# Effect of Fly Ash and Silica Fume on Compressive Strength, Sorptivity and Carbonation of SCC

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## Abstract

In this paper, ASTM C 618 Class F Fly Ash (FA) at 25%, 30%, 35% and 40% and Silica Fume (SF) at 5%, 10%, 15% and 20% replacement of Portland Cement (PC) CEM I 42.5 in SCC was used to evaluate the effect of types and quantity of powder additions on compressive strength and permeations properties of SCC. To this end, eight types of SCC were designed, in comparison with Vibrated Traditional Concrete (VTC). The results indicated that SCC specimens with SF15 had the highest compressive strength with 73.87 MPa for 130 days. The sorptivity values of SCC specimens with FA and SF were lower than those of VTC specimens regardless of type and quantity of powder additions. On the other hand, the carbonation resistance of VTC was higher than that of SCC specimens containing both SF and FA for all accelerated carbonation periods. Consequently, it can be said that type and quantity of powder additions had an important effect on the correlation among the compressive strength and permeation properties of SCC.

Keywords: *self-compacting concrete, mineral admixtures, compressive strength, sorptivity, carbonation*

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## 1. Introduction

Self-Compacting Concrete (SCC), first used in Japan in the late nineteen eighties (*Okamura et al.,* 1995), is a new kind of concrete that combines a high flowability and a high segregation resistance obtained by a large amount of fine particles and the use of superplasticizers. In addition to these, the self-compactability of concretes may provide considerable advantages such as reducing the construction time and labour cost, enhancing the filling capacity of highly congested structural members, etc. (Khayat and Morin, 2002). The use of the fine mineral admixtures in SCC is inevitable to enhance its self-compactibility characteristics and to reduce the material cost of the Self-Compacting Concrete (SCC). Due to the presence of the large amount of fine particles, the pore structure is somewhat different from the pore structure of Vibrated Traditional Concrete (VTC). It is generally accepted that the durability of concrete is related to the characteristics of its pore structure. Degradation mechanisms of concrete often depend on the way potentially aggressive substances can penetrate into the concrete, possibly causing damage.

The influence of pozzolanic finer supplementary binders such as Pulverized Fuel Ash (PFA) and Silica Fume (SF) on the carbonation has been mostly studied for Vibrated Traditional Concrete (VTC) (Atis, 2003; Jones *et al.*, 1997; Jiang *et al.*, 2000; Papadakis, 2000; Khan and Lynsdale, 2002; Khunthongkeaw, 2006). The general agreement from these studies for the use of

PFA and SF in VTC for carbonation is that the partial replacement of cement with PFA or SF increases carbonation. Because, in pozzolan concrete, the quantity of CH will be significantly reduced by the lower quantity of Portland Cement (PC) and consumption by pozzolanic reaction. Hence, the extent of chemical interaction (and binding of $CO_2$) will be reduced compared to NC (Thomas and Matthews, 1992). Papadakis (2000) has demonstrated, for mortars containing various amounts of fly ash and silica fume as partial cement replacements that carbonation depth increases with increase in pozzolan content. The more rapid carbonation of mortars made with blended cements is accounted for by the reduced total amount of CaO in the system available for carbonation. Zhu and Batros (2003) found that compared with VTC, SCC shows a lower permeability and absorption by capillary action, which might be attributed to the less porous zone and refinement of pore structure whilst the research carried out by Assié *et al.* (2007) confirmed that SCC can be considered to be as useful and durable as VTC in terms of physicochemical properties. Moreover, it was verified that SCC had more homogeneous and denser the interfacial zone around embedded reinforcement and coarse aggregate particles compared to VTC (Petrov, 2001; Petersson *et al.*, 1998; Tragardh, 1999) leading to an improved durability characteristics of SCC. On the other hand, According to the published materials, there have been limited in number literatures that report the effect of mineral additions on carbonation of SCC whilst researches about

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the fresh and engineering properties of SCC have been carried out adequately. In this study, the effect of type and quantity of powder additions on the compressive strength, water sorptivity and carbonation of SCC were experimentally examined. Furthermore, relationships among these properties investigated were analyzed in this paper.

