WORKABILITY ASSESSMENT FOR POLYSTYRENE AGGREGATE CONCRETE

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ABSTRACT

Incorporating expanded polystyrene granules in a concrete matrix can produce lightweight polystyrene aggregate concrete of various densities. This paper examines the suitability of the DIN 1048: Compaction Index test to the polystyrene aggregate concrete having the unit weight of 1600, 1800 and 2000 kg/m$^3$. A comparison is made between the compaction index and slump. It was found that workability of polystyrene aggregate concrete could be classified in terms of the compaction index. The compaction index ranges are 1.03 to 1.13, 1.14 to 1.29, 1.30 to 1.40, and 1.41 to 1.52 for high, medium, low and very low degrees of workability, respectively. For a given workability, the slump of concrete is significantly affected by its unit weight.

1. INTRODUCTION

Workability, which is an important property of concrete, affects the rate of placement and the degree of compaction of concrete. Inadequate compaction leads to reductions in both strength and durability of concrete. Therefore, testing for workability of concrete is required to achieve good quality in-situ concrete. The fundamental characteristics to define the workability include viscosity, cohesion, mobility, stability, compactability, pumpability and finishability. Most national and international standards consider the workability tests namely, the slump test, the compacting factor test and the vebe test, depending on the degree of workability by measuring one or more of the characteristics of concrete. These workability measurements are influenced by the unit weight of concrete. Therefore, an assessment of workability for lightweight concrete using these tests often subjected to judgment based on experience and susceptible to misinterpretation by non-experienced persons.

Lightweight concrete can be produced by partially replacing the normal weight coarse aggregate particles with expanded polystyrene granules. The particle and bulk densities for the polystyrene aggregate used are 58 and 17 kg/m$^3$, respectively. The expanded polystyrene aggregate is commercially available with suitable chemical coating, which is necessary to achieve a uniform dispersion of the beads in the fresh concrete mixture and to avoid segregation during mixing and handling of concrete. The polystyrene has negligible water absorption due to its closed cellular structure. Cook (1983) reported that the standard workability tests are not suitable for the polystyrene aggregate concrete, since they are sensitive to the unit weight of concrete. Bartos (1992) found that compaction index based on the German Standard DIN 1048.1 (1977) is more suitable for assessing the workability of lightweight concrete. Suitability of the compaction index test to assess the workability of polystyrene aggregate concrete is investigated in this study. The workability of polystyrene aggregate concrete is classified, in terms of the compaction index and an empirical relationship between the compaction index and slump will be discussed. This paper forms a part of an extensive study at the University of Technology, Sydney on the production and properties of polystyrene aggregate concrete. Some of the findings were reported elsewhere (Sri Ravindrarajah (1993, 1994, 1999)).
2. EXPERIMENTAL DETAILS

2.1 Materials
General purpose Portland cement (ASTM Type I) was used as the binder in the concrete mixtures. Dune sand and river sand, in equal weight proportions, were used as fine aggregate. The dune and river sands were 87 and 57% finer than the 600µm size, respectively. Crushed expanded polystyrene granules angular in shape with a non-toxic chemical coating and having a mean diameter of 3.7mm were used in the concrete mixtures. Basalt, having a maximum aggregate size of 10mm with a fineness modulus of 6.95 was used as coarse aggregate.

2.2 Mix compositions
Normal weight concrete mixtures with cement contents of 350, 420, 490, and 560kg/m³ and the fine aggregate content of 45% of the total aggregates were used in the reference mixtures. The polystyrene aggregate concrete mixtures having the unit weights of 1600, 1800 and 2000kg/m³ were produced by replacing 70, 50 and 30% of the coarse aggregate by volume, respectively with the polystyrene aggregate. In addition, for the 1800kg/m³ concrete mixture the fine aggregate content was varied to 35, 45, and 55% of the total aggregate. The water content was varied from 180 to 270kg/m³ to achieve concrete mixtures with a wide range of workability.

2.3 Compaction Index test (DIN 1048: Part 1)
The compaction index test is based on the assumption that the denseness of uncompacted fresh concrete is controlled by its workability and the volume of uncompacted concrete increases with the decrease in workability. Therefore, a measure for the workability of concrete can be obtained by filling a cylinder with loose fresh concrete, in a standard way, and relating its volume to its fully compacted volume. Hence, the compaction index of concrete is the ratio of the height of the cylinder to the height of compacted concrete and it decreases with the increase in the degree of workability of concrete.

