# “MECHANICAL PROPERTIES OF STEEL FIBROUS CONCRETE”

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**Abstract**

This paper studies the tensile strength of steel fibrous concrete, four different percentage of fibers where used to find out the effect of the addition of steel fibers on the tensile strength of concrete using the splitting, flexural, and compressive strength of concrete. Test results from this study and earlier published data were used in a regression analysis to derive empirical equations for tensile strength of SFC. The following relationships were derived; splitting strength and the compressive strength of fiber and normal concrete, the relationship between the flexural and compressive strength of SFC and compressive strength of normal concrete, and the splitting cylinder strength and the flexural strength of SFC.

**Key Words**: Steel fiber concrete, tensile strength.

# "الخواص الميكانيكية للخرسانة المسلحة بالألياف الفولاذية"

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**الخلاصة**

هذا البحث يتناول دراسة مقاومة الشد للخرسانة المسلحة بالألياف الفولاذية .أربع نسب مختلفة من الألياف الفولاذية تم استخدامها لإيجاد تأثير إضافة هذه الألياف على مقاومة الشد للخرسانة باستخدام فحص الانفلاق،الانثناء، ومقاومة الانضغاط للخرسانة.

نتـائج (٥٢) فحـص مـن هـذه الدراسـة ومـن الدراسـات المنشـورة سـابقا تـم اسـتخدامها لعمـل تحليـل تراجعـي لغـرض اشـتقاق معـادلات تجريبيـة لإيجـاد مقاومـة الشـد للخرسـانة المسـلحة بالألياف الفولاذية.

المعـادلات التجريبيـة تتضـمن العلاقـة بـين مقاومـة الانفـلاق ومقاومـة الانضـغاط للخرسـانة الاعتياديـة والخرسـانة المسـلحة بالأليـاف، العلاقـة بـين مقاومـة الانثنـاء ومقاومـة الانضـغاط للخرسـانة الاعتياديـة والخرسـانة المسـلحة بالأليـاف، العلاقـة بـين مقاومـة الانفـلاق ومقاومـة الانثناء للخرسانة المسلحة بالألياف الفولاذية.

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## Introduction

Reinforcement by randomly distributed short fibers is an effective technique for improving the toughness, impact resistance and tensile strength of concrete. Analytical simulation of the fibrous concrete behavior is, however, just emerging. Currently, such basic problems as modeling of the material constitutive behavior and developing a reliable formula for predicting the tensile strength of fibrous concrete in terms of the matrix and fiber properties are yet to be resolved.

From the discussion on the strength of compression and tension (both direct and flexure) test specimens it would be expected that the two types of strength are closely related. This is indeed the case but there is no direct proportionality, the ratio of the two strengths, as the compressive strength $f'_c$ increases, the tensile strength $f_t$, also increases but at a decreasing rate.

The tensile strength of concrete depends on the type of and method of test, so that the means of determining $f_t$ must be clearly stated.

The tensile strength of concrete can be measured by a direct tension on specially made concrete specimens, a flexural test on beams, or split test on cylindrical specimens.

In compression, fibers improve the post peak ductility, energy absorption capacity and to some extent, the strength of concrete. Very few analytical studies on the behavior of steel fiber concrete in compression have been reported in the literature.

The improvement in concrete compressive behavior resulting from steel fiber reinforcement is dependent on the volume fraction and aspect ratio of steel fibers, mechanical deformation of fibers, matrix mix proportions, maximum aggregate size, specimen geometry and loading versus casting direction [1].

Soroushian and Lee [1] suggested an empirical equation for the compressive strength of steel fibrous concrete $f'_{cf}$.

$$f_{cf} = f_c' + 3.6\frac{V_f l_f}{d_f}$$

……………………………………………...…..(1)

Where:

$f'_c$ = Compressive strength of normal concrete.

$f_{cf}$ = Compressive strength of steel fibrous concrete.

$V_f$ = Volume fraction of steel fiber.

$l_f/d_f$ = $l_f$ and $d_f$ are length and diameter of the fibers respectively.

Soroushian and Lee [1] also proposed the following equation to predict the tensile strength $f_{tf}$ of steel fibrous concrete.

$$f_{tf} = f_t'(1 + 0.016 N_f^{1/3} + 0.05\pi . d_f . l_f . N_f)$$

………………………...….(2)

Where:

$f_{tf}$ = Tensile strength of SFC (MPa).

$f'_t$ = Tensile strength of matrix (MPa).

$N_f$ = Number of fibers per unit cross sectional area.

$$N_f = \beta_1 (4V_f / \pi d_f^2)$$

……………………………………………………..(3)

$\beta_1$= Orientation factor of the fiber.

Mansur and Paramasivam [2] found that the plastic theory could be satisfactorily employed provided the direct tensile strength $f_{tf}$ is calculated from the following equation proposed by Mangat [3].

$$f_{tf} = f_t'.v_m + 0.34(\frac{l_f}{d_f}).V_f$$

…………………………………...……(4)

Where:

$f'_t$ = direct tensile strength of the matrix.

$V_m$ = Volume of the matrix.

$V_f$ = Volume fraction of the fibers.