## 2. Experimental Program

### 2.1 Materials

Portland Cement (PC) CEM I 42.5 produced according to TS EN 197-1 (2011), class F fly ash according to ASTM C 618 (2001) and silica fume were used as cementitious materials. The chemical composition and physical properties of PC, FA and SF are given in Table 1. Natural sand with a fineness modulus of 3.05 and gravel with a nominal maximum size of 20 mm were used as the aggregates for all mixture. The relative density values for 0-7, 7-15 and 15-20 mm were 2.63, 2.64 and 2.66 $g/cm^3$, and absorption rates were 1.57%, 1.0% and 0.7%, respectively. More-over, melamine sulfonate polymer based for vibrated traditional

concrete and modified polycarboxylates based polymer for SCC, which had specific gravity of 1.22 and 1.06 $g/cm^3$, respectively, were used as the chemical admixtures.

### 2.2 Mix Proportions

Assuming saturated-dry surface conditions for the aggregates, the mix proportions for vibrated traditional and self-compacting concretes are summarized in Table 2. While VTC and SCC-PC was prepared by only ordinary Portland cement as binder, other SCC mixes were prepared by replacing from 25 to 40% at 5% intervals of cement with FA and 5 to 20% at 5% intervals of cement with SF on mass-for-mass basis to study the effect of type and amount of pozzolans on the compressive strength and permeation properties of SCC. A water-cementitious material ratio (w/cm) of 0.38 was adopted for all mixes. High-range water reducing chemical admixture dosages in a range of 1.44%, 1.35% and 1.78% for SCC with only PC, SCC with FA and SF, respectively, was selected to maintain slump flows at 705 ± 4 mm whilst superplasticizer dosage in a range of 1.57% for VTC with low slump (68 mm) was selected.

In order to identify the SCC mixes, SCC with only PC, fly ash or silica fume is designated as "PC", "FA" and "SF", respectively. The numerical value after "FA" and "SF" represents weight percentage of FA and SF incorporated as cement replacement.

### 2.3 Workability Tests for Fresh Concretes

While workability of VTC was measured the slump test according to ASTM C143 standard (2002) using slump test, mix designs for self-compacting concretes were developed by means of trial mixes based on guidance given in EFNARC (2005). For SCC mixes, slump flow, $T_{50cm}$, L-box and sieve segregation resistance tests described in EFNARC (2005) were carried out. The fresh concrete properties of the ten different concretes are summarized in Table 3. The results obtained from these tests showed that SCC mixes had in general good flow, filling and passing ability as well as segregation resistance (see Table 3). As can be seen in Table 3 that the segregation resistance of SCC with FA increased when FA content increased from 25% to 40%

Table 1. Chemical Composition and Physical Properties of PC, FA and SF (%)

| Component | PC (%) | FA (%) | SF (%) |
|---|---|---|---|
| $SiO_2$ | 20.2 | 58.82 | 91 |
| $Al_2O_3$ | 5.8 | 19.65 | 0.58 |
| $Fe_2O_3$ | 3.23 | 10.67 | 0.24 |
| CaO | 64.1 | 2.18 | 0.71 |
| MgO | - | 3.92 | 0.33 |
| $SO_3$ | 2.66 | 0.48 | - |
| Chloride ($Cl^-$) | 0.006 | - | - |
| LOI | 2.58 | 0.91 | 1.84 |
| Specific gravity ($g/cm^3$) | 3.1 | 2.08 | 2.2 |
| Specific surface area ($cm^2/g$) | 3484 | 3812 | 96.5%<45 μm |
| Compressive strength (MPa) | | | |
| 2 days | 23.7 | - | - |
| 7 days | 44.0 | - | - |
| 28 days | 55.2 | - | - |

Table 2. Mix Proportions ($kg/m^3$)

| Mixtures | VTC | SCC-PC | SCC with FA | | | | SCC with SF | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 25% | 30% | 35% | 40% | 5% | 10% | 15% | 20% |
| $w/cm^a$ | 0.39 | 0.36 | 0.39 | 0.38 | 0.38 | 0.38 | 0.36 | 0.38 | 0.40 | 0.40 |
| Cementitious | 350 | 500 | 500 | 500 | 500 | 500 | 450 | 450 | 450 | 450 |
| Cement | 350 | 500 | 375 | 350 | 325 | 300 | 427.5 | 405 | 382.5 | 360 |
| FA | - | - | 125 | 150 | 175 | 200 | - | - | - | - |
| SF | - | - | - | - | - | - | 22.5 | 45 | 67.5 | 90 |
| Aggregate sizes (mm) | | | | | | | | | | |
| 0-7 | 800 | 893 | 910 | 910 | 910 | 910 | 990 | 990 | 990 | 990 |
| 7-15 | 500 | 450 | 450 | 450 | 450 | 450 | 450 | 450 | 450 | 450 |
| 15-20 | 650 | 285 | 285 | 285 | 285 | 285 | 285 | 285 | 285 | 285 |
| WR | 5.50 | - | - | - | - | - | - | - | - | - |
| HRWR | - | 7 | 6.75 | 6.75 | 6.75 | 6.75 | 8.00 | 8.00 | 8.00 | 8.00 |

