An Experimental Study on the Determining the Bingham Parameters for Fresh Self-Compacting Concrete Mix using Concrete Shear Box Method

Ajay Nand¹, Girish S²

¹Infrastructure Construction and Management, RASTA-Center for Road Technology, VTU, Bangalore, Karnataka, India
²Department of Civil Engineering, B M S College of Engineering, VTU, Bangalore, Karnataka, India.

ABSTRACT
In the present study, the determining the Bingham parameters of self-compacting concrete (SCC) by using the shear box method under static condition. The SCC mixes were developed by absolute volume fraction method. The developed SCC mixes were tested for both empirical methods as per EFNARC guidelines and rheological method by using concrete shear box. The results show that the concrete shear box test can be used as an instrument for finding the Bingham parameters of fresh SCC mixes under static condition.

Keywords: Bingham Parameter, Concrete Shear Box, Plastic Viscosity, Rheology, Self-compacting concrete, Yield Stress, Volume Fraction Method.

I. INTRODUCTION
Concrete rheology is new material science approach methodology for flow characterization of fresh concrete. It is deals with the “study of flow and deformation of complex fluid under applied force” [1]. The main aim of rheology is predicting the complex fluid flow that would be produced due to applied forces [2-4]. Basically, the concrete is a heterogeneous material, and it exhibits complex behaviour in fresh state [5]. To predict the flow behaviour of such complex fluid is not possible in existing empirical test methods [6,7]. There are more than 40 test methods are existed for characterizing the fresh SCC [6,7]. Among the test methods, the slump flow test in more commonly used and accepted test method [8]. Unfortunately, the slump flow test does not indicate the any small variations in mix proportioning can lead to problems with workability of SCC mixes [8]. Furthermore, these test methods are all empirical in nature [8] and their results are based on either time or distance. Such methods called as single point methods [8]. These single point methods do not provide a comprehensive flow characterization of SCC. For better understanding and measuring the workability of fresh SCC by rheological test method [8].

In rheological test method, fresh SCC is considered as a non-Newtonian complex fluid [9-12]. In rheological test method, the flow of SCC is characterized by two parameters viz: yield stress and plastic viscosity [9-12]. The yield stress is related to concrete slump and the resistance to the flow or speed of the flow represent plastic viscosity of the fresh concrete [9-12]. Generally, yield stress and plastic viscosity were measured using rheometers through Bingham model [13-15]. Majority of rheometers measure the dynamic
yield stress, and few rheometers measure the static yield stress [16,17]. There are various rheometers available and each having its own advantages and limitations [16,17]. Many authors and researchers have attempted several experimental and analytical studies to measure the rheological properties of fresh concrete other than rheometers. These include using numerical simulation, analytical finite element models. Based on this they have developed the correlation between slumps, slump flow, Vebe and flow test to rheological values [18].

In 1956 L’Hermite and Tournon [19] used direct shear box to measure the shearing strength of fresh concrete. They found that the normal stress is linearly increasing with shear stress up to 0.18 MPa and 0.16 MPa for fresh concrete mixes having w/c ratio of about 0.55 and 0.65 respectively. The direct shear box test was used to assess the cohesive shear strength of fresh concrete and the test results were not assessed in-terms of rheological properties.

In 2009, Girish et al., [20] extended the L’Hermite work. They developed a new unique procedure to find the rheological properties of normal concrete and SCC mixes by using the direct shear box test with low shear rate. The results show that the obtained rheological properties are higher than rheometers values, but trend was like rheometer results. Chung-Ho Huang et al., [21] developed new Active Rheometer (ARM) for flowable concrete for measuring the rheological properties. The test results show that ARM rheometer has better reliability and accuracy than the standard Brookfield viscometer test results. They conclude that ARM is sensitive enough to measure the rheological properties of flowable concrete.

Tanigawa and Mori [22] investigated the flow and deformation of fresh concrete by simulation method and carried out experimental work for validation. Ahmet Bilgil [23] investigated the rheological properties of fresh concrete by numerical mathematical model. They developed the relationship between the workability and rheological properties during placing conditions into formwork with and without admixture. The results show that, with admixture, mixes have higher slump and less aggregate segregation when compared to without admixture for the same mix ingredients. They concluded that slump decreases as yield stress increases for both concrete mixes. Gonzalez-Taboada Iris et al., [24], studied the rheological properties of self-compacting recycled concrete (SCRC) by using workability box method. The results show that workability box is a much more effective instrument to design a SCRC mix with a suitable fresh behaviour than the usual empirical tests. It may be observed that, 2015, Girish and Santhosh [25-27] carried out studies on rheological properties of normal concrete. In their limited study, the findings show that concrete shear box can be used for finding the rheological properties of fresh concrete and the results show good repeatability and reproducibility of the results.

In 2018, Girish, Ajay et al [28,29] carried out the investigation on determining the rheological properties of fresh normal concrete using direct shear box.

