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EVALUATION OF MECHANICAL PROPERTIES OF HIGH PERFORMANCE SELF-CONSOLIDATED CONCRETE ENHANCED BY DISCRETE STEEL AND POLYPROPYLENE FIBERS

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Abstract: High performance self-consolidating concrete HP-SCC is one of the most complex types of concrete which have the capacity to consolidated under its own weight, have excellent homogeneity and high durability. This study aims to focus on the possibility of using industrial by-products like Silica fumes SF in the preparation of HP-SCC enhanced with discrete steel fibers (DSF) and monofilament polypropylene fibers (PPF). From experimental results, it was found that using DSF with volume fraction of 0.50 %; a highly improvements were gained in the mechanical properties of HP-SCC. The compressive strength, splitting tensile strength, flexural strength and elastic modulus improved about 65.7 %, 70.5 %, 41.7 % and 80.3 % at 28 days age, respectively with retaining the main properties of HP-SCC. Furthermore, using PPF with volume fraction up to 0.10 %; an enhancement in the compressive and elastic modulus of HP-SCC about 47.4 % and 31 % was obtained at age of 28 days, respectively. Moreover, using PPF with volume fraction of 0.15 %, the splitting tensile strength and flexural strength of HP-SCC improved about 44.5 % and 20.3 %, respectively.

Keywords: *self-consolidated concrete, mechanical properties, steel fibers, polypropylene fibers.*

تقييم الخواص الميكانيكية للخرسانة عالية الأداء الذاتية الرص المعززة بالألياف الحديدية المنفصلة وألياف البولي بروبلين

الخلاصة: تعتبر الخرسانة العالية الأداء والذاتية الرص واحدة من أعقد أنواع الخرسانة التي لها القابلية على الرص تحت تأثير وزنها الذاتي فضلاً عن تجانسها الممتاز وديمومتها العالية. هذه الدراسة العملية تهدف إلى إستخدام أبخرة السليكا كمنتج صناعي ثانوي في إنتاج الخرسانة عالية الأداء والذاتية الرص والمعززة بألياف حديدية منفصلة وألياف البولي بروبلين أحادية الشعيرة. بينت نتائج الفحوصات العملية، إن أستخدام الألياف الحديدية المنفصلة بنسبة ٠,٥ % من حجم الخرسانة أدى إلى تحسن عالي في الخواص الميكانيكية لها حيث زادت كل من مقاومة الأنضغاط ، مقاومة إنفلاق الشد، مقاومة الإنثناء و معامل المرونة بنسبة ٦٥,٧ % ، ٧٠,٥ % ، ٤١,٧ % ، ٨٠,٣ % وعلى الترتيب لمعدل النماذج الخرسانية المختلفة وبعمر ٢٨ يوماً. علاوة على ذلك، إن أستخدام ألياف البولي بروبلين أحادية الشعيرة بنسبة لاتتجاوز ٠,١٠ % من حجم الخرسانة أدى إلى زيادة مقاومة الأنضغاط ومعامل المرونة للخرسانة عالية الأداء والذاتية الرص بنسبة ٤٧,٤ % ، ٣١ % بعمر ٢٨ يوماً، على الترتيب. أيضاً، إن أستخدام الألياف الأخيرة بنسبة حجمية مقدارها ٠,١٥ % أدى إلى تحسن مقاومة إنفلاق الشد ومقاومة الإنثناء للخرسانة وبعمر ٢٨ يوماً لمعدل النماذج الخرسانية المختلفة بنسبة ٤٤,٥ % ، ٢٠,٣ %، على الترتيب.

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1. Introduction

Self-consolidated concrete (SCC) is normal or high-strength concrete that is able to flow and consolidated under its own weight and without any vibration. On the same time, it is cohesive enough to fill spaces of almost any size and shape without segregation or bleeding. This makes SCC particularly useful wherever placing is difficult, such as in heavily reinforced concrete members or in complicated formwork.

Early SCC mixtures achieved fluidity through the addition of superplasticizers to conventional concrete mixtures while dramatically increasing the water–cementitious material (w/cm) ratio [1]**.** The fundamental rheological properties of SCC are based on low yield stress, moderate viscosity and retention of the kinetic energy of the flowable mix by reducing the volume fraction of coarse aggregate. These measures are necessary for imparting the requested fluidity, segregation resistance and prevention of inter-particle collision and blocking. A low yield stress is attained by incorporation of adequate contents of superplasticizer. The flow characteristics are further modified by changing the aggregate volume fraction, coarse-to-fine aggregate volume, and the composition of the other ingredients. The viscosity is controlled by the contents of the free water, superplasticizer, and the volume fraction of the solids in the mix [2]**.**

In recent years, significant attentions have been given to the use of the pozzolan silica fume as a concrete property-enhancing material by partial replacement of portland cement. Silica fume (SF in brief) can be used in a variety of cementitious products such as concrete, grouts, and mortars as well as elastomer, polymer, refractory, ceramic and rubber applications. Silica fume has also been referred to as silica dust, condensed silica fume, micro-silica, and fumed silica (this last term is particularly incorrect). ACI 116R-2000 gives the most appropriate term which is *silica fume* [3, 4]**.**

Silica fume is a high quality material used in the cement and concrete industry with typical dosage of 8–10% by weight of cement is added in concrete. The reported benefits of mineral admixtures are often associated with the harden properties of concrete; however, mineral admixtures may also influence the properties of wet concrete between the time of mixing and hardening in one or more of the following ways such as they may affect water demand, heat of hydration, setting time, bleeding, and reactivity [5-7].