a w/cm is water to cementitious materials (PC+FA or SF) ratio

Table 3. Properties of Fresh Concretes

| Mixtures | VTC | SCC-PC | SCC with FA | | | | SCC with SF | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | FA25 | FA30 | FA35 | FA40 | SF5 | SF10 | SF15 | SF20 |
| Slump (mm) | 68 | 709[b] | 709[b] | 702[b] | 705[b] | 701[b] | 707[b] | 701[b] | 708[b] | 707[b] |
| $T_{50cm}$ (s) | - | 2.30 | 2.44 | 2.56 | 3.00 | 2.89 | 2.30 | 1.80 | 1.20 | 1.00 |
| L-box; $H_2/H_1$ | - | 0.893 | 0.910 | 0.943 | 0.953 | 0.959 | 0.865 | 0.876 | 0.888 | 0.890 |
| Segregation (%) | - | 19.1 | 18.4 | 15.8 | 15.2 | 14.4 | 15.3 | 17.9 | 19.8 | 22.0 |

[b] Slump Flow (mm)

whilst this did not valid for SCC with SF specimens due to its higher fineness compared to FA. VTC specimens were cast on a vibrating table to ensure optimum compaction, whilst the SCC specimens were cast without any vibration.

## 2.4 Test Methods
### 2.4.1 Compressive Strength Test

The compressive strength test was conducted on 150 mm cube concretes for the ages of 3, 7, 28 and 130 days in accordance with ASTM C39 standard (2002).

### 2.4.2 Capillary Water Absorption Test

Three specimens of 100 mm cubes for sorptivity test were prepared for each mixture. Measurements of capillary water absorption were carried out to determine the sorptivity coefficient of concrete specimens, which were pre-conditioned in oven at $110\pm5^oC$ until a constant weight and then cooled down within dessicators 24 h to achieve a constant moisture level. Then, four sides of the concrete specimens were sealed by paraffin to avoid evaporative effect as well as to maintain uniaxial water flow during the test and the opposite faces were left open. Before the specimens were located on water, their initial weights were measured to the nearest 0.01 g. As shown in Fig. 1, a surface of concrete cube, which was paralel to the direction of casting, was exposed the water on the plane of 100 mm×100 mm by placing it in a tray and rested on glass rods to allow the free access of water to the inflow surface. The water level in the tray was maintained at about 4-5 mm above the base of the specimens during these experiments. Immediately after the immersion of the cube surface into water, the water absorption was measured with scale of 0.1 g readability at intervals of 5, 10, 30, 60, 240 and 1440 min.

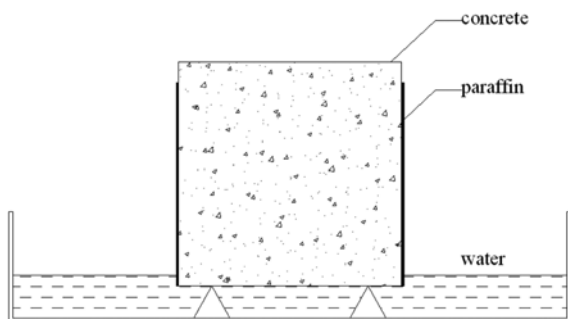The sorptivity coefficient can be calculated by the following expression:



Fig. 1. Experimental Set-up for Water Sorptivity Test

$$\frac{Q}{A} = k\sqrt{t} \qquad (1)$$

Where $Q$=the amount of water absorbed in $(cm^3)$; $A$=the cross-section of specimen that was in contact with water $(cm^2)$; $t$=time (s); $k$=the sorptivity coefficient of the specimen $(cm/s^{0.5})$. The sorptivity coefficient was obtained from the slope of the linear relation between $Q/A$ and $\sqrt{t}$ using the smallest square method in MS Excel.

