Third International Symposium on Self-Compacting Concrete

Reykjavik, Iceland
17-20 August 2003

EDITED BY
Ó. WALLEVIK
AND
I. NIELSSON

The Icelandic Building Research Institute

RILEM Publications S.A.R.L.
Committee Members

Scientific Committee

Åke Stranlundh, Sweden, Chairman of RILEM TC 188-CSC
Per Billberg, Sweden, Secretary of RILEM TC 188-CSC
Harald Beizel, Germany
Rui Khairul Van, USA
Vinçiane Dieryck, Belgium
Alcira Oreh, Canada
Ian Gibb, UK
Julian J. Gidley, Scotland
Michael Khapko, New Zealand
Andreas Leemann, Switzerland
Indriði Ínasson, Iceland
Thomas Osterberg, Sweden
David Revuelta, Spain
Geert De Schutter, Belgium
Mohammed Sonen, Scotland
Ólafur H. Wallevik, Iceland, chairman

International Advisory Committee

Dirk Bager, Denmark
H. Wim Buurman, Netherlands
Denis Beaupre, Canada
Chao, Vin-Chen, Taipei
François Cussigh, France
Peter Domone, UK
Mas Emborg, Sweden
Kavinda Gettu, Spain
Steinar Helland, Norway
Terry Holland, USA
Frank Jacobs, Switzerland
Klaus Juvás, Finland
Hans Reinhardt, Germany
C. I. Tan, Singapore
Qin Weimin, China

Local Organizing Committee

Arnir Isberg
Edda S. Sveinsdottir, chairman
Eyþór R Thórahallsson
Gísli Guðmundsson
Gudni Jónsson
Györg Sigurdsson
Heiði Haakasson
Leo Jonsson
Sveinbjörn Sveinbjörnsson
Rognvaldur S. Gissiason
40. PRE-TESTING OF SELF-COMPACTING CONCRETE WITH VARIOUS MINERAL ADDITIVES AND ADMIXTURES
Katarina Paulin

47. A COMPARATIVE STUDY ON THE USE OF MINERAL AND CHEMICAL TYPES OF VISCOSITY ENHANCERS IN SELF-COMPACTING CONCRETE
Burak Polatçıl, Met Uluç Yardımcı, Ebulen Baradan

48. USER FRIENDLY SELF-COMPACTING CONCRETE IN PRECAST PRODUCTION
M Carradi, R. Khurana, R. Magarotto

49. PERFORMANCE OF SELF-CONSOLIDATING CONCRETE MADE WITH VARIOUS ADMIXTURE COMBINATIONS
S.-D. Hwang, D. Mayen-Reyna, O. Bonneau, K.H. Khayat

F. MIX-DESIGN AND PRODUCTION

Keynote lecture:

30. PRODUCTION OF SCC
François de Larrard, Bogdan Cazaciu, David Chopin, Eric Château

31. REFERENCE CONCRETES FOR EVALUATION OF TEST METHODS FOR SCC
Tine Aarre, Peter Domone

32. MIX DESIGN OF HS-SCC AND PRACTICAL APPLICATION
Indridi Nielsson, Ulafur H. Wallevik

33. DEVELOPMENT AND OPTIMISATION OF MEDIUM STRENGTH SELF-COMPACTING CONCRETE BY USING PULVERISED FLY ASH
Mohammad Serab, Ali Bahadori Jashomi, Peter M. Bartus

34. THE MIXTURE PROPORTION AND PROPERTY OF SCC
Lung-Sheng Li, Chao-Lung Hwang

35. DEVELOPMENT OF HIGH-STRENGTH SELF-COMPACTING CONCRETE WITH REDUCED SEGREGATION POTENTIAL
K. Srinivasaraj, D. Silva, K. Adamoukou

