The Effect of Steel Fibers and Silica Fume on The Mechanical Properties of High Strength Concrete

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Abstract— In last century, a lot of attempts were performed to upgrade and improve the mechanical behaviour of the concrete mix. By using several additions, concrete properties can be enhanced. Most important additions were the steel fiber and silica fume which give the concrete mix an enhancement in the compressive, tensile, and flexural strength. Eight concrete mixes were prepared. Eight samples divided into two groups, each group have four percentages for steel fiber (0%, 1% 1.5%, and 2%). The first group involved of (10%) silica fume, while the second group have (20%). Obtained results showed that the steel fiber and silica fume additions caused an increment in compressive strength, splitting strength and modulus of rupture. The higher compressive strength had additional strength by (33%) in the comparison with the reference sample for silica fume percentage (20%) and steel fiber (2%). Higher percentage for the additional strength for splitting and rupture strength was (74% and 93 %) respectively.

Index Terms— Steel fibers, Silica fume, mechanical properties, strength, flexural strength, compressive strength, ruptute strength.

1 Introduction

DUE Due to the technical and architectural requirement, new types of concrete were developed. Most important developed type was high strength concrete because this kind of concrete provide higher compressive strength and allow to the designer to construct higher building with less slab thickness and smaller columns to give more aesthetic to these designs.

By using of high strength concrete, the formwork can be removed in a little time with small amount of steel rebar in the high building which reduce the dead load. High strength concrete can be obtained by using the same material that used in normal strength concrete but with using additional techniques to get a material with long age and higher strength. Anyway, these days have a second revolution in concrete technology where the contradiction between high strength and low workability can be obtained by using the superplasticizers which allow to use a little amount of water. Some reduced water additives may reduce water by 0.25 of cement weight and at the same time give higher workability. High strength concrete became more common in Europe, America, and Japan.

2 Literature Review

First, Khaloo and Kim [1] examined the enhamcement in the concrete strength in addition of 0.5%, 1.0%, and 1.5% steel fibers, appeared an enhancement in the splitting tensile and compressive strengths by 1.0% fraction, while the rupture modulus increased to 1.5%.

Eren and Celik [2] examined effect of some additives such as steel fibers and silica fume on the concrete strength.
Chunxiang and Patnaikuni [3] showed that the $f'c$ of HSC having steel fiber improved by 24% after 76 day from casting. Marar et al. [4] showed that aspect ratio had an effect on the compressive strength.

Daniel and Loukili [5] investigated the addition of these materials which showed enhancement in the compressive strength by 15% with using the steel fiber.

Song [6] studied the mechanical properties of HSC with steel fiber addition, indicating the compressive strength amended with additions of steel fibers with different volume fractions. Maximum strength obtained with 1.5% fraction with a insignificant reduction with 2% fraction in comparison with 1.5%.

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3. EXPERIMENTAL WORK
3.1 Materials
3.1.1 Cement

All materials that used in this work are undergo to the physical and chemical test. Ordinary Portland Cement is used in this study is produced by Cresta cement factory. The chemical and physical analysis for cement is performed and gave a good result in the Iraqi limits for material tests No. 5/1984 [7]. Tables (1) and (2) shows these results.

Table 1 Chemical Analysis of Cement

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Compound Composite	Chemical Composite	% by Weight	Limits of Iraqi specification No.5/1984
Lime	Cao	63.96	-
Silica	Sio2	21.32	-
Alumina	Al2o3	4.58	-
Iron oxide	Fe2o3	3.25	-
Magnesia	Mgo	2.44	≤5
Sulfate	So3	2.32	≤2.8
Loss on ignition	L.O.I	3.61	≤4
Insoluble residue	I.R	1.17	≤1.5
Lime saturation factor	L.S.F	0.75	(0.66-1.02)%
Tricalcium silicate	C3S	50.69	-
Dicalcium silicate	C2S	18.28	-
Tricalcium aluminate	C3A	8.14	-
Tetracalcium alumminoferrite	C4AF	9.89	-