Swamy and Mangat [4] suggested a method of evaluating the tensile strength of fibrous concrete as follows:

$$f_{tf} = f_t'.V_m + 0.82\tau(\frac{l_f}{d_f}).(V_f)$$

………………………………………..(5)

Where:

τ=average intrfacial bond stress

Narayanan and Palanjian [5] accounted the variation in the bond characteristics due to different types of fibers by incorporating the term ($b_f$) in the second part of the above equation as follows:

$$f_{tf} = f_t'[1 + k(\frac{l_f}{d_f}).V_f.b_f]$$

………………………………………..…….(6)

Where:

K= a constant which account for factors like fiber orientation, bond characteristics of matrix, etc. and is largely independent of the fiber type, volume fraction and aspect ratio.

$b_f$ = bond factor.

Palanjian [6] suggested an empirical equation to predict the splitting strength of fibrous concrete:

$$f_{sp} = \frac{f_{cu}}{20 - \sqrt{\frac{l_f}{d_f}.V_f.b_f}} + 0.7 + \sqrt{\frac{l_f}{d_f}.V_f.b_f}$$

……………………..…….(7)

Where:

$f_{sp}$ = Splitting strength of SFC (MPa).

$f_{cu}$ = Cube compressive strength of concrete (MPa).

The mean value of (observed strength /predicted strength) for 52 tests was (1.04) with standard deviation of (0.078).

Narayanan and Toorani [7] found that the splitting strength of the steel fibrous concrete is in fact given by:

$$f_{sp} = 0.55\sqrt{f_{cu}}$$

……………………………………………………..(8)

Where the coefficient (0.55) is obviously dependent on the fiber content.

Narayanan and Green [8] used the experiments reported in a related study to predict the split cylinder strength of steel fiber reinforced concrete:

$$f_{sp} = \frac{f_{cu}}{A} + B$$

……………………………………………..………..(9)

Where:

A = a non dimensional constant equals to (15.5)

B = a dimensional constant with units of MPa equals to (0.8).

Soroushian and Bayasi [9] suggested the following equation to predict the ultimate tensile strength ($\sigma_{cu}$) of SFC applying the composite material concept.

$$\sigma_{cu} = 2\alpha\beta\tau_u(l_f / d_f)V_f + \gamma\sigma_m(1 - V_f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Where:

$\tau_u$ = Average interfacial bond stress at ultimate condition.

$l_f$ = Fiber length

$d_f$ = Fiber diameter.

$\alpha$ =Efficiency factor accounting for the random orientation of fiber ($\alpha$ =0.41).

$\beta$= Efficiency factor accounting for the fact that the crack crosses a fiber at a random location along its length $\approx$ [0.41-1].

$\gamma$ =A factor representing the fraction of the matrix strength contributing to the tensile strength $\gamma$ closes to (1.0).

This paper describes the methods of predicting the tensile strength of SFC and the relationship between the tensile strength of plain and steel fibrous concrete.

## Test Program

The concrete mix proportions was (1:2:4) with four fiber volume fractions [0, 0.4,0.8,1.2]% was added to the batches of concrete.

For each batch three beams for the flexural test, three cylinders for compressive strength tests and three cylinders for splitting test were carried out.

All the beams of particular strength and fiber volume fraction were cast from the batch of concrete cured and tested under identical environmental conditions.

## Material Properties

The fibers were shelled and deformed sections, the length of the fiber was 16mm, with aspect ratio $l_f/d_f$ =(21.8), normal concrete was used in the testing program. Ordinary Portland cement conforming to B.S 12 [11] was used throughout the investigation. River gravel graded according to ASTM (C-33) [12] specification with maximum aggregate size (19mm), and river sand is used and graded according ASTM (C-33) [12] passing sieve No. (4). The results of sieve analysis tests on representative Samples of coarse and fine aggregate are plotted in Fig (1). All the mixing was carried out using a horizontal rotating pan mixer. In order that balling and interlocking between fibers could be minimized, the fibers were fed in small quantities during the mixing process. Slump tests were carried out on each mix. The water cement ratio was variable to restrict the slump in the range of (68-70) mm; Fig. (2) shows sample of tested specimens of splitting and flexural strength.

The concrete compressive strength $f'_c$ was obtained by testing standard cylinders having a diameter of 150mm and height of 300mm. The modulus of rupture ($f_r$) was determined from flexural tests on 100x100x500 mm-long beams that were subjected to third –point loading over a span of 400 mm.

Splitting tensile tests were carried out on 150mm - diameter x 300-mm length cylinder.

## Prediction of Tensile Strength of Steel Fibrous Concrete

The experiments reported in this paper and in previous investigations reported in published literature Refs. [5, 7, 8, 10] as shown in Tables (1) and (2) were used in a regression analysis to find out a relationship between tensile and compressive strength of steel fibrous concrete as follows:

**Relationship between splitting strength and the compressive strength of SFC.**

The split cylinder strength of fibrous concrete could be predicted with sufficient accuracy from its compressive strength using the following equation:

$$f_{sp} = 0.116 \; f_{cf}$$

……………………………...………………..(11)

Where:

$f_{sp}$ = predicted split cylinder strength (MPa).

$f_{cf}$ = cylinder compressive strength of SFC (MPa).

