Effect of Silica Fume on Mechanical and Fresh properties of High Strength Self Compacting Concrete

C.D. Wagh¹ S.S. Jankar²
¹P.G. Student ²Associate Professor
¹,²Department of Applied Mechanics
¹,²Government College of Engineering, Aurangabad, India

Abstract— This study presents the effect of incorporating silica fume (S.F) on the mechanical and fresh properties of high strength self-compacting concrete (HSSCC) for a constant water/binder ratio of 0.28. Fly Ash replacement was kept constant at 25%. S.F mixtures with cement replacement of 7.5, 10, 12.5 and 15% were designed for high strength and slump flow range of 650 mm to 700mm. From the results, it was observed that 12.5% replacement level was the optimum level in terms of compressive strength. Beyond 12.5% replacement levels, the strength was decreased but remained higher than the control mixture. Compressive strength of 88Mpa was achieved at 12.5% replacement for 28 days while 101.21Mpa was obtained at 90 days. Splitting tensile strength values have also followed the same trend. Slump flow, T 500, V funnel and L box tests were carried out in order to investigate the fresh properties. In workability tests S.F concretes showed lower values compared to control. This investigation has shown that the local S.F has the potential to produce high strength self-compacting concretes.

Key words: High Strength Self-Compacting Concrete, Fly Ash, Silica Fume, EFNARC

I. INTRODUCTION

Throughout its history, concrete has often been called ‘liquid stone’. Before turning into an artificial stone, concrete is indeed fluid enough, for a short period, to flow and fill a moulds. This property has given the construction industry the ability to cast structural elements such as slabs, beams and columns. The property that governs this liquid phase of concrete is known as workability. Workability of concrete is defined as the ease by which the concrete can be mixed, transported, placed, compacted and finished [1]. Taking consideration into this important property of concrete in recent years, a lot of advancement has taken place in the construction industry. Self-compacting concrete (SCC) is one of those most remarkable developments in concrete technology, Due to many advantages it possess both in the fresh and the hardened state. The American Concrete Institute defines SCC as a "highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation [2]. An adequate compaction by skilled labour is required to obtain durable concrete structures. Studies to develop a solution for this problem led to the development of self-compacting concrete and was first reported in 1989 in Japan [3]. Since then, the use of self-compacting concrete in actual structures needed to obtain similar slump flow compared to concrete mix without increasing its cost, while reducing the dosage of superplasticizer needed to obtain similar slump flow compared to concrete made with Portland cement only. Also, the use of fly ash improves rheological properties and reduces the cracking potential of concrete as it lowers the heat of hydration of the cement. Studies have shown that fly ash replacement up to 30% results in a significant improvement of the rheological properties of flowing concrete [6]. In another study it was found that the compressive strength of SCC with silica fume grew very rapidly during the initial age and remained significantly higher, whereas the water absorption coefficient and water penetration depths remained very low. The durability of SCC improves significantly as the replacement levels of silica fume increased [7].

Heba A. Mohamed determined the suitable percentage of fly ash, and silica fume in SCC that gives the highest value of concrete compressive strength. The fly ash was used in SCC as it reduces the dosage of superplasticizer needed to obtain similar slump flow compared to concrete mixes made with only The obtained results showed that in case of mixes prepared with only replacement of fly ash the highest compressive strength was observed for 30% replacement while for silica fume only it was 15%. The highest compressive strength from all mixes was observed for the combination of 10% Fly ash and 10% silica fume replacement [8]. In order to extend the general concept of HSSCC concrete and its applications to a wider range of infrastructure construction, this paper outlines the results of a research project aimed at producing and evaluating the behavior of High strength SCCs incorporating class F fly ash and silica fume when ordinary Portland cement (OPC) was used.

II. GUIDE LINE REFERENCE

This work was carried out as per the European guidelines EFNARC-2005 [9]. The following Table 1 shows the specific ranges for concrete ingredients. Table 2 shows the acceptance criteria for SCC.
III. EXPERIMENTAL PROGRAM

A. Materials Used

The following materials were employed:

The cement used in all mixture was Ordinary Portland cement (OPC) of 53 grade conforming IS 12269-1987 [9]. In addition fly ash and silica fume was also used as a mineral additive. Their chemical composition is specified in Table 3.