36. THE STUDY ON MIXTURE PROPORTION OF GRADATION OF AGGREGATE FOR SCC
Yuan-Yuan Chen, Chi-Ts Tsai, Chan-Lung Hwang

37. CHARACTERISATION OF FILLER
Helena Moolberg Busnec
A COMPARATIVE STUDY ON THE USE OF MINERAL AND CHEMICAL TYPES OF VISCOSITY ENHANCERS IN SELF-COMPACTING CONCRETE

Barak Feleknas, Metin Yeşil Yarımçı, Bulent Baradan

Department of Civil Engineering, Dokuz Eylul University, Kaynaklar Kampusu, 35160, Buca-Izmir, Turkey

ABSTRACT: It is important to maintain adequate viscosity in order to obtain sufficient fluidity in self-compacting concrete. If the viscosity is too high or too low, there is a risk of blocking when fresh concrete is forced to pass through narrow obstacles. On the other hand, if the viscosity is too low, the ability to maintain its fluidity is reduced. Liquid components of concrete (water and superplasticizers) have a tendency to decrease the viscosity of fresh concrete at different magnitudes, so there is a need to use viscosity enhancers for highly fluid and stable concretes. There are two ways of increasing the viscosity of concrete: first to increase the powder content, second to incorporate a viscosity-modifying chemical admixture.

The aim of this paper is to present the results of an experimental study between self-compacting concretes incorporating two types of powders (C-type fly ash, limestone powder) and semi-synthetic cellulose-based chemical type of viscosity modifiers. Self-compatibility and compressive strength tests have been performed comparatively on both series. Test data indicated that powder-type viscosity modifiers are more effective in both fresh and hardened state properties. The better performance of mineral powders in the fresh state, can be explained by relatively increased volume of paste which has an important role on the fluidity and stability properties. In the hardened state, the effectiveness of powders can be attributed to the increased solid phase of paste suspension resulting in a denser microstructure. Also, the Pozzolanic properties of fly ash contributed to the strength development of self-compacting concrete.

KEYWORDS: SCC, Viscosity enhancers, fly ash, starch, semi-synthetic cellulose derivative.

I. INTRODUCTION

In the last decades Self-Compacting Concrete (SCC) is being increasingly used in construction, yet many mix-proportioning methods have been developed and proposed (Karaman & Occhii, 1990, Sedran & de Larrard, 1990, Bui & Montgomery, 1999, Su et al., 2001, Seah et al., 2001). Self-compatibility refers to the ability of fresh mixtures to deform and undergo change in shape and pass through obstacles under its own weight without exhibiting segregation, thus ensuring proper filling of the formwork and high performance. Deformability of concretes is generally achieved by limiting the volume of coarse aggregate to reduce the inter-particles collision and the flow resistance. On the other hand the resistance to segregation is achieved by reducing the water to cementitious materials ratio, increasing the cohesiveness of the paste (Yuhla et al., 1999).

In general, SCC must exhibit low yield value and adequate workability (moderate viscosity). In order to achieve the optimum mix design of SCC, it is important to use the right combination of powder or chemical type viscosity modifiers (Senekl et al., 2009).
The stability of fresh concrete refers to its ability to resist bleeding, sedimentation and segregation that depends on the cohesiveness and viscosity of the mixture (Khayat, 1998). Highly stable mixtures that can flow readily into place with limited consolidation effort can be obtained by combining proper concentrations of viscosity-modifying admixtures (VMA) and a high range water reducer (HRWR). Commonly used VMAs in concrete include cellulose derivatives and polysaccharides of microbial sources, in particular wean gum (Khayat & Guizani, 1997).

Khayat (1995) classified the water-soluble VMA’s as follows:
1. Natural polymers, including starches, guar gum, locust bean gum, alginites, agar, gum arabic, wean gum, xanthan gum, thrombin gum, and gellan gum, as well as plant protein.
2. Semi-synthetic polymers, such as decomposed starch and its derivatives, cellulose-ether derivatives and electrolytes.
3. Synthetic polymers, including those based on styrene and vinyl.

