Effect of Silica Fume Addition on The Mechanical Properties of Concrete

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***Abstract*— Although the practice of using supplementary cementitious materials (pozzolan) such as silica fume in concrete mixtures has been growing in since the 1970s, no enough information is published addressing the optimum replacement percentage that can produce a well performed concrete. Thus, the current experimental study was carried out to investigate the effect of silica fume (SF) replacement (5, 10 and 15%) on mechanical properties of concrete for water to binder ratios (0.5). Performance of silica fume concrete specimens was compared to specimens made with CEMI (42.5 N). Compressive , flexural strength and split tensile strength were evaluated at 7, 28, 56 and 90 days of curing. Workability of fresh concrete mixes was assessed using a slump test. The carbonation depths were also tested using 100 mm cube specimens at 90 days of curing. Replacement of cement by silica fume reduced the workability of concrete and increased the water demand. On the other hand, improvement in the compressive, flexural and tensile strength of concrete was noticed as the replacement by silica fume increases. Replacement of cement by 15% SF showed highest compressive flexural and tensile strength by about 41.8, 37.8 CEMI concrete mixes at age of 90 days**.

***Keywords*—silica fume, compressive strength; flexural strength, carbonation depth, workability.**

I. INTRODUCTION

Concrete is one of the most common material used in the construction industry. the practice of using supplementary cementitious materials (pozzolan) such as fly ash, slag and Silica Fume(SF) in concrete mixtures has been growing in north America since the 1970s. In addition, Pozzolan materials might be used as a partial replacement of Portland cement or blended cement in concrete, depending on the properties of the materials and the desired effect on concrete. During the last four decades, researches were carried out on the use of cement additions to improve the properties of concrete and it has become widely used in construction. However, the dosage of these materials should be controlled in which an overdose of these materials might has a negative effect on concrete properties[1,2].

Silica fume was first 'obtained' in Norway, in 1947, when extracted from the exhaust gases of silicon, ferrosilicon and other metal alloy. The major portion of these fumes was a very fine powder composed of a high percentage of silicon dioxide, which is of high quality for use in the cement and concrete industry. [2,3]. Silica fume reacts with calcium hydroxide released by the hydration of Portland cement to form Calcium Silicate Hydrate (CSH) and other cementitious compounds. In addition to the pozzolanic reaction between the amorphous silica in silica fume and calcium hydroxide produced by the hydration of Portland cement, silica fume contributes to the progress of hydration of the latter material. it can enhance various properties of concrete such as, strength, permeability and durability. This contribution arises from the extreme fineness of the silica fume particles which provide nucleation sites for calcium hydroxide. Thus, early strength development takes place

With regard to strength, High compressive strength is generally the first property associated with silica fume concrete. In the USA it is common to use 100–130 MPa concrete in tall buildings, and 83 MPa silica fume concrete was used to build the 79-storey office block at 311 South Wacker in Chicago. 100 MPa silica fume concrete was used in the Petronas Towers in Kuala Lumpur. Therefore, The use of silica fume is found to be an appropriate admixture that can be used to produce a High Performance Concrete (HPC) by enhancing strength and durability [2,4].

In previous researches the silica fume replacement percentage for obtaining maximum 28 days strength of concrete ranged from 10 to 20% [5-9],while Panjehpour et al [10] stated that, According to the Florida Department of Transportation (2004), the quantity of cement replacement with silica fume should be between 7% and 9% by mass of cementation materials. Therefore, there is a disagreement in the optimum silica fume replacement percentage for improving mechanical properties of concrete.

This study investigate The mechanical properties of concrete with an objective to find an optimum dose of silica fume replacement. Different researchers have arrived at different optimum value. In this experimental study, the effect of partial replacement of cement by SF (0, 5, 10 and 15%) on mechanical properties of concrete were investigated. Performance of SF concrete specimens was compared to specimens made with CEMI. water to binder ratios (0.5) were used. Compressive flexural and split tensile strength were evaluated at different curing ages (7, 28, 56 and 90 days). Slump test was also performed on fresh concrete mixes as well as carbonation depth at age of 90 days.