In recent year, Girish and Ajay [30,31] carried out the studies on rheological properties of fresh concrete using concrete shear box method. In the present study focus on determine the Bingham parameters or rheological properties of SCC using concrete shear box through Bingham model under static condition.

II. EXPERIMENTAL WORK

Materials
The characteristics of the materials used are shown in Table I.

### TABLE I

**MATERIAL PROPERTIES**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Specific Gravity</th>
<th>Specific surface (m²/kg)</th>
<th>Water absorption (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement – OPC 53 Grade</td>
<td>3.10</td>
<td>280</td>
<td>-</td>
<td>Conforming to IS: 12269-2013 [32].</td>
</tr>
<tr>
<td>Fine aggregate – River Sand</td>
<td>2.6</td>
<td>-</td>
<td>2.0</td>
<td>Conforming to Zone-II as per IS: 383-2016 [33].</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>2.7</td>
<td>-</td>
<td>0.9</td>
<td>Crushed angular aggregates.</td>
</tr>
<tr>
<td>GGBS</td>
<td>2.8</td>
<td>425</td>
<td>-</td>
<td>Conforming to IS:12089 [34]</td>
</tr>
<tr>
<td>Superplasticizer (SP)</td>
<td>1.08</td>
<td>-</td>
<td>-</td>
<td>Confirming to IS: 9103[35]</td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>Confirming to IS: 456-2000 [36]</td>
</tr>
</tbody>
</table>

**Mix Design**

In the present work, six different SCC mixes were developed by absolute volume fraction method [37,38]. Two different volumes of pastes of 0.38 and 0.42 were chosen. The water contents of 170 and 190 l/m³ and cement contents of 300, 375, and 450 kg/m³ along with filler (slag) were used. The mix proportion details are presented in Table II. Through the marsh cone test optimize the dosage of SP and kept constant throughout the experimental program. A modified mixing procedure was adopted to achieve the mixes [38].

### TABLE III

**DETAIL OF MIX PROPORTION FOR SCC MIXES (IN KG/M³)**

<table>
<thead>
<tr>
<th>Mix</th>
<th>Cement</th>
<th>GGBS</th>
<th>Powder</th>
<th>fa (°)</th>
<th>Ca</th>
<th>Water</th>
<th>Vp</th>
<th>SP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>300</td>
<td>322</td>
<td>80</td>
<td>82</td>
<td>170</td>
<td>0.3</td>
<td>8</td>
<td>1.2</td>
</tr>
<tr>
<td>S2</td>
<td>375</td>
<td>252</td>
<td>80</td>
<td>82</td>
<td>170</td>
<td>0.3</td>
<td>8</td>
<td>1.1</td>
</tr>
<tr>
<td>S3</td>
<td>450</td>
<td>182</td>
<td>80</td>
<td>82</td>
<td>170</td>
<td>0.3</td>
<td>8</td>
<td>1.0</td>
</tr>
<tr>
<td>S4</td>
<td>300</td>
<td>375</td>
<td>75</td>
<td>76</td>
<td>190</td>
<td>0.4</td>
<td>8</td>
<td>0.9</td>
</tr>
<tr>
<td>S5</td>
<td>375</td>
<td>308</td>
<td>75</td>
<td>76</td>
<td>190</td>
<td>0.4</td>
<td>8</td>
<td>0.8</td>
</tr>
<tr>
<td>S6</td>
<td>450</td>
<td>238</td>
<td>75</td>
<td>76</td>
<td>190</td>
<td>0.4</td>
<td>2</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Legend: fa = fine aggregate, Ca = Coarse aggregate

**Testing Procedures**

The fresh SCC mixes were tested for rheological properties by concrete shear box test (Fig.1) and empirical tests as per EFNARC guidelines [39]. The working principle of concrete shear box is like direct shear box, that is, applying the normal stresses and displacement rate to the concrete sample (150mm x 150mm x 150 mm) and measure the shear resistance force (kN) and displacement (mm). The details of the experimental methodology are shown in Fig.2.
Figure 1: Concrete Shear box [31]

Figure 2: Experimental Methodology Adopted for Testing the Fresh Properties of SCC mixes

**Determination of Bingham Parameters of SCC mixes**

The methodology followed to determine the Bingham parameters of SCC mixes using shear box was based on previous studies [31]. Fig.3 shows the procedure for finding the rheological properties of SCC mixes. Two mix proportions were used in this study.