Good quality aggregates have been procured for this investigation. Crushed granite with nominal grain size of 20 mm, 12.5 mm and 6.3 mm in varying percentage were used as coarse aggregate confirming to IS 383-1970 [11]. Well-graded river sand of maximum size 4.75 mm were used as fine aggregates confirming to IS 383-1970 [11]. The specific gravities and other properties of aggregates were determined experimentally as per IS2386- part-III [12] and is given in Table 4 and Table 5.

Commercially available poly carboxylate ether (PCE) – based Super-plasticizer (SP) from BASF was used in all the concrete mixtures. It is an F-type high range water reducer, in conformity with IS 9103: 1999 [13]. Its properties are given in Table 6.

For HSSCC there is no specific method of design mix. In the present investigation Guidelines from EFNARC 2005 are used. In order to achieve high strength lower w/c ratio of 0.28 is adopted. From the trial mix proportions of the concrete the high strength is achieved at a replacement of cement by fly ash at a 30%. Hence the fly ash of 25% is used as a replacement of cementitious material for all mixes also it helps to achieve good flowability and slump retention which is not possible with mixes of only S.F replacement. In the present investigation determination of Hardened properties and fresh properties of five HSSCC mixes at different silica fume replacement levels i.e. (0%, 7.5 %, 10%，12.5% and 15 %) is carried out. The proportions are presented in Table 7.

Several trial mixes were conducted to determine the optimum dosage of superplasticizer for each of the mixtures in order to achieve the required self-compacting properties as per EFNARC standards. The dosage of superplasticiser for each mix was carefully selected as over dosage may induce bleeding and strength retardation. As far as the aggregate grading is concerned, in the present investigation the percentage fractions of aggregates used for 20 mm – 16%, 12.5 mm – 20%, 6.3 mm – 16% and 4.75 mm – 48% of the total aggregate content respectively [14]. Blending aggregates in this fashion will result in high strength cohesive self-compacting concretes. The mix proportions are given in Table 8.
C. Mixing and Casting details

All the materials were mixed using a pan mixer with a maximum capacity of 80 litres. The materials were fed into the mixer in the order of coarse aggregate, OPC, fly ash, silica fume and sand. The materials were mixed dry for 1.5 min. subsequently three-quarters of the water was added, and the mixing is continued for 3 min. afterwards the mixing is stopped and materials sticked to the edges and corners of the mixer are scrapped which are again mixed by hand followed by the superplasticiser and the remaining water while mixing continued for a further 4 min in order to obtain a homogenous mixture. Upon discharging from the mixer, the self compactibility tests were conducted on the fresh properties for each mixture. The fresh concrete was placed into the steel cube moulds and compacted without any vibration. Finally, surface finishing was done carefully to obtain a uniform smooth surface.

D. Fresh Concrete Tests

For determining the self-compactibility properties (slump flow, V-funnel flow time, L-box blocking ratio) tests were performed on all the mixtures. The order of testing is:

- Slump flow test and measurement of T500 time.
- V-funnel flow test.
- L-box blocking test, respectively. The tests were performed in accordance with EFNARC [8] standards.

E. Casting and curing process

The following specimens were cast from each mixture:

- Six 100x100x100 mm cubes for the compressive strength test at age of 3 days and 7 days.
- Six 150x150x150 mm cubes for compressive strength test at age of 28 days and 90 days.
- Six 100x200 mm cylinders for the splitting tensile test at age of 28 days and 90 days.

After casting, all the specimens were covered with plastic sheets or cling sheet and water saturated burlap, and left at room temperature for 24 h. The specimens were demoulded after 24 h of casting and were then cured in water at approximately 27°C until the testing day as specified by IS 516-1959 [15].