### 2.4.3 Accelerated Carbonation Test

As known, the process of carbonation is actually a long-term reaction. Therefore, an accelerated carbonation testing system has to be used to carbonate the concrete in short-term. Cross and longitudinal section of the accelerated carbonation tank used in this study was given in Fig. 2. Cubes $100\times100\times100$ $mm^3$ were stored in a climate chamber at $20\pm2^oC$ and $90\pm5\%$ relative humidity at for 28 day prior to testing. These specimens were placed inside of the accelerated carbonation tank and the lid of the tank was tightly closed. Specimens were exposed at the 40% of $CO_2$ and 55% relative humidity during periods of 6, 24 and 72 hours.

After completion of the test, the specimens were taken out of the tank and the depth of carbonation was measured by treating the surface of a freshly broken concrete cube specimen with a pH indicator that was 1% solution of phenolphthalein in 70% ethyl alcohol. In the non-carbonated part of the specimen where the concrete is still highly alkaline, purple-red coloration is occured, while in the carbonated part of the specimen, where due to the carbonation the alkalinity was reduced and no coloration occured. The carbonation depth were measured a digital compass with 0.01 mm sensitivity. Each result reported is the average depth carbonation "D" at two points perpendicularly to three faces of the broken concrete cube using three specimens. The mean value of the depth of carbonation "D" is visualised in Fig. 3. This method for measuring the depth of carbonation was also used by Ramezanianpour (1987), Claisse (1988) and Paillere *et al.* (1986).

## 3. Results and Discussion

### 3.1 Compressive Strength Development

Compressive strength results of VTC, SCC with only PC and SCC specimens with FA/SF were presented in Figs. 4(a) and 4(b), respectively, for 3, 7, 28 and 130 days. It can be observed from Fig. 4 that SCC with SF had the highest compressive strength
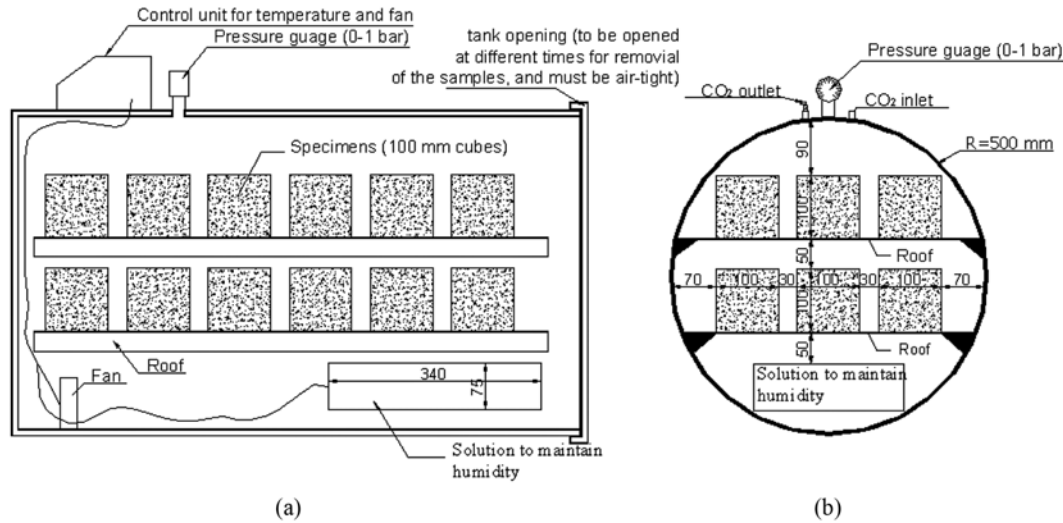
Fig. 2. Longitudinal and Cross-section of the Accelerated Carbonation Tank
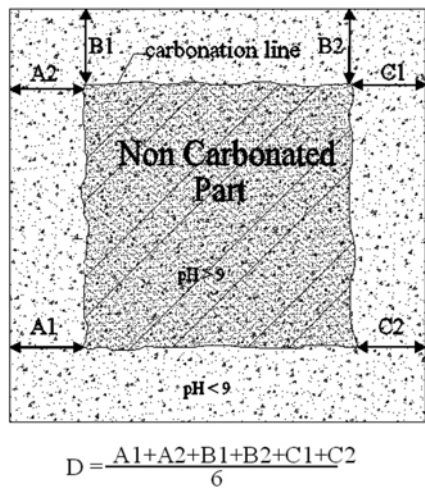


