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Effect of fly ash and silica fume on compressive strength of self-compacting concrete under different curing conditions

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Abstract This study presents an experimental study on self-compacting concrete (SCC) with two cement content. The work involves three types of mixes, the first consisted of different percentages of fly ash (FA), the second uses different percentages of silica fume (SF), and the third uses a mixture of FA and SF. After each mix preparation, nine cylinder specimens are cast and cured. Three specimens are cured in water for 28 days, three specimens are cured in water for 7 days, and three specimens are left in air for 28 days. The slump and V-funnel test are carried out on the fresh SCC and concrete compressive strength values are determined. The results show that SCC with 15% of SF gives higher values of compressive strength than those with 30% of FA and water cured specimens for 28 days give the highest values of compressive strength.

1. Introduction

Self-compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self weight with little or no vibration effort, and which is at the same time cohesive enough to be handled without segregation or bleeding of fresh concrete. SCC mixes usually contain superplasticizer, high content of fines and/or viscosity modifying additive (VMA). Whilst the use of superplasticizer maintains the fluidity, the fine content provides stability of the mix resulting in resistance against bleeding and segregation. The use of fly ash and blast furnace slag in SCC reduces the dosage of superplasticizer needed to obtain similar slump flow compared to concrete mixes made with only Portland cement [1].

It is estimated that SCC may result in up to 40% faster construction than using normal concrete [2,3]. The elastic modulus and shrinkage of SCC didn't differ significantly from the corresponding properties of normal concrete [4]. The results of tests carried out by Al-Feel and Al-Saffar [5] to study the effect of curing methods on the compressive, splitting, and flexural strength of self-compacting concrete showed that water cured specimens gave the highest results of concrete compressive strength, splitting tensile strength, and flexural strength than specimens cured in air by about 11%, 10%,

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and 11% respectively. The results also indicated that SCC gave high early concrete compressive strength. Ren and Wang [6], studied the application of high fly ash content concrete (HFCC) with dipy construction formwork. Their test results showed that, with the replacement of fly ash increase the strength of HFCC up to 50%.

The research carried out by Bentz et al. [7], indicated that curing conditions have significant effect on the degree of hydration of cement. They showed that for specimens (initially cured at 100% relative humidity (RH) for 6 or 12 h) exposed to 90% RH, hydration process discontinued as all remaining capillary water was lost due to evaporation. Whilst curing under sealed condition, in particular for concretes with W/C ratio of 0.4 or over, or keeping the surface as saturated were adequate.

The tests carried out by Yazicioglu et al. [8] to investigate the influence of curing conditions on the mechanical properties of self-compacting concrete, demonstrated that water cured specimens always have the highest values followed by sealed-cured specimens and air-cured irrespective of type and age of concrete and test methods. For both concrete compressive and tensile strength tests, the SCC with silica fume gives the highest values followed by SCC with fly ash and then PC concrete for all curing periods and conditions. An experimental program carried out by Ravikumar et al. [9], aimed at producing and evaluating SCC made with high volumes of kiln ash. The results of this study suggested that quarry dust (QD), silica fume (SF) and kiln ash (KA) combinations can improve the workability of SCC, more than QD, SF and KA individually. KA can also have a positive influence on the mechanical properties at early ages while SF improved bond between aggregate–matrix resulting from the formation of a less porous transition zone in concrete. SF can better reducing effect on total water absorption while QD and KA will not have the same effect, at 28 days.

2. Objectives of the study

The main objective of this study is to determine the suitable percentage of fly ash, and silica fume in SCC that gives the highest value of concrete compressive strength. As well as studying the influence of different curing conditions.

3. Experimental program

In this investigation, 450 cylinders are tested to investigate concrete compressive strength of SCC with different percentages of fly ash, silica fume and the combination of fly ash and silica fume respectively. In addition to investigate the effect of curing conditions on concrete compressive strength. All test specimens are 100 mm in diameter and 200 mm in length as show in Fig. 1. In this study, the major test parameters are: cement content, the percentage of fly ash, the percentage of silica fume, and water curing periods.

Figure 1 The test specimens.

Table 1 Chemical composition of silica fume.

