CHAPTER 6

MIX PROPORTIONING OF SELF-COMPACTING CONCRETE WITH MINERAL ADMIXTURES

6.1 INTRODUCTION
The flowing property and self compacting ability of SCC depends on the correct proportioning of ingredients and the dosage of superplasticizer. The optimum dosage of superplasticizer varies with the mineral admixtures. In this study the optimum dosage of superplasticizer for each mineral admixture at different replacement levels is determined. High-strength self-compacting concrete (M60) is developed and checked for its self compactability with Japanese Standard for Civil Engineering specifications.

6.2 MIX PROPORTIONING
A simple mix design method was proposed by Nan Su et al (2001) for the development of self-compacting concrete was used in this study for M60 concrete using silica fume, metakaolin and fly ash. In this method, the volume ratio of aggregate after lubrication and compaction in SCC was assumed between 59 and 68%. Packing factor (PF) which is the ratio of mass of aggregate of tightly packed state in SCC to that of the loosely packed state plays an important role. Clearly, PF affects the content of aggregates in SCC. A higher PF value would imply a greater amount of coarse and fine aggregates used, thus, decreasing the content of binders in SCC. Consequently, its flowability, self- compacting ability and compressive strength will be reduced. On the other hand, a low PF value would mean an increased shrinkage of concrete. As a result, more binders are required,
thus, raising the cost of materials. In addition, excess binders used would also affect the workability and durability of SCC. Therefore it is important to select the optimal PF value in the mix design method so as to meet the requirements for SCC properties, and at the same time taking economic feasibility into consideration.

**Step 1  Determination of coarse and fine aggregate contents**

Assuming Packing factor  = 1.12

*Amount of fine aggregates (Ws) needed per unit volume of SCC:*

\[ W_s = \text{Bulk density of loose fine aggregates} \times \text{PF} \times \text{volume ratio of fine aggregate} \]

\[ = 1491 \times 1.12 \times 0.58 = 968.6 \text{ kg/m}^3 \]

*Amount of coarse aggregates (Wg) needed per unit volume of SCC:*

\[ W_g = \text{Bulk density of loose coarse aggregate} \times \text{PF} \times \text{volume ratio of coarse aggregate} \]

\[ = 1501 \times 1.12 \times 0.42 = 706.1 \text{ kg/m}^3 \]

**Step 2  Determination of cement content**

Assuming each kg of cement can provide a compressive strength of 0.14 MPa for SCC at 28 days.

*Weight of cement (Wc) needed per unit volume of SCC for 60 MPa strength:*

\[ W_c = \frac{60}{0.14} = 429 \text{ kg/m}^3 \]

**Step 3  Determination of mixing water content required by cement**

For M60 concrete w/b ratio can be taken as 0.35

*Amount of mixing water (Wwc) needed for cement:*

\[ W_{wc} = 0.35 \times 429 = 150.15 \text{ kg/m}^3 \]
Step 4  Determination of Mineral admixtures Content

According to the flow table tests (ASTM C 230), sand and the same dosage of SP, the

\( \text{w/b is 0.35,} \)

Volume of mineral admixtures \((V_{\text{MA}})\) assuming 1.5% of air content

\[
V_{\text{MA}} = 1 - \left[ \left( \frac{706}{1000 \times 2.65} \right) - \left( \frac{968.6}{1000 \times 2.65} \right) - \left( \frac{429}{1000 \times 3.15} \right) - \left( \frac{150.15}{1000 \times 1} \right) - 0.015 \right]
\]

\[
= 1 - 0.266 - 0.3655 - 0.1362 - 0.15 - 0.015 = 0.0673 \text{ m}^3/\text{m}^3
\]

Volume of SF \((V_{\text{SF}})\) content (max 10% by weight of cement)

\[
V_{\text{SF}} = \frac{0.1 \times 429}{2.2 \times 1000} = 0.02 \text{ m}^3
\]

Volume of MK content \((V_{\text{MK}})\) (max 10% by weight of cement)

\[
V_{\text{MK}} = \frac{0.1 \times 429}{2.5 \times 1000} = 0.0172 \text{ m}^3
\]

Volume of fly ash \((V_{\text{FA}})\) content

\[
V_{\text{FA}} = V_{\text{MA}} - V_{\text{SF}} = 0.0673 - 0.02 = 0.0473 \text{ m}^3
\]

*Weight of fly ash \((W_{\text{FA}})\) content:*

\[
W_{\text{FA}} = 0.0473 \times 2000 = 94.6 \text{ kg/ m}^3
\]

