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Strength Development Models of Concrete with Silica Fume As Fine Aggregate Replacement Material

Dr. Ahmed M. Ashteyat[1]

[1] Applied Science University, Amman, Jordan.

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Abstract

An extensive experimentation was performed to study the strength development of concrete in which fine aggregate was partially replaced with silica fume. Mathematical models were developed using statistical techniques to predict the compressive strength of such concrete. Water-to-cement ratio was varied from 0.50 to 0.60 and fine aggregate replacement level ranged from 0 to 15

Index terms— Concrete, fine aggregate replacement, predication models, compressive strength, silica fume.

1 Introduction

ilica Fume (SF) is generally used as a replacement of cement, as an admixture in concrete, and in manufacturing of cement. Economic and environmental considerations played a great role in advancing its usage. SF, composed of submicron particles of silicon dioxide, is produced by electric arc furnaces as a by-product waste of the production of metallic silicon or ferrosilicon alloys. SF incorporation could enhance the concrete basic properties in both the fresh and hardened states. It improves compressive strength, durability, depletion of cement alkalis, resistance to chloride and sulphate penetration, and continued micro structural development through a long-term hydration and pozzolanic reaction (Lam et al., 1998;Zain et al., 1999;Nassif et al., 2003;Demirboga and Gul, 2006;Gonen and Yazicioglu, 2007;Sata et al., 2007;Yazici, 2008).

The literature is rich with standard codes of practice, guidelines, and predication models to estimate the compressive strength of SF concrete. The majority used SF as a mineral admixture or as a cement replacement material (Slanicka, 1991 **??** with grading shown in Figure 1. Absorption and specific gravity tests were performed for fine and coarse aggregate according to ASTM C127 and ASTM C128 specifications, respectively. Tap water (W) needed for the mix design was adjusted based on the absorption of aggregate. 4. Three series of tests designated as series I (mix A, B, C, and D), series II (mix E, F, G, and H), and series III (mix I, J, K, and L) were prepared with three water-tocement (W/C) ratios of 0.50, 0.55, and 0.60, respectively. In each series, the replacement level (R) of fine aggregate with silica fume, was 0, 5, 10, and 15% by weight. The cement content (C) varied from 384 to 400 kg/m 3 . The cementitious materials content (CM = C + SF) varied between 385 and 450 kg/m 3 resulting in four water-to-cementitious materials (W/CM) ratios of 0.50, 0.48, 0.46, and 0.44 for test series I, of 0.55, 0.53, 0.51, and 0.49 for test series II, and of 0.60, 0.58, 0.55, and 0.53 for test series III.

2 c) Preparation and casting of test specimens

All experiments were conducted in a laboratory under a controlled environment and were properly monitored. Specimens used were standard cylinders of 150 x 300 mm. Concrete mixes were made in a powerdriven 90-liter revolving type drum mixer conforming to ASTM C192. The dry constituents were mixed in the rotating mixer with a speed of 40 rpm. The standardized mixing procedure was as follows: cement, fine aggregate and SF were mixed first; then water and coarse aggregate were added. The overall mixing time was about 4 minutes. The time, sequence, and method of adding the aggregate and SF for each batch remained unchanged and simulated good field practice. W/C = water-to-cement ratio, R = silica fume replacement level of fine aggregate, P = silica fume-to-cementitious materials ratio (SF/CM), W/CM = water-to-cementitious materials ratio, SF = silica fume, C

