ABSTRACT: Plastic cracking of concrete such as plastic settlement and plastic shrinkage cracking is directly related to the bleeding of concrete, which is a natural time-dependent process in a fresh concrete mix. A portion of the mixing water together with very fine materials finds its way to the surface of the concrete during this process. The rapid rate of initial bleeding slows down with the elapsed time and the bleeding process may continue to occur for a period up to 2 hours. When the concrete is placed by pumping it is become necessary to have control over the bleeding capacity to achieve stable concrete mixes under pressure. Both the bleeding rate and bleeding capacity of concrete are affected by the amount of very fine materials in concrete as well as the mix compositions. This paper reports the results of an extensive study on the effects of binder materials and the mix compositions on the rate of bleeding and the bleeding capacity of freshly mixed concrete. The parameters used in this study were the water content, superplasticiser dosage, granulated blast-furnace slag as fine aggregate replacement, fly ash for cement replacement, and fly ash as an addition material. The results obtained with a number of fresh concrete mixes indicated the existence of a direct correlation between the bleeding capacity and the initial bleeding rate. The empirical expression developed will be useful to predict the bleeding capacity based on the initial bleeding rate.

KEYWORDS: Bleeding, bleeding rate, fly ash, ground granulated blast-furnace slag, superplasticiser, plastic cracking, granulated blast furnace slag, fine aggregate, compressive strength, slump.

1. INTRODUCTION

Bleeding of concrete may be considered as the physical migration of water towards the top surface. It is not always favourable as it increases finishing times, produces laitance at the surface, decreases strength, wear resistance and bond strength and causes poor bonds between successive lifts. However, bleeding is also a necessary part of the life of the concrete. It replaces water lost by evaporation and prevents concrete surface from drying out too quickly before it has attained sufficient tensile strength to resist cracking. Plastic cracks form within 3 to 5 hours after the concrete is placed while the concrete is still in the plastic state. Plastic settlement cracks occur only when there is a relatively high amount of bleeding and settlement and there is a restraint to settlement in one form or another. Plastic shrinkage cracking is basically caused by rapid drying of concrete surface when the rate of evaporation exceeds the rate of bleeding (Lerch (1957)). Therefore, bleeding may be viewed as a necessary evil or a benefit depending upon specific circumstances of the job site.

The results of an experimental investigation into the influence of binder materials and mix parameters on the bleeding rate and bleeding capacity of concrete are reported. The parameters studied are: (a) water content; (b) superplasticiser dosage; (c) fly ash as addition or substitution to cement; (d) ground granulated blast-furnace slag as substitution to cement; and (e) granulated blast-furnace slag as substitution to fine aggregate. Results correspond to the mixes with cement supplementary materials are reported in this paper. The bleeding rate of the concrete mixes were monitored over up to 3 hours period and the relationship between bleeding capacity and initial bleeding rate is proposed.
2. EXPERIMENTAL INVESTIGATION

2.1 Materials

Either Type GP cement or Type GB cement (containing 35% or 62% ground granulated blast-furnace slag, produced according to AS 3972, were used in producing the concrete mixes. Coarse aggregate used was a combination of 20mm and 10 mm single sized crushed basalt. Combined coarse and fine Napean River sands were used as fine aggregate. Commercially available low calcium NSW fly ash was used to partially replace cement. Ground granulated blast-furnace slag from Australian Steel Mill Services was used. The water absorption capacity of this slag was 0.8%. Superplasticiser, containing a sulphonated polymer was used.

Table 1: Mix Compositions (kg/m³) of the Control Concrete Mix

<table>
<thead>
<tr>
<th>Cement</th>
<th>Water</th>
<th>20mm Coarse aggregate</th>
<th>10mm Coarse aggregate</th>
<th>Coarse sand</th>
<th>Fine sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>345</td>
<td>195</td>
<td>730</td>
<td>270</td>
<td>550</td>
<td>220</td>
</tr>
</tbody>
</table>

2.2 Mix Proportions

Commercially available Grade 32 control mix was used as the control mix and its mix compositions are given in Table 1. In Series A, two additional water contents of 208 and 221 litres per cubic metre were used. In Series B, fly ash was added to the control mix in proportions of 10, 20%, 30% and 40% of cement by weight. In Series C, superplasticiser dosages of 0.5, 1, 2 and 3 times the recommended levels. In Series D, fly ash and ground granulated blast-furnace slag were used to partially replace the cement. The replacement levels when fly ash was used were 10, 20, 30, and 40% by weight. In the other hand, Type GB cement containing 35% (slagment) and 62% (marine cement) slag contents were used. In Series E, granulated blast furnace slag was used to replace the coarse sand in proportions of 25, 50, 75 and 100% by weight.