As seen from Table III, the slump flow values varied from 600 mm to 700 mm; T50 values are varies from 2.7 sec to 4.5 sec; J-ring values from 3.0mm to 7.0mm and V-funnel values varies from 5.5 sec to 8.0 sec for different Vp, aggregate and water contents. These values are within the EFNARC guidelines ranges [39]. As powder content or Vp increases, the slump flow values increase. This is possible due to better coating of aggregates at higher powder or paste which in term reduces the inter-particle friction. Also increase in Vp

<table>
<thead>
<tr>
<th>Mix</th>
<th>Powder (kg/m³)</th>
<th>Water (lt/m³)</th>
<th>Vp (%)</th>
<th>Slump flow (mm)</th>
<th>T50 (sec)</th>
<th>J-ring (mm)</th>
<th>V-funnel (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>622</td>
<td>170</td>
<td>0.3</td>
<td>600</td>
<td>4.0</td>
<td>6.0</td>
<td>8.0</td>
</tr>
<tr>
<td>S2</td>
<td>627</td>
<td>170</td>
<td>0.3</td>
<td>625</td>
<td>4.5</td>
<td>5.0</td>
<td>8.5</td>
</tr>
<tr>
<td>S3</td>
<td>632</td>
<td>170</td>
<td>0.3</td>
<td>640</td>
<td>3.5</td>
<td>4.0</td>
<td>7.0</td>
</tr>
<tr>
<td>S4</td>
<td>675</td>
<td>190</td>
<td>0.4</td>
<td>660</td>
<td>3.2</td>
<td>7.0</td>
<td>6.0</td>
</tr>
<tr>
<td>S5</td>
<td>683</td>
<td>190</td>
<td>0.4</td>
<td>680</td>
<td>3.0</td>
<td>6.0</td>
<td>6.4</td>
</tr>
<tr>
<td>S6</td>
<td>688</td>
<td>190</td>
<td>0.4</td>
<td>700</td>
<td>2.7</td>
<td>3.0</td>
<td>5.5</td>
</tr>
</tbody>
</table>

**TABLE III**

**EMPIRICAL TEST RESULTS OF SCC**

**III. RESULTS AND DISCUSSION**

Figure 3: Procedure for Finding the Bingham parameters of Fresh Concrete [31]
implies less aggregate content, thus more space between the aggregates.

The Fig.4,5,6 shows, typical graph for finding the rheological properties of SCC mixes (mix S1), similarly calculated the yield stress and plastic viscosity for SCC mixes. The values are tabulated in Table IV.
<table>
<thead>
<tr>
<th>Mix</th>
<th>Powder (kg/m³)</th>
<th>Water (lt/m³)</th>
<th>Vp (%)</th>
<th>Yield stress (MPa)</th>
<th>Plastic viscosity (MPa·sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>622</td>
<td>170</td>
<td>0.3</td>
<td>1.2</td>
<td>1250</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td>10.0</td>
</tr>
<tr>
<td>S2</td>
<td>627</td>
<td>170</td>
<td>0.3</td>
<td>1.1</td>
<td>1050</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td>9.5</td>
</tr>
<tr>
<td>S3</td>
<td>632</td>
<td>170</td>
<td>0.3</td>
<td>1.0</td>
<td>9500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td>8.0</td>
</tr>
<tr>
<td>S4</td>
<td>675</td>
<td>190</td>
<td>0.4</td>
<td>0.9</td>
<td>8500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td>4.7</td>
</tr>
<tr>
<td>S5</td>
<td>683</td>
<td>190</td>
<td>0.4</td>
<td>0.8</td>
<td>5500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td>S6</td>
<td>688</td>
<td>190</td>
<td>0.4</td>
<td>0.8</td>
<td>3500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td>3.0</td>
</tr>
</tbody>
</table>

As seen from Table IV, the values of yield stress and plastic viscosity obtained in this study are termed as relative since the values are not absolute. It can be observed from the table that for a given cement and water content, as the volume of paste is increased, the value of relative yield stress decreases. At low paste contents the inter-particle friction dominates resulting in higher relative yield stress which is clearly brought out by the concrete shear box test. Many researchers have reported correlation between the yield stress and slump flow [40]. They found that the yield stress and plastic viscosity decreased as slump flow increased. Fig.7 and Fig.8 shows the correlations between slump flow versus yield stress and plastic viscosity.

![Slump flow versus Yield Stress](image1.png)

**Figure 7**: Correlation between Slump Flow and Yield Stress

As seen from Fig.7, the yield stress is more when the slump flow is less and vice versa. Similar relationship was observed by other researchers using different rheometers [40].

![Slump flow versus Plastic Viscosity](image2.png)

**Figure 8**: Correlation between Slump Flow and Plastic Viscosity

As seen from Fig.8, the plastic viscosity decreases as the slump flow increases for different Vp. Similar kind of observation was seen in the works of Murata and Kikukawa and Wallevick [40]. The results are based on test values using rheometers. Yield stress and plastic viscosity values and the result of T50 and V-funnel, do not show fair correlation and similar observations have been seen by other researchers [40].

**IV. CONCLUSION**

The results of this experimental study have shown the effective use of concrete shear box in determining the...
Bingham parameters of fresh SCC. This study validates the application of the Bingham model to SCC in general for finding the yield stress and plastic viscosity of the mix.

V. ACKNOWLEDGEMENT

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