For this equation the correlation coefficient (R) =0.991 with standard deviation equals to (0.1406) and coefficient of variation equals to 0.1378, the average value of experimental/calculated of 52 test results that are used in regression analysis is (1.02).

Fig.(3) shows the relationship between the splitting strength and compressive strength of SFC, Fig.(4) shows the experimental with the predicted values using Equation (11) of the splitting strength.

**Relationship between splitting strength and the compressive strength of normal concrete.**

The regression analysis was done to predict the relationship between the split cylinder strength of SFC and compressive strength of normal concrete:

$$f_{sp} = 0.104 \ f_c' + 0.00795 \ V_f \frac{l_f}{d_f}$$

…......................(12)

Where:

$f_c'$ =compressive strength of plain concrete.

$V_f$ =fiber volume fraction.

$l_f/d_f$ = aspect ratio of the fiber.

The correlation coefficient of this equation is (0.985), the S.D is (0.263) and coefficient of variation equals to 0.2505, and the exp./cal. is (1.05).

Fig.(5) shows the relationship between the splitting strength and compressive strength of normal concrete with different fiber content. Fig. (6) shows the experimental with the predicted values of the splitting strength.

**Relationship between flexural strength and the compressive strength of SFC.**

$$f_r = 0.183 f_{cf}$$

……………………………………...……………(13)

The correlation coefficient of this equation is (0.986) and the S.D is (0.177) and coefficient of variation equals to 0.1757, and the exp./cal. is (1.007). Fig.(7) shows the relationship between the flexural strength and compressive strength of SFC. Fig.(8) shows the experimental with the predicted values of the flexural strength.

**Relationship between flexural strength and the compressive strength of normal concrete.**

$$f_r = 0.149 f_c' + 0.015 V_f \frac{l_f}{d_f}$$

……………………………………………….(14)

The correlation coefficient of this equation is (0.99) and the S.D is (0.355) and coefficient of variation equals to 0.328, and the exp./cal. is (1.08). Fig.(9) shows the relationship between the flexural strength and compressive strength of normal concrete.

**Relationship between the splitting strength and the flexural strength of SFC.**

The relationship of the split cylinder strength and flexural strength of steel fiber reinforced concrete was found using the regression analysis of (38) test results as follows:

$$f_r = 2.63 + 0.24(f_{sp})^{1.76} + 0.005 V_f . \frac{l_f}{d_f}$$

……………………………….(15)

The correlation coefficient of this equation is (0.945) and the S.D is (0.095) and coefficient of variation equals to 0.095, and the exp./cal. is (1.0), Fig.(10) shows the experimental with the predicted values of the flexural strength, Fig. (11) represent the predicted with the experimental results using Eq. (15).

## Conclusions

The detailed relationships in this study can be used to predict the different mechanical properties of steel fibrous concrete. More test results may lead to a more realistic assessment of the mechanical properties.

**Table (1) Mix properties and Results**

| Mix | $V_f$ % | Slump-mm | W/C | $f'_c$ (MPa) | $f_{sp}$ (MPa) | $f_r$ (MPa) |
|---|---|---|---|---|---|---|
| A | 0 | 70 | 0.615 | 18.1 | 1.98 | 3.67 |
| B | 0.4 | 69 | 0.62 | 23.7 | 2.91 | 5.32 |
| C | 0.8 | 68 | 0.61 | 29.7 | 3.76 | 5.81 |
| <u>D</u> | 1.2 | 69 | 0.62 | 34.8 | 4.82 | 7.43 |