The incorporation of a VMA affects the aqueous phase of the cement paste where chains of the water-soluble polymer can inhibit some of the free water in the system, thus reducing the free water content and enhancing the viscosity of the paste. The increase in VMA dosage increases significantly the viscosity of the aqueous phase that improves the capacity of the paste to suspend solid particles. It also increases the yield value of the paste that limits the deformability of the concrete. Therefore, HRWR is needed to maintain a relatively low yield value; hence, any loss in fluidity can be regained without significantly reducing the stability of the concrete. When an excessive dosage of HRWR is added to the concrete, the cohesiveness can decrease, in addition to the greater free water content resulting from the use of superplasticizers that can result in more bleeding. The superplasticizer can delay the setting time, hence necessitating a stable concrete for longer duration (Khayat, 1998).

VMA is mainly used to reduce the variability of the SCC that can arise from changes in material properties and placement conditions (Hibino, 2000 - Sedran, 2000). This can provide more flexibility in selecting basic mixture ingredients that are economically accessible. The VMA controls bleeding and renders the concrete more robust, while the low water content provides mostly the required level of viscosity (Khayat et al., 1999). Okamura and Ozawa (1994) showed that using viscosity agent, the water content per m3 could be varied with as much as 15% without imposing SCC properties. But if there is change in water content can take place unnoticed, the water-cement ratio is changed, thus also affecting the strength of hardened concrete (Embreg, 2000).

The viscosity agents showed different degrees of effectiveness on cohesion of the fresh mixes. Even small additions of such admixtures may have a significant impact on the fresh concrete properties. Those showing a very powerful effect were difficult to control, and those with a weak effect were not able to keep cohesiveness. A combination of agents of both types may keep this effect under control (Pettersson, 1995-1). Most viscosity agents entrain a lot of air that can reach up to 15 percent in some cases (Khayat, 1995). Air content can be reduced by using an antifoaming agent with a dosage from 0.25-0.50% of the superplasticizer content in combination with the viscosity agent (Pettersson, 1995-2). Alternatively, wean gum, a kind of natural water soluble polysaccharide, is very effective in stabilizing SCC and little activity at the air-water interface and thus, does not generate foam or entrap large volumes of air. However, its cost is the main problem (Roe et al., 1999).
When the viscosity agents are used in ordinary ready-mixed concrete plants, additional process are needed such as establishing weighing equipment for the viscosity agents or inserting the viscosity agent powder into the mixer by hand (Yamamuro, 1999). However due to the small quantities of viscosity agents required, it may be difficult to achieve accuracy of dosage (Tviksta, 2000).

Another way to enhance the stability of fluid concrete is to increase the concentration of fine particles. The incorporation of one or more powder materials having different morphology and grain size distribution, can improve particle packing density and reduce interparticle friction and viscosity, hence improving deformability, self-compaction, and stability (Sonebi et al. 2000). The use of powder materials such as fly ash, blast furnace slag, or limestone filler can enhance the grain-size distribution and particle packing, thus ensuring greater cohesion (Khayat & Guizani, 1997).

According to Fesselmann (1997-2), the viscosity agent that maintains the cohesion of the concrete, a certain quantity of filler must also be introduced to the mixture. With new generation superplasticizers and fibers, the viscosity agents are normally not required. Only for special applications an extra viscosity agent may be used.

2. EXPERIMENTAL STUDY

The aim of this study is to compare viscosity agents with different mineralogical and chemical origin, in order to optimise the viscosity of SCC. To obtain self-compaction and desired strength requirements it is important to find out the right type and quantity of viscosity modifiers in combination with a superplasticizer.

2.1 Material Properties

2.1.1 Cement

The chemical and physical properties of Type-I Portland Cement used in this study are presented in Table 1. PC 42.5 was a product of Cemmenta Cement Plant, İzmir, Turkey.