= cement, CM = cementitious materials (SF+C), W = water, FA = fine aggregate, CA = coarse aggregate. and = compressive strengths of concrete at 7, 28, and 56 day, respectively. d) Testing of the specimens Compressive strength tests were performed at age of 7, 28, and 56 days. The specimens were tested in a dry state following the moist curing. Prior to compression testing, the top and bottom ends of the each specimen were capped with sulfur mortar conforming to the requirements of ASTM C617. A compression machine, conforming to ASTM C39, was used for all compression strength testing at a load rate of 0.15 MPa/s. The compressive strength of specimens was recorded as load was gradually applied until failure. The average of 3 specimens was used to report the compressive strength of each mix. High quality control requirements in terms of mixing, curing, and testing of specimens were strictly followed during the experimental phase. Tests not adhering to such requirements were rejected and repeated. compressive strength was obtained as 39.62 MPa at 5% replacement level with a W/C ratio of 0.50 and W/CM ratio of 0.48 (mix B), while the minimum value was 27.13 MPa obtained at the control specimens at a W/C ratio of 0.60 and W/CM ratio of 0.60 (mix I). When the W/CM ratio decreased, the compressive strength of concrete increased for all ages and replacement levels compared to the corresponding control mix. The results indicated that the strength benefits were increased as the age increased.

3 III.

4 Results and Discussion

Molds were covered to prevent loss of water from evaporation. Specimens were kept for 24 hours in molds at a temperature of 23° C in the casting room; and then cured in a water tank for the specified time at a temperature of 23° ± 1° C.

Compressive strength for all concrete mixes was determined at 7, 28, and 56 days of curing as shown in Table 4. Figures 2, 3, and 4 show the variation of compressive strength with SF replacement levels for test series I (W/C = 0.50), II (W/C = 0.55), and III (W/C = 0.60), respectively. Test results show that the compressive strength of concrete mixes with 5, 10, and 15% replacement levels (mix B, C, and D), (mix F, G, and H), (mix J, K, and L), were higher than their corresponding control concretes, (mix A, E, and I), respectively.

squares that leads to the best fitting line of a postulated form to a set of data was used to form regression models between the dependent variable and independent variables. SPSS software was utilized to develop the strength prediction models based on the available data. Stepwise calibration procedure was then used to form the multiple linear regression models and to determine the critical and non critical influencing variables. F-test and t-test were used to verify the choice of models and critical variables with a significant level of 5%.

Statistical analysis of the results of the three series of tests produced the following 3 models with their corresponding coefficient of determination (R 2). The compressive strength of SF concrete + + ? ? = sf f (2) (R 2 = 0.959) (2)+ + + ? ? = sf f (4) (R 2 =0.914)

In developing the above models the W/C ratio was used instead of W/CM ratio since most of control mixes (without silica fume) are defined with W/C ratio during the initial design stage. The effect of the addition of the silica fume to the mix is accounted for by the term silica fume-to-cementitious materials ratio P = SF/CM = SF/(C+SF). As shown in Table 4, when the cementitious materials content CM increases, the P term increases from 0 to 0.113 for each test series accounting for the silica fume contribution to strength enhancement. To have a more precise investigation of model 4, a comparison between the actual and predicated compressive strength values was plotted. As seen in Figure 5, there existed an excellent agreement between the actual and predicted compressive strength values. This demonstrated that model 4 could be used reliably to predicate the compressive strength of concrete made A comparison in terms of the statistical parameters (Min, Max, Median, Mean, Range, Standard Deviation, and Coefficient of Variation) of the actual and predicated compressive strength results is believed to be useful. As seen in Table 5, the statistical parameters of model 4 are relatively close to the distribution parameters of actual strength values within a 5% deviation. Thus, model 4 produces reliable and accurate predication values and could be used conveniently to estimate the compressive strength of concrete with silica fume used as fine aggregate replacement material.

5 c) Applications

The strength of conventional concrete can generally be estimated with good accuracy based on strength charts or by experience if mix proportions, age, and curing conditions are known. However, when SF is used as fine aggregate replacement material the exact The proposed four models are capable to provide a quick solution for strength estimation of mixes where fine aggregate is partially replaced with SF. With these models, strength of silica fume concrete at a particular age can be estimated over a range of replacement levels and W/C ratios. The suggested models would be of value in the design process of such concrete mixes where specific target strength needs to be achieved at a certain age or can be used to modify any basic concrete mix so that the concretes with and without silica fume have similar strengths.