*Weight of silica fume \((W_{\text{SF}})\) content:*

\[
W_{\text{SF}} = 0.02 \times 2200 = 44 \text{ kg/ m}^3
\]
Weight of metakaolin (W_MK) content:

\[ W_{MK} = 0.0172 \times 2500 = 43 \text{ kg/m}^3 \]

Step 5 Determination of the mixing water content required for mineral admixtures
Assuming water to mineral admixtures ratio to obtain same consistency as that of cement as 0.4, then,

Water Content for FA \( W_{WFA} = 0.4 \times 94.6 = 37.8 \text{ kg/m}^3 \)

Water content for SF \( W_{WSF} = 0.4 \times 44.0 = 17.6 \text{ kg/m}^3 \)

Water content for MK \( W_{WMK} = 0.4 \times 43.0 = 17.2 \text{ kg/m}^3 \)

Step 6 Determination of SP dosage
The solid content of SP (Conplast 430) given by the manufacturer is 40%. The marsh cone test was conducted on various combination of cementing materials with w/b of 0.35. The optimum dosage of SP for cement with fly ash, cement with fly ash and silica fume and cement with fly ash and metakaolin was found to be 1.8% by weight of total binder where as for cement alone and cement with fly ash the optimum dosage was found to be 1.2%. According to the Marsh cone test results, for the combinations of mineral admixtures, the optimum dosage of SP was taken as 1.8% of the total binder content for meeting the SCC requirements (JSCE) as referred by Nan Su et al (2001) specified in Table 6.1. The Marsh cone test results of various replacement levels of mineral admixtures with cement are shown in Fig. 6.1.
Fig. 6.1 Optimum dosage of super plasticizer for various mineral admixtures with cement for the water binder ratio of 0.35

Table 6.1 Specifications of SCC proposed by JSCE

| Class of filling ability of Concrete | 30 – 60 | 60 – 200 | ≥ 200 |
| Construction condition | ≥ 350 | 100 – 350 | ≤ 100 |
| Minimum gap between reinforcement (mm) | | | |
| Amount of reinforcement (kg/m³) | | | |
| Filling height of U-box test (mm) | ≥300 (rank R1) | ≥300 (rank R2) | ≥300 (rank R3) |
| Absolute volume of Coarse aggregates per unit volume of SCC (m³/m³) | 0.28 – 0.30 | 0.30 – 0.33 | 0.30 – 0.36 |
| Flowability Slump flow (mm) | 650 – 750 | 600 – 700 | 500 – 650 |
| Segregation resistance ability | Time required to flow through V-funnel (seconds) | 10 – 20 | 7 – 20 | 7 – 20 |
| Time required to reach 500 mm of slump flow (seconds) | 5 – 25 | 3 – 15 | 3 – 15 |
Dosage of SP

For developing high-strength self-compacting concrete, either silica fume or metakaolin has to be added to improve the strength and in addition to that fly ash also to be added to improve the workability and for reducing cost. Therefore, four mixes were tried with different combinations of mineral admixtures with cement.

(i) Silica fume (10%) and fly ash

\[ W_{SP} = \text{Optimum dosage of superplasticizer} \times (W_C + W_{FA} + W_{SF}) \]

\[ W_{SP} = 0.018 \times (429 + 94.6 + 44) = 10.2 \, \text{kg/m}^3 \]

(ii) Metakaolin (10%) and fly ash

\[ W_{SP} = \text{Optimum dosage of superplasticizer} \times (W_C + W_{FA} + W_{MK}) \]

\[ W_{SP} = 0.018 \times (429 + 94.6 + 43) = 10.2 \, \text{kg/m}^3 \]

(iii) Fly ash, silica fume (5%) and metakaolin (5%)

\[ W_{SP} = \text{Optimum dosage of superplasticizer} \times (W_C + W_{FA} + W_{SF} + W_{MK}) \]

\[ W_{SP} = 0.018 \times (429 + 94.6 + 22 + 21.5) = 10.2 \, \text{kg/m}^3 \]

(iv) Fly ash

\[ W_{SP} = \text{Optimum dosage of superplasticizer} \times (W_C + W_{FA}) \]

Here, \( V_{FA} = V_{MA} = 0.0673 \, \text{m}^3 \)

\[ W_{FA} = 0.0673 \times 2000 = 134.6 \, \text{kg} \]

\[ W_{SP} = 0.018 \times (429 + 134.6) = 7.78 \, \text{kg/m}^3 \]
Step 7  Adjustment of mixing water content needed for SCC

*Amount of water in SCC*

In Conplast 430, the solid content is about 40% and hence, remaining 60% liquid content should be reduced from water content,