<table>
<thead>
<tr>
<th>Oxide composition</th>
<th>SiO₂</th>
<th>AI₂O₃</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>SO₃</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>CI</th>
<th>Free</th>
<th>Loss</th>
<th>C/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>63.62</td>
<td>19.69</td>
<td>5.19</td>
<td>3.38</td>
<td>0.93</td>
<td>0.25</td>
<td>0.80</td>
<td>0.012</td>
<td>1.18</td>
<td>1.16</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specific gravity</th>
<th>Specific surface Blaine (m²/kg)</th>
<th>Visc set time (min)</th>
<th>Compressive strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Final</td>
<td>2 days</td>
</tr>
<tr>
<td></td>
<td>3.15</td>
<td>339</td>
<td>195</td>
</tr>
</tbody>
</table>

2.1.2 Aggregate

The coarse aggregates were crushed limestone with a 15 mm maximum aggregate size. As fine aggregate, river sand was used. The physical properties of aggregates are given in Table 2. In mix proportioning stage, two types of gradations were used and referred as fine and coarse grading. Grading curves are presented in Fig. 1. In the mix-proportioning step aggregates were used in saturated surface dry condition. The other properties of aggregates were in conformity with the related standards (TS 796).
Table 1. Physical properties of aggregates

<table>
<thead>
<tr>
<th></th>
<th>Specific Gravity</th>
<th>Absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed limestone (5-15mm)</td>
<td>2.71</td>
<td>0.39</td>
</tr>
<tr>
<td>River Sand (0-4mm)</td>
<td>2.50</td>
<td>1.43</td>
</tr>
</tbody>
</table>

*Saturated surface dry condition

Figure 1. Grading curves of coarse and fine mixes.

2.1.3 Superplasticizer

The superplasticizer (SP) was a "polycarboxylate-acid" type, commercially branded as HES 100 "Smartflow" produced by Koken Science and Technology Production Corporation, Izmir, Turkey. It is an ASTM C 494, F-type high-range water reducer. The solid content, pH and specific gravity of admixture were 35.7 percent, 6.5 and 1.11, respectively.

2.1.4 Viscosity Modifiers

Two mineral and two chemical admixtures from different sources were employed in order to increase the viscosity of mixes. Mineral additions were limestone powder and fly ash. A semi-synthetic cellulose derivative (SSCD) in powder form was used as chemical viscosity modifier and powder starch was also introduced as organic viscosity modifier.

A quarry flintstone dust (limestone powder), which is basically a waste product in the production of concrete aggregates during the crushing process, was used as an inert additional powder in order to enhance viscosity. Its specific gravity and Blaine fineness were 2.38 and 443 m²/kg respectively.

Fly ash has been introduced as another powder type of viscosity modifier. With its pozzolanic nature it is also especially effective in long term strength development. Its specific gravity and Blaine fineness were 2.06 and 290 m²/kg respectively. The other properties were also in conformity with the related standards (ASTM C311 & ASTM C618).

2.2 Experimental Program

The experimental study has been planned in two stages. First, the influence of four types of viscosity modifiers on fresh and hardened properties of concrete with two types of aggregate gradings were investigated. Second, the effect of viscosity modifying agents on setting time of mortars were determined.

All agents were used in powder form but limestone powder and fly ash were also employed as additional filler materials in high quantities to answer the powder need of SCC without incorporation of chemical viscosity modifier. SSCD and starch were used at low amounts as
chemical admixtures. All mixes have the same amounts of cement and water content with two types of aggregate gradings named as fine and coarse respectively. The mixture proportions are presented in Table 3.