**Table (2) shows the data that are used in the regression analysis.**

| No. | Ref. | $V_f$ % | $l_f / d_f$ | W/C | $f_{cf}$ (MPa) | $f_{sp}$ (MPa) | $f_r$ (MPa) |
|---|---|---|---|---|---|---|---|
| 1 | 8 | 0.50 | 50.00 | 0.48 | 36.10 | 4.51 | --- |
| 2 | 8 | 1.00 | 50.00 | 0.48 | 44.82 | 4.79 | --- |
| 3 | 8 | 1.50 | 50.00 | 0.48 | 36.03 | 4.58 | --- |
| 4 | 8 | 2.00 | 50.00 | 0.48 | 44.08 | 4.60 | --- |
| 5 | 8 | 0.50 | 50.00 | 0.57 | 24.47 | 2.93 | --- |
| 6 | 8 | 1.00 | 50.00 | 0.57 | 25.50 | 3.49 | --- |
| 7 | 8 | 1.50 | 50.00 | 0.57 | 16.80 | 2.82 | --- |
| 8 | 8 | 0.50 | 50.00 | 0.68 | 18.75 | 1.97 | --- |
| 9 | 8 | 1.00 | 50.00 | 0.68 | 30.40 | 3.49 | --- |
| 10 | 8 | 1.50 | 50.00 | 0.68 | 24.08 | 2.96 | --- |
| 11 | 8 | 0.50 | 50.00 | 0.85 | 12.50 | 1.93 | --- |
| 12 | 8 | 1.00 | 50.00 | 0.85 | 8.23 | 1.30 | --- |
| 13 | 5 | 0.00 | 0.00 | 0.5 | 44.90 | 3.60 | 4.62 |
| 14 | 5 | 1.00 | 97.00 | 0.5 | 46.50 | 5.18 | 7.78 |
| 15 | 5 | 1.50 | 97.00 | 0.5 | 48.32 | 5.55 | 8.63 |
| 16 | 5 | 2.00 | 97.00 | 0.5 | 52.16 | 6.11 | 9.73 |
| 17 | 5 | 0.00 | 0.00 | 0.5 | 31.60 | 2.51 | 3.46 |
| 18 | 5 | 1.00 | 97.00 | 0.5 | 33.70 | 3.95 | 6.16 |
| 19 | 5 | 2.00 | 97.00 | 0.5 | 37.12 | 4.96 | 8.86 |
| 20 | 5 | 3.00 | 97.00 | 0.5 | 43.68 | 5.67 | 9.78 |
| 21 | 5 | 2.00 | 49.00 | 0.5 | 32.80 | 3.75 | 4.98 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 22 | 5 | 4.00 | 49.00 | 0.5 | 37.20 | 4.21 | 6.78 |
| 23 | 5 | 6.00 | 49.00 | 0.5 | 43.20 | 5.49 | 8.82 |
| 24 | 5 | 1.00 | 81.00 | 0.5 | 35.30 | 4.24 | 6.14 |
| 25 | 5 | 1.00 | 104.00 | 0.5 | 36.24 | 4.54 | 7.20 |
| 26 | 5 | 1.00 | 156.00 | 0.5 | 37.76 | 5.13 | 8.12 |
| 27 | 5 | 1.00 | 75.00 | 0.5 | 33.76 | 3.45 | 4.86 |
| 28 | 5 | 1.00 | 97.00 | 0.5 | 33.68 | 3.68 | 5.00 |
| 29 | 5 | 1.00 | 104.00 | 0.5 | 35.68 | 3.81 | 6.21 |
| 30 | 5 | 1.00 | 78.00 | 0.5 | 29.30 | 3.35 | 4.40 |
| 31 | 5 | 1.00 | 47.00 | 0.5 | 29.44 | 3.05 | 4.20 |
| 32 | 5 | 1.00 | 97.00 | 0.5 | 32.50 | 3.56 | 5.56 |
| 33 | 5 | 1.00 | 97.00 | 0.5 | 42.10 | 5.15 | 7.96 |
| 34 | 5 | 1.00 | 97.00 | 0.5 | 43.90 | 5.38 | 7.72 |
| 35 | 5 | 1.00 | 97.00 | 0.5 | 43.90 | 5.38 | 7.72 |
| 36 | 5 | 1.00 | 97.00 | 0.5 | 46.80 | 5.61 | 7.48 |
| 37 | 5 | 2.00 | 97.00 | 0.5 | 35.04 | 4.61 | 7.60 |
| 38 | 5 | 2.00 | 97.00 | 0.5 | 36.60 | 5.10 | 7.54 |
| 39 | 5 | 2.00 | 97.00 | 0.5 | 36.64 | 5.07 | 7.45 |
| 40 | 5 | 2.00 | 97.00 | 0.5 | 36.64 | 5.07 | 7.45 |
| 41 | 7 | 0.00 | .00 | 0.38 | 57.60 | 5.55 | --- |
| 42 | 7 | 0.00 | .00 | 0.47 | 40.20 | 4.20 | --- |
| 43 | 7 | 0.00 | .00 | 0.56 | 26.40 | 3.30 | --- |
| 44 | 7 | 0.70 | 150.00 | 0.38 | 59.76 | 6.30 | --- |
| 45 | 7 | 0.70 | 150.00 | 0.47 | 42.00 | 5.25 | --- |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 46 | 7 | 0.70 | 150.00 | 0.56 | 32.40 | 4.05 | --- |
| 47 | 10 | 0.00 | .00 | --- | 32.75 | 2.80 | 4.40 |
| 48 | 10 | 1.00 | 60.00 | --- | 35.39 | 4.80 | 5.10 |
| 49 | Present | 0.00 | .00 | 0.615 | 18.10 | 1.98 | 3.67 |
| 50 | Present | 0.40 | 21.80 | 0.62 | 23.70 | 2.91 | 5.32 |
| 51 | Present | 0.80 | 21.80 | 0.61 | 29.70 | 3.76 | 5.81 |
| 52 | Present | 1.20 | 21.80 | 0.62 | 34.80 | 4.82 | 7.43 |