Constituent	Content (%)
SiO_2	97
Fe_2O_3	0.5
Al_2O_3	0.2
CaO	0.2
MgO	0.5
K_2O	0.5
N_2O	0.2
SO_3	0.15
C_1	0.01
H_2O	0.5

Table 2 Mix proportions for cement content = 450 kg/m^3.

Cement content (kg/m^3)	450[a]
Water content (kg/m^3)	189
Coarse aggregate (kg/m^3)	612
Fine aggregate (kg/m^3)	1109
W/C ratio	0.42

[a] The quantities of FA and SF are used as the replacement of cement content by percentage as shown in Table 4.

Table 3 Mix proportions for cement content = 550 kg/m^3.

Cement content (kg/m^3)	550
Water content (kg/m^3)	231
Coarse aggregate (kg/m^3)	612
Fine aggregate (kg/m^3)	909
W/C ratio	0.42

Table 4 The percentages of FA and SF to cement for both cement content.

Mix No. [a]	Type I (FA/cement) %	Type II (SF/cement) %	Type III (FA and SF/cement) %
1	(10/90)	–	–
2	(15/85)	–	–
3	(20/80)	–	–
4	(25/75)	–	–
5	(30/70)	–	–
6	(35/65)	–	–
7	(40/60)	–	–
8	(50/50)	–	–
9	–	(10/90)	–
10	–	(15/85)	–
11	–	(20/80)	–
12	–	–	(10 and 10/80)
13	–	–	(15 and 10/75)
14	–	–	(20 and 10/70)
15	–	–	(25 and 10/65)
16	–	–	(30 and 10/60)
17	–	–	(40 and 10/50)
18	–	–	(15 and 15/70)
19	–	–	(20 and 15/65)
20	–	–	(25 and 15/60)
21	–	–	(30 and 15/55)
22	–	–	(35 and 15/50)
23	–	–	(20 and 20/60)
24	–	–	(25 and 20/55)
25	–	–	(30 and 20/50)

[a] Each mix consisted of 9 cylinders.

Table 5 Typical acceptance criteria for SCC.

Test method	Unit	Typical range of values	
		Min	Max
Slump-flow	mm	650	800
The spread diameter (T_{50})	s	2	10
V-funnel	s	6	12

3.1. Materials properties

The constituent materials for the production of SCC are discussed as follows:

3.1.1. Cementations materials

Ordinary Portland Cement (OPC) is used in all test specimens, the tests carried out on the used cement to determine its physical properties according Egyptian Code of Practice [10]. Fly ash and silica fume are used as a replacement of the cement content by different percentage to reduce the dosage of chemical admixtures needed to obtain the required slump flow. The chemical composition of Silica fume are given in Table 1.

3.1.2. Aggregates

20 mm nominal maximum size dolomite is used as coarse aggregate and the fine aggregate was the natural sand free from impurities.

3.1.3. Chemical additives

In this study, Viscocrete 5930 is used to increase the flow capability of the concrete and improve the viscosity. The used dosage of Viscocrete was 2% of the total volume of concrete.

3.2. Mix proportions

For this study, two cement contents are used (i.e., 450 kg/m^3 and 550 kg/m^3), the quantities of materials used for two cement content are illustrated in Tables 2 and 3. Three types of concrete mix are chosen, the first one (type I) was combination of plain concrete (PC) and fly ash (FA), the second (type II) was combination of PC and silica fume (SF), and the third one (type III) was combination of PC, FA, and SF. The percentages of FA and SF to cement are shown in Table 4.

4. Tests of fresh SCC

To evaluate the ability of SCC in the flowability and viscosity, the slump-flow test and V-funnel test are carried on the fresh SCC. Typical acceptance criteria for SCC are listed in Table 5. In slump test, the cone is filled with concrete and then lifted vertically and the time measurement is started as shown in Fig. 2. The spread diameter T_{50} (i.e., the time of flow to reach a diameter of 500 mm) and the general visual appearance of the concrete are recorded. V-funnel test is used to evaluate the viscosity of SCC, the test is carried out by filling a funnel with about 12 l of concrete and then measured the time in seconds that the concrete takes to drain of the funnel as shown in Fig. 3. The results obtained from these tests indicated that, SCC mixes had good filling and passing ability as well as segregation resistance, the time recorded for 500 mm diameter of concrete, the final concrete diameter, and the time in V-funnel increased with the increase in the percentage of fly ash and silica fume.