In recent years, a great deal of interest has been shown in fiber-reinforced concrete, and today there is much ongoing research on the subject. The fibers used are made from steel, plastics, glass, and other materials. Various experiments have shown that the addition of such fibers in convenient quantities (normally up to about 1% or 2% by volume) to conventional concretes can appreciably improve their characteristics. The use of fibers has increased the versatility of concrete by reducing its brittleness. The reinforcing bar provides reinforcing only in the direction of the bar, while randomly distributed fibers provide additional strength in all directions [8].

The incorporation of steel fibers improves engineering performance of structural and non-structural concrete, including better crack resistance, ductility, and toughness, as well as greater tensile strength, resistance to fatigue, impact, blast loading, and abrasion. The incorporation of fibers can significantly modify rheological properties as fibers, by their geometrical forms, interact with the aggregate, hence increasing the internal resistance to flow. Such interference should be reduced, and a proper suspension of solids particles is necessary to prevent segregation in the vicinity of restricted areas that can result in blockage of the flow. Typically, the reduction in fiber length and decrease in the nominal size of aggregate and aggregate volume reduce such internal resistance to flow and increase workability [9].

Polypropylene fiber is synthetic and man-made fibers which are resulting from research and development in the petrochemical and textile industries. Polypropylene fibers are the most popular of the synthetics. They are produced in an extrusion process and can be chopped to specific lengths. Some benefits include chemical inertness, hydrophobic properties, and lighter weight. Many tests have been conducted on composites containing polypropylene fibers at volumes ranging from 0.1 to 10 percent; however the properties of these composites vary greatly depending on fiber volume, geometry, and composition of the concrete matrix [10].

2. Research Objectives

The main objectives of this paper are to investigate the mechanical properties of High Performance Self-Consolidated Concrete HP-SCC enhanced by six different percentages of discrete steel and monofilament polypropylene fibers. Furthermore, Silica Fume (SF) was added as a partial replacement of Portland cement in all concrete mixes as a property-enhancing material. Other aim of this paper is to identify the influence of the considered variables in the effectiveness of fibers. The considered variables were:

1. Effects of fibers on early age strength of HP-SCC.
2. Effects of volume fraction of fiber reinforcement on HP-SCC.
3. Effects of superplasticizer on the fresh and hardened properties of HP-SCC.

3. Experimental Program and Test Results

In this study, five types of concrete mixes were tested. Both fresh SCC and hardened samples were tested. The total number of the tested specimens was (180) which were tested in compressive strength, tensile strength, elastic modulus and flexural strength (modulus of rupture) in three ages (1day, 3-days and 28-days). Materials and additives properties, concrete mix proportions and fresh and hardened concrete tests which performed in this work are listed herein.

3.1. *Materials and Additives*

3.1.1. *Cement*

Al-Mass ordinary Portland cement Type I ((Iraqi, Mass Bazian Company) cement was used. The cement was tested and checked according to Iraqi specifications, IQS No.5, 1984 [11]. Physical and chemical properties of the used cement are shown in Tables 1 and 2, respectively.

Table 1. Physical Properties of Cement*

Physical Properties		Test Results	Limits of Iraqi Specification No.5/1984
Specific surface area (Blaine method) (m^2/kg)		315	≥ 230
Soundness (Le-Chatelier method) (mm)		0.66	<10
Setting time (Vicat's method)	Initial setting (hrs:min.)	2:10	≥ 45 min.
	Final setting (hrs:min.)	4:15	≤ 10 hrs
Compressive strength (MPa)	3 days	22.90	≥ 15
	7 days	33.80	≥ 23

*These tests were carried out in the lab of Central Organization for Standardization and Quality Control

Table 2. Chemical Composition and Compounds of Cement*

Oxide Composition	Abbreviation	Percentage by Weight	Limit of Iraqi Specification No.5/1984
Lime	CaO	62.35	–
Silica	SiO2	21.45	–
Alumina	Al2O3	4.95	–
Iron Oxide	Fe2O3	3.37	–
Sulphate	SO3	2.45	≤ 2.8 %
Magnesia	MgO	4.75	≤ 5.0 %
Potash	K2O	0.36	–
Soda	Na2O	0.2	–
Loss on ignition	L. O. I.	0.73	≤ 4.0 %
Insoluble residue	I. R.	1.24	≤ 1.5 %
Main Compounds (Bogue's Equations)			
Tricalcium Silicate	C3S	57.74	–
Dicalcium Silicate	C2S	14..21	–
Tricalcium Aluminate	C3A	8.92	–
Tetracalcium Alumino- Ferrite	C4AF	10.34	–

*These chemical tests were carried out in the lab of Central Organization for Standardization and Quality Control.

3.1.2. *Fine Aggregate*

AL-Ukhaider natural fine aggregate with a maximum size of (4.75) mm was used throughout this work. Tables 3 and 4 shows the grading and the physical properties of fine aggregate, respectively. Test results shows that the fine aggregate grading and sulfate content were within the requirements of the Iraqi specification, IQS No.45, 1984 [12].

Table 3. Grading of Fine Aggregate

Sieve Size (mm)	Cumulative Passing (%)	Limits of the Iraqi Specification No.45/1984, Zone 3
4.75	100	90 - 100
2.36	86.5	75 - 100
1.18	69.8	55 - 90
0.60	57.5	35 - 59

0.30	24.9	8 - 30
0.15	3.5	0 - 10

Table 4. Physical Properties of Fine Aggregate

Physical Properties	Test Results	Limits of the Iraqi Specification No.45/1984
Specific Gravity	2.65	–
Sulfate Content %	0.2	≤ 0.5 %
Absorption %	1.70	–
Bulk Density (Kg/m^3)	1665	-

3.1.3. *Corse Aggregate*

Crushed gravel with maximum size of (١٤ mm) from Al-Niba'ee region was used. The grading of coarse aggregate conforms to the Iraqi specification, IQS No.45, 1984 as shown in Table 5. Table 6 shows the physical properties of the coarse aggregate.