(i) *Silica fume (10%) and fly ash*

\[ W_w = W_{wc} + W_{wfa} - 0.6 \times W_{sp} \]
\[ = 150.15 + 37.8 + 17.6 - (0.6 \times 10.2) \approx 200 \text{ kg/m}^3 \]

(ii) *Metakaolin (10%) and fly ash*

\[ W_w = W_{wc} + W_{wfa} - 0.6 \times W_{sp} \]
\[ = 150.15 + 37.8 + 17.2 - (0.6 \times 10.2) \approx 200 \text{ kg/m}^3 \]

(iii) *Silica fume (5%), metakaolin (5%) and fly ash*

\[ W_w = W_{wc} + W_{wfa} + W_{wsf} + W_{wmk} - 0.6 \times W_{sp} \]
\[ = 150.15 + 37.8 + 8.8 + 8.6 - (0.6 \times 10.2) \approx 200 \text{ kg/m}^3 \]

(iv) *Fly ash*

\[ W_w = W_{wc} + W_{wfa} - 0.6 \times W_{sp} \]
\[ = 150.15 + (0.4 \times 134.6) - (0.6 \times 7.78) \approx 200 \text{ kg/m}^3 \]

Step 8  Trial batches and tests on SCC properties

Trial batches were made using the contents of materials determined as above and their proportions are shown in Table 6.3.
6.3 EXPERIMENTAL METHODS

6.3.1 Slump flow test

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. The procedure is based on the test method for determining the slump of concrete as usual. Usual slump cone of top diameter 100 mm, bottom diameter 200 mm and a height of 300 mm as shown in Fig. 6.2 (a) was used. The spread of the concrete, after the slump cone lifted shown in Fig. 6.2 (b) was measured. The diameter of the concrete spread was measured after the concrete had stopped flowing. Diameter of concrete circle is a measure for filling ability of the concrete. It is the most commonly used test, and give good assessment of filling ability.

(a) Slump cone  
(b) Slump flow  

Fig 6.2 Slump cone test
6.3.2 V funnel test

According to the “Funnel flow test method” in “Guide to Construction of High Flowing Concrete” issued by the JSCE, this test measures the viscosity of concrete, and can also determine the arching effect of aggregate. The flow time through the funnel is measured as the time taken to see daylight appearance when viewed from above.

It consists of a funnel with a rectangular cross section at both top and bottom. The top dimensions are 490 mm x 75 mm and the bottom opening is 70 mm x 75 mm. The total height is 572 mm with a 150 mm long straight section. The concrete was poured into the funnel with a gate blocking the bottom opening. When the funnel was completely filled, the bottom gate was opened and the time for the concrete to flow out of the funnel was noted. The time was called V-flow time. Fig. 6.3 shows the dimensions of V funnel and the flow of concrete.

![V funnel test](image)

(a) Dimensions of V funnel (mm)  
(b) Flow of concrete through V funnel

Fig. 6.3 V funnel test

145
6.3.3 U tube Test

This test is recommended by Okamura (1996) in the “Guide to Construction of High Flowing Concrete” issued by JSCE. The properties of concrete such as passing ability through reinforcement and self compacting ability can be assessed in a good manner through this test. The filling height of concrete, which passed through the gaps of rebars of the U-test under its own weight, indicates the degree of the compacting ability of the concrete. Normally, the requirement of filling height of SCC is 300 mm from bottom of U tube according to the specification of Table 6.1.

The typical U tube with its dimensions were given in the Fig. 6.4. This figure gives the complete details of the U tube test Setup. The equipment consists of a rectangular vessel with a round bottom. The top rectangular portion is about 280 mm x 200 mm in cross section and is 450 mm long followed by a 150 mm high round bottom with a radius of 140 mm. A sliding gate is fixed in the middle. The degree of compactability is assessed by the height of concrete reaches in the first leg after flowing through the obstacle in the bottom. To stimulate the obstruction created by the reinforcing bars to the concrete flow, three deformed bars are placed in the round bottom.

The test is performed by first completely filling in the left chamber with concrete. While the sliding door between the two chambers was closed. The door was then opened and the concrete flows past the rebars into the right chamber. SCC for use in highly congested areas should flow to about the same height in the two chambers. The criterion adopted, in this study, is that if the filling height was more than 70% of the maximum height possible, the concrete is considered self compacting. Fig. 6.5 shows the test in progress before and after flow of concrete.
Fig. 6.4 Details of U-Tube

(a) Before flow  (b) After flow

Fig. 6.5 U Flow test

(a) Before flow  (b) After flow
6.3.4 L box test

It consists of a L shaped tubular configuration with a vertical leg of dimension 700 mm x 200 mm x 80 mm and a horizontal leg of same length but cross section 160 x 200 mm. The two legs are separated by a sliding vertical gate. Concrete is filled in the vertical leg and when the gate is opened, it flows into the horizontal part. The length of flow through the rebars into the trough was measured. This test measures the plastic viscosity. Fig.6.6 shows the dimensions of L box and Fig.6.7 shows when the test in progress.