A perspex cylinder with 150mm diameter and 300mm high was loosely filled with fresh concrete. A tamping steel rod fitted with a 50mm diameter steel disc was used to compact the concrete by hand and a total of 75 strokes were used to achieve full compaction. The cylinder size, diameter of the disc attached to the tamping rod and the number of strokes used for compaction were determined after an extensive preliminary investigation. A perspex collar to fit the inside of the cylinder was used to assist the measurement of the height of compacted concrete.

2.4 Mixing and testing of fresh concrete
In order to achieve a proper mixing of the polystyrene aggregate, it was necessary to mix all other ingredients in the normal way prior to the gradual addition of the polystyrene aggregate. The concrete produced was tested for the unit weight, the slump and the compaction index. In addition, the concrete mixtures in the perspex cylinder were subjected to vibration to determine the time required for the first air bubbles to escape. Since the entrapped air bubbles can easily escape from wet mixes, the first air bubbles escaping time to some degree can indicate the degree of the workability of concrete.

3. RESULTS AND DISCUSSION

3.1 Effect of mix compositions on compaction index
Figure 3.1 shows the effect of water to cement ratio on the compaction index for the reference and polystyrene aggregate concrete mixtures. The compaction index decreased with the increase in the water to cement ratio. From the steepness of the plots, it can be said that the workability of the concretes with the cement content of 350 kg/m³ is less sensitive to the
change in the w/c ratio compared to the concretes with the cement content of 560 kg/m$^3$. Figure 3.2 typically shows the effect of water content on the compaction index for the polystyrene aggregate concrete. When the water content is increased the compaction index is decreased indicating the increase in the workability of concrete.

Figure 3.1: Influence of cement content on the workability of polystyrene aggregate concrete

Figure 3.2: Effect of water content and unit weight on compaction index (Cement content = 350 kg/m$^3$)
3.2 Effect of unit weight

Beecrof (1992) found that an equal slump for the lightweight and normal weight concretes would not represent the same degree of workability. The results given in Figure 3.2 shows that the unit weight of concrete does not have any definite effect on the compaction index. This is not surprising as the compaction test does not utilise the weight of the concrete. Therefore, the workability of polystyrene aggregate concrete is not significantly affected by the unit weight of the concrete when the workability is assessed by the compaction index method.

![Figure 3.3](image-url)

**Figure 3.3:** Effect of fine aggregate content and water content on compaction index
(Unit weight = 1800 kg/m³)

![Figure 3.4](image-url)

**Figure 3.4:** Relation between compaction index and visual judgement of workability.
3.3 Effect of fine aggregate content (or aggregate grading)
Figure 3.3 shows that when the fine aggregate content is increased the compaction index of the polystyrene aggregate concrete mixture is increased, indicating the reduction in its workability. The sensitivity of the fine aggregate content on the workability is increased when the water content of the concrete mixture is reduced. In wet concrete mixtures, the availability of sufficient cement paste counter-balances the effect of the increasing surface area of the aggregate particles.

3.4 Interpretation of the test results
DIN 1048 (1977) specifies three ranges for the workability of concrete, in terms of the compaction index: 1.04 to 1.10 (high), 1.11 to 1.25 (medium) and 1.26 to 1.40 (low). In order to categorize the workability of polystyrene aggregate concrete, using either the compaction index or slump, the workability of the concretes were visually examined and judged. In addition, the air bubble escape time, which is the time taken for the first air bubble to reach the concrete surface during the compaction, was monitored.