Table 5. Grading of Coarse Aggregate

Sieve Size (mm)	Cumulative Passing (%)	Limitations of the Iraqi Specification No.45/1984
20.0	100	100
14.0	96	90 -100
10.0	68	50 - 85
5.00	7	0 -10
2.36	-	-

Table 6. Physical Properties of Coarse Aggregate

Physical Properties	Test Result	Limit of Iraqi Specification No. 45/1984
Specific gravity	2.63	-
Sulfate content %	0.065	≤ 0.1 %
Absorption %	0.63	-
Bulk Density (Kg/m^3)	1680	-

3.1.4. *Mixing water*

Clean water from water-supply network was used for mixing and curing.

3.1.5. *Pozzolanic material - silica fume (SF)*

A partial replacement of Portland cement with ultrafine material silica fume can improve significantly the strength and other properties of concrete [13]. SF is a by-product resulting from the reduction of high-purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys. Silica fume is a very fine powder consisting mainly of amorphous sub-micron particles with a mean diameter about 0.15 microns, with a very high specific surface area (min. 15 m2/gm). The chemical analysis of silica fume used in this study is shown in Table 7, while the physical properties are listed in Table 8. The results show that the silica fume conforms to the chemical and physical requirements of ASTM C1240-2015 [14].

Table 7. Chemical Analysis of Silica Fume*

Oxide Compositions	Oxide content %	ASTM C1240-05
SiO_2 ,content %	93.47	85% Min.
Loss on Ignition (LOI) %	3.82	6% Max.
Moisture Content	0.27	3% Max.

* According to manufacturer.

Table 8. Physical Properties of Silica Fume

Physical Requirements	Typical	ASTM C1240-05
Oversize percent retained on 45-µm	2.54 %	10.0 % Max.
Accelerated Pozzolanic Strength Activity Index with Portland cement (7 day)	126.07 %	105.0 % Min.
Specific Surface Area	22. 28 m^2/g	15 m^2/g Min.

* According to manufacturer.

3.1.6. *Superplasticizer*

High range water reducing admixture have an aqueous solution of modified polycarboxylate base commercially known (Sika ViscoCrete-5930) were used in this study. It conforms to ASTM C494 Type G and F admixture and ASTM C1017 Type I admixture according to manufacture company specifications. The technical description of HRWRA is shown in Table 9. HRWRA were poured simultaneously with gauging water into the concrete mixer.

Table 9. Technical Description of HRWRA*

Properties		Technical description
Appearance	Chemical	Aqueous solution of modified Polycarboxylate
	Form	liquid
	Color	Turbid liquid
Odor		none
Density		1.095 Kg/lt.
Toxicity		Non-Toxic under relevant health and safety codes
pH		7 - 9
Storage		1 years in original, unopened container

* According to manufacturer.

3.1.7. *Air-entraining agent (AEA)*

It was observed that the increasing of air content lead to decreasing the compressive strength of SCC. The reduction in compressive strength was about 4 MPa per 1 % increase in air content [15].

Therefore, in order to provide HP-SCC with a stable air void system, proper bubble size and spacing; *Air-entraining agent* AEA was added to all mixes. Total air content (AC) of 6% was adopted to design the air-entrained HP-SCC whereas 2% entrapped air content was considered in designing the non-air-entrained HP-SCC. This agent was added to the mixing water prior to its addition to other concrete components. AEA commercially known Sika Aer was used in all mixes. AEA used in this study confirmed to ASTM C260-10a [16], physical and chemical properties is shown in Table 10.

Table 10. Physical and chemical properties of AEA*

Properties		Technical description
Appearance	Chemical	Aqueous synthetic resin - dispersion type
	Form	liquid
	Color	Brown
Odor		none
Density		1.01 Kg/lt.
Toxicity		Non-Toxic under relevant health and safety codes
pH		7-8
Storage		1 years in original, unopened container

* According to manufacturer.

3.1.8. *Fiber reinforcement*

The major advantage of incorporating fibers in SCC is the elimination of vibration to consolidate the concrete and the enhancement of the stability of the SCC matrix [17]. Also, the adding of fibers will extend the range of applications of SCC; a reduction in workability due to fiber addition may become a handicap in practice [18]**.** Two types of reinforcing fibers were used in this study as listed herein:

3.1.8.1. *Discrete steel fibers (DSF)*

Discrete steel fibers were used in this experimental research. The DSF have a length, diameter and aspect ratio of 35 mm, 0.7mm and 50, respectively**.** Fibers are made from low carbon cold drawn steel wires and comply with ASTM A820-15 [19] type I and have a high tensile strength of 1100 MPa. The used volume fractions of steel fibers were (0%, 0.25% and 0.50%). The steel fibers used throughout the current study is shown in Fig.1(a).

3.1.8.2. *Monofilament polypropylene fibers (PPF)*

Monofilament polypropylene fibers commercially known (Sika Fiber PPM-12) were used in this study. PPF is made from monofilament polypropylene, have a length and diameter of 12 mm and 18 micron, respectively. PPF minimum tensile strength ranged 600-700 MPa and comply EN 14889-2 [20] per manufacturing company. The used volume fractions of PPF were (0 %, 0.10% and 0.15%). The polypropylene fibers used throughout the current study is shown in Fig. 1(b).