F. Test on Hardened Concrete

The unconfined compressive strength was obtained, at a loading rate of .23 MPa/s at the age of 3, 7, 28 and 90 days on 3000 KN machine conforming to IS 516: 1959 [15]. The average compressive strength of three specimens was considered for each age. The split tensile strength was also tested on the same machine at the age of 28 and 90 days at loading rate of 2.4 N/(mm²/min) as per IS 5816: 1999 [16].

IV. Test Results and Discussion

A. Fresh Concrete Properties

The Results of the fresh properties are as shown in Table 9. Results are discussed in detail as follows:

1) Super plasticizer dosage

In order to avoid segregation and bleeding the slump flow of mixes were fixed in between 650mm – 700 mm. from the table 7 it can be seen that the addition of silica fume in ordinary Portland cement and fixed 25% of Fly ash has a significant influence on the flow characteristics of SCC. It can be observed that as the silica fume content increases the demand for HRWR also increases. For 15% replacement SCC demanded 2.0% of HRWR while SCC with 0% silica fume required only 0.85% of HRWR.

2) Slump Flow and T500 Test

The slump flow is well within the designed slump range of 640mm-700 mm. all the mixes developed have satisfied the requirement. Though the T500 test results showed a significant variation. As the S.F content is increased the T500 time also showed growth gradually. The highest time is recorded for S.F 4 mix of 8 sec while the minimum time is shown by the C.C (control mix) with 4.2 sec.

3) V-Funnel Test

The V-funnel followed the same trend as that of T500. The maximum time of V- funnel is recorded for S.F 4 with 24 sec while minimum for CC with 13 sec. The V-funnel showed a gradual decrease with the increase in S.F content.

4) L-Box test

This test is representation of passing ability of the concrete mixes. Higher the L-box ratio higher is passing ability and vice versa. In case of L-box as the S.F content is increased the L-box ratio decreased i.e passing ability is decreased and vice versa.

The Results of the fresh properties is similar to the trends from the other researchers [17].

---

Table 7: mix percentages used

<table>
<thead>
<tr>
<th>Mix Code</th>
<th>Total Binder (kg)</th>
<th>Cement %</th>
<th>Fly Ash %</th>
<th>Silica Fume %</th>
<th>W/B ratio %</th>
<th>Admixture %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC.1</td>
<td>550</td>
<td>75</td>
<td>25</td>
<td>0</td>
<td>0.28</td>
<td>0.85</td>
</tr>
<tr>
<td>S.F 1</td>
<td>550</td>
<td>67.5</td>
<td>25</td>
<td>7.5</td>
<td>0.28</td>
<td>1.6</td>
</tr>
<tr>
<td>S.F 2</td>
<td>550</td>
<td>65</td>
<td>25</td>
<td>10</td>
<td>0.28</td>
<td>1.75</td>
</tr>
<tr>
<td>S.F 3</td>
<td>550</td>
<td>62.5</td>
<td>25</td>
<td>12.5</td>
<td>0.28</td>
<td>1.9</td>
</tr>
<tr>
<td>S.F 4</td>
<td>550</td>
<td>60</td>
<td>25</td>
<td>15</td>
<td>0.28</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 8: mix proportions