IV.

6 Conclusions

Extensive experimentation was performed to study the strength development of concrete made with silica fume as fine aggregate replacement material over a range of W/C ratios varying from 0.50 to 0.60, silica fume replacement levels ranging from 0 to 15%, and testing age of 7, 28, and 56 days.

Compressive strength of concrete, made with silica fume as fine aggregate replacement material, was higher than the control concrete at all ages. Compressive strength continued to increase with age for all silica fume replacement levels. The compressive strength increased as fine aggregate replacement level increased. This increase was maximum at a replacement level of about 10%.

On the basis of regression analysis of the experimental results, statistical models were developed to estimate the 7, 28, and 56 day compressive strength of concrete. The proposed models could serve as a useful tool for optimizing and predicting the strength of silica fume concrete over a range of replacement levels and W/C ratios. The suggested prediction models could be used to modify any basic concrete mix so that the concretes with and without silica fume would have similar strengths.

Silica fume can be used as a partial fine aggregate replacement material in concrete and such concrete can be used conveniently in structural applications with economical and environmental benefits. Short term economical advantages lie in the fact that utilization of waste product and saving of fine aggregate resources would reduce the cost of concrete production. Long term environmental advantages would be a reduction of environmental problems and hazards related to improper disposal of silica fume.

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Figure 1: Figure 1 :

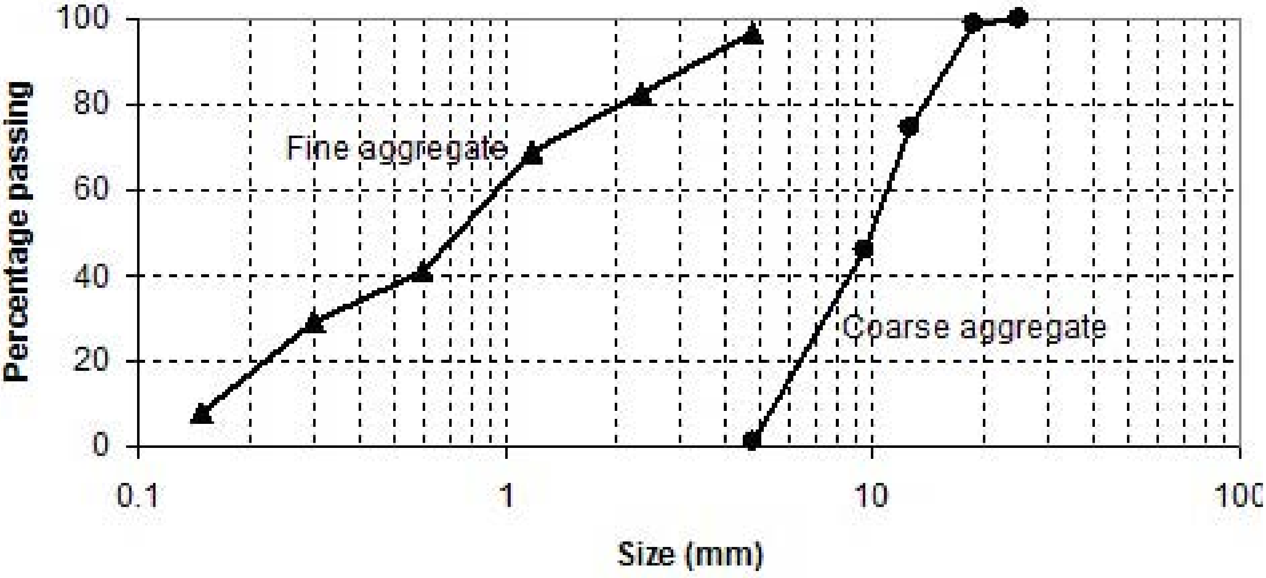

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Figure 2: Figure 2 :