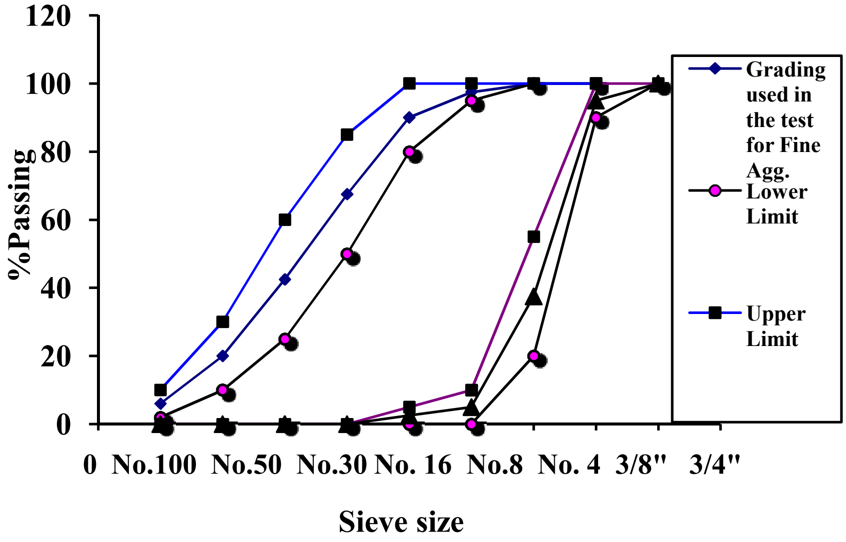
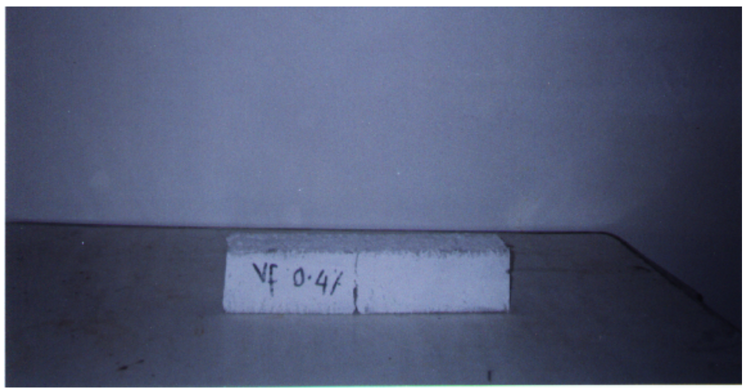



**Fig. (1) Grading Curves for Fine and Coarse Aggregate**


**a. Splitting test $V_f = 0.4\%$**




**b. Flexural test $V_f = 0.4\%$**

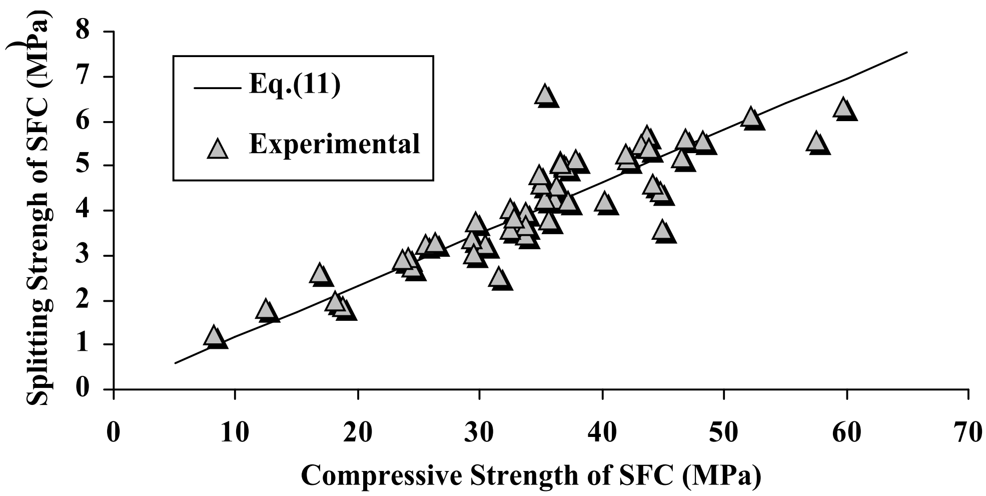
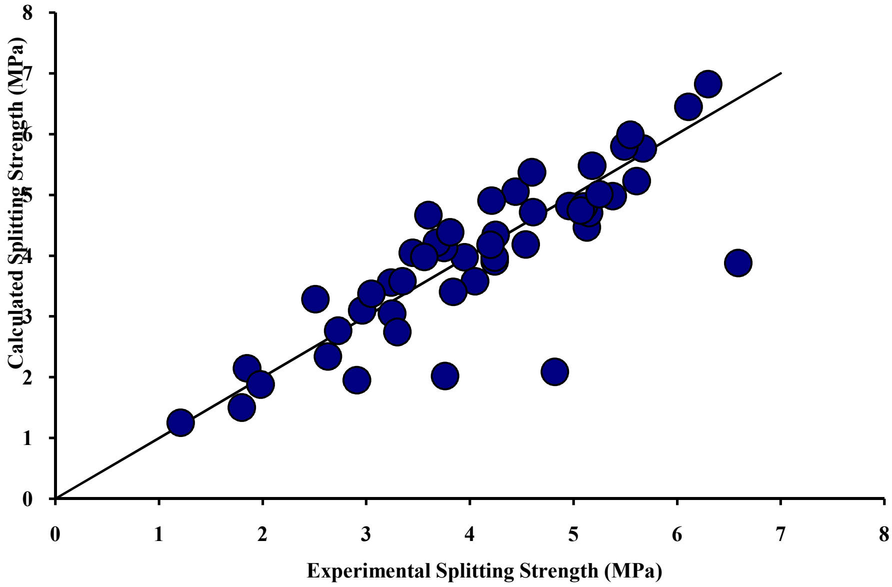



