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Properties of Normal and High-Strength self-Compacting Fibrous Concrete in Fresh and Hardened state

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Abstract

This paper studies the properties of normal and high strength self-compacting concrete in fresh and hardened state, six of self-compacting with normal and high strength concrete mixes were prepared with different percentage of fibers(0, 0.4%, and 0.8%) where used to find out the effect of the addition of steel fibers on the properties of self-compacting concrete in fresh state (Filling ability, Passing ability and Segregation resistance) and hardened state (compressive strength, splitting tensile strength, modulus of rupture, and modulus of elasticity) of concrete.

The study shows that the Addition of steel fibers in self-compacting concrete enhances compressive strength, tensile strength, modulus of rupture and modulus of elasticity relative to self-compacting concrete cast without steel fibers for both type of self-compacting concrete strength (normal strength (NSCC) and high strength (HSCC)).

Key words: concrete, self-compact, fresh properties, hardened properties, strength, fibrous, slump flow test.

خصائص الخرسانة ذاتيه الرص الاعتيادية والعالية المقاومة والمعززة بالألياف في حالتيها اللدنة والصلبة

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الخلاصة

يهدف البحث الى دراسة خواص الخرسانة ذاتية الرص في حالتيها اللدنة والصلبة ولهذا الغرض تم اعداد (6) خلطات خرسانية ذاتية الرص ذات المقاومة الاعتيادية والمقاومة العالية كما تم اضافة الالياف الحديدية وبنسب مختلفة (0 ، 0,4 ، 0,8) % وذلك لدراسة تاثيرها على خواص الخرسانة ذاتية الرص في حالتها اللدنة حيث تم دراسة قابليتها

على الملئ والمرور من خلال حديد التسليح ومقاومتها للانعزال ، اما في حالتها الصلبة فقد تم دراسة مقاومة الانضغاط ومقاومة الشد الانفصالي ومعامل الكسر ومعيار المرونة في حالتها الصلبة.

اوضحت الدراسة ان اضافة الالياف الحديدية له تاثير كبير على خواص الخرسانة في حالتها اللدنة كما انه يعزز من خواص الخرسانة في حالتها الصلبة حيت تزداد مقومة الانضغاط ومقاومة الشد الانفصالي ومعامل الكسر معيار المرونة لكلا النوعين من الخرسانة العادية والعالية المقاومة.

1. Introduction

The term Self-Compacting Concrete (SCC*)* refers to a “new” special type of concrete mixture, characterized by high resistance to segregation that can be cast without compaction or vibration. [1]

The use of SCC has gained wide acceptance in Japan since the late 1980s. Initially, it was developed to ensure proper consolidation in applications where concrete durability and service life were of concern. SCC was later used to facilitate construction operations and to reduce construction time and cost. For example, it has been used to cast sections with highly congested reinforcement and areas that present restricted access to placement and consolidation, including the construction of tunnel lining sections and the casting of hybrid concrete-filled steel tubular columns.[2],[3]

The use of SCC is spreading worldwide because of its very attractive properties in the fresh state as well as after hardening. The term SCC refers to a special type of concrete mixture characterized by high resistance to segregation that can be cast without compaction or vibration. Therefore, this type of concrete can minimize the problem of concrete placing.[4], [5]

This type of concrete enables faster construction and decreases labor requirements, as well as a number of health and safety benefits, such as reduced noise, and avoiding white finger syndrome due to holding vibrators for long periods. [5], [6]

2. Material properties

2.1 Cement

Ordinary Portland cement produced at Northern Cement Factory (Tasluja-Bazian) was used throughout this investigation, with the requirements of the Iraqi Standard Specification I.Q.S. No.5, 1984[7]

2.2 Fine aggregate

Natural sand brought from AL-Ukaidher region was used in concrete mixes for this investigation. The fine aggregate had (4.75mm) maximum size with rounded partial shape and smooth texture with fineness modulus of (2.78). The obtained results indicate that, the fine aggregate grading is within the Iraqi Specification No. 45/1984[8] as shown in **Figure (1).**