Figure 2 The slump-flow test.

Figure 3 The V-funnel test.

5. Test results and discussion

5.1. Concrete compressive strength

The obtained values of concrete compressive strength according to the different used percentage of FA and SF for both cement content are shown in Figs. 4 and 5. These figures indicate that, in type I (with FA) the higher the percentage of FA the higher the values of compressive strength until 30% of FA, after that the increase in the percentage of FA lead to decrease in values of concrete compressive strength. However, in type II with SF the highest value of concrete com-

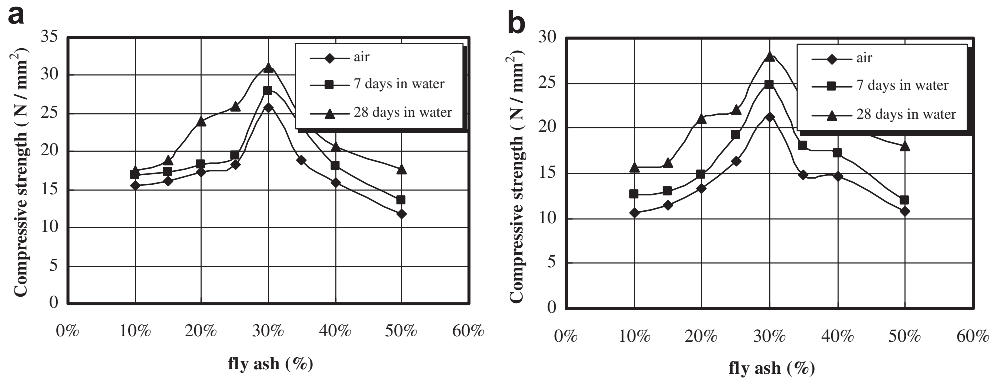

Figure 4 Compressive strength for type I: (a) cement content = 550 kg/m^3; (b) cement content = 450 kg/m^3.

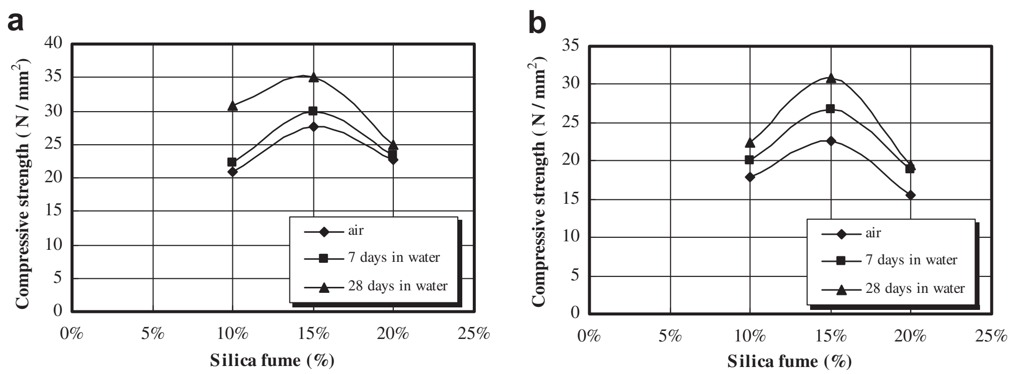

Figure 5 Compressive strength for type II: (a) cement content = 550 kg/m^3; (b) cement content = 450 kg/m^3.