(a) Discrete Steel Fibers (b) Monofilament Polypropylene Fibers

Figure 1. Types of reinforcing.

3.2. *Mixing Components and Fresh Tests of HP-SCC*

Depending on previous literatures and in compliance with the American standard ACI 237-07 [21] and to fulfill the scope of this research, trial mixes were performed in this study to obtain a cylindrical compressive strength of 35 MPa. The binder (cement and silica fume) contents of 400 kg/m3 was used including 10% SF and fixed quantity for both fine and coarse aggregates. The water to binder ratio W/B was 0.425 for all mixes. Regarding to additives, the AEE used was constant for all mixes while HRWRA was varied. Table 11 below illustrates all materials and additives quantities and proportions.

Table 11. Materials, Additive and Fibers Proportions.

Materials / Additives /Fibers		Mix 1 Control 10%SF	Mix 2 10%SF-0.25%DSF	Mix 3 10%SF-0.50%DSF	Mix 4 10%SF-0.10%PPF	Mix 5 10%SF-0.15%PPF
Type I Cement, Kg		360	360	360	360	360
Silica Fume, Kg		40	40	40	40	40
Total Binder Weight, Kg		400	400	400	400	400
Coarse Aggregate, Kg		850	850	850	850	850
Fine Aggregate, Kg		850	850	850	850	850
Air Entraining Agent, ml/m^3		150	150	150	150	150
High-Range Water Reducer, l/m^3		2.25	2.85	3.25	4.6	7
Fibers Volume fractions , %	Discrete Steel Fibers (DSF)	0	0.25	0.5	–	–
	Polypropylene Fibers (PPF)	0	–	–	0.1	0.15

The primary performance attributes of high performance Self-Consolidating Concrete (HP-SCC) are filling ability, passing ability and stability. These can be measured by a combination of tests that give an indication of the quality of the SCC. Currently there is only one ASTM-approved test method for SCC; however, several other test methods have been drafted and are in various stages of ASTM review. Tests were conducted on fresh HP-SCC as follows:

1. *Slump Flow Test*

   This test is performed according to According to ASTM C1611-14 [22] and it provide information on flowability and passing ability of self consolidated concrete and as shown in Fig. 2.

2. *T500 Test*

   Measures the rate at which the self consolidated concrete flows, i.e. the time it takes the slump flow patty to reach 500 mm.

3. *J-Ring Test*

   This test is performed according to According to ASTM C1621-14 [23]. It's the procedure to measure the passing ability of self consolidated concrete which is shown in Fig. 3.

4. *L-box Test*

   The L-box measures the filling ability and passing ability of the self consolidated concrete.

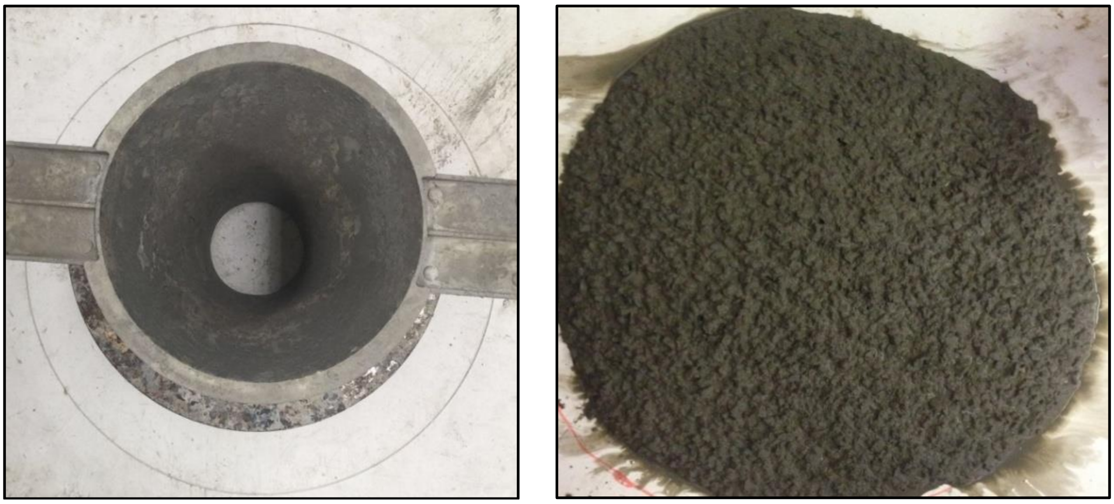

Figure 2. Slump Flow test.

Figure 3. J-ring test.

5. *Visual Stability Index Test*

The VSI test ranks the stability of the SCC on a scale of 0-3, with (zero) indicating highly stable self consolidated concrete and (three) indicating unacceptable SCC. The rating is based on the visual inspection of the slump flow patty immediately after its stops flowing.

Results of fresh HP-SCC tests for each mix are recorded and presented in Table 12.

Table 12. Tests Results for Fresh Mixes of HP-SCC.

HP-SCC Tests	*Mix 1 (Control) 10%SF*	*Mix 2 10%SF-0.25%DSF*	*Mix 3 10%SF-0.50%DSF*	*Mix 4 10%SF-0.10%PPF*	*Mix 5 10%SF-0.15%PPF*
Slump Flow, mm	640	630	610	580	510
T500, sec.	5	5.5	7	6	8.5
J-Ring, mm	550	530	480	460	425
L Box h2/h1	1.3	1.15	1.05	1	0.85
VSI	0	1	0	1	1
Air Content, %	6.5	7	6	6.5	6

3.3. *Tests of Hardened HP-SCC Samples*

In order to investigate the mechanical (strength) properties of HP-SCC in early age (1day) and other later ages (3 days, 28 days), cylindrical and prisms were casted with a dimensions of (100×200) mm and (100×100× 400), respectively in order to study the following properties:

3.3.1. Compressive strength of cylindrical HP-SCC specimens (100×200) mm according to ASTM C39/C39M-15a [24] and as shown in Fig. 4. The compressive strength is calculated from (1).

$$\boldsymbol{f_c' = P/A} \qquad (\mathbf{1})$$

Where, (f_c') is the compressive strength in (MPa), (P) is the maximum applied load in Newton and (A) is the cross-sectional area of the specimen in millimeters.