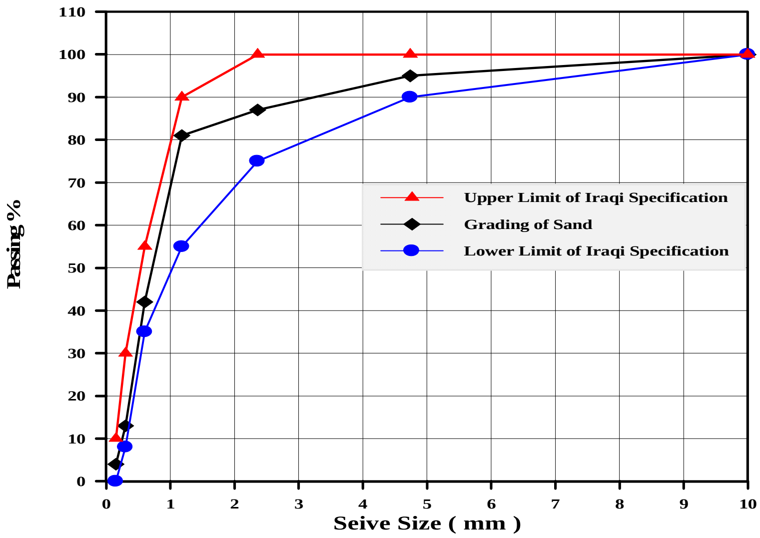

Fig .(1) Grading curve for fine aggregate with grading limits.[8]

2.3 Coarse aggregate

Crushed gravel of maximum size 10 mm brought from Al-Niba'ee region was used. **Figure (2)** show the grading of this aggregate, which conforms to the Iraqi Specification No.45/1984.**[8]**

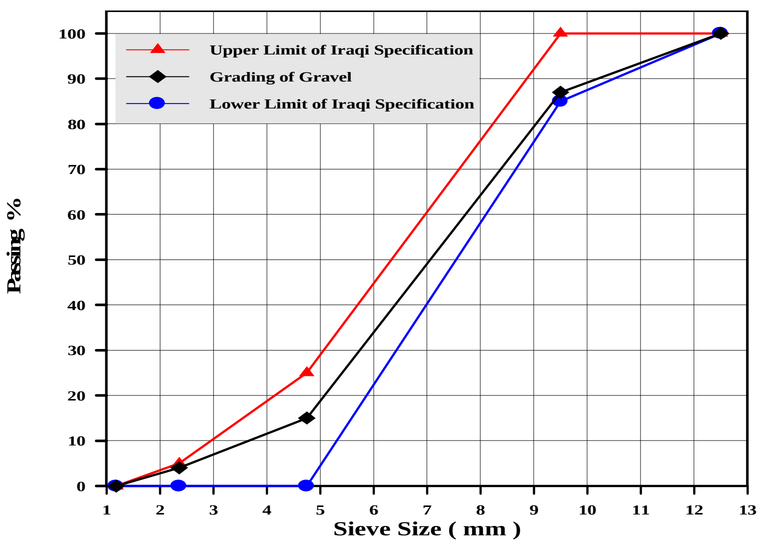

Fig .(2) Grading curve for coarse aggregate.[8]

2.4 Water

Ordinary tap water was used for both mixing and curing of all concrete specimens used in this investigation. It was free from injurious substances like oil and organic materials.

2.5 Steel Fibers

High tensile steel fibers crimped type was used with different volume fractions of (0, 0.4 and 0.8%). **Table (1)** shows the properties of the used steel fibers.

Table .(1) Properties of Steel Fibers

Property	Specifications
Density	**7860 kg/m^3**
Ultimate strength	**2000 MPa**
Modulus of Elasticity	**$200x10^3$MPa**
Strain at proportion limit	**$5650\ x10^{-6}$**
Poisson's ratio	**0.28**
Average length	**30 mm**
Nominal diameter	**0.375 mm**
Aspect ratio (L_f/D_f)	**80**

*From Manufacturer Catalogue

2.6 Superplasticizer:

A superplasticizer type sulphonted melamine and naphthalene formaldehyde condensates, which are known commercially as Gleniume-51, was used in this work.

2.7 Limestone powder (LSP)

This material is locally named "Al-Gubra". It is a white grinding material from lime-stones excavated from Al-Mosul province in the north of Iraq, Particle size of the limestone powder is less than 0.125 mm, it is confirm to EFNARC 2005[9]

3. Results of self-compacting concrete in fresh state

Self-Compacting Concrete (SCC) is defined by its behavior in the fresh state, to verify whether concrete meets certain requirements, which are explained in specifications and guidelines such as EFNARC, as stated in the previous chapter. The slump flow, T_{500} and L-box used for all mixes of this study are illustrated, **Table (4-1)** is based on the results of these three tests and the limitations of EFNARC, ACI-237R07[10] are listed.

