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High Performance of Silica Fume Mortars for Ferrocement Applications

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ABSTRACT

The current study deals with obtaining the high performance mortars to use in the applications of ferrocement. The main problem that has greatly affected the performance of mortar is the workability. A low water-cement ratio mostly resulted in increases in the compressive strength and led to the enhancement of durability characteristics, but decreases in the workability.

Workability becomes an important factors, as the mortar has to easily penetrate between the layers of the mesh wires. A reasonably workable with high strength cement mortar can be obtained by using a high cement content coupled with the use of silica fume and superplasticizers. In this investigation a series of compression tests were conducted on 50 mm cube and 150 ×300 mm, cylindrical specimens to obtain the compressive strength and the stress-strain behavior of mortar with silica fume and superplasticizers and flexural tests were conducted on 50 ×5 0 × 200 mm prism to obtain the modulus of rupture. The results of this study indicated that the variation in mortar strength depend on the water-to-binder ratio of the mix and percentages of cement replacing. The effects of these parameters on the stress-strain curves are presented. The best replacement percentage of silica is 3% was concluded in this study. From the experimental results a mathematical model has been developed to predict the 28-day compressive strength of silica fume mortar with different water-to-cementitious ratios and superplasticizers percentage

Keywords: Ferrocement; Mortar; Silica Fume; Strength**.**

أستخدام المونة عالية الأداء في تطبيقات الفيروسمنت

الخلاصة

في هذه الدراسة تم التركيز على انتاج مونة عالية الأداء لاستخدامها في تطبيقات الفيروسمنت المختلفة. غالبا ما تنتج الخلطة الكونكريتية ذات المحتوى المائي القليل مقاومة عالية ولكنها عادة ما تكون ذات قابلية تشغيل قليلة حيث ان لقابلية التشغيل أهمية كبيرة وخصوصا في استخدامات الفيروسمنت حيث نحتاج الى تغلغل المونة داخل فتحات المشبكات الحديدية الصغيرة جدا لذلك ان استخدام المونة الحاوية على نسبة معينة من السيليكا فيوم مع كمية مناسبة من الملدنات المتفوقة قد تنتج مونة عالية الاداء يمكن استخدامها بشكل واسع. في هذه الدراسة تم التعامل مع مجموعة من

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الخلطات الكونكريتية وبنسب مختلفة من السيليكا فيوم والملدنات المتفوقة لمعرفة مقاومة الانضغاط لمكعبات المونة ٥٠ × ٥٠ mm وصب مجموعة من الاسطوانات بابعاد ٣٠٠×١٥٠ mm لدراسة العلاقة بين الاجهاد والانفعال لمجموعة من الخلطات المختلفة وكذلك تم عمل مجموعة من المواشير بابعاد ٥٠×٥٠ ×٢٠٠ mm لدراسة مقاومة الانثناء. اوضحت النتائج بان التغير في المقاومة يعتمد على نسبة الماء الى (الاسمنت والسيليكا) وكذلك تعتمد على نسبة السيليكا المستخدمة. تم دراسة تاثير العاملين اعلاه كذلك من خلال رسم منحي الاجهاد والانفعال. استخدام نسبة ٣% من السيليكا فيوم بدلا من الاسمنت هي نسبة مثالية لانتاج مونة عالية الاداء ضمن النسب المستخدمة في هذه الدراسة . بالاعتماد على النتائج العملية تم اقتراح معادلة رياضية لحساب مقاومة الانضغاط لمونة الاسمنت الحاوية على السيليكا ولنسب مختلفة من(w/c) وللمضافات الملدنة .

INTRODUCTION

With the rapid progress in innovative construction techniques, application of ferrocement is becoming increasingly common for use in various structural engineering applications. This has led significant research activities for this material resulting in enhancement of chemical and physical properties and the overall behavior of this material.

Ferrocement is a composite material constructed by cement mortar reinforced with closely spaced layers of wire mesh [1-5]. The compressive strength is equal to that of the unreinforced mortar. It has been found that many ways to improve the mechanical properties of cementitious composites. In recent years, silica fume is one of the most recent pozzolanic materials currently used in concrete, the use of silica fume in concrete has been increasing rapidly; it has been used either as a partial replacement for cement or as an additive when special properties are desired. Addition of silica fume plays an important role in the improvement of the mechanical properties of concrete and/or mortar. The higher strength and low permeability are the two important results that obtained from added the silica fume to concrete, there are other properties that may enhance the behavior by addition of silica fume such as modulus of elasticity [6], drying shrinkage and resistance to reinforcing steel corrosion and sodium sulfate attack due to low permeability to water and chloride ions [7, 8, 9]. However, some unfavorable properties are associated with the addition of silica fume to concrete such as loss of slump and reduction in ductility.