$$D = \frac{A1 + A2 + B1 + B2 + C1 + C2}{6}$$

Fig. 3. Measurement of Carbonation Depth

followed by SCC with only PC, SCC with FA and VTC specimens for 7, 28 and 130 days. Because SF is a highly active mineral additive with its addition into concrete (Xincheng, 1999). However, SCC specimens with FA and SF had the lower compressive strength than SCC with only PC for 3 days due to the lower heat liberation and strength development of pozzolanic reactions whilst VTC specimens had the lowest compressive strength for all curing time. Results obtained from previous study (Demirboğa, 2003) have shown that at early ages all mineral admixture reduced compressive strength, especially reduction due to FA were very high. Moreover, SCC with SF15 had the highest compressive strength with 67.95 followed by SF20, SF10, SF5, FA25, FA40, FA30 and FA35 with 66.35, 62.81, 58.04, 49.39, 45.26, 45.11 and 42.51 MPa, respectively, for 28-day curing periods compared to the mixtures with mineral admixture. On the other hand, SCC with SF15 for both 28 days and 130 days had the highest compressive strength with 67.95 and 73.87 MPa, respectively. This also can be explained by the
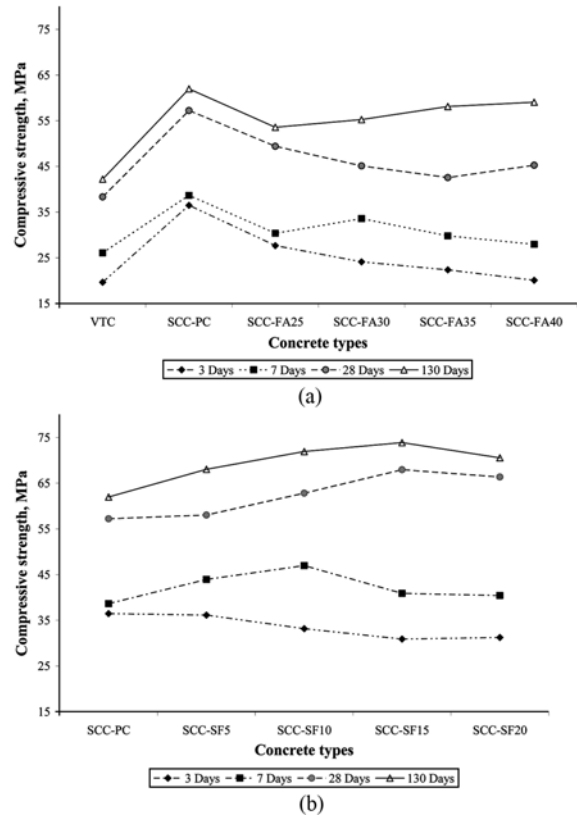


Fig. 4. Influence of FA/SF on Compressive Strength Development of SCC at 3, 7, 28 and 130 days: (a) VTC and SCC with Only PC and FA, (b) SCC With SF

pore size reduction and crystal refinement caused by the introduction SF with its very fine and reactive particles (Paulon *et al.*, 2004).

As for SCC with FA mixtures, FA40 had the highest compressive strength with 59.04 MPa for the periods of 130 days (Fig. 4a). Similar trend was obtained in another study performed by Khatib (2008) who found that SCC containing 40% FA shows

higher 56 days strength than the other FA mixes including the 20% FA mix.

## 3.2 Sorptivity-capilary Water Absorption

Figure 5 presents the experimental results of the sorptivity values of VTC, SCC with only PC and SCC with SF/FA. It is indicated that SCC mixtures with SF had the lowest sorptivity values compared to VTC, SCC with only PC and SCC with FA. Because SCC specimens with SF had the less porous zone and refinement of pore structure (Zhu and Batros, 2003; Bai *et al.*, 2002). Furthermore, it is clear from Fig. 5 that the water sorptivity values of SCC specimens with SF decreased with increase in the replacement level of SF from 5 to 20% indicating the filler effect of SF as well as puzzolanic activity (Goldman and Bentur, 1993; Tasdemir, 2003). However, there is systematic increase in absorption with increase in the replacement level of FA from 25 to 40%. SCC with FA mixes exhibited absorption values of less than or equal to 1.36%, which is considered to be a low water absorption (Concrete Society, 1988). This trend is similar to results obtained from elsewhere on SCC with FA (Khatib, 2008). Moreover, the sorptivity values of SCC specimens with FA except for FA25 were higher than that of SCC with only PC whilst VTC specimens had the highest sorptivity values in all specimens investigated. These could be attributed to high water-holding capacities of fly ashes due to porous structure (Fischer *et al.*, 1978). Also, Iyer and Stanmore (1999) found that water absorption, which is a function of particle size, increases the volume fraction of dense fly ash slurry if the fraction with maximum fines is added to dense fly ash slurry.