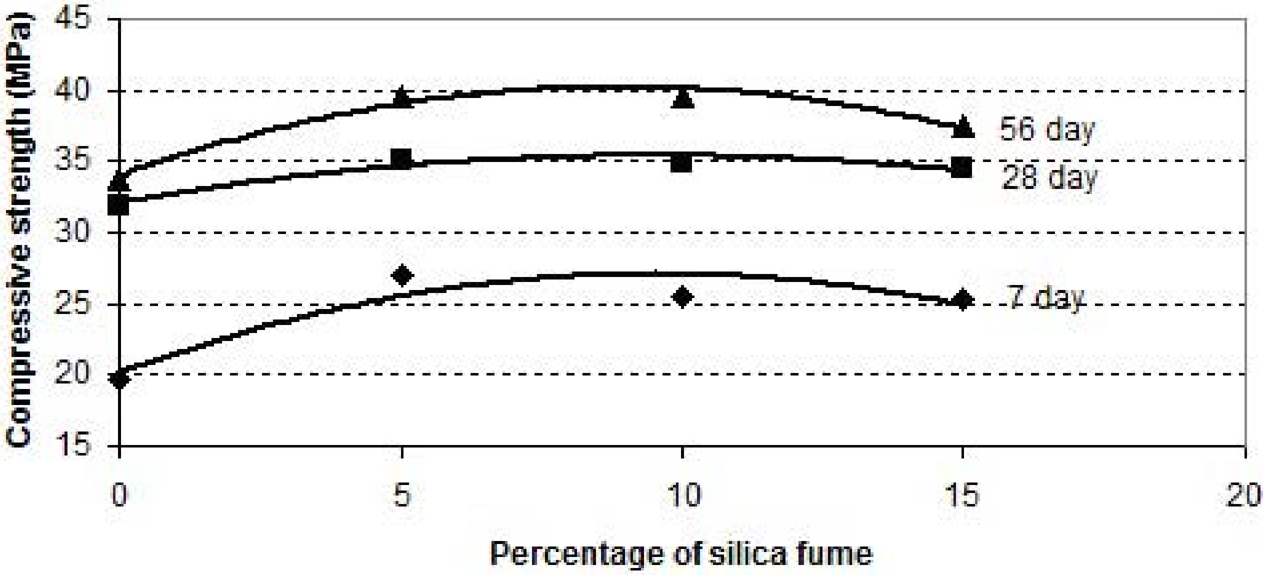

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Figure 3: Figure 3 :Figure 4 :

