A STUDY ON THE UTILIZATION OF RECYCLED CONCRETE AGGREGATES (RCA) IN BITUMINOUS CONCRETE

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ABSTRACT: Recycled Concrete Aggregates (RCA) are produced by crushing demolished concrete elements. RCA differ from fresh aggregates due to the cement paste attached to the surface of natural aggregates even after the process of recycling. This porous cement paste and other contaminations contribute to the lower particle density, high porosity, water absorption and variation in quality of the RCA. The main objective of this study is to investigate the performance of bituminous concrete made with various percentages of RCA. In the present study investigations were taken up on the possible applications of RCA in bituminous concrete. It was found that aggregate properties, volumetric properties of bitumen specimens containing RCA were relatively low compared to fresh aggregate properties, but the Marshall Stability value was higher for RCA compared to fresh aggregates with conventional bitumen and modified bitumen, the rutting deformation was higher for fresh aggregates compared to RCA. Some of these measured properties were within the acceptable limits, except the water absorption for 100% RCA, sample used in this study.

1. INTRODUCTION

With the spiraling increase in the construction activity, the amount of waste generated is also increasing day by day. Demolished concrete structures are proven to be a good source of construction material (Nik. D. Oikonomou 2004, Sumeda Paranavitthana, Abbas Mohajerani 2006, Akash Rao et al. 2006, P.R. Kumar and M.L.V. Prasad et al. Oct 2007, P.R. Kumar et al. Dec 2007, P.R. Kumar et al. March 2008 and, M. Heeralal, P.R. Kumar et al. 2009). RCA is produced by the process of crushing demolished concrete elements. RCA was initially used as a filler material and after many research works (Huang et al. 2005, C.S. Poon 2005, M. Heeralal, P.R. Kumar et al. 2009) it is now being utilised as a sub base material for road, non-structural concrete applications such as kerbs, driveways, footpaths, etc. RCA differ from fresh aggregates due to the amount of cement paste remaining on the surface of the original natural aggregates even after the process of recycling. This porous cement paste contributes to the lower particle density, higher porosity, variation in the quality of the RCA and the higher water absorption. In the present study some of the findings of an investigation of RCA on performance and properties of bituminous concrete grade I mix are dealt with.

2. NEED FOR THE STUDY

Bitumen as a paving material undergoes changes like permanent deformation, low temperature cracking, fatigue cracking, ageing and water receptivity due to high traffic intensity, high axle loads, variation in traffic and seasonal temperature variation.

There is already a reasonable good amount of research on bituminous concrete made using natural aggregate. The present study was hence taken up to investigate the effect of RCA on the performance of bituminous concrete mix. The present work aims to estimate the optimum binder content for the bituminous concrete mix replacing the natural aggregate with 0, 50 and 100% of RCA and conducting Marshall’s mix design to compare the results. Wheel tracking experiment with simulated wheel arrangement (5.6 kg/cm² contact pressure) for a specified number of repetitions (20000) on conventional bituminous concrete mixes was also carried out with a view to study the rutting potentiality of different dosages of RCA replacements in natural aggregate.

2.1 Sample Preparation for Marshall Mix Design

To control the gradation of the test specimens, the natural and recycled concrete aggregates were initially separated into various sized fractions and stored properly. The characteristics of the natural and recycled aggregate samples are shown in Table 1. When the test specimens were prepared, the aggregates were combined as per the gradation given in Mort & H [2001]. Each test specimen was batched separately. The composition of each size fraction relative to aggregate sources
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Table 1: Aggregate Test Results

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Properties</th>
<th>RCA %</th>
<th>IS standards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>1.</td>
<td>Aggregate impact value %</td>
<td>18.04</td>
<td>20.69</td>
</tr>
<tr>
<td>2.</td>
<td>Abrasion Value %</td>
<td>23.76</td>
<td>25.88</td>
</tr>
<tr>
<td>3.</td>
<td>Specific gravity</td>
<td>2.68</td>
<td>2.65</td>
</tr>
<tr>
<td>4.</td>
<td>Water absorption %</td>
<td>0.5</td>
<td>1.6</td>
</tr>
<tr>
<td>5.</td>
<td>Flakiness index %</td>
<td>10.62</td>
<td>9.46</td>
</tr>
<tr>
<td>6.</td>
<td>Elongation index %</td>
<td>9.45</td>
<td>10.15</td>
</tr>
<tr>
<td>7.</td>
<td>Combined FI &amp; EI</td>
<td>20.07</td>
<td>19.61</td>
</tr>
</tbody>
</table>

was maintained constant. The combined aggregate was placed in a hot oven and heated up to the required mixing temperature. The quantity of aggregate is taken so as to produce a batch, which would result in compacted specimen of 63.5 mm height. Bitumen binder of specified grade was also heated to the required temperature. The predetermined quantity of heated bitumen was poured in the heated aggregate. The mixing operation was carried out manually. After obtaining a homogeneous mix, the mix was placed in a preheated compaction mould. At the start of the compaction, desired compacting temperature was ensured.