There are many papers have been carried out within the last two decades on the use of Silica fume (SF) and superplasticizers (SP) in the concrete or mortar. Bhanja and Sengupta [10] performed an experimental study to determine the isolated effect of silica fume on the properties of concrete over a wide range of w/c ratios varying from 0.3 to 0.42 and silica fume replacement percentages ranging from 5 to 30. Toutanji and El-Korchi [11] presented an experimental study to evaluate the compressive strengths of silica fume cement paste and mortar at various water-cementitious ratios. The results showed that the increase in compressive strength of mortar containing silica fume, as a partial replacement for cement, greatly contributes to strengthening the bond between the cement paste and aggregate. Venkatesh and Natesan [12] Investigated on physico-mechanical properties of High performance concrete mixes, with different replacement levels of cement with silica fume. Duval1 and Kadri [13] considered a tests to investigated the workability and the compressive strength of silica fume concretes at low water-cementitious materials ratios with a naphthalene sulphonate superplasticizer. Huang and Feldman [14] have found that mortar without silica fume has a lower strength than cement paste with the same water-cement ratio, while mortar with 30% of the cement replaced by silica fume has a higher strength than cement silica fume paste with the same water-cementitious ratio. They concluded that the addition of silica fume to mortar results in an improved bond between the hydrated cement matrix and the sand in the mix. Rathish Kumar [15] conducted an experimental program to study the functional efficacy of an SF condensate used as a water reducing SP. The compressive strength and flow characteristics of the mortars were determined to decide their suitability for ferrocement works. Cheah Chee and Ramli [16] carried out an experimental study to evaluate the workability and compressive strength properties of structural grade mortar mixes with various cement: sand ratios ranging from 1:2.0-1:2.75 and varying water/binder ratio between 0.35 and 0.50. Throughout the laboratory investigation, the incorporation of super plasticizer in the mortar mix with cement: Sand ratio of 1:2.25 results in higher degree of enhancement in workability as compared to mortar mix with cement: Sand ratio of 1: 2.5 and resulted in reduction of compressive strength of hardened mortar mix.

In this study, we aim at defining the influence of the content of silica fume (SF) and superplasticizer (SP) on the workability, the compressive strength, modules of rupture and the stress-strain relationship. The laboratory investigation program of this study is designed to determine optimum proportion of mortar mix to achieve best strength performance with acceptable level of workability.

EXPERIMENTAL PROGRAM

Materials

The same materials (cement, sand, water, silica fume and superplasticizer) were used for all specimens throughout this investigation. The materials used in the program were tested to comply with the relevant ASTM standards.

Cement

The Ordinary Portland Cement was used throughout this investigation. The chemical compositions of cement used throughout this work are presented in Table 1. Results indicate that the cement conforms with the Iraqi standard No. 5/1984 [17].

Table (1) Chemical composition of cement.

No.	Chemical components	Tested cement %	Iraqi standard No. 5/1984 limits %
1	CaO	61.1	-
2	SiO_2	20.7	-
3	Al_2O_3	4.2	-
4	Fe_2O_3	4.5	-
5	MgO	5	≤ 5
6	SO_3	2	≤ 2.8
7	Lime Saturated Factor	1.01	0.66-1.02
8	Loss on ignition	3.9	≤ 4
9	Insoluble residues	1.3	≤ 1.5
10	C_3A	3.5	-

Fine Aggregate (Sand)

Natural sand brought from Al-Zubair region was used as a fine aggregate in this research. The sieve analysis test was conducted according to ASTM C33 [18]. Table 2 shows the grading of sand used in this work.

Water

Ordinary tap water was used for casting and curing the specimens.

Table (2) Sieve analysis of sand.

Sieve Size mm	Percent Passing			
	Sand used	Limits of Iraqi Specification No. 45/1984	ASTMC33-86	Cumulative retained %
4.75	95	90-100	90-100	5
2.36	86	75-100	80-100	14
1.18	74	55-90	50-85	26
0.60	57	35-59	25-60	43
0.30	19	8-30	10-30	81
0.15	2	0-10	2-10	98

Cement Mortar

The sand-cement mortar was mixed in the ratio of one part by weight of cement to two parts of sand. The water-cement ratios used are 0.325, 0.375, 0.425 and 0.475.