From **Table (2)** it can be noted that all mixes tests satisfy the requirements of EFNARC specification except the mix (HSCC-0.8) which exceeds the limitations by a small margin in slump flow test and T_{500} slump flow tests. However, the acceptance of deviation is based on ACI-237R-07[10] and EUROPEAN specifications and according to Advanced Concrete Masonry Center which suggests a value greater than 600 mm for slump flow and a value less than 7.0 second for T500 slump flow test for mixes is designed with characteristic cube strength not less than 60 MPa. Also in the practice, the mix (HSCC-0.8) is used in placing specimens without any problems.

Figures (3), (4) and (5) show the results of the slump flow test, T500 slump flow test and L-Box test for the normal and high strength self-compacting concrete with and without steel fibers that have been adopted in this investigation.

Table .(2) Tests results of fresh properties for SCC.

Mix designation	**Slump flow (mm)**	**T_{50} (sec)**	**L –box (H_2/H_1)**
NSCC	772	3	1
NSCC-0.4	745	3.5	0.95
NSCC-0.8	705	4.5	0.90
HSCC	732	4.5	0.91
HSCC-0.4	695	5	0.85
HSCC-0.8	645	6	0.80
Limits of EFNARC	650-800	2-5	0.8-1
Limits of ACI-237R-07	450-760	2-5	0.8-1