2.3 Batching, Mixing and Moulding of Fresh Concrete

Both fine and coarse aggregates were air-dry condition. The batch weights of these aggregates were corrected for their moisture conditions below the saturated surface dry conditions. Concrete ingredients were batched by weight. The aggregates were added first to the pan mixer followed by half of the required water. Aggregates were briefly mixed. Then cement and rest of the water were then added. Concrete was mixed for two minutes and left to stand for a further 2 minutes. When fly ash is used it was added together with the cement and superplasticiser was mixed with water. Immediately after mixing, the fresh concrete was used to cast 4 Nos. of 100mm cubes and 2 Nos. of 100mm diameter by 200mm cylinders for compressive strength testing at 1 day and 28 days. The cast specimens were removed from the steel mould after 24 hours and stored in water at 20°C. 2 Nos. of the cubes were tested immediately in direct compression to determine its 1-day strength and the other cubes and cylinders were kept in water until testing at the age of 28 days.

2.4 Testing of Concrete

Fresh concrete was tested for its wet density, slump and bleeding according to the Parts 3, 5 and 6 of Australian Standard AS1012: Testing of Concrete, respectively. The slump test was carried out after 10 and 60 minutes after mixing was completed to assess the slump loss. The cubes were tested for their compressive strength at the ages of 1 day and 28 days and cylinders were tested for their 28 days strength in accordance with AS1012: Part 9. Bleeding test was undertaken within 10 minutes of completion of mixing. Concrete was placed in a steel 254mm by 280mm high mould in two layers. Each layer was vibrated on a vibrating table to compact the concrete. The mould was then placed at an
angle of 11 degree and covered and left to stand for the duration of the test. Tilting the concrete mould enabled easy withdrawal of the bleed water from concrete. A pipette was used to draw off the bleed water at the intervals of 30 minutes up to 3 hours. The collected water was weighed in an electronic balance to record the weight of accumulated bleed water. Bleeding capacity is given by the following equation:

\[ \text{Bleeding capacity} \% = \frac{Q \times M}{(S \times V \times 10)} \ldots \ldots (1) \]

where, Q is the total bleed water (ml); M is the total batch mass of concrete from which sample was taken (kg); S is the mass of concrete in the test specimens (kg) and V is the free mixing water in the batch of concrete (litre).

Table 2: Properties of concrete containing fly ash as cement replacement

<table>
<thead>
<tr>
<th>Property</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (mm)</td>
<td>45</td>
<td>45</td>
<td>50</td>
<td>75</td>
<td>55</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>2360</td>
<td>2375</td>
<td>2355</td>
<td>2345</td>
<td>2335</td>
</tr>
<tr>
<td>Bleeding (%)</td>
<td>1.74</td>
<td>2.25</td>
<td>2.08</td>
<td>2.77</td>
<td>2.71</td>
</tr>
<tr>
<td>1-day cube strength (MPa)</td>
<td>14.1</td>
<td>13.1</td>
<td>11.0</td>
<td>8.8</td>
<td>7.3</td>
</tr>
<tr>
<td>28-day cylinder strength (MPa)</td>
<td>41.8</td>
<td>35.7</td>
<td>33.7</td>
<td>27.9</td>
<td>22.7</td>
</tr>
</tbody>
</table>

Figure 1: Effect of Cement Replacement with Fly Ash on Bleeding Capacity of Concrete

3. RESULTS AND DISCUSSION

3.1 Effect of Cement Replacement with Fly ash on Concrete Properties

Table 2 summarizes the properties of fresh and hardened concrete properties containing fly ash as a replacement to cement up to 40% by weight. Figure 1 shows the development of bleeding with elapsed time as a function of the fly ash content when it is used to replace cement in the control mix. Figure 2 shows the influence of fly ash content on the 28-day compressive strength of concrete.

The slump for the control concrete was 45mm and when cement was replaced with fly ash the slump has increased marginally. The maximum slump of 75mm was recorded for the mix with 30% cement replacement. Since the fly ash being a lighter material compared to cement and having spherical
particle shape, the improvement in workability was expected (Sri Ravindrarajah and Tam (1989)). The results also show that the density of concrete was marginally reduced for most of mixes with fly ash. The results shown in Figure 1 show that the bleeding rate and bleeding capacity are noticeably increased with the increase in the cement replacement level with fly ash. For all concrete mixes the rate bleeding was found to decrease with elapsed time as the cement begins to stiffen. After 2 hours the bleeding process was found to be insignificant for the chosen mix compositions. The initial bleeding rate was found to be sensitive to other factors such as amount of fine materials, water content, superplasticiser dosage and type of cement.

![Figure 1: BLEEDING RATE AND BLEEDING CAPACITY OF CONCRETE](image)

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Compressive strength of concrete after 1-day and 28 days was reduced significantly as the cement replacement level with fly ash was increased. 40% cement replacement caused the 1-day cube strength to drop from 14.1 MPa to 7.3 MPa, i.e. a drop of 48.2%. Similarly, the 28-day cylinder strength dropped from 41.8 MPa to 22.7 MPa, i.e. a drop of 45.7% as shown in Figure 2. The low calcium fly ash used being a slow reactive pozzolanic material had not surprisingly caused the observed reductions at both 1-day and 28-day strengths. If favourable curing conditions are maintained the strength reductions could be expected to reduce with time. It should be noted that the strength reduction of 19.4% was observed after 28 days when 20% cement was replaced with fly ash.