Silica Fume and Superplasticizer

The silica fume was in powder form containing 91.4% silicon dioxide (SiO2) and having a specific surface area of about 18,000 m^2/kg was used. The chemical properties of silica fume are given in Table (3). A high range water reducing admixture (superplasticizer) was used in preparing all the specimens in this investigation. Chemically it is Naphthalene formaldehyde sulphonate. It was used in its liquid state as a percentage of cement content (by weight).

Table (3) Chemical properties of silica fume.

SiO2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Loss of ignition
91.4	1.25	1.74	1.28	1.5	0.29	3.8

Experimental Procedure

The general objective of the previous researches was working with a number of mix design variables that affect the strength and find out an optimum combination by trial and error so that maximum strength is obtained. As a result, the individual contribution of the different parameters on the strength of mortar has not been properly assessed. The present experimental research program was carefully designed to determine the effect of silica fume incorporation with superplasticizer on mortar properties. Cement was replaced by silica fume at different constant water–binder ratios, superplasticizer was incorporated in all mixes; the content was adjusted for each mix to ensure that the slump within S3 class (slump between 100-150 mm and maximum allowable deviation on range limit is -20, +30 mm), keeping other mix design variables, like quality of ingredients, mix proportions, including the fine aggregate–binder ratios, mixing procedures, curing conditions and testing procedures, constant. The experimental program included four sets of mortar mixes, at w/binder ratios of 0.325, 0.375, 0.425 and 0.475, prepared by partial replacement of cement by equal weight of silica fume. Each set had mixes at five different percentages of cement replacement. The dosages of silica fume were 0% (control mix), 1.5%, 3%, 4.5% and 6% of the total cementitious materials. For the compressive strength determination, 50 mm cube specimens were used, while 150×300 mm cylinders were used to plot the stress strain curves, figure 1 shows the test setup of the cylinders. For flexural tensile strength, 50×50×200 mm beams were used. A point loading setup, was used for the flexural test. All the specimens were moist cured under water at room temperature until testing at 28 days. Each strength value was the average of the strength of three specimens. Specimens were tested according to ASTM standards. Tables 4 shows the details of mixes properties used in this study.

Table (4) Details of mortar mixes containing silica fume and superplasticizer.

Mix number	SF%	SP%	Cement Kg/m^3	Water Kg/m^3	w/(c+SF) ratio	Sand Kg/m^3
1	0	0.0	712	231	0.325	1424
2	1.5	3.1	701	231		1424
3	3	5.2	691	231		1424
4	4.5	7.4	680	231		1424
5	6	10.3	669	231		1424
6	0	0.0	712	267	0.375	1424
7	1.5	2.1	701	267		1424
8	3	3.7	691	267		1424
9	4.5	4.8	680	267		1424
10	6	7.0	669	267		1424
11	0	0.0	712	303	0.425	1424
12	1.5	1.4	701	303		1424
13	3	2.8	691	303		1424
14	4.5	4.1	680	303		1424
15	6	6.0	669	303		1424
16	0	0.0	712	338	0.475	1424
17	1.5	0.7	701	338		1424
18	3	2.4	691	338		1424
19	4.5	3.4	680	338		1424
20	6	5.0	669	338		1424

Figure (1) Cylinder Compressive strength and Compressometer with dial gauge.

RESULTS AND DISCUSSION

For all the mortar mixes, compressive, flexural strengths and stress-strain relationship were determined at the end of 28 days.

Effect of SF and SP Content on Workability and Compressive Strength

Figure (2) and Table (5) show the variation of compressive strength with silica fume replacement percentage and SP content. The content of SP was used for each mix to ensure that the slump stay within S3 class (slump between 100-150mm). From Table 4 it can be seen that with increasing the percentage of silica fume in the mix the SP should be increased to enhance the workability this indicate that the silica fume leads to decrease the workability of mortar. This may be due to the silica fume is finer than the cement, therefore the specific surface increase as the silica fume increases, in this case, more water and/or SP is needed to complete the process of hydration and for increasing the workability of mortar with silica fume.