<table>
<thead>
<tr>
<th>Mix code*</th>
<th>LPC</th>
<th>LPF</th>
<th>SCD-C</th>
<th>SCD-F</th>
<th>FA-C</th>
<th>FA-F</th>
<th>ST-C</th>
<th>ST-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/C**</td>
<td>0.55</td>
<td>0.55</td>
<td>0.55</td>
<td>0.55</td>
<td>0.55</td>
<td>0.55</td>
<td>0.55</td>
<td>0.55</td>
</tr>
<tr>
<td>W/IP*</td>
<td>0.31</td>
<td>0.31</td>
<td>0.55</td>
<td>0.55</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>IP/IP*</td>
<td>0.91</td>
<td>0.91</td>
<td>1.73</td>
<td>1.73</td>
<td>0.82</td>
<td>0.82</td>
<td>1.73</td>
<td>1.73</td>
</tr>
<tr>
<td>Cement (kg/m³)</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>Limestone powder (kg/m³)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fine/crude aggregate (by weight)</td>
<td>1.13</td>
<td>1.00</td>
<td>1.13</td>
<td>3.00</td>
<td>1.12</td>
<td>2.03</td>
<td>2.03</td>
<td>2.03</td>
</tr>
<tr>
<td>SP (cement % by weight)</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Starch (cement % by weight)</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
</tbody>
</table>

** Effective W/C and IP/IP ratio are given.

The self-compactibility of the mixes were maintained by adjusting the superplasticizer dosage. In fact, the mixed slump-flow (SF) value depends on the SCC mix design and the casting configuration. There is no single excellent SF value to reach. That is why it is important to characterize the mix-design before the start of works. It is important to define acceptance criteria in terms of SF values, according to the site specifications and the properties of concrete. In this study, the slump flow target range has been chosen rather wide due to the different characteristics of viscosity enhancers. Dosage of superplasticizer has been increased in order to obtain slump-flow values in the range of 85-90 cm without causing any significant segregation and bleeding. Due to the high viscosity of some mixes, measurements of slump flow were delayed for 1 min following the removal of the cone to give enough time for completion or flow.

After having the acceptable slump flow values without causing any significant segregation, the V-funnel, L-box and air content tests were conducted. The apparatus used in V-funnel and L-box were in conformity with the standard procedures given by EFNARC (2002). The air contents of fresh concrete were measured by using a pressure meter according to ASTM C231.

In order to investigate the strength development, nine 15-cm cubic specimens were prepared. The molds were tried without any compaction. Demolding of the specimens were planned to 24 hours after casting. However, in all mixes except the mixes with limestone powder, demolding after 24 hours was not possible due to the low strength development. These specimens were demolded two days after the preparation. After demolding, specimens were cured in lime water until the day of testing. The compressive strength test results for different ages (1, 2, 7 and 28 days) are presented in Table 6.

In order to investigate the influence of viscosity modifiers on setting time of mortars, four mixes with similar properties with the mortar phases of concrete mixes were prepared. The composition of mortar mixes and mini-slump flow values in conformity with the procedure given by EFNARC (2002) are shown in Table 4. The setting time measurements were conducted in accordance with T5 EN 460-2 by using a modified procedure. The only modification is on the determination of spread values. Spread values has not been kept
constant, since the aim of this part of study was to investigate the effect of combination of
viscosity modifiers and superplasticizer on setting time at exact dosages.

| Mortar mix proportions | C : W : LSP : FA | S | sp dosage | SSCD | ST | mini-slumpflow
|------------------------|------------------|---|-----------|------|----|----------------
| LSP                    | 1.84 : 1.03 : 0 | 7.23 | 1.8 | 2.2 | 208 |
| SSCD                   | 1.84 : 1.03 : 0 | 7.23 | 1.8 | 2.2 | 155 |
| FA                     | 1.84 : 1.03 : 0 | 7.23 | 1.8 | 2.2 | 222 |
| ST                     |                 | 7.23 | 1.8 | 2.2 | 175 |

3. TEST RESULTS AND DISCUSSIONS

3.1 Fresh Concrete Results and self-compactibility concept

The slump flow of mixes ranged between 62 and 66 cm which refers to the mean spread
diameter of concrete following the removal of the slump cone. The findings of fresh concrete
tests are presented in Table 5.