## 3.3 Carbonation Depth

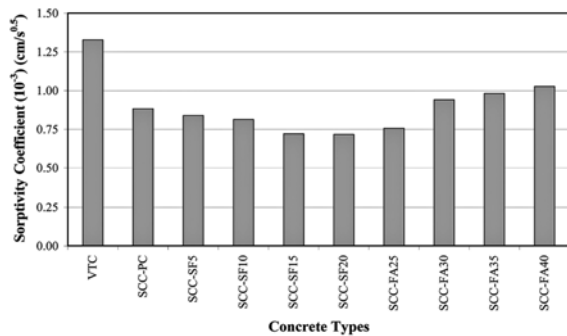Figure 6 shows effect of the replacement of PC by FA or SF in

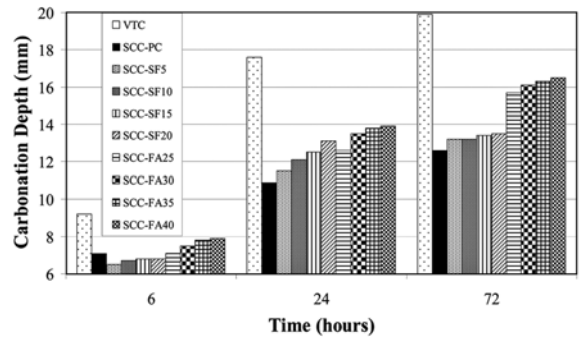Fig. 5. Influence of SF and FA on the sOrptivity Values of SCC

Fig. 6. Accelerated Carbonation Test Results of VTC, SCC with Only PC, SF and FA at 6, 24 and 72 hours

SCC on carbonation depth. The carbonation depth increased with time in all concrete mixes. It can be seen from Fig. 6 that the carbonation resistance of SCC specimens was higher than that of VTC specimens for all accelerated carbonation periods whilst the carbonation depth of SCC with only PC were the lowest at 24 and 72 hours accelerated carbonation periods. Moreover, the carbonation resistance of SCC specimens decreased with the increase of SF and FA content. Similar results were observed by Khunthongkeaw*et al.* (2006) and Bai *et al.* (2002) in studies conducted on fly ash concrete. Because, the concentration of the carbonatable constituents of cement (CH and CSH) reduces due to the use of FA and SF as partial replacement of cement, and thus the concrete carbonation accelerates (Papadakis, 2000). As a conclusion it can be said that the carbonation depth of SCC specimens with FA40 was the highest in SCC mixes for all accelerated carbonation periods. These findings are clearly in good agreement with many research reports (Atis, 2003; Khan and Lynsdale, 2002; Paillere *et al.*, 1986; Ho and Lewis, 1983; Byfors, 1985; Hui-sheng *et al.*, 2009). Because, in these studies mentioned above, it was generally found that the replacement of PC by FA in concrete increased the carbonation depth, however, the depth of carbonation increased slightly with SF. Furthermore, in this study, both VTC and SCC specimens had lower carbonation coefficient in comparison with previous study carried out by Gonen and Yazicioglu (2007) indicating the effect of cast technique (specimens with poor, medium and high compaction pores) as well as more powder due to SCC. On the other hand, Fig. 6 and Table 4 show that the carbonation depth values of SCC specimens with SF are not very different from each other at 6 and 72 hour accelerated carbonation periods when SF content changes from 5% to 20% whilst FA content in SCC had an effect

Table 4. Statistical Evaluation of the Effect of SF and FA Content on the Carbonation Depth

| SCC with SF | 6 hours | 24 hours | 72 hours | SCC with FA | 6 hours | 24 hours | 72 hours |
|---|---|---|---|---|---|---|---|
| 0 | 7.11[b] | 10.87[a] | 12.58[a] | 0 | 7.11[a] | 10.87[a] | 12.58[a] |
| 5 | 6.52[a] | 11.52[b] | 13.17[b] | 25 | 7.12[a] | 12.65[b] | 15.68[b] |
| 10 | 6.73[ab] | 12.17[c] | 13.26[b] | 30 | 7.49[b] | 13.52[c] | 16.14[c] |
| 15 | 6.80[ab] | 12.44[c] | 13.34[b] | 35 | 7.81[c] | 13.77[d] | 16.27[c] |
| 20 | 6.81[ab] | 13.18[d] | 13.54[b] | 40 | 7.90[c] | 13.87[d] | 16.43[d] |

*Values followed by the same letter do not present statistically significant difference within same column (Duncan test).

on the carbonation depth. Hence, it can be emphasized that the dosage of SF had insignificant effect except for 24 hours on the carbonation resistance of SCC (See Table 4).