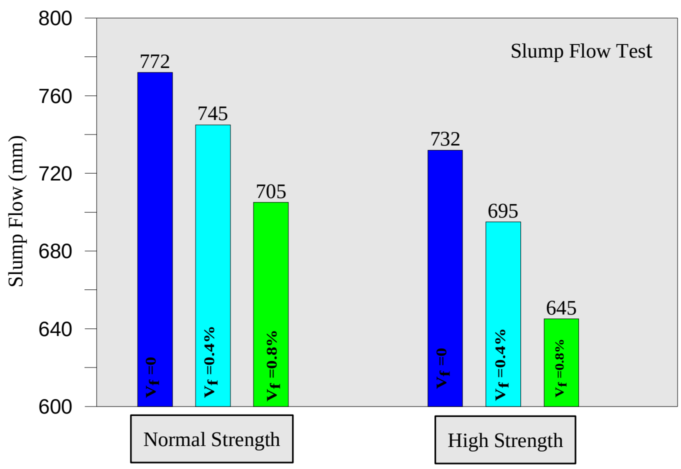

Fig .(3) Slump flow test results for six types of self-compacting concrete

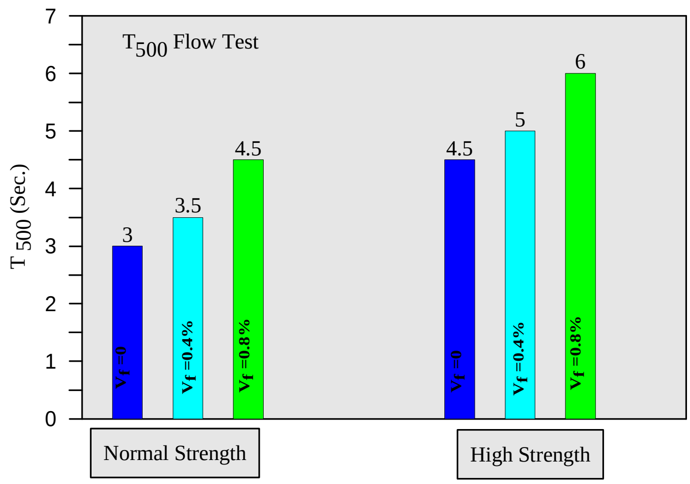

Fig .(4) T500 slump flow test results for six types of self-compacting concrete

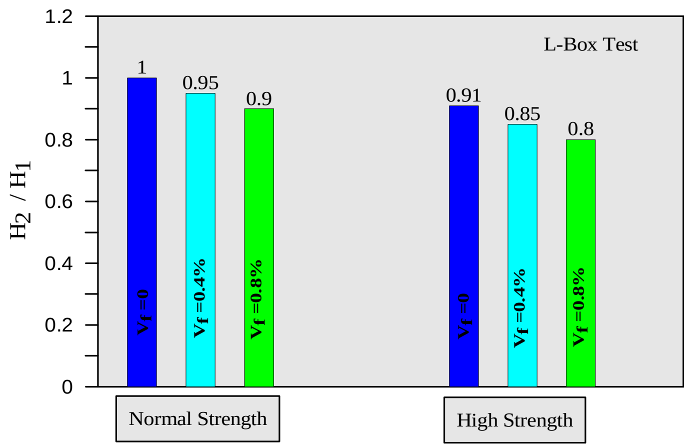

Fig .(5) L-Box test results for six types of self-compacting concrete

It is obvious from **Table (3)** and **Figures (3), (4), and (5)** that the addition of fibers with 0.4% and 0.8% decreases the slump flow by 4.05% and 10%, increases the T_{500} flow by 20% and 60% and decreases the ratio of H2/H1 by 3.09% and 11.11% respectively for normal strength self-compacting concrete.

For high strength, self-compacting concrete the addition of fibers by 0.4% and 0.8% decreases the slump flow by 5.8% and 14.06%, increase the T500 flow by 12.5% and 50% and decreases the ratio of H2/H1 by 4.55% and 13.58% respectively.

From above discussion, it can be noted that the workability of HSCC is less than that of NSCC. This is due to the use of higher quantity of cement and lower quantity of water and the workability of fibrous concrete is less than that of nonfibrous concrete. This reduction of workability is due to presence of steel fibers that work as obstacle for the motion of mix components.

Table .(3) Results of the fresh properties for self-compacting concrete

Test type	NSCC (Vf %)			% Variation due to increase Vf%		HSCC (Vf %)			% Variation due to increase Vf%		% variation between NSCC& HSCC (Vf %)		
	0	0.4	0.8	0.4	0.8	0	0.4	0.8	0.4	0.8	0	0.4	0.8
Slump	772	747	705	4.05	10	732	695	645	5.8	14.0	-5.2	-6.7	-8.5
T500	3	3.5	4.5	20	60	4.5	5	6	12.5	50	50	42.8	33.3
H2/H1	1	0.95	0.9	3.09	11.11	0.91	0.85	0.8	4.55	13.5	-9	-10.52	-11.1

4. Results of mechanical properties of self-compacting concrete in hardened state

The properties of self-compacting concrete in hardened state are important to understand the behavior of reinforced concrete corbels. SCC mixes should improve the hardened properties of this material. The mechanical properties that were studied in this investigation are the compressive strength (f 'c), splitting tensile strength (ft), modulus of elasticity (Ec) and modulus of rupture (fr). **Table (4)** shows test results and each value presented in this table represents the average value of three specimens.

4.1 Compressive strength (f 'c)

The most common mechanical properties of all tests on hardened concrete is the compressive strength test because it describes the characteristics of concrete that are qualitatively related to its strength and the intrinsic importance of the compressive strength of concrete in structural design.

Tables (4), (5), and **Figure (6)** show average test results of control specimens. It is obvious from the table and figure that there are only marginal improvements in compressive strength due to addition of steel fibers because the fibers act as aggregates of special shape in view of their small percentages in practical materials. Addition of 0.4 and 0.8 percent steel fibers to NSCC and HSCC resulted in 1.87 and 4.71 percent increase, 3.0 and 3.6 percent increase respectively.

The presence of steel fibers has a significant effect on mode of failure of control specimens as shown in **Figures (7), (8), (9)** and **(10)** and the fibers make failure mode more ductile.

Table .(4) Results of hardened properties for self-compacting concrete

Mix designation	f′c (MPa)	ft (MPa)	fr (MPa)	Ec (MPa)
NSCC	33.75	3.14	4.46	24945
NSCC-0.4	34.38	3.81	6.42	25448
NSCC-0.8	35.34	4.22	7.13	26549
HSCC	65.31	4.64	6.82	35647
HSCC-0.4	67.27	5.57	8.24	36932
HSCC-0.8	67.71	6.1	8.86	38024