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TABLE 1 Physical Properties of Cement

Physical Properties	Test Results	Limit of Iraqi specification
Fineness Using Blaine Air Permeability Apparatus (m2/kg)	382	≥230
Setting Time Using Vicats Method		
Initial (hrs:min)	2:00	≥45 min
Final (hrs:min)	3:45	≤10 hrs
Soundness Using Autoclave Method	0.22	<0.8
Compressive Strength of Morter		
3 day (MPa)	21.2	≥15
7day (MPa)	27.8	≥23
28day (MPa)	34.7	-

3.1.2 Silica Fume

Silica fume is a byproduct in the carbothermic reduction of high-purity quartz with carbonaceous materials like coal, coke, wood-chips, in electric arc furnaces in the production of silicon and ferrosilicon alloys. [8] A grey densified grade 920 D silica fume (which is a product from the manufacture of silicon or ferro-silicon metal) was used, which was imported from the Elkem company in UAE. Chemical composition and physical of silica fume used in this investigation is shown in table 3 and table 4.

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  (This information is optional; change it according to your need.)

TABLE 3 The physical analysis of silica fume.

Requirement	Analysis %	Limit of specification requirement ASTM C 1240
Sio2	88.21	>85
Moisture content	0.72	<3
L.O.I	4.32	<6
Percent Retained on 45μm (No.325) Sieve,Max	8	<10

TABLE 4 The physical analysis of silica fume.

Oxide composition	Oxide content %
Sio2	86.46
Al2o3	1.6
Fe2o3	1.11
Na2o	0.3
K2o	1.9
Cao	1.8
Mgo	1.9
So3	0.25
L.O.I.	4.02

3.1.3 Fine Aggregates

In this study, Natural fine sand is used in concrete mixes. Sulfate content of fine sand is 0.13%. The fineness modulus for fine sand is 2.3. Normal potable water is used for mixing and treatment purposes.

3.1.4 Steel Fibers

High tensile steel fibers hooked type was used with dissimilar volume fractions of (0, 1,1.5 and 2%) [9]. Table (4) shows the properties of the used steel fibers.

TABLE 5 Properties of hooked steel fiber.

Length	30
Diameter (mm)	86.46
Aspect Ratio (l/d)	55
Tensile strength N/mm2	1345 MPa

3.1.5 Superplasticizer

Commercially named Flocrete PC 260 which conforms to ASTM C494-99 [10] type A&G was used in the mixes.

3.2 The Experimental Program:

The experimental program was planned to investigate the effect of using steel fiber with two percent of silica fume divided into two groups. The first group (Mix 1 to Mix 4) have 100 kg/m3 silica fume while the other group (Mix 5 to Mix 8) have 200 kg/m3 which gave the same results approximately except the compressive strength for the second group which gave 68, 71, 78, and 91 MPa for steel fibers 0, 1, 1.5, and 2%. Table (5) shows the used mixes to obtain a concrete with high strength property.

Table (5): Details of the concrete mixtures.

(kg/m3)	Mix 1	Mix 2	Mix 3	Mix 4
Cement	900	900	900	900
Sand	1000	1000	1000	1000
Silica fume	100	100	100	100
w/c	0.22	0.22	0.22	0.22
Super plasticizer	2%	2%	2%	2%
Steel fibers	0%	1%	1.5%	2%

3.2.1 Sampling Process

In this study, preparation of the samples is performed firstly by add the cement and silica fume, then the addition of sand is implemented. After the mentioned materials, the water and superplasticizer respectively to the mix. To avoid the conglomerate in mix, the steel fiber added gradually in small amounts. To produce the concrete with uniform material consistency and good workability. For concrete mixes with a 2.0% volume of fibers, extra time was required for mixing. The freshly mix steel fiber-reinforced concrete was placed in two equal layers into a cylinder mold to cast a standard 100x200 mm cylindrical concrete specimen for a splitting tensile test,100x100x100mm cube mold for a compressive strength test and into a 100x100x500 mm beam mold for a flexure strength test. At the end of 24 h after consolidating, the specimen was removed from the mold and cured in water for 28 days. And then a strength test was performed.