3.3.2. Splitting tensile strength of cylindrical HP-SCC specimens (100×200) mm according to ASTM C496/C496M-11 [25] as shown in Fig. 5 and it is calculated according to (2).

$$\boldsymbol{f_t = (2P)/(\pi\, l\, D)} \qquad (\mathbf{2})$$

Where, (f_t) is the splitting tensile strength in (MPa), (P) is the maximum applied load in Newton, (l and D) are the length and the diameter of the specimen in millimeters, respectively.

3.3.3. Modulus of elasticity of cylindrical HP-SCC specimens (100×200) mm according to ASTM C469/C469M-14 [26]. The modulus of elasticity is calculated from (3).

$$\boldsymbol{E_c = (s_2 - s_1)/(\varepsilon_2 - 0.00050)} \qquad (\mathbf{3})$$

Where, (E_c) is the modulus of elasticity in (MPa), (S_2) is the stress corresponding to 40 % of ultimate load, (S_1) is the stress corresponding to a longitudinal strain, (ε_2) is the longitudinal strain produced by stress (S_2).

3.3.4. Flexural strength of HP-SCC (modulus of rupture) using simple beam with Third-Point loading prisms of (100×100×400 mm) according to ASTM C78-15 [27] and it is calculated from (4).

$$\boldsymbol{f_r = PL/(bd^2)} \qquad (\mathbf{4})$$

Where, (f_r) is the modulus of rupture in (MPa), (P) is the maximum applied load in Newton, (L, b and d) are the span length, average width and average depth of the specimen in millimeters, respectively.

The results for the first three tests mentioned above are shown in Table 13. Each listed result is the average of three tests specimen on each age of testing for all mixes of HP-SCC. Results of flexural strength of HP-SCC are shown in Table 14 which was also the average of three tests specimen for each mix of HP-SCC.

Table 13. Compressive Strength, Tensile Strength and Modulus of Elasticity of HP-SCC

Mix Types	*Compressive Strength (f_c'), MPa*			*Splitting Tensile Strength (f_t), MPa*			*Modulus of Elasticity (E_c), MPa*		
	1 day	3 days	28 days	1 day	3 days	28 days	1 day	3 days	28 days
Mix 1 (Control) 10%SF	14.58	25.18	37.58	1.72	2.32	3.08	18285	19898	26366
Mix 2 10%SF-0.25%DSF	23.36	36.65	55.91	2.45	3.56	4.31	22587	26290	35129
Mix 3 10%SF-0.50%DSF	28.94	43.71	62.29	3.22	4.20	5.25	24373	30709	37356
Mix 4 10%SF-0.10%PPF	24.96	32.05	55.41	2.49	3.33	3.94	26697	29090	34550
Mix 5 10%SF-0.15%PPF	24.63	29.61	53.32	2.16	2.85	4.45	22567	26145	32240

Table 14. Flexural Strength (Modulus of Rupture) of HP-SCC.

Mix Types	*Modulus of Rupture (f_r), MPa*		
	1 day	3 days	28 days
Mix 1- (Control) 10%SF	2.62	3.21	4.98
Mix 2 - 10%SF-0.25%DSF	3.82	5.70	7.12
Mix 3 - 10%SF-0.50%DSF	5.87	6.84	8.98
Mix 4 - 10%SF-0.10%PPF	3.06	4.01	5.47
Mix 5 - 10%SF-0.15%PPF	2.68	3.27	5.99

Figure 4. Compressive strength test.

Figure 5. Splitting tensile strength test.

4. Results and Discussions

4.1. *Fresh Mix Properties of HP-SCC*

Figures 6 through 9 illustrate the workability measurements and fresh properties of the selected HP-SCC mixes which were evaluated according to the international standards. The workability tests were made on fresh HP-SCC immediately after mixing including slump flow, T500, L-box and J- ring tests in additional to the VSI as a visual inspection of the slump flow of HP-SCC.

The values of the slump flow tests of HP-SCC ranged between 640mm and 510mm and T500 test values were in the range of 5 to 8.5 sec as listed in Table 12. These values are accepted as they were within acceptable criteria of HP-SCC enhanced with fiber reinforcement. Therefore, all mixes are assumed to have a good consistency and workability from the filling ability concept. Regardless to fibers type, all the mixes indicated there where a decrease in the slump flow and an increase in the T500 with the increment of the fibers in the mixes.

The incorporation of DSF gives a slight decrease in the slump flow by 1.6 % and 4.9 % for the mixes 2 and 3 in comparison with non-fibrous reference mix 1. Moreover, the incorporation of PPF gives a larger decrease in the slump flow by 10.3 % and 25.5 %

for the mixes 4 and 5, respectively compared with reference mix 1 also and as shown in Fig. 6. Increasing the amount of superplasticizer in mixes 2 and 3 containing DSF were almost to maintain a close value of the slump flow for HP-SCC without fibers reference mix 1 while the incorporation of PPF in mixes 4 and 5 increased the cohesion of HP-SCC despite the increasing of HRWRA in these mixes.

