were higher by 12.5%, 75%, 137.5%, at the fractions of 0.5%, 1.0%, and 2.0%, respectively, compared to plain concrete. But the enhancement reduced to 93.7% at 3.0% fraction volume.

The MOR for horizontally aligned SSFRC improved slightly with increasing the volume fraction from 2.2% to 7.2% to 8% to 8.1% with fiber content 0.5%, 1.0%, 2.0%, and 3.0%, respectively. This can be attributed to the expanding of spirals after cracks at mid span of beam, in absence of high effect of fibers to resist the tensile stress at first crack as in case of plain concrete. The MOR for SSFRC*(interlocking spiral) improved from 6.25% to 8.75% to 37.5% to 62.5% with fiber content 0.5, 1.0, 2.0, and 3.0% respectively due to the absence of voids, balling, and clumping in spiral fibers.

3.4 Flexural Toughness

Flexural toughness is the energy absorbed in deflecting beam by a specified amount, being the area under a load-deflection *(P-δ)* curve for the 100x100x500mm beam tested at third-point in bending [9]. Index toughness (I) for SFRC, SSFRC, and SSFRC* reflects the improvement in flexural toughness over the non-reinforced concrete. The widely estimated indices are *15* at 38, *I10* at 5.58, and *I20* at 10.58. All the three indices reached unity, assuming that the non fiber-reinforced matrix is elastic-brittle. Such results are illustrated in Table 3. For SFRC the toughness indices increased their values with increasing volume fraction of fibers up to 2.0%. The *15, /I10,* and *I20* values were 10.7, 20.5, and 35.1, respectively, at the fraction of 2.0%. But the values decreased to 8.6, 14.54, and 22.19 with volume fraction 3.0%, compared with the values at 2.0% volume fraction. For SSFRC* (interlocking), the toughness indices increased their values with increasing volume fraction of fibers up to 3.0%. The *15, I10, and I20* values were 9.76, 18.78, and 35.8, respectively, at the fraction of 3.0% Figures 3 and 4.

Table 3: Flexural toughness indices at various fiber volume fractions for SFRC and SSFRC*

Fibre volume	SFRC			SSFRC* (interlocking)		
	toughness index			toughness index		
fraction (%)	I5	I10	I20	I5	I10	I20
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	8.41	15.8	99	5.32	10.92	22.5
2	10.7	20.5	35.1	6.7	14.42	30.2
3	8.6	14.54	22.19	9.66	18.78	35.8

3.5 Impact Resistance

Table 4, presents the impact resistance test results on SFRC, SSFRC (V-H), and SSFRC*. Each strength test result was the average of three test specimens. The impact resistance of SFRC improved to different extents in response to fiber volume fractions up to 2.0%. Using SSF, the above property improved up to 3.0% fractions. It can be shown, compared with plain concrete, that is the impact resistance at initial cracking of SFRC was increased to twice of that with 0.5% fiber content to 5.34 times with 2.0% fiber content, but was decreased to 4.33 times with fiber content 3.0%, compared with value at 2.0% volume fraction Fig.6. It can be noticed; using SSF (V) and SSF (H) that there is noticeable enhancement in impact resistance compared with plain concrete. This can be attributed to separating spiral fibers from each other and generating crack openings between them, when using SSF (V). Also, it can be attributed to expanding the horizontal spirals at mid span of beam when using SSF(H), without high effect of fiber to resist impact loading nearly (such as in plain concrete). Using SSF*, the impact resistance at initial cracking of SSFRC* was increased from 2 times with 0.5% fiber to 3 times with 3.0% fiber content by volume. Also, impact resistance at failure increased greatly from 62.5 times to 91.75 times to 98 times to 116.75 times with fiber content 0.5, 1.0, 2.0, and 3.0% by volume, respectively Table 4. This can be attributed to interlocking spiral fibers together and resist impact loading until de-bonding (fracture) rather than pullout, which means great energy absorption more than other types of fiber reinforced concrete.