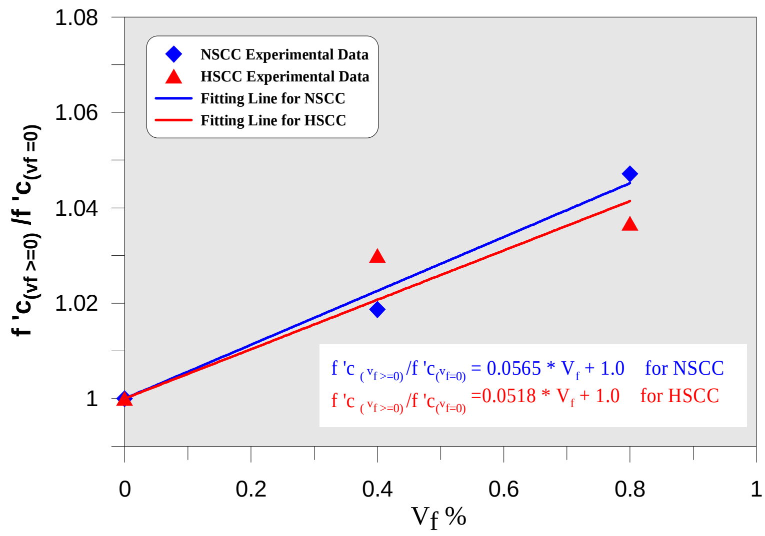

Fig .(6) Relationship between compressive strength and volumetric ratio of steel fibers for both NSCC and HSCC mixes

Table (5) Mechanical properties results of the of hardened state of Self-Compacting Concrete

Mechanical properties	NSCC			% Variation due to increase V_f%		HSCC			% Variation due to increase V_f%		% variation between NSCC& HSCC		
	V_f %					V_f %					V_f %		
	0	0.4	0.8	0.4	0.8	0	0.4	0.8	0.4	0.8	0	0.4	0.8
f'_c	33.75	34.38	35.34	1.87	4.71	65.31	67.27	67.71	3.00	3.68	93.51	95.67	91.60
f_t	3.14	3.81	4.22	21.34	34.39	4.64	5.57	6.1	20.04	31.47	47.77	46.19	44.55
f_r	4.46	6.42	7.13	43.95	59.87	6.82	8.24	8.86	20.82	29.91	52.92	28.35	24.26
Ec	24945	25448	26549	2.016	6.43	35647	36932	38024	3.61	6.67	42.90	45.13	43.22

Fig .(7) Failure of NSCC cylinders without steel fibers

Fig .(8) Failure of HSCC cylinders without steel fibers

Fig .(9) Failure of NSCC cylinders with steel fibers

Fig .(10) Failure of HSCC cylinders with steel fibers

4.2 Splitting tensile strength (ft)

Splitting tensile strength is an important property of hardened concrete, since the cracking in concrete is most generally due to the tensile stress that occurred under load, or due to environmental changes. Previous investigations by many researchers prove that the tensile strength of concrete is much lower than the compressive strength.

Tables (4), (5), and **Figures (11), (12)** show the tensile splitting strength increase with the increase of in compressive strength. Test results reveal that when the compressive strength increases by 93.51 percent the tensile splitting strength increases by 47.77 percent.

Addition of 0.4 and 0.8 percent steel fibers to NSCC and HSCC resulted in 21.34 and 34.39 percent increase and 20.04 and 31.47 percent increase respectively. **Figure (11)** shows that the experimental data is close to ACI 318M-2011 Code[13] and is higher than value proposed in reference(11)for both types of self-compacting concrete.

$$f_t = 0.56\sqrt{f'_c} \qquad \text{ACI 318M-2011} \qquad \text{------------ (1)}$$

$$f_t = 0.842\,(f'_c)^{0.391} \qquad \text{Proposed by reference(11)} \qquad \text{------------ (2)}$$

As for the compressive strength results, the steel fibers have significant effect on the mode of failure of control specimens so that the failure becomes more ductile in both types of mixes (NSCC and HSCC) as shown in **Figures (13), (14), (15) and (16).**