Moreover, the values of T500 which represents the time required for the concrete to flow and reach a circle with a diameter of 500mm were increased due to addition of fiber reinforcement. The incorporation of DSF increased T500 by 10 % and 40 % for the mixes 2 and 3 in comparison with non-fibrous reference mix 1. Furthermore, the incorporation of PPF gives a decrease in the slump flow by 20 % and 70 % for the mixes 4 and 5, respectively as shown in Fig. 7.

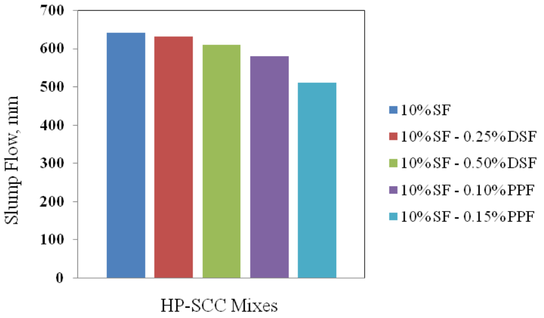

Figure 6. Slump flow value for HP-SCC mixes.

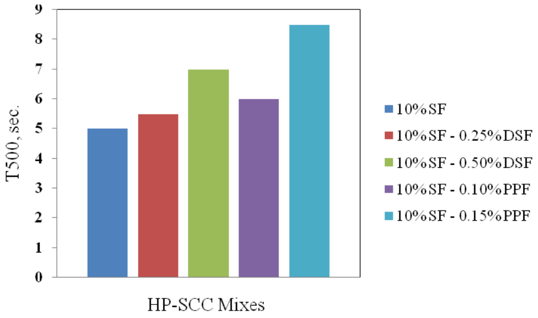

Figure 7. T-500 test for HP-SCC mixes.

Other fresh HP-SCC test was the L-Box test. The values of the ratio h_2/h_1 for HP-SCC mix lie in between 0.9 and 1.3 which shown previously in Table 12. These results were accepted per SSC criteria as it's typically greater than 0.9 excepting one value for mix no.5 which was 0.85 as it is slightly less than SCC criteria. The incorporation of DSF gives a decrease in the ratio h_2/h_1 by 13.1 % and 23.8 % for the mixes 2 and 3 compared with non-fibrous reference mix 1. In additional, the incorporation of PPF gives a decrease in the ratio h_2/h_1 by 30 % and 52.9 % for the mixes 4 and 5, respectively compared with reference mix 1 as shown in Fig.8. The reference HP-SCC mix 1 have the highest values of h_2/h_1 among all the mixes, while the mix no. 5 10%SF-0.15%PPF have the lowest h_2/h_1 values among all mixes which is explained due to its high consistency. Therefore, most of HP-SCC mixes are assumed to have a good passing ability from the passing ability point of view.

The passing ability values listed in Table 12 were determined via J-Ring flow test**.** The diameter of the slump flow was measured to provide the J-Ring flow values after the HP-SCC flows through the sixteenth rod of 16 mm diameter of the J-Ring and onto the slump flow board.

J-Ring values of HP-SCC mixes lie in-between 425 mm and 550 mm. The incorporation of DSF decreases flow diameter of the HP-SCC in the J-Ring test by 3.8 % and 14.6 % for the mixes 2 and 3 compared with reference mix 1. Furthermore, the incorporation of PPF decreases flow diameter of the HP-SCC in the J-Ring test by 19.6 % and 29.4 % for the mixes 4 and 5, respectively compared with non-fibrous reference mix 1 and as shown in Fig. 10. It's noted that a definite adverse of HP-SCC mixes 3, 4 and 5 on the flow of J-Ring test which is due to high mix cohesion and the obstacles of the J-Ring bars that it decrease flow diameter comparing with reference mix 1 and as shown in Fig.9**.**

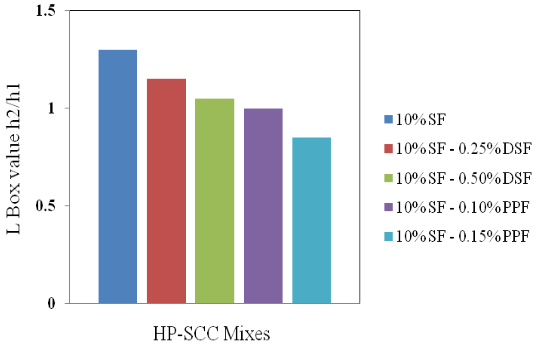

Figure 8. L-Box test for HP-SCC mixes

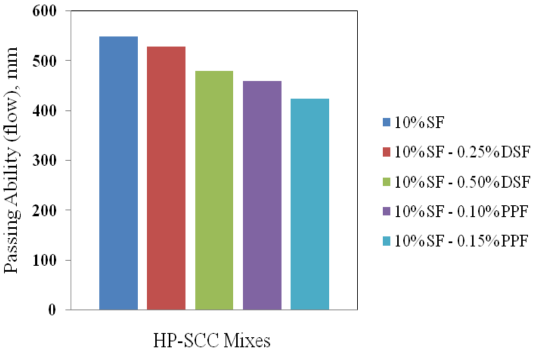

Figure 9. J-Ring test for HP-SCC mixes

4.2. Hardened Properties of HP- SCC

Figures 10 through 13 illustrate the influence of age and fibers content on the compressive strength, Splitting tensile strength, flexural strength and the modulus of elasticity of HP-SCC.