II. EXPERMINTAL PROGRAMME

A. Materials Properties

In this study, silica fume concrete mixes were made of CEMI cement replaced with (0%, 5%,10%, 15%) silica fume. CEMI cement (42.5N) , manufactured by Helwan Company-Egyp and conformed to the requirement of BS EN 197-1:2011 [11] was used. The chemical composition of the cement are given in Table (I). The silica fume was obtained from Ash Sika Egypt for construction chemicals, and conformed to BS EN 13263-1:2005 +A1:2009 [12]. The chemical composition of the cement is presented in Table (I)

Natural sand with an apparent specific gravity of 2.63 and absorption of 0.5% was used. Crushed siliceous aggregate with maximum size (10 mm), were used, complying with BS EN 12620:2002+A1:2008 [13]. Some physical and mechanical properties of the aggregate used in this investigation are given in table (II).

TABLE I.
CHEMICAL COMPOSITION OF CEMI AND SF

Chemical Composition (%)	CEMI	**SF**
SiO_2	22.19	94.3
CaO	62.74	0.64
Al_2O_3	4.08	0.33
Fe_2O_3	3.16	1.09
Na_2O	0.2	0.35
K_2O	0.5	0.67
MgO	1.09	0.47
SO_3	3.1	0.31
LOI	**2.52**	**1.76**

TABLE II.
PHYSICAL AND MECHANICAL PROPERTIES OF COARSE AGGREGATE

property	
Apparent Specific gravity	**22.19**
Absorption(%)	**62.74**
Impact value (% Fines)	**4.08**
Crushing value (% Fines)	**3.16**

B. Mixture proportions and Mixing Procedure

Mix design proportioning was performed by using weight-batching method and was designed in accordance with the Building Research Establishment (British method)[14]. Proportioning of concrete mixtures is shown in Table III. All mixtures were mixed in a laboratory pan mixer with a capacity of 56 liters. The mix ingredients placed in the mixer was in the following order; dry aggregates and cement were mixed in the mixer for 30 seconds then water was added gradually in 15 seconds and the mixing continued for 2 minutes. Therefore, the total mixing time was 3 minutes for each concrete mixture. After mixing, A series of 100-mm cubes and prisms (100 x 100 x 500 mm) concrete specimens were cast in pre-oiled moulds and fully compacted using vibration table and the top surface was leveled and finished by trowel.

C. Curing of Test Specimens

After casting, the specimens were covered with wet hessian and plastic sheets for the first 24 hours at laboratory temperature 20±2°C. After 24 hours, specimens were removed from the mould and kept in water curing at 20°C until the test age.

TABLE III.
PROPORTIONS OF CONCRETE MIXES (KG/M^3)

MIX	Mix Proportions (Kg/m^3)				
	CEMI	**Silica fume**	**w/b**	**Sand**	**Coarse Aggregate**
M-0	380	0	0.5	1145	850
M-5	361	19	0.5	1145	850
M-10	342	38	0.5	1145	850
M-15	323	57	0.5	1145	850

D. Curing of Test Specimens

After casting, the specimens were covered with wet hessian and plastic sheets for the first 24 hours at laboratory temperature 20±2°C. After 24 hours, specimens were removed from the mould and kept in water curing at 20°C until the test age.

E. Test Methods

The workability of freshly mixed concrete was measured by using slump test according to BS EN 12350-2:2009 [15] .Compressive strength were performed on standard 100 mm cubes according to BS 1881:Part 116:1983[16]. For flexural strength test, prisms of 100x100x500 mm were used. Each prism was supported on a steel roller bearing near each end is loaded through similar steel bearings placed at the third points on the top surface according to BS EN 12390-5. The size of standard cylinder mould (150 x300 mm) used for splitting tensile test and the test performed according to BS 1881 part 117:1983. For each test three specimens were tested at 7, 28, 60 and 90 days of water curing. Carbonation is generally tested by indirect method using phenolphthalein. A solution of phenolphthalein indicator is applied onto cut concrete surface. The uncarbonated concrete shows a violet colour, while the carbonated concrete with a lower pH remain grey.