## 3.4 Correlation among Compressive Strength, Water Sorptivity and Carbonation Coefficient of SCC

An approach was made to correlate the compressive strength to the sorptivity and the carbonation coefficient of SCC. Regression analysis using method of least squares was carried out based on the experimental data of compressive strength at 28 days, sorptivity and carbonation coefficient at 72 hours for only SCC mixtures with SF/FA. In statistical analyses, each mix data of SCC with SF/FA were invidually used to find the regression line.

The coefficients of the exponential regression equation with the correlation coefficient for relation among compressive strength, sorptivity and carbonation resistance of SCC specimens are given in Figs. 7(a), (b) and 8. It was observed from Figs. 7(a) and 7(b) that the relation is of exponential form for relation between both compressive strength-sorptivity. However, the compressive strength and the sorptivity of SCC with FA/SF suggested the presence of inverse type of relationship between them; the higher the compressive strength, the lower the water absorption (Güneyisi and Gesoğlu, 2008). The correlation coefficient between the sorptivity coefficient and compressive strength for SCC with SF was $R^2$ of 0.88, suggesting good correlation between them while the data obtained from SCC with FA mixtures exhibited more scatter with $R^2$ of 0.74 (see Fig. 7a). It is suggested that this is a

result of the much finer pore structure of the paste in SCC that contains SF, which will allow hydration to proceed uninhibited (Bai *et al.*, 2002).

On the other hand, it can be seen from Fig. 7(b) that the correlation coefficients $R^2$ between the carbonation coefficient and compressive strength were 0.78 and 0.71 for SCC specimens with SF and FA, respectively. And, the carbonation coefficients of SCC with FA decrease with increase in the compressive strength, which is similar to the trend of concrete observed by various researchers (Atis, 2003; Sulapha *et al.*, 2003; Castro *et al.*, 2000). This can be attributed to the reason that both carbonation and compressive strength are significantly controlled by pore structure of concrete especially for SCC specimens with FA (Khunthongkeaw *et al.*, 2006). However, also as pointed out by Kulakowski *et al.* (2009) the carbonation coefficient increases with the increase in SF content whilst the compressive strength of SCC specimens with SF exihibits improvements. Since SF starts reacting earlier than FA (Pane and Hansen, 2005), SF cannot competely block the pores to prevent the ingress of $CO_2$ at a later time as FA. But, the values of carbonation coefficient exhibited a slight increase with 4% whilst the replacement of PC by SF increases from 5% to 20% and the compressive strength indicated an important increase with 15%. Hence, it can be said that SF content and the compressive strength development had not an important effect on the carbonation resistance of SCC with SF.

Compared with the correlations between sorptivity and carbonation coefficient of SCC, the sorptivity coefficient has correlation with carbonation coefficient, of which exponential correlation coefficients is $R^2$=0.90 and 0.99 for SCCs with SF and FA, respectively (see Fig. 8). There is a strong correlation between sorptivity and carbonation coefficient as the binder composition of PC-SF or FA in SCC is varied. It can be observed from Fig. 8 that the carbonation rate of SCC specimens with FA increases with increase in the sorptivity, while the replacement of PC by FA increases from 25% to 40% at 5% intervals. However, the carbonation and the sorptivity coefficient of SCC with SF had inverse type of relationship, that is, the carbonation rate of SCC specimens with SF increases with decrease in the sorptivity, while the replacement of PC with SF increases from 5% to 20%
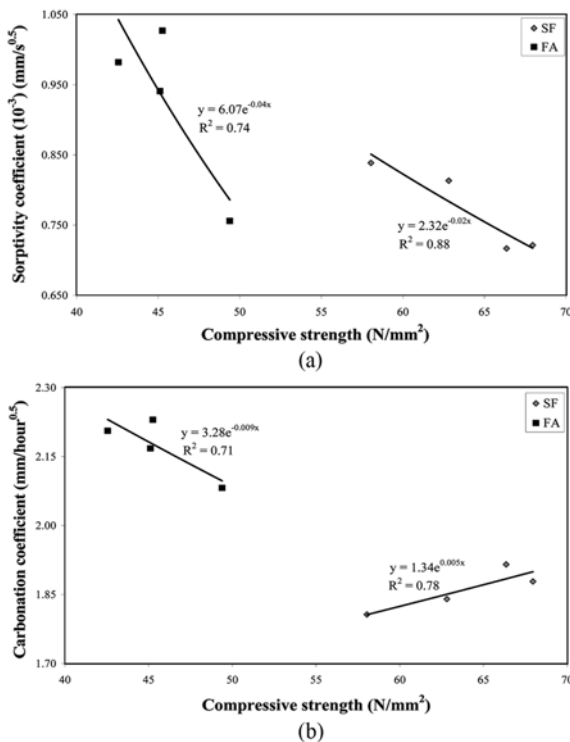