<table>
<thead>
<tr>
<th>Mix no</th>
<th>LP-C</th>
<th>LP-F</th>
<th>SSCD-C</th>
<th>SSCD-F</th>
<th>FA-C</th>
<th>FA-F</th>
<th>ST-C</th>
<th>ST-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump-flow (cm)</td>
<td>66</td>
<td>69</td>
<td>66</td>
<td>65</td>
<td>70</td>
<td>73</td>
<td>73</td>
<td>66</td>
</tr>
<tr>
<td>V-funnel time (sec)</td>
<td>20</td>
<td>24</td>
<td>14</td>
<td>13</td>
<td>15</td>
<td>21</td>
<td>22</td>
<td>12</td>
</tr>
<tr>
<td>L-box blocking ratio (h/y)</td>
<td>0.85</td>
<td>0.85</td>
<td>0.75</td>
<td>0.85</td>
<td>0.85</td>
<td>0.95</td>
<td>0.95</td>
<td>0.3</td>
</tr>
<tr>
<td>Air Content (%)</td>
<td>3.1</td>
<td>3.5</td>
<td>3.8</td>
<td>4.2</td>
<td>4.2</td>
<td>4.2</td>
<td>4.2</td>
<td>4.2</td>
</tr>
</tbody>
</table>

As can be seen from Table 5, starch showed no significant increase in viscosity. Its
performance was negligible. On the other hand SSCD showed a powerful effect on viscosity
with very low dosages but at the same time, it increased the superplasticizer demand of the
mixes.

Nevertheless, mineral viscosity enhancers were more effective than the chemical types. The
highest viscosity (long V-funnel time) and the lowest yield stress (large slump-flow diameter)
were obtained with the mixes incorporating fly ash. Fly ash provided a higher viscosity and
lower yield stress than limestone powder. With fly ash it was possible to get a higher slump
flow without increasing the risk for segregation. On the other hand, for self-compactibility
the incorporation of fly ash required a higher dosage of superplasticizer than the limestone
powder.

The results of blocking tests in L-box presented in Table 5, indicate that the lean mixes
produced by using SSCD and starch having a low paste content had a tendency for blockage.
Consequently, in mix proportioning of SCC with SSCD and starch, addition of mineral
powder was necessary to increase the volume paste to avoid blocking.

The L-box blocking ratios obtained from mixes with richer paste content (LSP, LSP-C, FA-F and FA-C) indicate that, the finer the aggregate grading gives the better the resistance
to blocking. But it must be kept in mind, that for the same aggregate content, smaller
aggregate diameters leads to more interparticle contacts, than coarser aggregates due to its
higher specific surface area. These contacts definitely increase the yield stress.
3.2 Mortar Setting Times

The setting times of mortar mixes are presented in Figure 2. The investigated mortars were prepared by using a cement with 105 & 175 minutes of initial and 175 final setting times respectively. From the figure it is clear that if starch and SSCD are used, the setting times delayed in different manners. The retardation of setting time can be attributed to the high content of superplasticizer requirement (~5% by weight of cement) due to side retarding effects of superplasticizers. Starch extended the final set time to an unacceptable time period. However, the increase of initial setting time was tolerable. On the other hand, SSCD showed a delaying effect on both the initial and final setting times.

![Figure 2. Setting time of mortars](image)

As shown in Figure 2, the mix prepared with LSP gave the lowest retardation effect on setting time. The results were confirmed with the different allowable formwork removal times.

The results obtained from setting time measurements showed that fly-ash can lengthen the setting times of mortars in combination with superplasticizer. Banou et al. (2000) reported the similar findings.

In this study, all chemical type viscosity agents delayed the setting time. However, Petersson (1990) reported that some chemical type of viscosity agent reduced the setting time. The effect of viscosity agent on setting also depends on the type and amount.

3.3 Compressive Strength Developments

The most critical influence of a viscosity agent is to change in concrete strength development. The strength development of mixes is presented in Table 6 and plotted in Figure 3 and 4.