**Fig. (3) Relationship between Splitting and Compressive Strength of SFC**



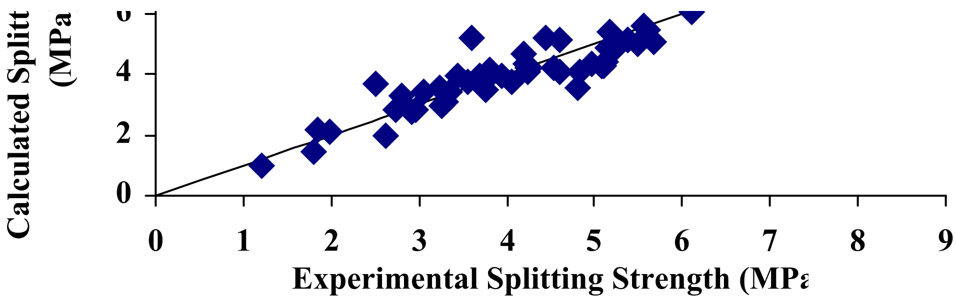




Fig. (4) Experimental and Calculated Splitting Strength Using Eq.(11) .

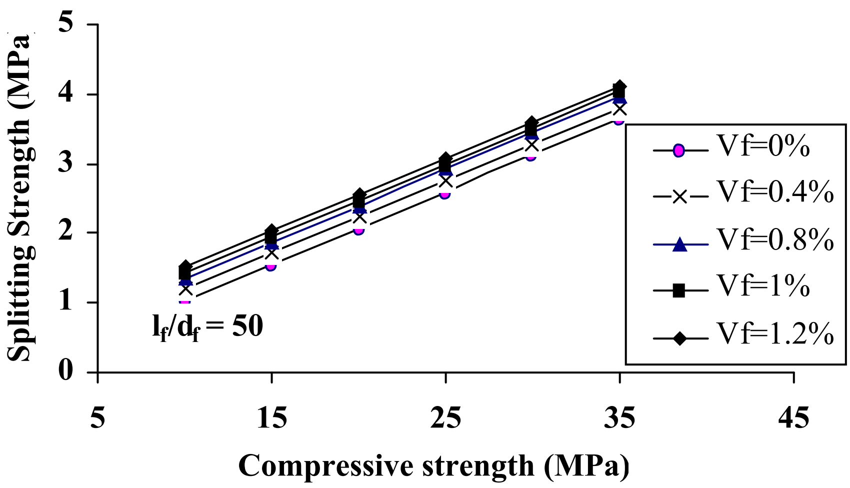



Fig. (5) Relationship between the Splitting Strength with the Compressive Strength of Normal Concrete for Different Fiber Content Using Eq. (12).

Fig. (6) Experimental and Calculated Relationship for the Splitting Strength of SFC Using Eq. (12)

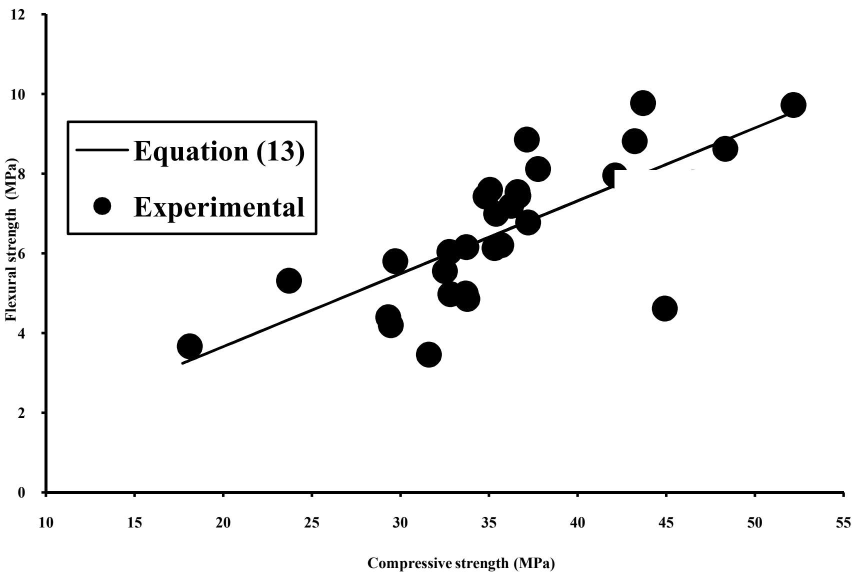



Fig. (7) Relationship between the Compressive Strength of SFC and Flexural Strength.

Fig. (8) Experimental and Calculated Flexural Strength of SFC Using Eq. (13).