![Fig. 6.6 Dimensions of L box.](image)

![Fig 6.7 L box test](image)
6.3.5 Compressive strength test

As per IS: 516-1959, 150 mm concrete cubes with proportion shown in Table 6.2 and 6.3 were produced and cured in water in room temperature for 28 days compressive strength and tested using AIMIL compression testing machine of 2000 kN capacity.

6.4 RESULTS AND DISCUSSION

For obtaining optimum PF value, four mix proportions were developed for different PF values of 1.12, 1.14, 1.16 and 1.18 using fly ash alone with cement. Table 6.2 shows the mix proportions for M 60 concrete for different PF values and their corresponding test results. Fig 6.8 shows the compressive strength of SCC decreasing with increasing packing factor value. PF value is closely related to compressive strength, by adjusting PF to 1.18, 1.16, 1.14 and 1.12, the SCC thus obtained could satisfy the compressive strength requirements of 50, 58, 64 and 68 MPa, respectively. From the test results given in Table 6.2, it was observed that the compressive strength for PF value of 1.12 is the maximum. For the self compactability, slump test values, L flow test results, U box test results and V flow times were also compared. As for slump values, the diameter of concrete spread is maximum of 700 mm for PF = 1.12 and 1.14. In U Box test, the filling height was greater than 300 mm for all PF values except for PF = 1.18 (Fig.6.9). In L-flow test, the length of flow is maximum for PF = 1.12 and minimum for PF = 1.18. In V-funnel test, the flow times were observed for the PF values of 1.12, 1.14, 1.16 and 1.18. When PF was 1.12, 1.14 or 1.16, the V-funnel flow time was 12, 14 or 18 seconds, respectively, which meets the requirement of rank R1 as specified in Table 6.1. When PF was 1.18, the V-funnel flow time was 8 seconds, which satisfies the rank R2 requirement. From the above discussion, for the PF value of 1.12 the compressive strength and
workability properties were highly satisfied. Fig. 6.10 shows that the ratio of fine aggregate volume to mortar volume was 47.5 - 53.52%, which was higher than the value of 40% presented by Okamura. Hence, the content of fine aggregates in the SCC prepared by this method would be rather high, so that it could meet the requirements of flowability, self-compacting ability, segregation resistance as well as high compressive strength (50 - 68 MPa), thus affecting the elastic modulus of SCC. On the other hand, compressive strength of SCC was found to be inversely proportional to sand content in mortar. It was obvious that this proposed mix design method requires much less binders. For example, in the case of SCC with $f_{ck} = 68$ MPa, the amount of binders used is only 575 kg/m$^3$, while that of cement was only 429 kg/m$^3$. Thus, considering all the above aspects, to obtain maximum strength and self compactability, PF value of 1.12 was found to be optimum. Having PF = 1.12, four different mixes were developed with different combinations of mineral admixtures used and their proportions are tabulated in Table 6.3.

Table 6.2 Workability related properties and 28 days compressive strength of self compacting concrete mixes with different packing factors.

<table>
<thead>
<tr>
<th>Packing Factor</th>
<th>Compressive strength (MPa)</th>
<th>Water content (m$^3$)</th>
<th>Binder volume (m$^3$)</th>
<th>Sand (m$^3$)</th>
<th>Coarse aggregate (m$^3$)</th>
<th>Slump flow diameter (mm)</th>
<th>L-flow test (mm)</th>
<th>V-funnel flow time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.12</td>
<td>68</td>
<td>200.7</td>
<td>203.6</td>
<td>365.6</td>
<td>266.48</td>
<td>700</td>
<td>700</td>
<td>10</td>
</tr>
<tr>
<td>1.14</td>
<td>64</td>
<td>186.1</td>
<td>188.3</td>
<td>372.0</td>
<td>274.34</td>
<td>700</td>
<td>690</td>
<td>8</td>
</tr>
<tr>
<td>1.16</td>
<td>58</td>
<td>177.4</td>
<td>177.3</td>
<td>378.4</td>
<td>279.25</td>
<td>650</td>
<td>680</td>
<td>7</td>
</tr>
<tr>
<td>1.18</td>
<td>50</td>
<td>168.0</td>
<td>166.2</td>
<td>384.9</td>
<td>284.15</td>
<td>600</td>
<td>600</td>
<td>8</td>
</tr>
</tbody>
</table>
Fig. 6.8 Effect of aggregate packing factor on compressive strength

