Improvement of Self-Compacting Cement Slurry for Autoclaved SIFCON Containing High Volume Class C Fly Ash

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**Slurry Infiltrated Fiber Concrete (SIFCON)**

can be described as a special type of steel fiber-reinforced cement composite.

These composites are produced with fiber volume fraction values between 5 to 20% depending on fiber type.

### PRODUCTION METHOD

- Fibers are pre-placed in the forms.
- Cement rich slurry is poured or pumped into the forms.

SIFCON have superior mechanical properties such as compressive, tensile, shear, flexural strength with extraordinary toughness values.

Superior toughness property indicates the potential of using SIFCON in seismic resistant structures.
Four main factors that affect behavior of SIFCON

- Slurry strength
- Fiber volume
- Fiber alignment
- Fiber type

A cement rich flowable slurry is used as a binder in SIFCON production.

High cement content of the slurry causes:

- Excessive heat of hydration
- High production cost

These problems can be solved by using mineral admixtures.
The 28-day strength of standard cured specimens can be achieved at about only 24 h. by autoclave curing in case of reactive siliceous material incorporation.

Without silica, rapid formation of different hydration products under autoclave curing, results in a porous & weak microstructure that leads to lower compressive strength.

In stead of silica fume, fly ash, ground granulated blast furnace slag and fine quartz can be used as a silica source.

In this study, Class C fly ash was used as a silica source and effects on fresh and hardened properties of autoclaved SIFCON have been investigated.
EXPERIMENTAL STUDY

Replacement ratio of Class C FA: 20 – 40 – 60 % of cement (by weight)

Tests on slurry

(on fresh slurry)
- Mini flow test
- V funnel test
- J penetration test

(on autoclaved hardened slurry)
- Flexural test
- Compressive str. test

Tests on autoclaved SIFCON

- Flexural test
- Compressive str. test (both parallel and perpendicular to fibers)
- Splitting tensile test (both parallel and perpendicular to fibers)
SP dosage was regulated to obtain similar flow diameter and adequate viscosity (without any bleeding and segregation).
### Materials

#### Cementitious materials

**Portland Cement (CEM I-42.5 – N)** & **Class C fly ash (Soma Power Plant)**

<table>
<thead>
<tr>
<th>Chemical Composition (%)</th>
<th>Physical Properties of Cement</th>
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<tbody>
<tr>
<td></td>
<td>Cement</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>20.05</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>5.62</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>2.17</td>
</tr>
<tr>
<td>CaO</td>
<td>62.92</td>
</tr>
<tr>
<td>MgO</td>
<td>1.14</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>0.30</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.85</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>2.92</td>
</tr>
<tr>
<td>Cl$^-$</td>
<td>0.0096</td>
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<tr>
<td>Loss on ignition</td>
<td>3.84</td>
</tr>
<tr>
<td>Insoluble residue</td>
<td>0.63</td>
</tr>
<tr>
<td>Free CaO (%)</td>
<td>0.52</td>
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</tbody>
</table>
Aggregate
Crushed limestone with a maximum size of 500 µm

Superplasticizer
Polycarboxylate type meeting standard specifications of ASTM C 494 Type F

Fiber
Hooked and steel fibers.
Fiber dimensions: 30 mm long with the diameter of 0.55 mm.
The aspect ratio and tensile strength of the fiber are 55 and 1100 MPa, respectively.
**FRESH STATE TESTS**

- **Mini flow test**
  - Final spread diameter was measured in two perpendicular directions and the average diameter value was recorded as final spread in mm. The time required to reach 20 mm diameter was also measured by using a stopwatch and regarded as t20 time.

- **V-funnel test**
  - Fresh slurry was poured into the funnel without any vibration effort. The time was measured from opening the gate to when it is possible to see light for the first time. This flow time was regarded as V-funnel time in sec.

- **J-penetration test**
It is used to assess filling ability of the slurry into the fiber network.

The door of the apparatus is closed and the section for fibers is filled with a random pour of 1.9 kg of fibers which correspond to 8% by volume.

Slurry is cast into the higher column of the equipment, where no fibers are present, to a height of 470 mm.

After casting the slurry into the J-FPT apparatus the door is opened and the slurry is allowed to pass through the fibers.

The decrease of slurry height in higher column of apparatus after opening the door is measured. 270 mm descending of slurry level regards as **FULL** penetration.
Flexural and compressive strength of the slurry (without fibers) were determined on prismatic samples (40×40×160 mm) which cast without any vibration energy.
Fiber volume was calculated according to the volume of the mold for each specimen. Fiber volume of the samples was 8%.

At the first stage, fibers were pre-placed into the molds and then fresh slurry was poured without any vibration effort.