Figure 1: Mixing Process for the steel fiber concrete.

Figure. 2. Different components in HSC.

4. Results and discussion

4.1 Effect of fibres & silica fume content on Compressive Strength of High Strength Concrete:

The compressive strength was evaluated using six cubes (100 x 100 x 100 mm) the first three cubes were tested at 7 days and the other were tested at 28 days according to BS [11].

For the first group, the compressive strength showed increasing with increasing steel fibres ratio as presented in table 6. The increment was by (0%, 9%, 19%, and 30%) for steel fiber percent (0%, 1%, 1.5%, 2%) respectively. Concerning the second group, $f'c$ appeared an increment by (0%, 4.4%, 14.7%, and 33.8%) for the same increasing of steel fiber percent. Silica fume amount have a significant effect on the compressive strength with the same amount of steel fiber because this material ultrafine material with spherical particles reduce the permeability and fill all the voids inside the concrete mix giving the mix more cohesive.

Changing the amount of the silica for the same amount of steel fiber improved the $f'c$ by (13-20)% in comparison with the former amount for the first group.

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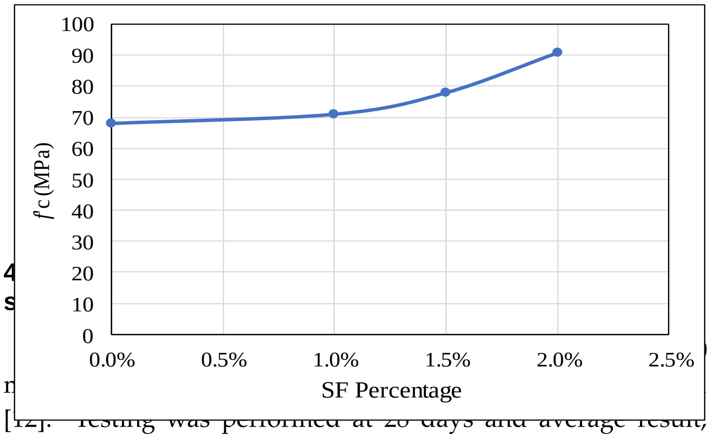
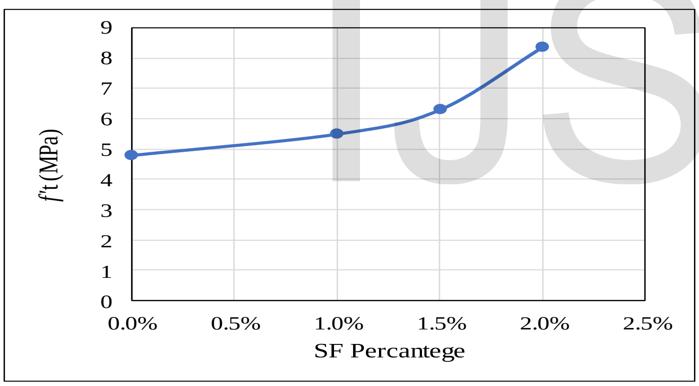


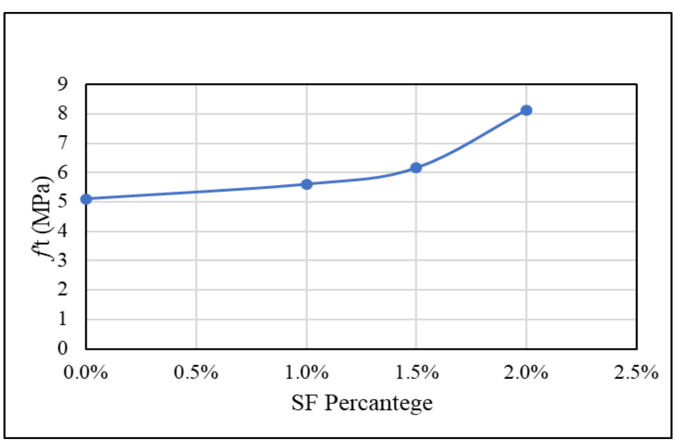
[12]. Testing was performed at 28 days and average result, respectively, the average value of three specimens for each mix and age was determined and recorded in Table 6.