Fig. 6.9 Effect of packing factor on filling height of U-box

Fig. 6.10 Relationship between fine aggregate volume ratio, compressive strength and packing factor.
Table 6.3  Mix proportions of SCC for M60 concrete with different combinations of mineral admixtures

<table>
<thead>
<tr>
<th>Mix</th>
<th>Coarse aggregate (kg/m³)</th>
<th>Sand (kg/m³)</th>
<th>Cement (kg/m³)</th>
<th>FA (kg/m³)</th>
<th>SF (kg/m³)</th>
<th>MK (kg/m³)</th>
<th>Water (kg/m³)</th>
<th>SP (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>706</td>
<td>968.6</td>
<td>429</td>
<td>94.60</td>
<td>44.00</td>
<td>--</td>
<td>200</td>
<td>10.20</td>
</tr>
<tr>
<td>M2</td>
<td>706</td>
<td>968.6</td>
<td>429</td>
<td>94.60</td>
<td>--</td>
<td>43.00</td>
<td>200</td>
<td>10.20</td>
</tr>
<tr>
<td>M3</td>
<td>706</td>
<td>968.6</td>
<td>429</td>
<td>109.22</td>
<td>22.00</td>
<td>21.50</td>
<td>200</td>
<td>10.20</td>
</tr>
<tr>
<td>M4</td>
<td>706</td>
<td>968.6</td>
<td>429</td>
<td>134.60</td>
<td>-</td>
<td>-</td>
<td>200</td>
<td>7.78</td>
</tr>
</tbody>
</table>

Table 6.4 shows the test results for the mix proportions given in Table 6.3. From this table, it was observed that M1 mix giving high strength of 75 MPa with flowing properties by the addition of silica fume with fly ash.

Table 6.4 Workability related properties and compressive strength for mixes with different combinations of mineral admixtures

<table>
<thead>
<tr>
<th>Mix</th>
<th>Compressive strength (MPa)</th>
<th>Water content (m³)</th>
<th>Binder volume (m³)</th>
<th>Sand (m³)</th>
<th>Coarse aggregate (m³)</th>
<th>Slump flow diameter (mm)</th>
<th>L-flow test (mm)</th>
<th>V-funnel flow time (sec)</th>
<th>Filling Height in U box (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>75</td>
<td>200</td>
<td>207.2</td>
<td>366</td>
<td>266.5</td>
<td>650</td>
<td>680</td>
<td>10</td>
<td>300</td>
</tr>
<tr>
<td>M2</td>
<td>72</td>
<td>200</td>
<td>208.0</td>
<td>366</td>
<td>266.5</td>
<td>680</td>
<td>690</td>
<td>8</td>
<td>300</td>
</tr>
<tr>
<td>M3</td>
<td>70</td>
<td>200</td>
<td>209.6</td>
<td>366</td>
<td>266.5</td>
<td>690</td>
<td>690</td>
<td>7</td>
<td>300</td>
</tr>
<tr>
<td>M4</td>
<td>68</td>
<td>200</td>
<td>203.5</td>
<td>366</td>
<td>266.5</td>
<td>700</td>
<td>700</td>
<td>4</td>
<td>320</td>
</tr>
</tbody>
</table>
6.5 CONCLUSIONS

- The aggregate PF determines the aggregate content and influences the strength, flowability and self compacting ability. The optimum PF value is 1.12 for getting high strength concrete with self compactability.

- SCC designed and produced with the proposed mix design method contains more sand but less coarse aggregates. Thus the passing ability through gaps of reinforcement can be enhanced.

- The optimum dosage of superplasticizer for cement with mineral admixtures was found to be 1.8\% of the weight of binder.

- SCC with fly ash and silica fume combination gave high strength than other concrete mixes.

- In this method of design, the volume of sand to mortar was in the range of 47.2-47.7\% for different mineral admixtures. The volume of sand to mortar was in the range of 47.5\% - 53.52\% for different PF values.

- The water content of SCC produced by the proposed method is 200 kg/ m\(^3\) for the high compressive strength.

- The amount of binders used in the proposed method can be less than that required by other mix design methods due to the increased sand content.

- Among the three mineral admixtures, fly ash improves the flow characteristics whereas silica fume and metakaolin improves the strength. Hence the combination of mineral admixtures produces SCC with high strength.