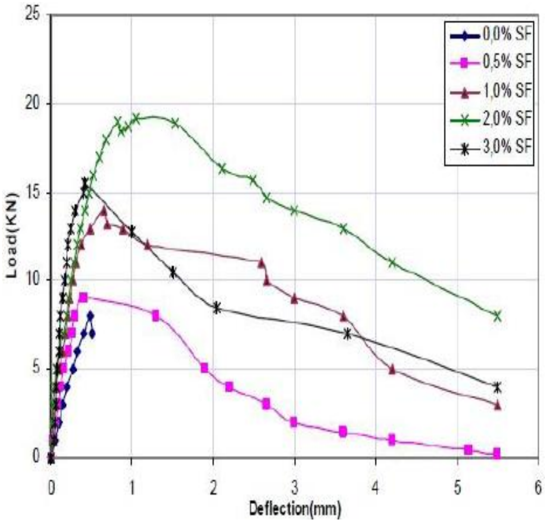

Fig.3. Load-deflection curves from deflection tests (Various content of SF)

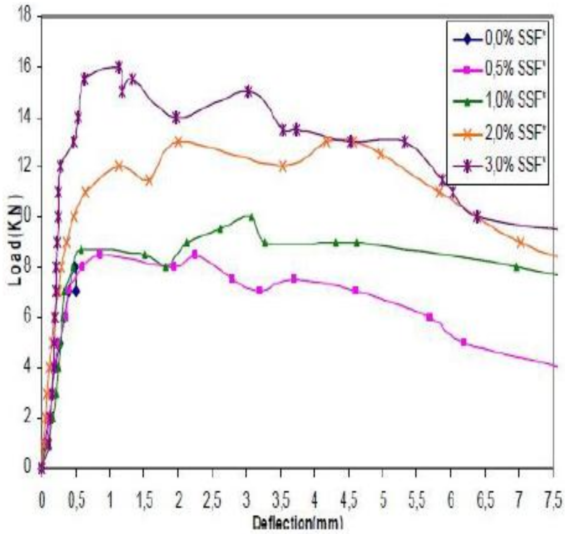

Fig.4. Load-deflection curves from deflection tests (various content of SSF*)

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Table 4: Impact resistance test results (28 days age) – relative increase in I.R.

Type of Concrete		Fiber Volume Fraction %	Impact resistance				% increase in I.R.	
			Initial Cracking		Failure		Initial Cracking	Failure
			No.of Blows	I.R. (N.m)	No.of Blows	I.R. (N.m)		
SFRC		0	3	378	4	504	_	_
		0.5	6	756	40	5040	100	900
		1	8	1008	66	8316	167	1550
		2	16	2016	135	17010	434	3275
		3	13	1630	90	11310	333	2150
SSFRC	V	0.5	3	378	4	504	_	_
	H		3	378	4	504	_	_
	V	1	3	378	5	630	_	25
	H		3	378	5	504	_	_
	V	2	3	378	8	630	_	25
	H		3	378	7	504	_	_
	V	3	3	378	5	630	-	25
	H		3	378	4	504	-	-
SSFRC*		0.5	9	1134	250	31500	200	6150
		1	11	1386	367	46242	266	9075
		2	12	1512	392	49392	300	9700
		3	12	1512	167	58812	300	11575

IV. CONCLUSIONS

1. The compressive strength of plain concrete improved with addition of steel fibers up to 2.0% by volume, but decreased at 3.0% fraction compared to 2.0% fraction. The enhancement in compressive strength has reached 34%.
2. Using spiral steel fibers increases the compressive strength with fibers content up to 3.0% by volume. The maximum enhancement reached 55.8% at 3.0% fraction.
3. The splitting tensile strength of concrete improved with increasing steel fibers up to 2.0% fraction, but decreased at 3.0% fraction. The maximum enhancement reached 49% at 2.0% fraction. Using spiral steel fibers, more enhancement with increasing the fibers content up to 3.0% fraction is noticed. The maximum enhancement reached 85.5% at 3.0% fraction.
4. The addition of SF to plain concrete leads to an increase in the modulus of rupture of 138% at 2.0% fraction. But using SSF in different orientations, with and without interlocking the spirals, a little and different enhancement in values of modulus of rupture was noticed. Using, SSF (H), and SSF*(V) the enhancement reached 8.0%, and 63%, respectively at 3.0% fraction.
5. The ASTM toughness indices I5, I10, and I20 increased as SF content increased up to 2.0%, but they decreased at 3.0% fraction compared to 2.0% fraction. The enhancement in toughness indices were 10.7, 20.5, and 35.1%, respectively. Using SSF*, the toughness indices increased as SSF content increased up to 3.0% fraction and the enhancements were 9.76, 18.78, and 35.8, respectively.
6. The impact resistance of concrete improved by addition of SF about 33 times more than plain concrete at 2.0% by volume. But using SSF without interlocking the spirals, there was no improvement in impact resistance compared with plain concrete.
7. The important and significant improvement was the great increase in impact resistance values, using interlocking spiral steel fibers. The increase was about 116, and 5.1 times that of plain concrete, and SFRC, respectively at 3.0% by volume.

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