4.2.1. Compressive strength

Results listed in Table 13 shows that all concrete specimens exhibited a continuous increase in compressive strength with curing age. This is referred to the increase of the bond strength between the concrete ingredients and the continuous hydration process during curing process. The influence of age and fibers content on the compressive strength is shown in Fig. 10. There was a considerable improvement in compressive strength for all HP-SCC mixes including fibers relative to the control mix 1 without fibers. The percentage of increase in the compressive strength for mixes 2 and 3 containing DSF measure relative to reference mix 1 at 28 days curing age were 48.8 % and 65.7%, respectively; while the percentage increase in compressive strength for mixes 4 and 5 containing PPF in comparison with reference mix 1 at 28 days curing age were 47.4% and 41.9%, respectively. The increase in compressive strength for HP-SCC containing both types of fibers may be due to increasing of HRWRA dosage and the uniform dispersion of fibers throughout the flowable HP-SCC which leads to more consistent and internal integrity. This behavior is in good agreement with previous finding [28]**.**

Furthermore, it’s obvious that increasing volume fraction of PPF from 0.1% to 0.15% leads to decrease in the compressive strength. This may be referred to the low modulus of elasticity of the polypropylene fiber and the increasing of the HRWRA to retain and maintain the flowability and passing ability in the fresh state of HP-SCC. As a result, failure occurred with lower loading value for mix 5 when compared with mix 4 in all testing ages.

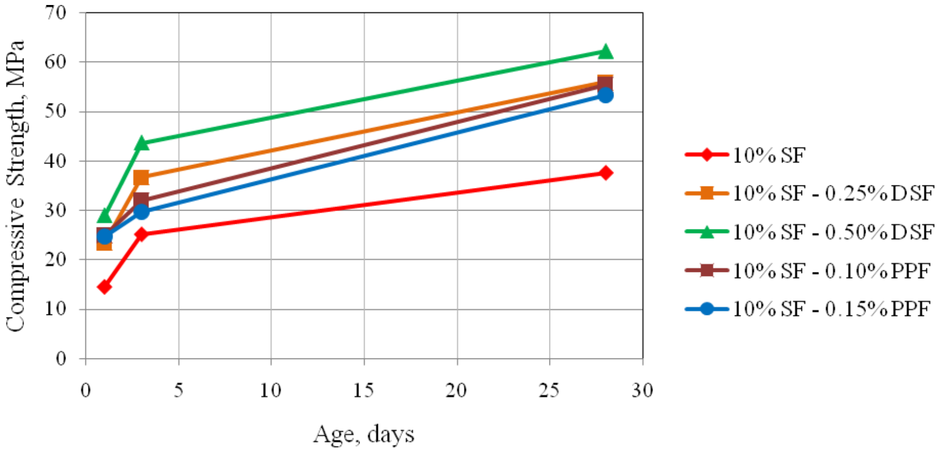

Figure 10. Compressive strength developments of HP-SCC

4.2.2. Splitting tensile strength

The developments of splitting tensile strength with age for all HP-SCC are shown in Fig. 11. An improvement was obtained in the splitting tensile strength for all fibrous HP-SCC mixes relative to reference non-fibrous mix 1. The percentage of increase in the splitting tensile strength for mixes 2 and 3 containing DSF compared with reference mix 1 at 28 days were 39.9 % and 70.5%, respectively; while the percentage of increase in the splitting tensile strength for mixes 4 and 5 containing PPF in comparison with reference mix 1 at 28 days were 27.9% and 44.5%, respectively. The improvements in splitting tensile strength of all HP-SCC containing both types of fibers may be explained due to the action of fibers as crack arrestors and the superplasticizer.

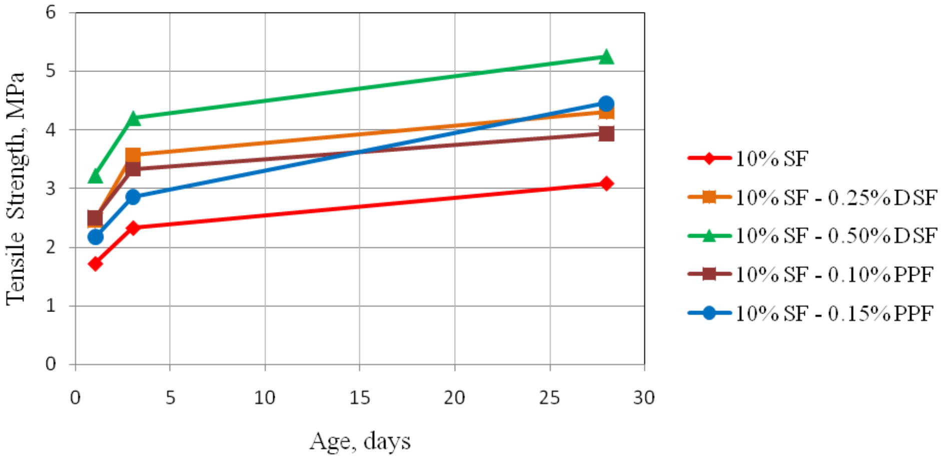

Figure 11. Splitting tensile strength developments of HP-SCC.

4.2.3. Modulus of elasticity

For all HP-SCC mixes, the influence of age and fibers content on the modulus of elasticity is shown in Fig. 12. There was a considerable improvement in the elastic modulus for all HP-SCC mixes including both types of fibers relative to the control mix 1 without fibers. The percentages of increase in the modulus of elasticity for mixes 2 and 3 containing DSF measured relative to mix 1 age 28 days were 33.2 % and 41.7%, respectively. Also, the percentage of increase in the modulus of elasticity for mixes 4 and 5 containing PPF in comparison with reference mix at 28 days curing age were 31% and 22.3%, respectively. The enhancement in the elastic modulus for HP-SCC containing both types of fibers may be mainly due to reinforcement fibers and additional chemical admixtures.