Figure.5: Effect of fiber volume on splitting tensile strength for first group.

Figure.6: Effect of fiber volume on splitting tensile strength for second group.

4.3 Effect of fibres & silica fume content (%) on Flexural





Strength (f_r):

A prism specimen with dimensions of 100×100×500 mm was used throughout this test. Prisms are tested using the one-point loading with simple span between support of 450 mm according to the ASTM C293 – 02 [13]. Silica fume amount have no effect on the *ft* and *fr* with the same amount of steel fiber because this material considered a filling material without improve the tensile and flexural properties

Figure.7: Effect of fiber volume on modulus of rupture for 1st group.

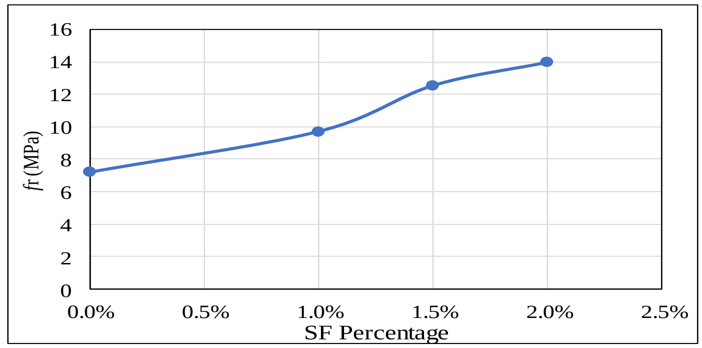
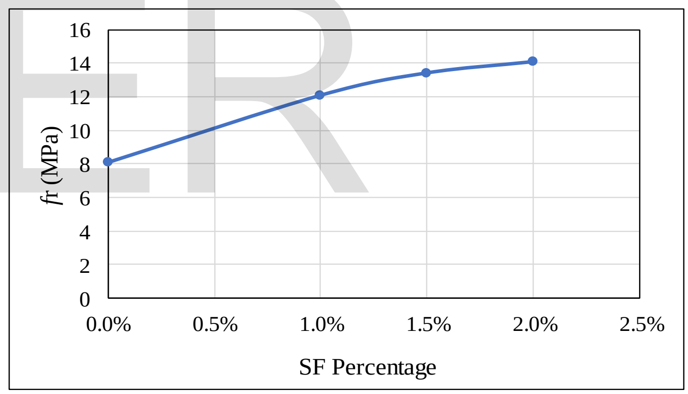


Figure 8: Effect of fiber volume on modulus of rupture for 2nd



group.

Figure.9: Compressive and splitting strength tests for HSC.

5. Conclusions:

1. The compressive strength of HSC improved with additions of steel fibers at various volume fractions. The strength ranged from 9.15% to 30.3% higher for the fractions from 1% to 2.0% and silica fume 10%. Also, the compressive strength of HSC improved with additions of steel fibers ranged from 4.4% to 33.8% higher for the fractions from 1% to 2% and silica fume 20%.

2. The splitting tensile strength and modulus of rupture of HSC both improved with increasing fiber volume fraction. The splitting tensile strength ranged from 14.6% to 74% higher for the fractions from 1% to 2.0% and silica fume 10%. And the modulus of rupture ranged from 34.7% to 93.75% higher for the fraction from 1% to 2.0% and silica fume 10% . The splitting tensile strength ranged from 7.1% to 59.4% higher for the fractions from 1% to 2% and silica fume 20%. And the modulus of rupture ranged from 49.38% to 74% higher for the fractions from 10% to 20% and silica fume 20%.

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