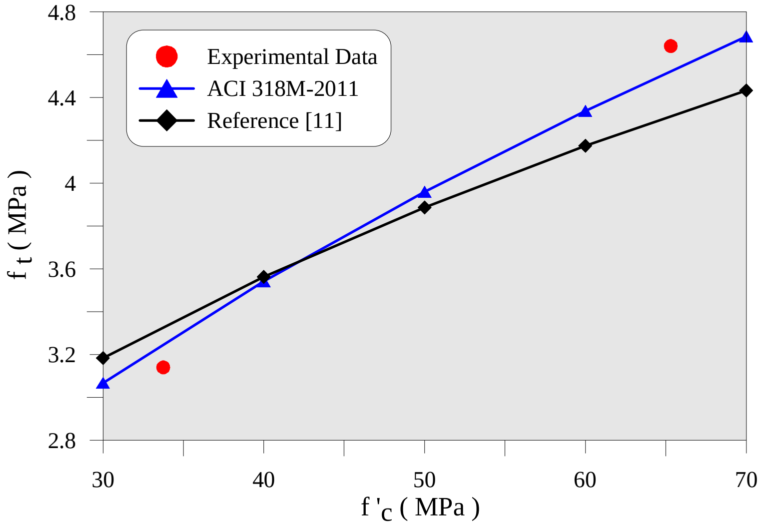

Fig .(11) Relationship between compressive strength and tensile splitting strength for nonfibrous concrete

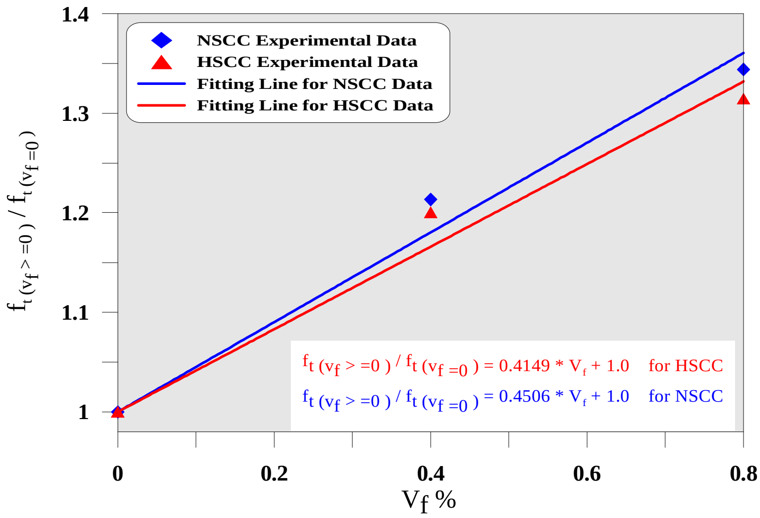

Fig .(12) Relationship between volumetric steel fibers and tensile splitting strength for both NSCC and HSCC mixes

Fig .(13) Splitting failure of nonfibrous NSCC cylinder

Fig .(14) Splitting failure of nonfibrous HSCC cylinder

Fig .(15) Splitting failure of fibrous NSCC cylinder

Fig .(16)Splitting failure of fibrous HSCC cylinder

4.3 Modulus of Rupture (f r)

Modulus of rupture (f r) is the maximum tensile stress of concrete tested in flexural, and can be calculated from the formula used for elastic materials, ($f_r = \frac{MC}{I}$) by testing a plain concrete beam.

It is obvious from the experimental results that the modulus of rupture increases with the increase in compressive strength. **Figure (17)** shows the relation between the compressive strength and modulus of rupture, when the compressive strength increases by the 93.51 percent the modulus of rupture increases by 52.92 percent as shown in **Tables (4)** and **(5).**

The experimental results of this work are compared with the equations, adopted by ACI 318M-2011 Code and reference [12]. The comparison indicate that the experimental results are higher than that of the ACI Code values and lower than the values proposed by reference(12) as shown in the **Figure (17).**

$$f_r = 0.62\sqrt{f_c'} \quad \text{ACI 318M-2011} \qquad \text{------------ (3)}$$

$$f_r = 0.8618\ (f_c')^{0.53} \quad \text{Proposed by reference (12)} \qquad \text{------------ (4)}$$

The presence of steel fibers has a significant effect on the modulus of rupture, when the volumetric steel fiber ratio increases to 0.4 percent and 0.8 percent for NSCC and HSCC, the modulus of rupture increases by 43.95 percent and 59.87 percent and 20.82 percent and 29.91 percent respectively as shown in **Figure (18)** and **Tables (4) and (5).**