Fig. 7. Effect of SF and FA on Correlation between Compressive Strength: (a) Sorptivity Coefficient, (b) Carbonation Coefficient of SCC
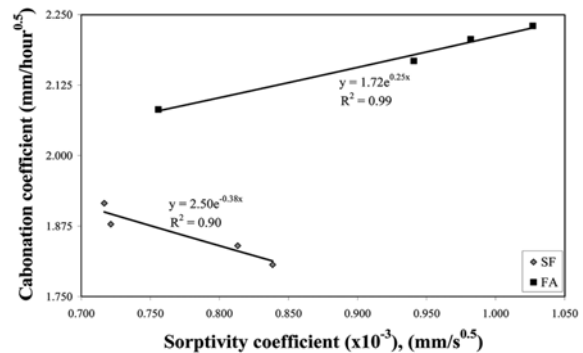


Fig. 8. Effect of SF and FA on Correlation between Sorptivity and Carbonation Coefficient of SCC

at 5% intervals. Finally, it can be emphasized that type and quantity of powder additions had an important effect on the correlation among the compressive strength, sorptivity and the carbonation coefficient of SCC.

## 4. Conclusions

1. SCC specimens with FA and SF had the lower compressive strength than SCC with only PC for 3 days whilst VTC specimens had the lowest compressive strength for all curing time. SCC with SF had the highest compressive strength for 7, 28 and 130 days. Furthermore, SCC with FA40 had the highest compressive strength with 59.04 MPa for the periods of 130 days compared to mixtures containing FA.

2. SCC mixtures with SF had the lowest sorptivity values followed by VTC, SCC with only PC and SCC with FA. Furthermore, the water sorptivity values of SCC specimens with SF decreased with increase in the replacement level of SF from 5 to 20% whilst the water sorptivity values of SCC specimens with FA systematically increased with increase in the replacement level of FA from 25 to 40%.

3. The carbonation resistance of VTC was lower than that of all SCC specimens for all accelerated carbonation periods. The carbonation resistance of SCC specimens decreased with the increase of SF and FA replacement. Moreover, the carbonation depth of SCC specimens with FA was the highest in all concrete mixes for all accelerated carbonation periods. On the other hand, it can also be seen from statistical evaluation that dosage of SF had insignificant effect except for 24 hours on the carbonation resistance of SCC.

4. Relationships between the compressive strength and sorptivity are of exponential form whilst the compressive strength and the sorptivity of SCC with FA/SF suggested the presence of inverse type of relationship between them with $R^2$ of 0.88 and of 0.74, respectively. Moreover, the correlation coefficients $R^2$ between the carbonation coefficient and compressive strength were 0.78 and 0.71 for SCC specimens with SF and FA, respectively. The carbonation coefficients of SCC with FA decrease with increase in the compressive strength. But, the carbonation coefficients of SCC with SF increase with increase in the compressive strength. Because SF couldn't competely block the pores to prevent the ingress of $CO_2$ as FA at a later time, due to the property of its earlier reacting in comparison to FA.

5. Relationships between sorptivity and carbonation coefficient is also exponential form. The sorptivity and the carbonation coefficient of SCC specimens with SF and FA had good correlation with $R^2$ of 0.90 and 0.99, respectively. However, the carbonation rate of SCC specimens with FA increases with increase in the sorptivity whilst the carbonation rate of SCC specimens with SF increases with decrease in the sorptivity when FA and SF content increases from 25% to 40% and 5% to 20% at 5% intervals, respectively.

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