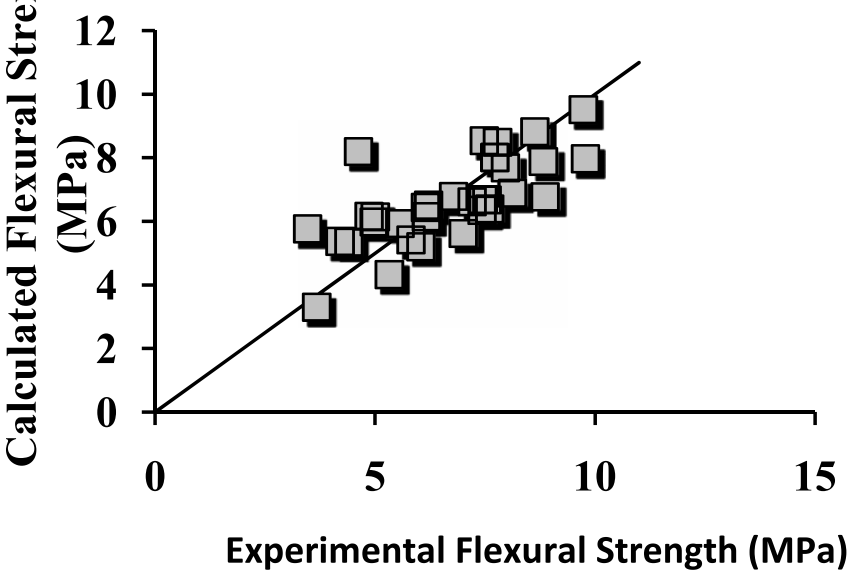
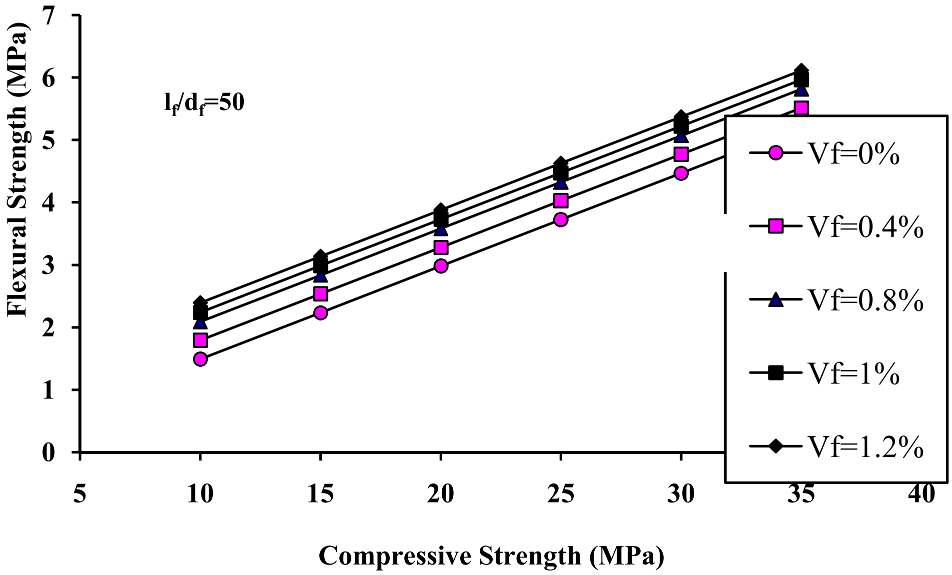
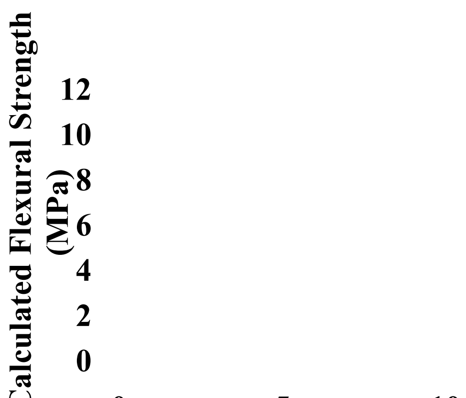



Fig. (9) Flexural Strength Using Eq. (14) with the Compressive Strength for Different % of Fiber Content.



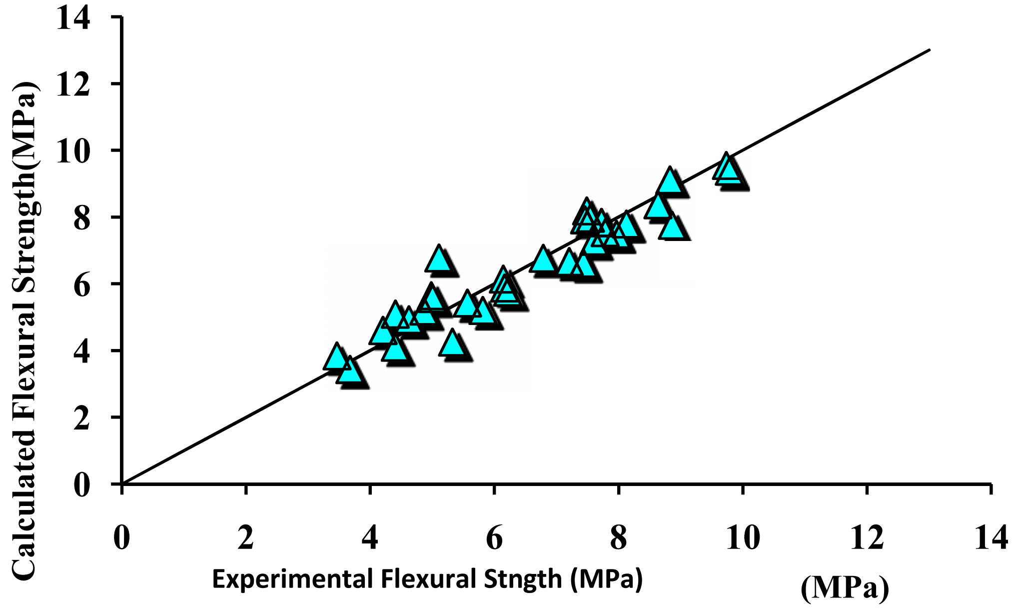



Fig. (10) Experimental with Calculated Flexural strength Using Eq. (15)