The visual appraisal of workability involved touching, patting, trowelling, and other similar actions; to experience several properties of the concrete mixtures, such as wetness, mobility, compatibility, plasticity, and cohesiveness. Neville (1987) emphasised that the visual appraisal, apart from its subjective nature, if carried out by a sufficiently experienced person, is probably no less useful as an index of workability than any other methods for measuring workability. Figure 3.4 shows the relationship between workability, as judged by visual observation, and the compaction index. Demarcation of any changes in the workability for the concrete mixtures is indicated by the scatter and discontinuity at the points of transition. Within a given range of workability, the results showed that visual assessment by an experienced person is a reliable method for assessing the workability of polystyrene aggregate concrete.
Table 3.1: Classification of workability for polystyrene aggregate concrete

<table>
<thead>
<tr>
<th>Apparent workability</th>
<th>From Fig. 3.4</th>
<th>From Fig. 3.5</th>
<th>Mean Compaction Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>1.41-1.52</td>
<td>1.41-1.52</td>
<td>1.41-1.52</td>
</tr>
<tr>
<td>Low</td>
<td>1.30-1.40</td>
<td>1.29-1.40</td>
<td>1.30-1.40</td>
</tr>
<tr>
<td>Medium</td>
<td>1.14-1.29</td>
<td>1.13-1.28</td>
<td>1.14-1.29</td>
</tr>
<tr>
<td>High</td>
<td>1.03-1.13</td>
<td>1.04-1.12</td>
<td>1.03-1.13</td>
</tr>
</tbody>
</table>

Spindel (1964) stated that the minimum time of vibration required to achieve full compaction gives a good indication of the workability of fresh concrete. Since it is difficult to determine the end point during compaction, the air bubble escape time was used to assess the workability of concrete. The relationship between the air bubble escape time, the compaction index, and the workability are shown in Figure 3.5. Similar transition points between the workability zones are noted in Figures 3.4 and 3.5. Table 3.1 classifies the workability of polystyrene aggregate concrete based on the air bubble escape time and the compaction index.

Figure 3.6: Relationship between Compaction Index and Slump

3.5 Relation between compaction index and slump
Figure 3.6 shows the relationship between the compaction index and the slump for the polystyrene aggregate concrete. Since the slump test and the compaction index test measure the stability and compactability of fresh concrete, respectively, a general relationship between them can be seen from the results. Any increase in the slump of concrete is indicated by a reduction in the compaction index. The results also show that the compaction index is more sensitive to low workability whereas the slump is more sensitive to high workability.
Table 3.2: Characterisation of workability for polystyrene aggregate concrete

<table>
<thead>
<tr>
<th>Apparent workability</th>
<th>DIN:1048 Compaction index</th>
<th>Compaction Index (measured)</th>
<th>Slump (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>very low</td>
<td>&gt; 1.45</td>
<td>1.41 - 1.52</td>
<td>-</td>
</tr>
<tr>
<td>low</td>
<td>1.26 - 1.45</td>
<td>1.30 - 1.40</td>
<td>less than 10</td>
</tr>
<tr>
<td>medium</td>
<td>1.11 - 1.25</td>
<td>1.14 - 1.29</td>
<td>10 - 40</td>
</tr>
<tr>
<td>high</td>
<td>1.04 - 1.10</td>
<td>1.03 - 1.13</td>
<td>greater than 40</td>
</tr>
</tbody>
</table>

The slump of polystyrene aggregate concrete is lower than normal weight concrete of comparable workability due to the reduction in the unit weight as indicated by Newman and Bremmer (1980). Using Table 3.1 and Figure 3.6, the workability of polystyrene aggregate concrete can be classified in terms of the compaction index and the slump. It is interesting to note that DIN1048 ranges for the compaction index for various degrees of workability for the normal weight and lightweight concretes are in close agreement with the results obtained in this study for the polystyrene aggregate concrete.

4. CONCLUSIONS

1. Similar to the normal weight concrete, the workability of polystyrene aggregate concrete is influenced by the water to cement ratio, fine aggregate content, and water content.
2. The unit weight has no significant influence on the workability as measured by the DIN1048 compaction index.
3. The DIN compaction index is sensitive to the variations in the composition of concrete and more sensitive to the low workability than for the high workability.
4. The compaction index ranges for the polystyrene aggregate concrete are 1.03 to 1.13, 1.14 to 1.29, 1.30 to 1.40, and 1.41 to 1.52 for high, medium, low and very low degrees of workability, respectively.

5. REFERENCES


DIN 1048 (1977), Part 1, chapter 3.1.1, Concrete according to German Standards, (Ed. B. Dartsch), Dusseldorf: Beton-Verlag, 1977, pp. 50 - 52.