Introduction of a chemical viscosity agent considerably decreased the early strength values. On the contrary, mixes with limestone filler have revealed increases in earlier strength values. Similar results have been presented by Petersson (1990). They have also claimed that limestone filler can also replace cement. This may be explained by the use of a cement, rich in C3S being very reactive at early ages. And also by the presence of powdered limestone, which influences early age hydration of cement that leads to formation of a denser structure and does not possess any pozzolanic activity. Rose et al. (1999) claimed that the reaction of very fine limestone with C3S leads to the formation of calcium carboaluminate which contributes to the early strength development of SCC mixes.
The use of fly ash together with Portland cement causes a reaction between glassy phase of fly ash and calcium hydroxide generated from the hydration of Portland Cement, which leads to the formation of additional C-S-H gel and results in higher density and strength (Dahou et al., 2000). On contrary to limestone filler, fly ash contributes to the late strength of mixes due to its pozzolanic nature.

As can easily be seen from Fig. 3, FA-F mix has reached 28 day compressive strength value of 58.1 MPa. It should not be forgotten that, this SCC composition has a cement dosage of 340 kg/m³. It is not an easy task to reach this value in conventional concrete with this cement content.

As for usage of SCCD showed detrimental effects both on the early and 28-days compressive strength. This effect can be explained by the high water absorption property of the chemical. SCCD absorbed a huge proportion of the mixing water and increased the superplasticizer need. High dosage of superplasticizer retarded the setting time as expected. High volumes of absorbed water lead to the formation of un-impinged pores filled with water, which has negative effects on strength.
4. CONCLUSIONS

The following conclusions can be drawn at the end of this study:

- It is a better choice to maintain the stability of self-compacting concrete by using limestone powder and fly ash rather than chemical admixtures such as starch or semi-synthetic cellulose derivative (SSCD). Performance of mineral powder rich mixes were much better than lean mixes with viscosity-enhancing organic or semi-organic admixtures on both self-compatibility, setting time and on compressive strength development.

- The best performance, on early strength development has been obtained by incorporation of limestone powder. Also superplasticizer requirement is lowest for self-compatibility for both of the two aggregate gradings when compared with the other viscosity modifiers. Mixes with fly ash showed poor early strength development due to the slow pozzolanic reaction nature of fly ash. However the best performance on 28 days compressive strength has been observed in mixes with fly ash. By incorporating fly ash, it was possible to produce high strength self-compacting concrete (~60 MPa) with cement contents as low as 140 kg/m³.

- The highest viscosity (long V-funnel time) and the lowest yield stress (large slump-flow diameter) have been obtained with mixes incorporating fly ash. With fly ash it was possible to get self-compatibility with a higher slump flow without increasing the risk of segregation.

- The influence of aggregate content on blocking is more significant when the paste content is not sufficient. Mixes with SCCD and starch, containing high proportions of aggregate showed poor performance in blockage problems.

The richness of paste content is beneficial with the fines the aggregate grading in terms of resistance to blocking. But it must be kept in mind that, for the same aggregate content, smaller aggregate diameters leads to more interparticle contacts, than coarser aggregates due to its higher specific surface area. These contacts definitely increase the yield stress.

Outlook for further research

This study has shown the effect of separate use of two types of mineralogical and two types of chemical viscosity modifiers on SCC with the same superplasticizer. Combinations of different types, viscosity agents and superplasticizers may be examined. The use of optimum combination of powder and chemical type viscosity agents may reduce the paste volume without blocking problems with acceptable setting time and may improve the mechanical properties of concrete. Also, the durability properties of these admixtures have to be examined.

REFERENCES

RILEM Symposium on Self-Compacting Concrete, A. Skarendahl and Ö. Pettersson eds., pp.373-384.


21. TS 706 (1998), Aggregates for Concrete (written in Turkish), Turkish Standards Institute, Ankara, Turkey.