III. RESULTS AND DISSCUTIONS

A. Fresh Mix Properties

The results of slump test are presents are presented in Figure 1. As the Figure shows, concrete workability decreased as the replacement by silica fume increases in all concrete mixes. Concrete mix made with CEMI – 0 % silica fume showed that the value of slump (95 mm), while the slump decreased up to 23 mm for mix made with CEMI – 15 % silica fume. This can be attributed to that the decrease in the workability with silica fume is due to high specific surface of silica fume , lead to an increase in water demand to maintain mixing and control the concrete workability [2,5] and this confirmed the gained findings.

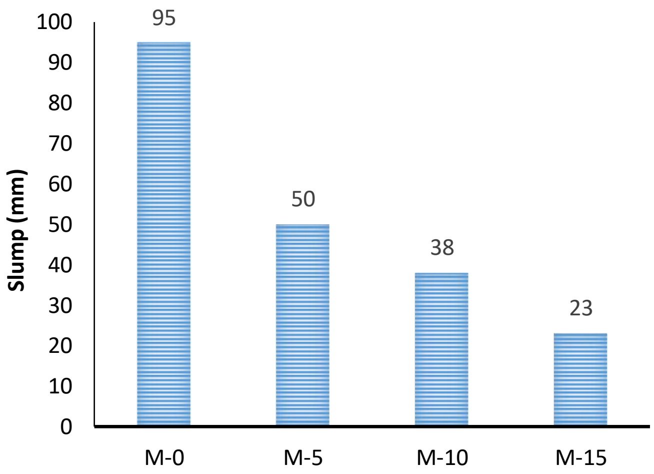

Fig. 1. Slump values of concrete made with different silica fume replacement percentage.

B. Compressive Strength

Figure 2 illustrated the results of compressive strength development. For all concrete specimens, there is an increase in compressive strength values with age. It can also be seen that increase in the content of silica fume lead to improvement in the strength of concrete and the highest value of compressive strength (59 MPa) was recorded for M-15 concrete specimens at 90 days. There is an increase by 48% for concrete with 15% silica fume after 28 days compared to CEM I concrete (M-0) followed by an increase of 26% , 10% for concrete with 10% and 5% silica fume respectively. It was also noticed that the optimum percentage of replacement is 15% in which an early age strength of (37 MPa) was recorded. This is in agreement with previous investigations [2, 17], confirms that the addition of silica fume to a concrete mix will increase the strength of that mix by between 30 % to 100%.

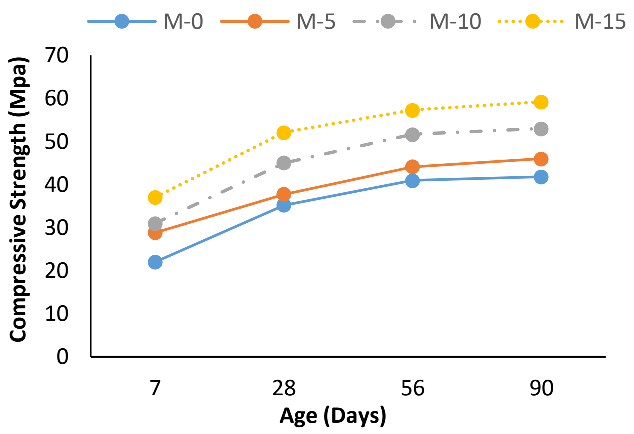

Fig. 2. Compressive Strength Development of concretes made with different replacement levels of silica fume up to 90 days

C. *Flexural Strength*

The results of flexure strength are shown in Figures 3. It can be seen that the flexural strength values increased gradually with the passage of time. At age of 7 days, specimens made with 15% silica fume showed the highest value of a high flexurural strength (3.35 MPa). Values of 3.05,2.87 and 2.57 were recorded for M-10, M-5 and M-0 concrete respectively. In addition, an obvious increase in flexural strength was noted as the replacement level of silica fume increases in which a value of 7.1 MPa was recorded at 90 days for M-15 concrete compared to 5.25 Mpa for M-0concrete.