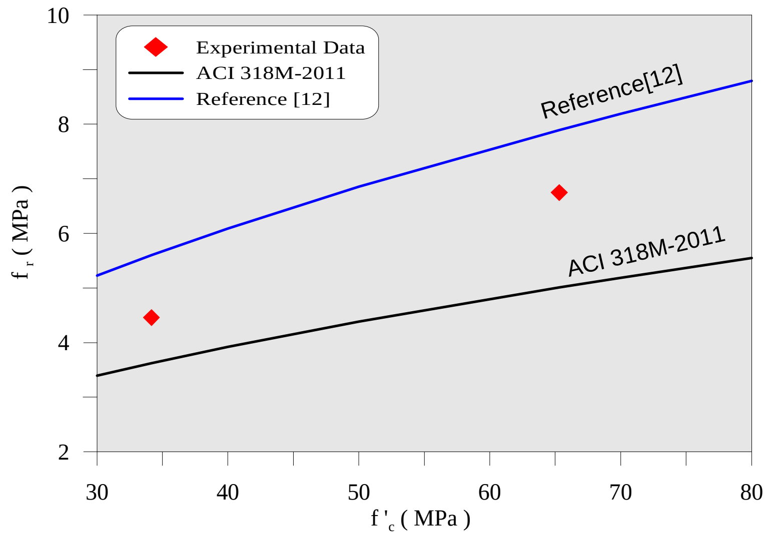

Fig .(17) Relationship between compressive strength and modulus of rupture for nonfibrous concrete

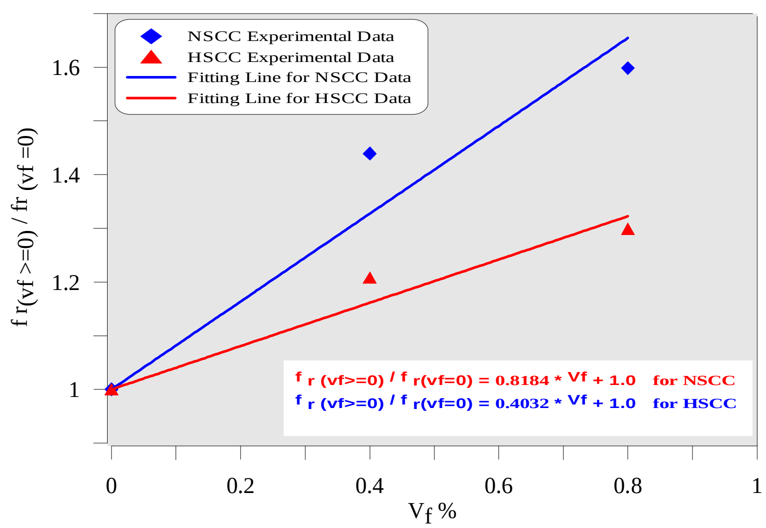

Fig .(18) Relationship between volumetric steel fibers and modulus of rupture for both NSCC and HSCC mixes

4.4 Modulus of elasticity (EC)

Modulus of elasticity it is one of the most important elastic properties of concrete, it can be obtained using a compressive test on concrete cylinders. The modulus of elasticity can be defined as the stress change with respect to strain in with the elastic range.

The experimental results show that the modulus of elasticity increases with the increase in compressive strength, **Table (4), (5),** and **Figure (19)** explain the relationship between these parameters, so that when the compressive strength increases by 93.51 percent the modulus of elasticity increases by 42.9 percent.

Also, **Figure (19)** shows the comparison between experimental results and the value predicted by the expressions adopted by ACI 318M-2011 Code[13] and the values proposed by reference [11].

$$E_c = 4700\sqrt{f'_c} \quad \text{ACI 318M-2011} \qquad \text{-------------(5)}$$

$$E_c = 5607\left(f'_c\right)^{0.436} \quad \text{Proposed by reference [11]} \qquad \text{--------------(6)}$$

It is found that the presence of steel fibers has a significant effect on the modulus of elasticity. When the volumetric steel fiber ratio increases to 0.4 percent and 0.8 percent, for NSCC and HSCC the modulus of elasticity increases by 2.02 percent and 6.43 percent and 3.61 percent and 6.67 percent respectively as shown in **Table (4), (5),** and **Figure (20).**