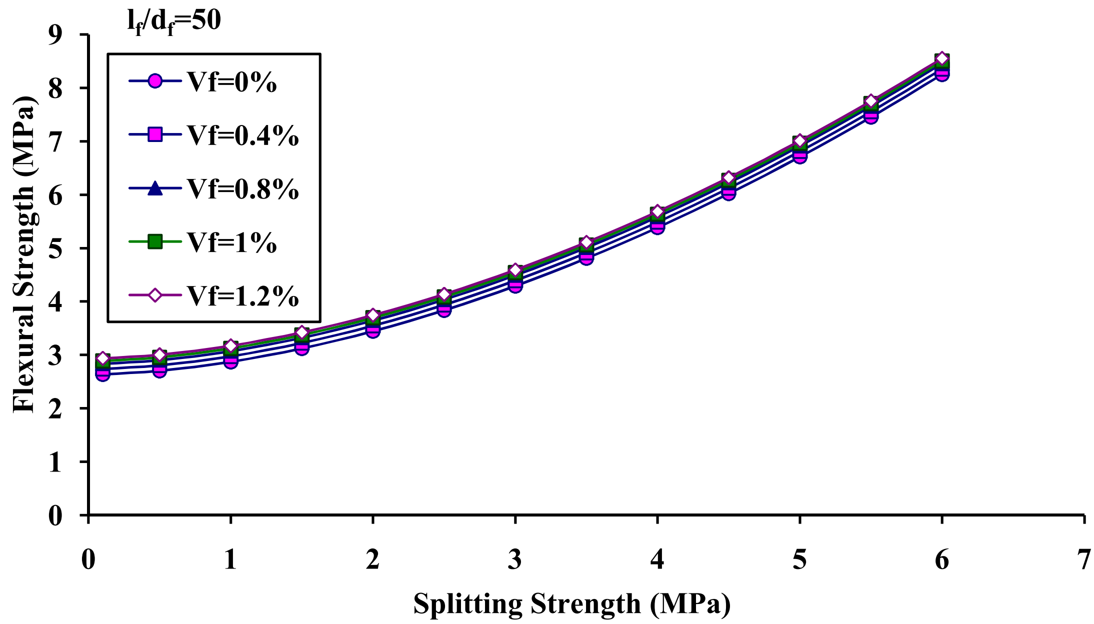



Fig. (11) Flexural Strength with Splitting Strength Using Eq. (15)

for Different % of Fiber Content

References

1) Soroushian, P., and Lee," Constitutive modeling of steel fiber reinforced concrete under direct tension and compression", Proc. The Inter. Conf. On recent developments in fiber reinforced cements and

concrete, 18-20 Sept. 1989,Cardiff (U.K), Swamy and Barr., Elsevier Science pp. 363-377.
2) Mansur, M.A. and Paramasivam, P.," Steel fiber reinforced concrete beams in pure torsion", International Journal of cement composites and lightweight concrete, Vol. 4, No. 1, February 1982, pp. 39-45.
3) Mangat, P.S., "Tensile strength of steel fiber reinforced concrete", Cement and concrete Research, Vol. 6, No. 2, March 1976, pp. 245-52.
4) Swamy, R.N. and Mangat, P.S.," Flexural strength of steel fiber reinforced concrete ", Proceeding of the Institution of civil engineers, London, Vol. 57,part 2, December 1974, pp. 701-7.
5) Narayanan, R. and Kareem-Palanjian, S. "Steel fiber reinforced concrete beams in torsion ", The international Journal of cement and light weight concrete, Vol. (5). No. 4 November 1983, pp. 235-245.
6) Palanjian, A. S. K., "Fiber reinforced concrete beams in torsion, bending and shear", Ph.D. Thesis, university of Wales (1984).
7) Narayanan, R., Toorani- Goloosalar Z., " Fiber reinforced concrete in pure torsion and in combined bending and torsion", Proc. Inst. civ. Engrs, part 2, 1979, 67, Dec., pp. 987-1001.
8) Narayanan, R., and Green, K. R., "Fiber reinforced concrete beams in combined bending and torsion", The Indian concrete Journal, August 1981, pp. 222-232.
9) Soroushian, P. and Bayasi, Z., "Prediction of the tensile strength of fiber reinforced concrete", A critique of composite material concept", Sp. 105-4, SP, Shah and Batson Editors, 1987, pp. 71-84.
10) Denis Michel, other authors, "The effect of steel fiber and epoxy coated reinforcement on tension stiffening and cracking of reinforced concrete", ACI Material Journal, January-February 1996, Vol. (1), No. 93-M8, pp. 61-68.
11) British Standard Institute (B.S 12), "Ordinary and rapid hardening Portland cement", 1978.
12) ASTM (C-33), "Specification for concrete aggregate", 1978.