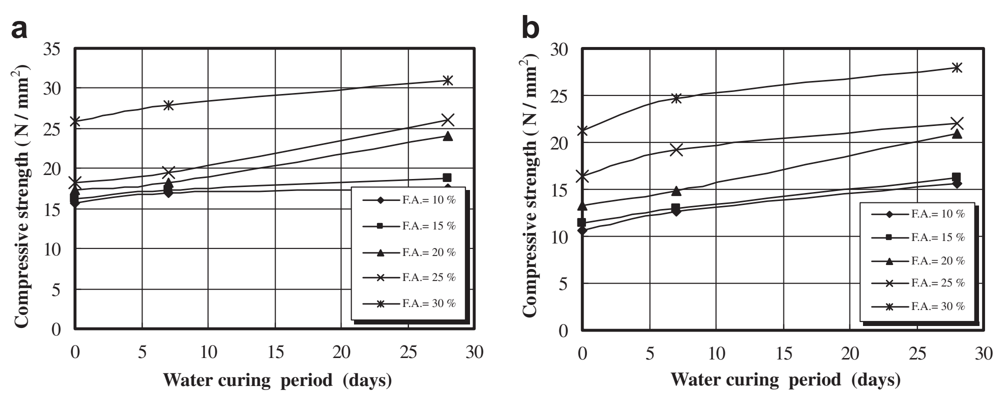

Figure 6 Effect of curing conditions on compressive strength of type I: (a) cement content = 550 kg/m^3; (b) cement content = 450 kg/m^3.

pressive strength is obtained from 15% of SF. It can be noticed that specimens of type II with 15% of SF as a replacement cement content gives higher values of concrete compressive strength than specimens of type I with 30% of FA by about 12% and 10% for 550 kg/m^3 and 450 kg/m^3 cement content respectively. The values of concrete compressive strength versus water curing periods are plotted in Figs. 6 and 7. It can be seen that the highest value of compressive strength for all test cases is obtained from specimens cured in water for 28 days followed by those cured in water for 7 days, and air cured specimens are given the lowest value of compressive strength. Figs. 8–10 give the comparison between two cement content for values of compressive strength with different percentage of FA, SF and FA and SF. The results show that the best percentage for combination of FA and SF is 10% of FA and 10% of SF for both cement content, where the values

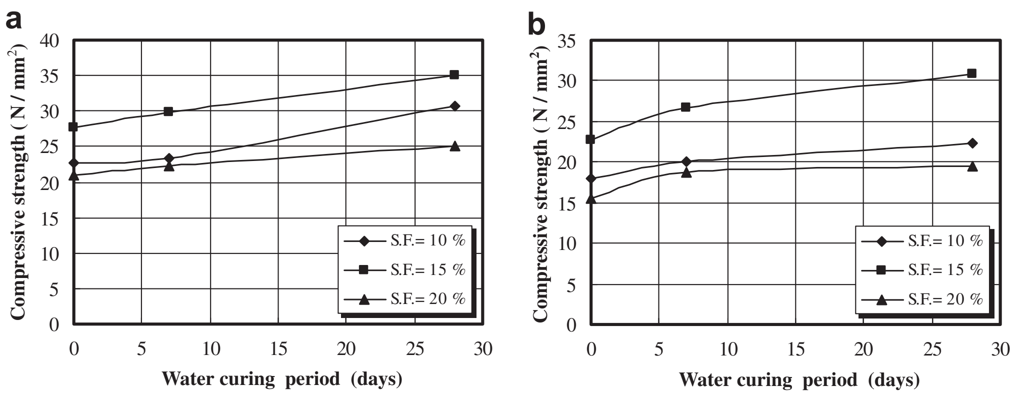

Figure 7 Effect of curing conditions on compressive strength of type II: (a) cement content = 550 kg/m^3; (b) cement content = 450 kg/m^3.

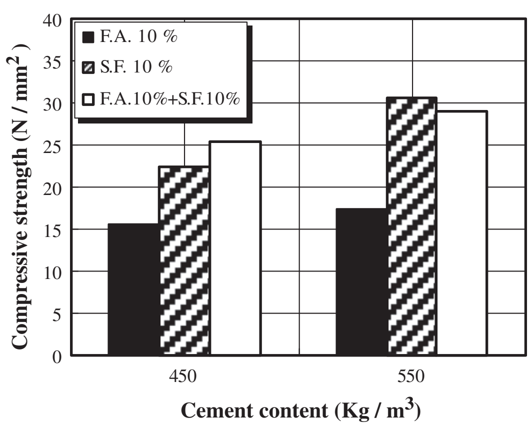

Figure 8 Comparison of compressive strength of type I, II, and III with ratio 10%.