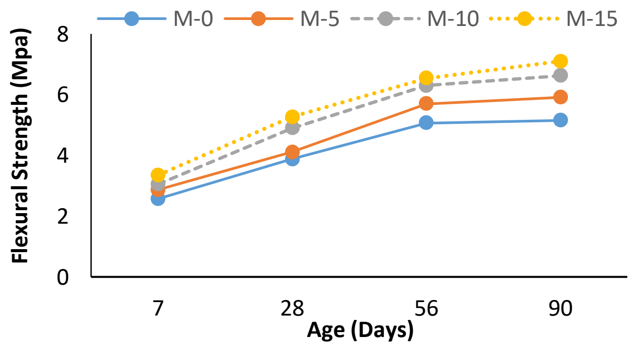

Fig. 3. Flexural Strength Development of concretes made with different replacement levels of silica fume up to 90 days

D. *Splitting Tensile Strength*

The results of splitting tensile strength of concrete with varying silica fume content is shown in Figure 4. It was noticed that the tensile strength values increased gradually over the age. There is a slight increase in tensile strength values as the replacement level of silica fume increased in which a value of about 5.3 MPa was recorded at 90 days for M-15 concrete compared to 3.75 Mpa for M-0 concrete. This behaviour is similar to that observed by others [16] who also concluded that increase in the use of silica fume in concrete did not significantly increase the splitting tensile strength of concrete and become insignificant beyond 15%.

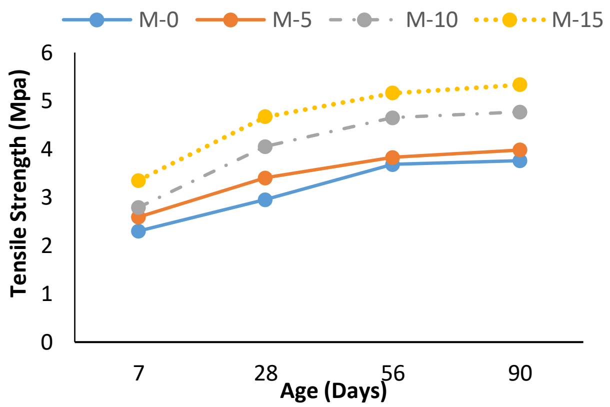

Fig. 4. Splitting Tensile Development of concretes made with different replacement levels of silica fume up to 90 days

An overall comparison illustrated that, An increase in the compressive strength using silica fume will result in a similar relative increase in the flexural strength, which a direct relationship between flexural strength and compressive strength indicates that concrete with the highest compressive strength should correspondingly have the highest tensile strength[2].

E. *Concrete Carbonation*

The results of carbonation depth of concrete curried for 90 days are shown in Figure 5. The results revealed that the resistance of concrete to carbonation increased as the percentage of replacement increases. M-0 concrete showed the highest carbonation depth approximately (4mm), while about 1 mm of carbonation depth was noticed in M-10 concrete. On the other hand, no signs of carbonation was recorded in concrete made with 15% silica fume showed the highest resistance to carbonation. This behavior is similar to that observed by others [18-20].

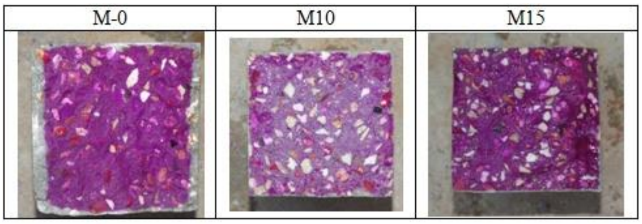

Fig. 5. Visual observation of Carbonation of Concrete made with silica fume

V. CONCLUSIONS

The following findings can be drawn from the obtained experimental results:

- High replacement by silica fume results in reduction in the workability of concrete and increase water demand.
- The replacement of cement by silica fume causes an increase in compressive strength of concrete and the optimum replacement level of silica fume is 15%.
- The flexural strength of concrete increase significantly with the replacement by 15% silica fume .
- 5.concrete with higher silica fume content showed positive effect, which M-15 concrete showed the highest resistance to carbonation.

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