The compressive strength values at different w/(c+SF) ratios were plotted at each silica fume replacement percentage; this is clear from Figure (2). The results indicate that the strength of mortar with silica fume increases up to 3% replacement percentage of silica fume with superplasticizer dosage with regardless the w/c ratio; beyond this percentage the strength was started to decrease. In other words, 3% is the best percentage used in this study. The maximum value of compressive strength was obtained as 63.8 MPa at 3% replacement level at a water/ cement ratio of 0.325, and the minimum value is 39.5 MPa was obtained at 6% silica fume with a water/cement ratio of 0.425. Three mechanisms have been listed for the strength enhancement by SF [19-22]: the first one attributed the improve in strength to pore size refinement and matrix densification, the second one going to reduction in the content of $Ca(OH)_2$ (CH) when using SF may be enhancement strength and the last one attributed the strength enhancement to cement -aggregate interfacial zone refinement. While Larbi and Bijen [23] explained that in the presence of SF, the pozzolanic reaction reduces the CH content in cement, which leads to increase the compressive strength. Silica fume changes the orientation of CH crystals in the zone, resulting in less micro cracking at the transition zone. The optimum benefit of the addition of silica fume is attained when it is used in combination with superplasticizer. This combination increases the cohesiveness of the fresh composites and reduces the water content. These factors facilitate the formation of a more densely compacted matrix at the interfacial zone which significantly improves the transition zone and, thus, the compressive strength of the system [6]. On the other hand, the observed decrease in the strength of mortar due to the addition of silica fume can be explained by the fact that larger increase in silica fume contents in mortar lead to a surplus of the small-sized fraction, which begins to move apart Portland cement grains, causing unpacking of the system and thus leading to a considerable decrease in the strength of the mortar [24].

A statistical regression analysis was performed for the results of compressive strength using the multiple regression method with Mattlab program [25] and the unknown parameters were determined. The validity of the model predicted was investigated by the ratio of the predicted to experimental values of 28-day compressive strength of mortar as shown in Table 5. The parameters that used to propose the model are silica fume replacement percentages, w/c ratios and superplasticizers percentages. The proposed model is:

$$f_{cup} = 61.43(SF) - 2.18(SP) + 2.04(^{W}/_{C}) - 34.59$$

where: f_{cup}: predicted compressive strength of mortar; SF: silica fume percentage; SP: superplasticizers percentage; w/c: water to cement ratio.

Effect of SF and SP Content on Flexural Strength

The variations of flexural strength with silica fume replacement percentage and SP content are summarized in Table (5) and Figure (3). It is observed that in general silica fume incorporation increases the of flexural strength of mortar. It important to mention that, since the dosage of SP is varied with the silica fume replacement percentage, then the variations in the compressive and flexural strength would occur not only due to variations in the silica fume contents but also may be due to change in the dosage of SP. Figure (3) exhibits that very high percentages of silica fume do not guaranty increase the flexural strength, and the significantly increases in flexural strength is found within 3% of silica fume for all the w/(c+SF) ratios, 0 – 3% replacements considerably improve the flexural strength with respect to control specimens. The initial filling of the voids by silica fume significantly improves the strength, but at higher levels, the improvements decrease. On computing the percentage gains in flexural strength of silica fume mortar with respect to control at 0.325, 0.375, 0.425 and 0.475 water/(c+SF) ratios, the values of the average gains at 1.5%, 3%, 4.5% and 6% replacement levels are obtained as 11%, 42%, 21% and 5%, respectively.

The flexural strengths almost follow the same trend as the 28 days compressive strength does. The results of the present investigation indicate that the optimum silica fume replacement percentage for 28 days flexural tensile strength is 3% and the increasing dependent on water cementitious material ratio of the mix.