![Figure 2: EFFECT OF FLY ASH AS CEMENT REPLACEMENT AND ADDITION ON 28-DAY COMPRESSIVE STRENGTH](image)

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Table 3: Properties of concrete containing fly ash as addition

<table>
<thead>
<tr>
<th>Property</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>2355</td>
<td>2375</td>
<td>2375</td>
<td>2355</td>
<td>2350</td>
</tr>
<tr>
<td>Bleeding (%)</td>
<td>1.76</td>
<td>1.60</td>
<td>2.11</td>
<td>0.89</td>
<td>0.71</td>
</tr>
<tr>
<td>28-day cylinder strength (MPa)</td>
<td>35.5</td>
<td>44.4</td>
<td>39.6</td>
<td>38.4</td>
<td>45.0</td>
</tr>
</tbody>
</table>

3.2 Effect of Fly ash Addition on Concrete Properties

Table 3 summarizes the effect of fly ash addition on the properties of concrete in both fresh and hardened states. Figure 3 shows the bleeding rate and bleeding capacity of concrete as a function of the fly ash addition. Initial bleeding rate and bleeding capacity of concrete were significantly reduced with the increase as the fly ash addition was increased. The bleeding capacity of concrete with no fly ash addition was 1.76%. When fly ash was added to the mix equal to 10% of the cement weight, the bleeding capacity was dropped to 1.60%. This was gradually reduced as the fly ash content was
increased and when the addition was 40% of cement weight, the bleeding capacity was reduced to 0.71%. As the fine material (cement plus fly ash) content was increased it is not surprising that the bleeding was reduced significantly. As seen from Figure 2 and Table 2, the compressive strength at 28 days also found to improve with the fly ash addition because of the increased cementitious material content in the concrete mix. However, no clear relationship between the fly ash content and the improvement in strength was noted.

![Figure 3: Effect of Fly Ash Addition on Bleeding Capacity of Concrete](image)

Table 4: Properties of concrete containing ground granulated blast-furnace slag

<table>
<thead>
<tr>
<th>Slag content (%) by weight</th>
<th>0</th>
<th>35</th>
<th>62</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (mm)</td>
<td>45</td>
<td>65</td>
<td>50</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>2360</td>
<td>2375</td>
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</tr>
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<td>2.08</td>
</tr>
<tr>
<td>1-day cube strength (MPa)</td>
<td>14.1</td>
<td>9.6</td>
<td>3.2</td>
</tr>
<tr>
<td>28-day cylinder strength (MPa)</td>
<td>41.8</td>
<td>40.6</td>
<td>25.8</td>
</tr>
</tbody>
</table>

![Figure 4: Effect of Cement Replacement with Ground Granulated Slag on Bleeding Capacity of Concrete](image)
3.3 Effect of Cement Type on Concrete Properties

Table 4 shows the properties of concrete in fresh and hardened states when Type GP and GB cements were used. Type GB cement consisted of 35% and 62% ground granulated blast-furnace slag. Figure 4 shows the development of bleeding with elapsed time for the concrete mixes with these two types of cements. The cement type used marginally affected the slump of concrete. However, bleeding capacity was increased when Type GB cement was used instead of the Type GP cement. No direct relationship between the slag content and bleeding rate was noted.

Compressive strength after 1 day was significantly reduced when the Type GB cement was used instead of Type GP cement. It dropped from 14.1MPa to 9.6 and 3.2 MPa when the slag contents of 35% and 62% were used, respectively. Therefore, the strength reductions were 32% and 77% when cement with 35% and 62% slag contents were used, respectively. Similarly, 28-day strength was also reduced with the use of the Type GB cement. The corresponding strength reductions were 3% and 38%, respectively.

3.4 Relationship between Initial Bleeding Rate and Total Bleed Water

Powers (1939) showed that bleeding in concrete occurs in two phases. The first phase is a virtually constant bleeding rate, q (ml/h). In the second phase, the bleeding rate is continually decreased with elapsed time. Schiessl and Schmidt (1990) reported that the total bleeding capacity, Q (ml) is closely related to the initial bleeding rate q (ml/h). From the bleeding test results with 25 concrete mixes in this study, the following empirical equation is proposed:

\[
Q = 1.31q + 5.97
\]

The advantage of this relationship is that it could be used as a quick and easy method to predict the quantity of bleed water (Q) knowing the initial rate of bleeding (q) for the first 30 to 60 minutes. Once Q is known, bleeding capacity can be estimated using Eqn. (1).

4. CONCLUSIONS

1. Bleeding capacity of concrete is increased with the increase in the cement replacement level with fly ash.
2. Large addition of fly ash (30 to 40% by cement weight) reduced the bleeding capacity of concrete.
3. Use of blended cement with slag increased the bleeding capacity of concrete.
4. Relationship between initial bleeding rate (q ml/h) and total bleed water (Q ml) is given by:
   \[
   Q = 1.31q + 5.97,\text{ which can be used to estimate the bleeding capacity of concrete.}
   \]

5. ACKNOWLEDGEMENT

Author wishes to thank the contribution of Mr. Geoffrey Baker who conducted the experimental work at the University of Technology, Sydney under the Author’s guidance.

6. REFERENCES