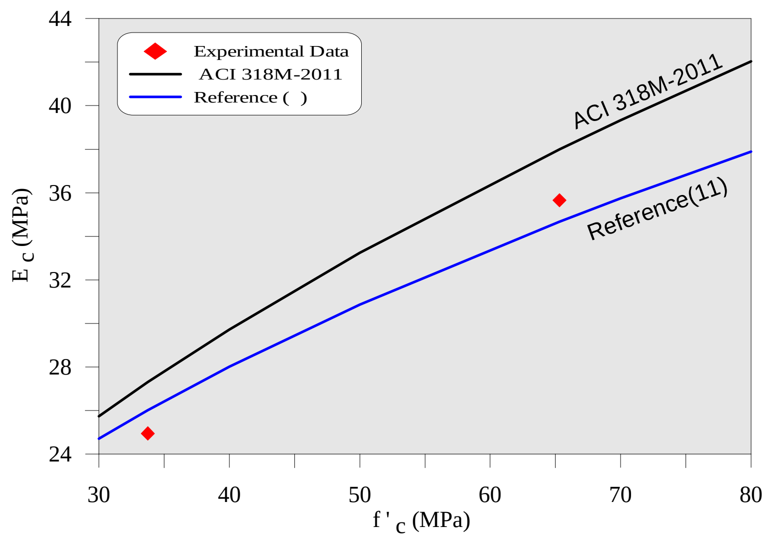

Fig .(19) Relationship between compressive strength and modulus of elasticity for nonfibrous concrete

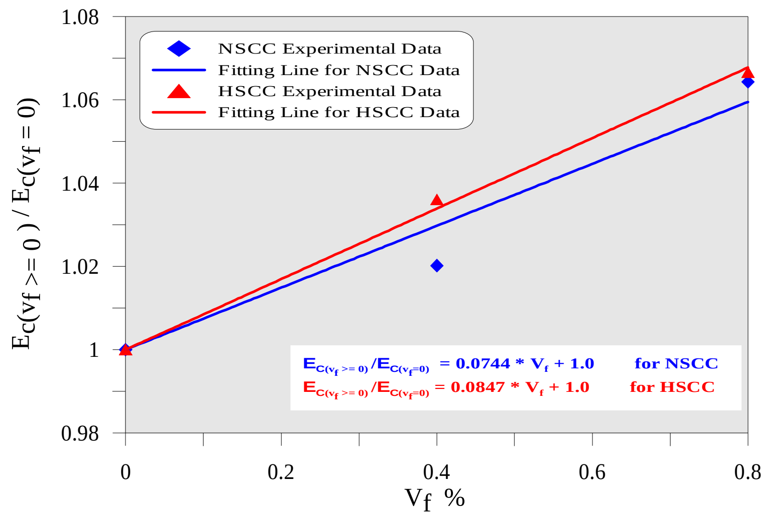

Fig .(20) Relationship between volumetric steel fibers and modulus of elasticity for fibrous and nonfibrous concrete

5. Conclusions

1. For normal strength self-compacting concrete the addition of steel fibers in 0.4% and 0.8% decreases the slump flow by 4.05% and 10%, increases the T500 flow is 20% and 60%, and decreases the ratio of H_2/H_1 with 3.09% and 11.11% respectively.
2. For high strength self-compacting concrete the addition of fibers in 0.4% and 0.8% decrease the slump flow by 5.8% and 14.06% increase the T_{500} flow by 12.5% and 50% and decrease the ratio of H_2/H_1 by 4.55% and 13.58% respectively
3. The standard tests show that steel fibers in self-compacting concrete enhances compressive strength, tensile strength, modulus of rupture and modulus of elasticity relative to self-compacting concrete cast without steel fibers.

   a) Addition 0.4% and 0.8% steel fibers to NSCC and HSCC increases the compressive strength by 1.87%, 4.71% and 3.0%, 3.6% respectively.
   b) Addition of 0.4% and 0.8% steel fiber to NSCC and HSCC increases the tensile strength by 21.34%, 34.39% and 20.04%, 31.47% respectively.
   c) The presence of steel fibers has a significant effect on the modulus of rupture, it is found that when the volumetric ratio of steel fibers increases to 0.4% and 0.8 % for NSCC and HSCC, the modulus of rupture increases by 43.95 %, 59.87 % and 20.82 %, 29.91% respectively.
   d) Steel fibers have a significant effect on the modulus of elasticity, when the volumetric steel fiber increases to 0.4 % and 0.8% for NSCC and HSCC, the modulus of rupture increases by 2.02 % and 6.43 % and 3.61 % and 6.67 % respectively.

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