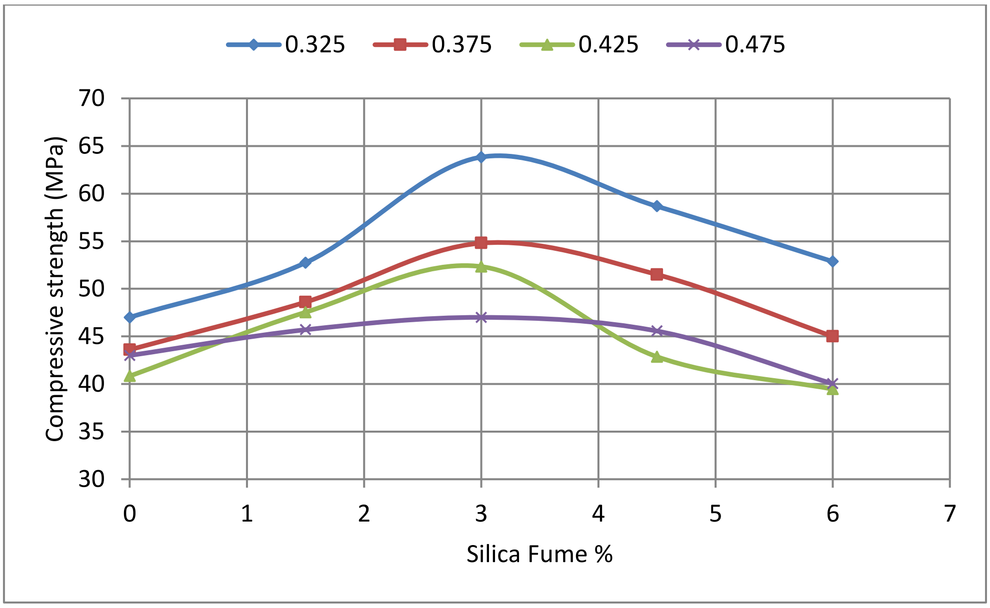

Figure (2) Variation of 28-day compressive strength with percentage replacement of silica fume.

Table (5) Strength and slump of mortar mixes.

Bach No.	Slump (mm)	Experimental compressive strength value f_{cu} (MPa)	f_{cup}/f_{cu}	Flexural strength f_r (MPa)
1	0	47	0.94	6.4
2	150	52.7	0.99	6.9
3	110	63.8	1.17	10.8
4	120	58.7	1.06	8.4
5	100	52.9	0.91	8.3
6	120	43.6	0.90	5.6
7	120	48.6	0.98	5.8
8	150	54.8	1.11	7.0
9	150	51.5	1.06	6.3
10	120	45	0.91	5.5
11	110	40.8	0.87	5.9
12	100	47.5	1.03	7.1
13	100	52.3	1.13	9.2
14	100	42.9	0.95	8.1
15	120	39.5	0.86	6.0
16	120	43	0.96	6.0
17	100	45.7	1.06	6.7
18	140	47	1.08	7.0
19	120	45.6	1.08	6.2
20	120	40.0	0.95	5.5

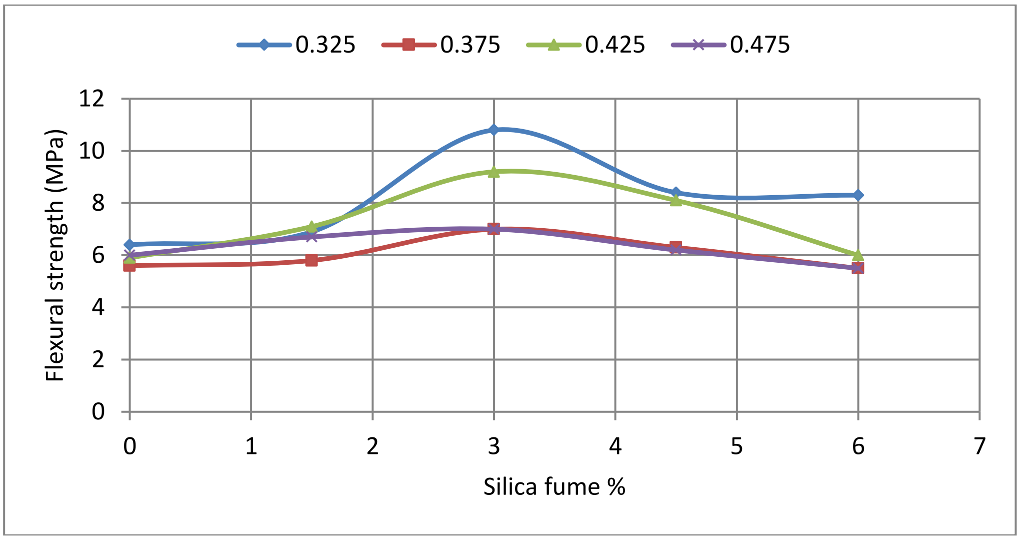

Figure (3) Variation of 28-day flexural strength with percentage replacement of silica fume.