Compressive and splitting tensile strength were determined on 100 mm –cube specimens

Flexural strength and toughness were determined on prismatic specimens
The specimens were kept in the molds for 16 h at room temperature of 20±2 °C. After demolding, the specimens were autoclaved at 210 °C and under 2.0 MPa pressure for 8 hours. After completion of their autoclave period, the specimens were kept in laboratory atmosphere at 20 ± 2 °C for 24 h, and then compressive, splitting tensile and flexural tests were applied at the age of 2 days, after their preparation.
Prismatic specimens were subjected to flexural strength test according to ASTM C348. The specimens were loaded from their mid span and the clear distance between simple supports was 120 mm. The compressive strength tests were performed following the flexural tests. The two broken pieces left from flexural test were subjected to compressive strength test.
TESTS ON AUTOCLAVED SIFCON SAMPLES

COMPRESSIVE and SPLITTING TENSILE STRENGTH TESTS

100 mm – cubic specimens was used in compressive and splitting tensile test
FLEXURAL STRENGTH AND TOUGHNESS

Prismatic specimens with 305 mm length, 60 mm width and 25 mm height were used.

Four point bending test.

Flexural specimens were tested at the loading rate of 1 mm/min up to mid-span deflection of 15 mm.

Load – displacement curve was logged to a computer at 5Hz frequency.

The toughness is defined as the area under the load-displacement curve up to the mid-span displacement of 15 mm.
FRESH SLURRY SHOULD SATISFY THESE CRITERIA

- APPROPRIATE FLOWABILITY
- ADEQUATE VISCOSITY
- HIGH FILLING ABILITY (FULL J-PENETRATION)

Many trial slurry mixtures were prepared to satisfy these criteria.

The mixtures which have 340-380 mm spread diameter, V-funnel flow time of between 5-13 sec. and full J penetration were accepted as suitable mixtures.

Over SP dosages than optimum values determined by trials resulted in bleeding and segregation, while lower dosages resulted in insufficient fluidity and/or excessive viscosity.
EXPERIMENTAL RESULTS

**Fresh Slurry Properties**

<table>
<thead>
<tr>
<th></th>
<th>FA0</th>
<th>FA20</th>
<th>FA40</th>
<th>FA60</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP dosage (%)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Spread $t_{20}$ (sec)</td>
<td>1.1</td>
<td>2.0</td>
<td>1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Final spread (mm)</td>
<td>340</td>
<td>360</td>
<td>380</td>
<td>380</td>
</tr>
<tr>
<td>V-funnel time (sec)</td>
<td>6.0</td>
<td>7.7</td>
<td>7.2</td>
<td>12.1</td>
</tr>
<tr>
<td>J-penetration</td>
<td>full</td>
<td>full</td>
<td>full</td>
<td>full</td>
</tr>
</tbody>
</table>

SP dosage has been increased with an increase in FA content due to high absorption capacity of FA.

Final diameter of the mixes were between 340 – 380 mm

FA60 mixture gave the highest V-funnel time and $t_{20}$ spread time as a result of higher viscosity.

Despite the relatively high viscosity of FA60 slurry J-penetration test was satisfied.
EXPERIMENTAL RESULTS

Effect of FA replacement on compressive and flexural strength of the autoclaved slurry (without fibers)
Compressive and flexural strengths of FA containing slurry mixtures are higher than that of no FA containing slurry mixture.

Increasing the FA replacement ratio significantly increased the compressive strength of the mixtures. Similar trend was observed in flexural strength up to 40% FA replacement. Above this ratio flexural strength was not changed significantly.

60% FA replacement has resulted about 229% and 121% increase in compressive and flexural strength, respectively.
The effect of FA on compressive and splitting tensile strength of SIFCON samples in both loading to perpendicular and parallel to the fibers.
Loading directions affects the SIFCON performance.

Increasing the FA content has positively affected the compressive and splitting tensile strength of autoclaved SIFCON mixtures in both loading perpendicular and parallel to fibers

Loading perpendicular to the fibers gave higher strength values than loading parallel to the fibers in all FA replacement ratios
Effect of FA replacement ratio on perpendicular to parallel strength ratio in compressive and splitting tensile tests.
Perpendicular to parallel strength ratio remarkably decreased with increasing FA ratio for both compressive and splitting tensile strength.

Incorporation of FA in autoclaved SIFCON reduced sensitivity to anisotropy possibly due to the increased slurry strength.
Load - displacement curves of autoclaved SIFCON mixtures containing different amounts of FA.
Fly ash replacement has positively affected the flexural behavior of SIFCON. This behavior can be attributed to the improvement in matrix phase, which also improves the bond strength between the fibers and matrix as well as the compressive and flexural strength.

Residual strength at 15 mm displacement was also higher in FA40 and FA60 series than FA0 and FA20 series.
The effect of FA replacement on flexural strength and toughness
While the flexural strength of FA0 mixture, which doesn’t have any fly ash, is 28.3 MPa., flexural strength of FA60 mixture that containing 60 % Class C fly ash is 59.1 MPa with increasing of 109 %

Toughness values of FA60 specimens increased about 127% compared to FA0 specimens
CONCLUSIONS

Test results showed that, FA incorporation increased the viscosity of slurry. However, it can be controlled with using proper amount of SP. Thus, high volume FA slurry, that has proper flowability and filling ability into high volume fiber network without vibration effort, can be produced.

J penetration test is a useful tool to assess the filling ability of SIFCON slurry into the fiber network.

Class C fly ash replacement improved the mechanical behavior of autoclaved slurry and SIFCON specimens remarkably. Test results indicated that fly ash can be used as a silica source for autoclave curing. Class C fly ash replacement seems to be feasible solution for SIFCON production especially under autoclave curing.
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for their material supports
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