<table>
<thead>
<tr>
<th>Mix Code</th>
<th>Cement Content (kg)</th>
<th>Fly Ash Content (kg)</th>
<th>Silica Fume Content (kg)</th>
<th>Water (Liters)</th>
<th>Admixture</th>
<th>F.A (kg)</th>
<th>C.A 20 mm (kg)</th>
<th>C.A 12.5 mm (kg)</th>
<th>C.A 6.3 mm (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC.1</td>
<td>412.50</td>
<td>137.50</td>
<td>0.00</td>
<td>162.68</td>
<td>4.68</td>
<td>775.39</td>
<td>282.69</td>
<td>347.06</td>
<td>274.62</td>
</tr>
<tr>
<td>S.F 1</td>
<td>371.25</td>
<td>137.50</td>
<td>41.25</td>
<td>162.56</td>
<td>8.80</td>
<td>764.35</td>
<td>278.67</td>
<td>342.11</td>
<td>270.71</td>
</tr>
<tr>
<td>S.F 2</td>
<td>357.50</td>
<td>137.50</td>
<td>55.00</td>
<td>162.53</td>
<td>9.63</td>
<td>761.28</td>
<td>277.55</td>
<td>340.74</td>
<td>269.62</td>
</tr>
<tr>
<td>S.F 3</td>
<td>343.75</td>
<td>137.50</td>
<td>68.75</td>
<td>162.49</td>
<td>10.45</td>
<td>758.21</td>
<td>276.43</td>
<td>339.37</td>
<td>268.53</td>
</tr>
<tr>
<td>S.F 4</td>
<td>330.00</td>
<td>137.50</td>
<td>82.50</td>
<td>162.46</td>
<td>11.00</td>
<td>755.45</td>
<td>275.43</td>
<td>338.13</td>
<td>267.56</td>
</tr>
</tbody>
</table>
Effect of Silica Fume on Mechanical and Fresh properties of High Strength Self Compacting Concrete (IJSRD/Vol. 4/Issue 10/2016/179)

<table>
<thead>
<tr>
<th>Mix Code</th>
<th>Test Conducted</th>
<th>Compressive Strength Mpa</th>
<th>Splitting Tensile Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T50</td>
<td>0</td>
<td>Days</td>
</tr>
<tr>
<td>CC1</td>
<td>4.2</td>
<td>680</td>
<td>13</td>
</tr>
<tr>
<td>S.F 1</td>
<td>6.4</td>
<td>665</td>
<td>18</td>
</tr>
<tr>
<td>S.F 2</td>
<td>7.1</td>
<td>652.5</td>
<td>19</td>
</tr>
<tr>
<td>S.F 3</td>
<td>7.7</td>
<td>645</td>
<td>22</td>
</tr>
<tr>
<td>S.F 4</td>
<td>8</td>
<td>655</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 9: Fresh properties of SCC

B. Hardened concrete Properties

1) Compressive Strength Test

After outlining the performance of SCCs during its fresh state, it is necessary to understand the performance of these concretes during its hardened state. In this study, the mechanical properties of all the SCCs are investigated through compressive strengths, splitting tensile strengths. Compressive strength tests were carried out at 3, 7, 28 and 90 days and the results are presented in Table 10. Fig. 1 shows the variation of compressive strengths at 28 and 90 days with respect to the Silica Fume replacement. As noted from the results shown in Fig. 1, the compressive strength of SCC increased drastically from 7.5% to 12.5% replacement of silica fume but started to decline at 15% replacement. High compressive strength of nearly 100 Mpa has been obtained at 12.5% replacement at 90 days than the other S.F mixes including the 0% replacement, where a high strength of 84.85 Mpa is obtained at 90 days. The trend is similar to results obtained elsewhere on SCC containing silica fume [17].

2) Split Tensile Strength

The split tensile strength followed the same trend as that of the compressive strength with the maximum value of 5.44 Mpa for S.F 3 mixes at 28 days age it can be noted from the Table 10. Fig. 2 this proves that the addition of silica fumes increases the tensile strength of concrete.

V. CONCLUSIONS

This study discusses an experimental program carried out to investigate the effects of incorporating silica fume replacement on the flow characteristics of SCC when OPC was used in the fresh state, and mechanical properties in the hardened state. The following conclusions can be drawn according to the results of this study-

1) High Strength Self compacting concrete up to a strength of 100Mpa can be developed with the partial replacement of Fly ash and silica fume

2) It can be seen that the optimum content for replacement of silica fume is 12.5% when OPC is used.

3) Though increase in Silica fume content increases the strength of SCC but in order to maintain the constant slump flow for the same the amount of the HRWRA content is also increased.

4) As the S.F content is increased the fresh properties of SCC tends to decrease.

REFERENCES


[2] ACI Committee 237, Self-Consolidating Concrete (ACI 237R-07), American Concrete Institute, Farmington Hills, Michigan, April (2007).