Stress -Strain Relationship

The variation in mortar strength obtained by varying a combinations of factors such as the water to binder ratio, percentages of cement replacing by silica fume. From Table (4 and 5) it can be noted that use of the same water to binder ratio for a particular series yields mortars with different strengths depending on mix contents.

Figures (4) through 7 show the comparison of the stress-strain curves of mortars with constant water to binder ratio. It may be observed that there is a considerable difference in the shape of the four curves of samples tested. Also it can be seen that using the silica fume with superplizteser increase the compressive strength but slightly decreases in ductility. It can be seen that the optimum silica fume replacement percentage is not a unique one but depend on SP content and w/c ratio.

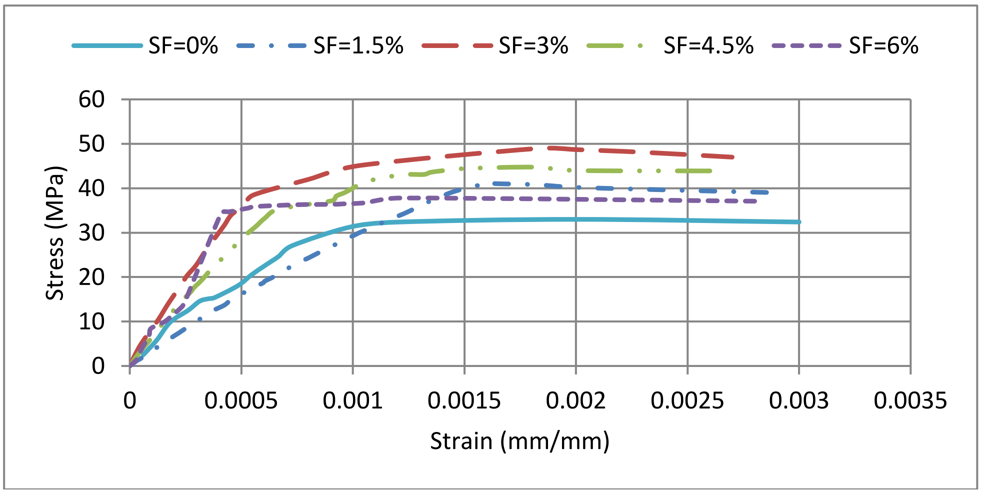

Figure (4) Stress-strain curves of specimens with w/(c+SF) equal to 0.325.

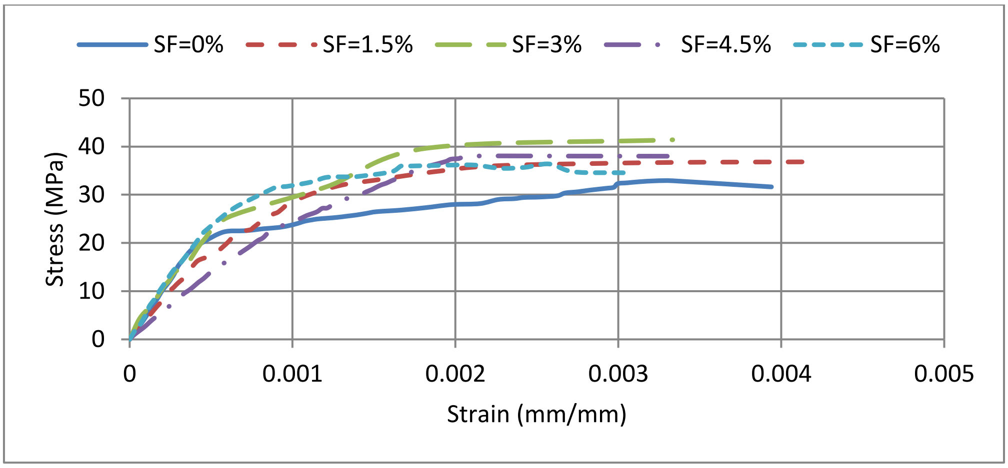

Figure (5) Stress-strain curves of specimens with w/(c+SF) equal to 0.375.