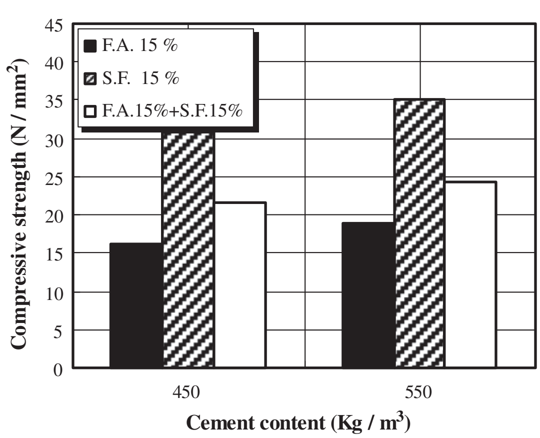

Figure 9 Comparison of compressive strength of type I, II, and III with ratio 15%.

of concrete compressive strength in this case higher than the values in case of 15% FA and 15% SF by about 19% and 18% for 550 kg/m^3 and 450 kg/m^3 cement content respectively. While, the increase can be estimated by about 24% and 22% respectively in case of 20% FA and 20% SF, where these increment percentages of concrete compressive strength are shown in Tables 6 and 7.

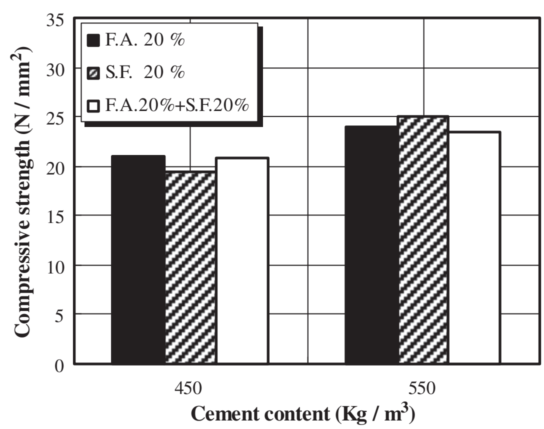

Figure 10 Comparison of compressive strength of type I, II, and III with ratio 20%.

5.2. Failure mode

The modes of failure are shown in Figs. 11 and 12. It can be seen from these figures that no segregation occurred in tested SCC mixes, because of the good distribution of aggregate in concrete matrix. The failure may happened in aggregate as shown in Fig. 11 or in the matrix as shown in Fig. 12 and this referred to there is a good bond between aggregate and matrix.

6. Conclusions

This paper presents an experimental program to describe the effect of curing conditions on the SCC with different percentage of FA and SC to determine the best percentage of FA, SC, or their combination with regard to concrete compressive strength. Based on the obtained results, the following main conclusions can be drawn:

- The higher the percentage of FA the higher the values of concrete compressive strength until 30% of FA. However, the highest value of concrete compressive strength is obtained from mix containing 15% SF.
- SCC mixes with 15% SF as a replacement of cement content give higher values of concrete compressive strength than those with 30% FA by about 12% and 10% for 550 kg/m^3 and 450 kg/m^3 cement content respectively.

Table 6 Increment percentage of concrete compressive strength from 15% FA and 15 % SF to 10 % FA and 10 % SF.

Concrete compressive strength (N/mm^2) (FA 10% + SA 10%)		Concrete compressive strength (N/mm^2) (FA 15% + SA 15%)		Increment percentage (%)	
450 kg/m^3 Cement content	550 kg/m^3 Cement content	450 kg/m^3 Cement content	550 kg/m^3 Cement content	450 kg/m^3	550 kg/m^3
25.4	29.1	21.5	24.4	18	19

Table 7 Increment percentage of concrete compressive strength from 20% FA and 20 % SF to 10 % FA and 10 % SF.

Concrete compressive strength (N/mm^2) (FA 10% + SA 10%)		Concrete compressive strength (N/mm^2) (FA 20% + SA 20%)		Increment percentage (%)	
450 kg/m^3 Cement content	550 kg/m^3 Cement content	450 kg/m^3 Cement content	550 kg/m^3 Cement content	450 kg/m^3	550 kg/m^3
25.4	29.1	20.8	23.4	22	24

Figure 11 The mode of failure in aggregate.

Figure 12 The mode of failure in the matrix.

- The highest value of compressive strength for all test cases is obtained from specimens cured in water for 28 days and the lowest value is obtained from air cured specimens.
- SCC with 10% FA and 10% SF gave the highest value of concrete compressive strength for SCC consisted of combination of FA and SF.

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