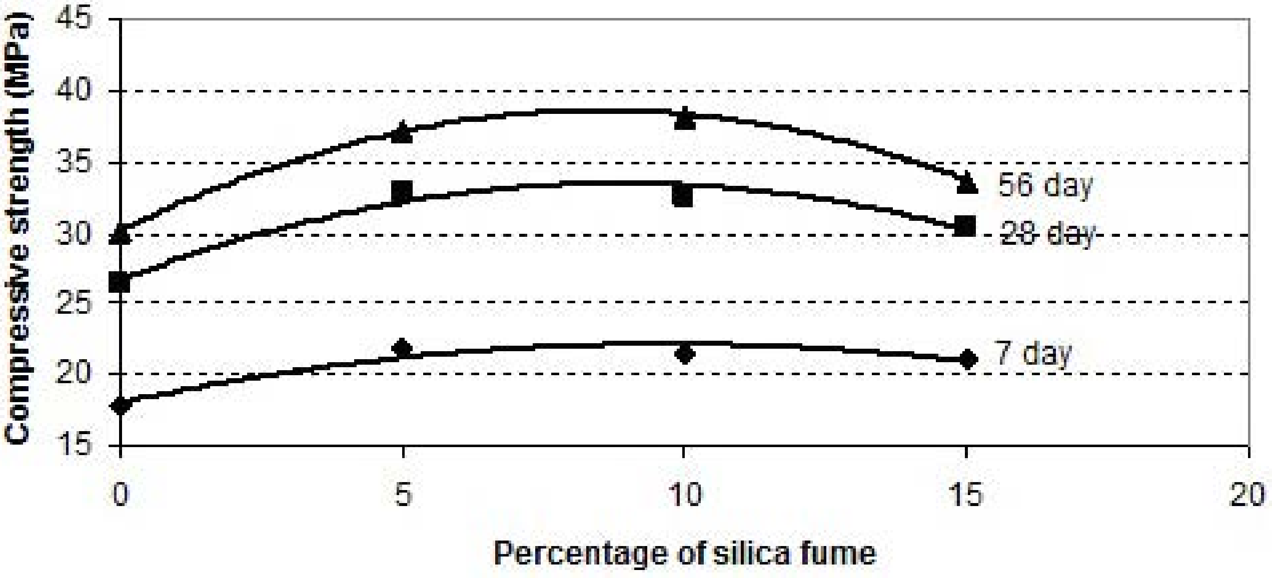

Figure 4:

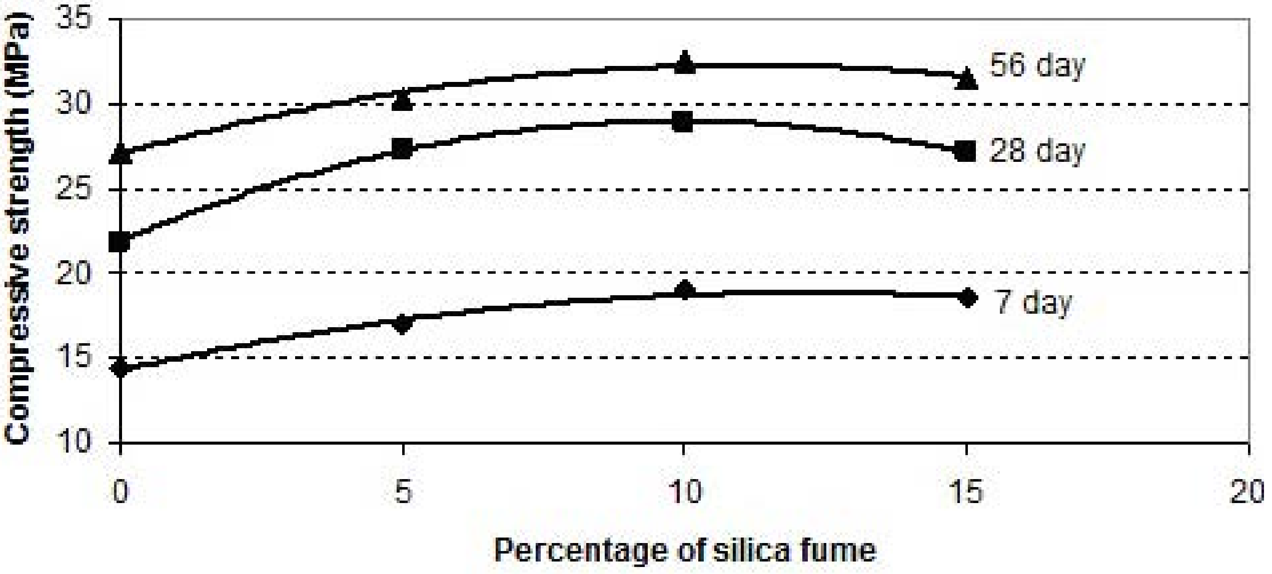

Figure 5:

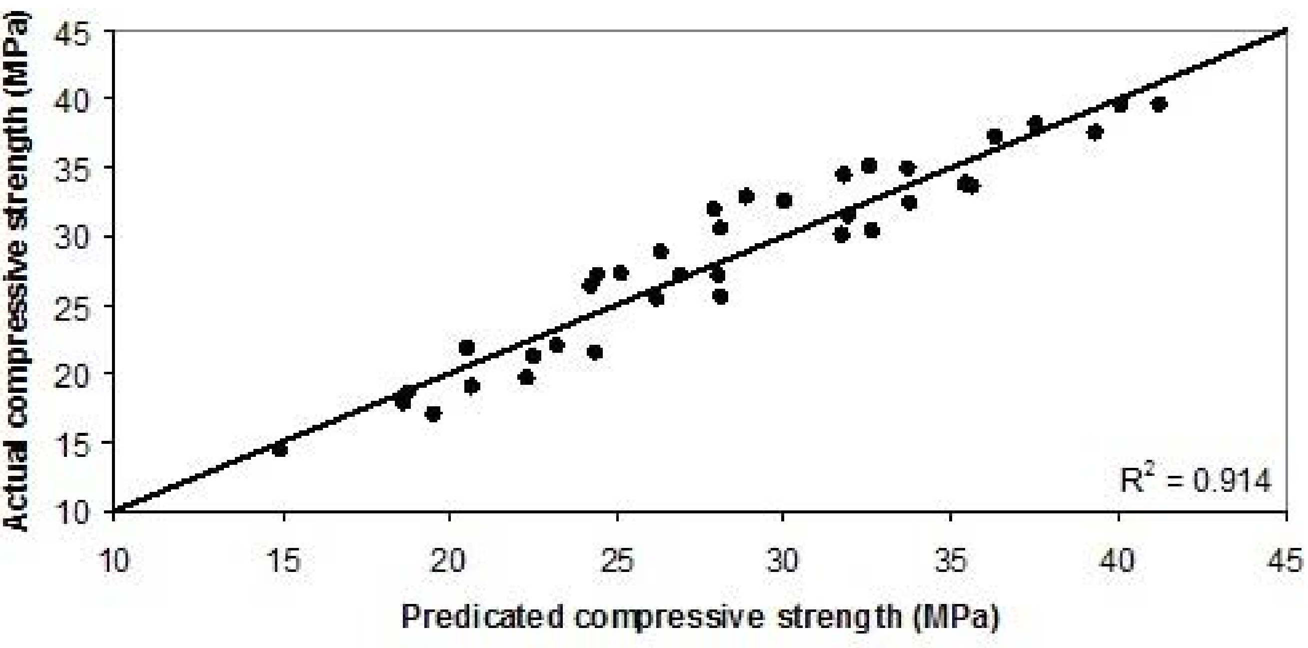

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Figure 6: Figure 5 :

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II. Experimental Procedure

a) Materials

Ordinary Portland cement (C) type I, conforming to ASTM C150, was used with properties listed in

Figure 7: Table 1 .

1

Property	Value
Fineness (90-?m sieve)	8.3
	281
Normal consistency (%)	28
Vicat setting time (min)	
Initial	145
Final	260
Specific gravity	3.15

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Figure 8: Table 1 :

2

Property	Value	
Table 3 : Physical properties of aggregate		
Property	Fine aggregate	Coarse aggregate
Specific gravity	2.46	2.75
Specific gravity (SSD)	2.50	2.78
Apparent relative density	2.56	2.83
Los Angeles abrasion (%)	N/A	20.50
Absorption (%)	1.62	1.05
Fineness modulus	2.73	6.53
Voids (%)	36.7	38.1
	1705	1617

Figure 9: Table 2 :

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[Note: May © 2012 Global Journals Inc. (US) J Unit weight (kg/m 3) Series Mix W/C R P W/CM Weight (kg/m 3) Compressive strength (MPa)]

Figure 10: Table 4 :

5

predicated strength values

	f	sf Model 4	Deviation
Unit	MPa	MPa	%
Min	14.370	14.941	-4.0
Max	39.620	41.237	-4.1
Median	29.465	28.088	4.7
Mean	28.449	28.452	0.0
Range	25.250	26.296	-4.1
Std. Deviation	6.935	6.630	4.4
Coef. of Variation	0.243	0.233	4.1
R 2	1.000	0.914	-4.0

Figure 11: Table 5 :

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