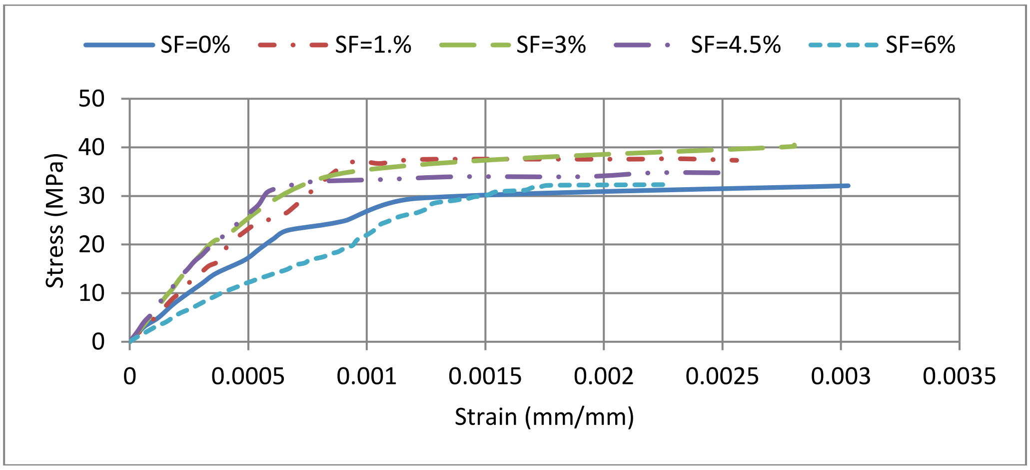

Figure (6) Stress-strain curves of specimens with w/(c+SF) equal to 0.425.

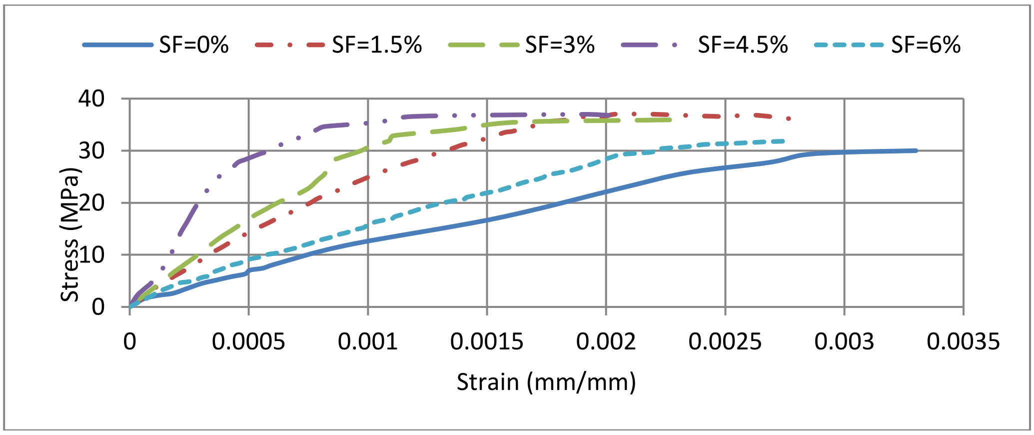

Figure (7) Stress-strain curves of specimens with w/(c+SF) equal to 0.475.

CONCLUSIONS

This paper presents an experimental investigation to determine the effect of silica fume and superplasticizer combinations on the compressive strength, flexural strength and stress-strain relationship of mortar at water to binder ratios ranging from 0.325 to 0.475 and cement replacements of 0% to 6%. From the results of this study, it can be concluded that silica fume and superplasticizer combinations can improve the strength of mortars. Considerably, a higher value of 28 days compressive strength is 63.8 MPa was achieved at 3% admixing level by weight of cement. The increase in strength can be attributed to the improved the hydrated cement matrix and the sand bond resulting from the formation of a less porous transition zone in the silica fume mortar. Optimum percentage of silica fume to achieve maximum compressive strength varies with the water content. 3% of silica fume with w/c is 0.325 it is the best percentage obtained in this study.

The silica fume and superplasticizer combinations can be used to get a high strength mortar reached to 63.8 MPa at the end of 28 day compressive strength, with reasonable workability to use in many applications of ferrocement. These mortar also exhibited a 28 day high flexural strength. From stress-strain curves for different water to binder ratio, it can be concluded that using the silica fume with superplasticizer increase the compressive strength but slightly decreases in ductility.

A statistical model has been developed, which can serve as a useful tool for predicting the compressive strengths of silica fume mortars for w/c ratios ranging from 0.325 to 0.475.

REFERENCES

[1]. Naaman, A. E. Ferrocement and Laminated Cementitious Composites. Ann Arbort, Michigan, USA: Techno Press 3000; 2000. p. 372.