Furthermore, it's clear that increasing volume fraction of PPF from 0.1% to 0.15% leads to a decrease in the elastic modulus. This may be referred to the low modulus of elasticity of the polypropylene fiber and the increasing of the HRWRA to retain and maintain the flowability and passing ability in the fresh state of HP-SCC.

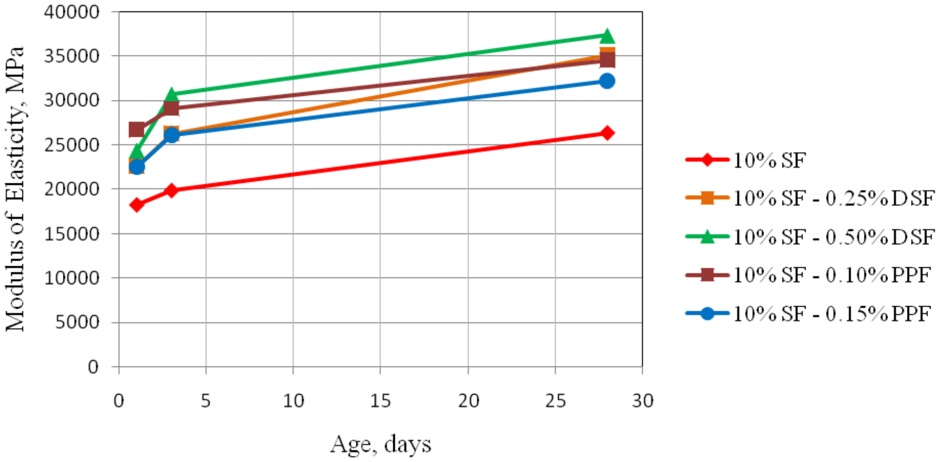

Figure 12. Modulus of elasticity developments of HP-SCC

4.2.4. Modulus of rupture (flexural strength)

The developments of flexural strength with age for all HP-SCC are shown in Fig. 13. An improvement was obtained in the modulus of rupture for all HP-SCC mixes including fibers relative to control mix 1 without fibers. The percentage of increase in the flexural strength for mixes 2 and 3 containing DSF compared with reference mix 1 at 28 days were 42.9 % and 80.3%, respectively. While the enhancement in the splitting tensile strength for mixes 4 and 5 containing PPF in comparison with non-fibrous reference mix 1 at 28 days were 9.9% and 20.3%, respectively. The improvements in splitting tensile strength of all HP-SCC containing both types of fibers may be explained due to the action of fibers as crack arrestors and additional quantity of superplasticizer to sustain the mechanical properties of self consolidated concrete.

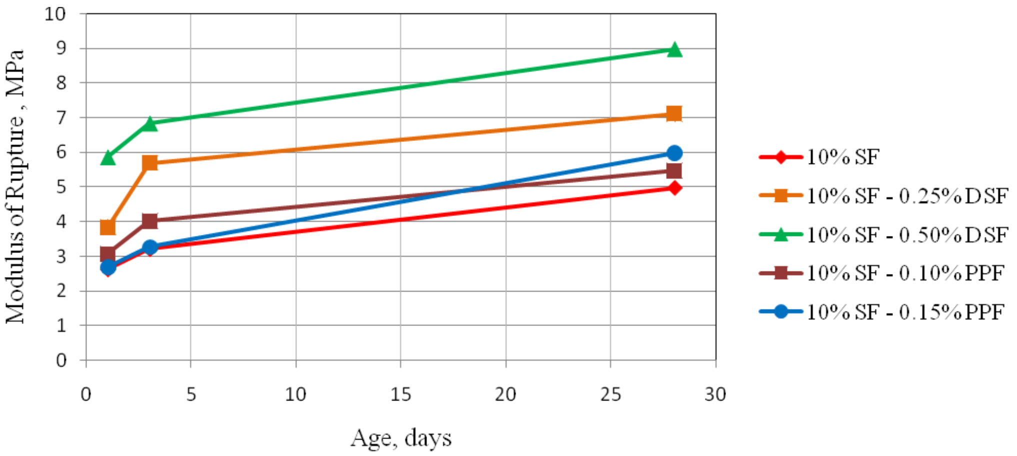

Figure 13. Modulus of rupture developments of HP-SCC

5. Conclusions

Based on the experimental work test results in this paper, the following conclusions can be drawn:

1. HP-SCC could be achieved using raw materials available locally.
2. Both types of fiber reinforcements have affected workability properties of SCC concrete. That's effect was overcome either by increasing superplasticizer or water content moderately.
3. There were considerable improvements in compressive strength for all HP-SCC mixes including fibers relative to reference non-fibrous mix 1 reaches 65.7% percent in mix 3 at age of 28 day and contains 0.5% volume fraction DSF.
4. A considerable improvement also in splitting tensile strength were obtained for all HP-SCC mixes including fibers relative to the control mix 1 without fibers reaches 70.5% percent in mix 3 at age of 28 day and contains 0.5% volume fraction DSF.
5. Enhancement also gained in the elastic modulus for all HP-SCC mixes including fibers relative to the control mix1 without fibers reaches 41.7% percent in mix 3.
6. Considerable improvements also gained in the flexural strength for all HP-SCC mixes including fibers relative to the control mix1 without fibers reaches 80.3% percent in mix 3.
7. For all mix proportions investigated, the recommended volume fraction of PPF up to 0.1% due to the adverse effects of increasing PPF on the compressive strength and modulus of elasticity of HP-SCC more than this percentage.

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