[2]. Shah P. New Reinforcing Materials in Concrete. Journal of ACI, 1974; 71(5): 257-262.

[3]. Paul B K, Pama R P. Ferrocement. International Ferrocement Information Center, IFIC Pub., 1978.

[4]. Lee, S. L. Raisinghani, M, Pama R P. Mechanical Properties of Ferrocement. FAO Seminar on the Design and Construction of Ferrocement Vessels, 1972.

[5]. ACI Committee 549. State-of-the Art Report on Ferrocement. ACI, 549-R97, in Manual of Concrete Practice, ACI, Detroit, 1997.

[6]. Galeota, D. Giammatte M. Stress-Strain Relationship of Normal and Lightweight Concrete with Silica Fume Under Uniaxial Compression. Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, SP-114, ACI, Detroit, 991, 1989.

[7].Carette,G. and Malhotra V. Mechanical Properties, Durability, and Drying Shrinkage of Portland Cement Concrete Incorporating Silica Fume. Cement, Concrete, and Aggregates, 1983; 5(3).

[8]. Berke N. Resistance of Microsilica Concrete to Steel Corrosion, Erosion, and Chemical Attack. Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, SP-114, ACI, Detroit, 861, 1989.

[9].Cohen M.D, Bentur A. Durability of Portland Cement-Silica Fume Pastes in Magnesium Sulfate Attack and Sodium Sulfate Solurion. ACI Journal of Materials, 1988; 85(148).

[10]. Bhanja S, Sengupta B. Investigations on the Compressive Strength of Silica Fume Concrete Using Statistical Methods. Cement and Concrete Research, 2002; 32: 1391–1394.

[11]. Toutanji H. A. The Influence of Silica Fume on the Compressive Strength of Cement Paste and Mortar. Cement and Concrete Research, 1995; 25(7): 1591–1602.

[12].Venkatesh B, Nateshan SC. Some investigations on silica fume concrete, The Indian concrete Journal, 2004:57-60.

[13]. Duval1 R, Kadri H. Influence of Silica Fume on the Workability and the Compressive Strength of High Performance Concretes. Cement and Concrete Research, 1998; 28(4): 533-547.

[14]. Huang Cheng-Yi, Feldman R. Influence of Silica Fume on the Microstructural Development in Cement Mortars. Cement and Concrete Research, 1985; 5(285).

[15]. Kumar P. R. High Performance Superplasticized Silica Fume Mortars for Ferrocement works. Architecture and Civil Engineering, 2010; 8(2): 129 – 134

[16]. Cheah Chee Ban, Mahyuddin R. Optimization of Mix Proportion of High Performance Mortar for Structural Applications. Engineering and Applied Sciences, 2010; 3 (4): 643-649.

[17]. (I.O.S. 5 / 1984) المواصفة العراقية رقم (٥) لسنة ١٩٨٤ للإسمنت البورتلاندي

[18]. American Society of Testing and Materials (ASTM) (2002). ASTM C-33, West Conshohocken, PA.

[19]. Cohen M.D. A Look at Silica Fume and its Actions in Portland Cement Concrete. Indian Concrete. 1990:429– 438.

[20]. Mak L., Torii K. Strength Development of High Strength Concretes with and without Silica Fume Under the Influence of High Hydration Temperatures. Cement and Concrete Research, 1995; 25 (8): 1791–1802.

[21]. Zhang M.H. Gjorv O.E. Effect of Silica fumes on Cement Hydration in Low Porosity Cement Pastes. Cement and Concrete Research. 1991; 21 (5): 800–808.

[22]. Prashant Y, Nagarnaik P, Pande A. Performance of steel fiber on standard strength concrete in compression. International J. of civil and structural Eng. 2011; 2(2): 483-492

[23]. Larbi J.A, Bijen J.M. Orientation of Calcium Hydroxide at the Portland Cement Paste-Aggregate Interface in Mortars in the Presence of Silica Fume A Contribution, Cement and Concrete Research, 1990; 20: 461–470.

[24]. Sobolev K.G, Soboleva SV. High Strength Concrete Mix Design and Properties Optimization. In: Proceedings of the Fourth International Conference on Concrete Technology in Developing Countries, Gazimagusa, Turkey, 1996.

[25]. Toolbox User's Guide for Use with MATLAB, 2010.