The compaction was done by a standard hammer of 4.5 Kg weight falling from 45.7 cm height by giving 75 blows on each of the face and sample was cooled for 24 hours at room temperature before being extracted using standard extraction procedure. Five specimens were prepared for BC grade I for RCA (0, 50, 100%) aggregate gradations recommended by MORT & H (2001) at 4 to 6% Bitumen Content at an increment of 0.5%.

2.2 Sample Testing

After 24 hours the sample was remoulded and the specimen was weighed to get the dry air mass. After that the specimen was immersed in water to get the mass in water. The test specimens after extraction were placed in water bath at 60°C for 30 minutes placed with its axis horizontal to the test head. The complete assembly was quickly placed on the base plate of the compression machine test setup. The flow dial gauge was placed over the guide rod and dial gauges of the proving ring and flow value were adjusted to zero. The machine was set to operation for applying load until the maximum value was reached. The values of maximum load and the flow dial gauges are recorded and the load was released. From the observed readings the Marshall Stability and Flow values were obtained and the other values are determined by analytical procedure. Before testing the sample, the weight of the sample in air and the weight of the sample in water were found. Since the height of the sample was also measured by averaging number of measurements around the periphery of the sample.

2.3 Stability and Flow Analysis

Optimum Bitumen Content (OBC) has been obtained by taking the average of the bitumen contents at which the mix has maximum bulk specific gravity, maximum stability and 4% design Air Voids from the graphs. Trials on Grade-I Conventional Bitumen mix have resulted in Optimum Bitumen Content of Bituminous Concrete with RCA (0, 50,100%). In addition to the OBC, other requisite parameters have been computed using the formulae in equations 1, 2 and 3 and the properties at OBC are presented in graphically. From the graphs OBC and other properties were calculated.

1. Percent Air Voids ($V_v$) = \( \frac{G_t - G_b}{G_t} \times 100 \)

2. Bulk Specific Gravity ($G_b$) = \( \frac{W_{air}}{W_{air} - W_{water}} \)

3. Theoretical Specific Gravity ($G_t$) = \( \frac{100}{W_1 + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4}} \)

where,

- $W_1$ = Percent by weight of coarse aggregate in total mix
- $W_2$ = Percent by weight of fine aggregate in total mix
- $W_3$ = Percent by weight of filler in total mix
- $W_4$ = Percent by weight of bitumen in total mix
- $G_1$ = Apparent specific gravity of coarse aggregate
- $G_2$ = Apparent specific gravity of fine aggregate
- $G_3$ = Apparent specific gravity of filler
- $G_4$ = Apparent specific gravity of bitumen

The Percent of Voids in Mineral Aggregate (VMA) = $V_v + V_b$

Volume of Bitumen ($V_b$) = $G_b \times (W_4/G_4)$

Percent Voids Filled with Bitumen (VFB) = $(100 \times V_b)/VMA$

The variation of the variation of the bitumen binder content versus the VFB (%) is shown in Figure 1, while the variation of the % Bitumen versus the Flow Value in mm is shown in Figure 2.
2.4 Selection of Optimum Binder Content

The optimum binder content was finally selected based on the combined results of Marshall Stability flow, density analysis and void analysis. Optimum bitumen binder content can be arrived by adopting the following procedure. The details of the variation are shown in Figures 3–5.

2.5 Calculation of OBC

From the Figure 3, the percentage of Bitumen versus Marshall Stability value is the Marshall Stability Value peak value noted as $B_1$. From Figure 4, the percentage Bitumen versus $G_b$ the peak value is noted as $B_2$ and from Figure 5 that is the percentage bitumen versus at a bitumen percentage of 4% of voids is noted as $B_3$. The Optimum Bitumen Content is $OBC = (B_1 + B_2 + B_3)/3$.

2.6 Rutting Test

The rutting test was carried on a small scale laboratory based simulated wheel track test for evaluating the conventional grade Bituminous Concrete G-I Mixes with respect to permanent deformation characteristics, roller compacted samples were prepared on a calibrated roller compaction equipment. The mould was of $30 \text{ cm} \times 30 \text{ cm} \times 7.5 \text{ cm}$ and a compacted thickness of 6 cm. Each sample was allowed to stay in the mould for 24 hours and extracted later. After 24 hrs the mould was placed on a Wheel tracking equipment as shown in Figure 6.
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The load on the test wheel assembly was adjusted to result in a contact pressure of 5.6 Kg/cm², which is the usual contact pressure intensity observed in the field. Later, wheel-tracking test was performed on all the samples and the progressive rut depth values were noted down from the dial gauge attached for every 1000 revolutions test was performed for 20,000 revolutions on three RCA % BC G-I mix. Permanent deformation observations for Bituminous Concrete Mix of G-I for three RCA replacements were plotted and presented in graph and table. Visual representation of the rut depth for RCA 0, 50, 100% replacements in natural aggregate as shown in Figure 7 and the trends are represented in Table 2.

Table 2: Variation of Wheel Load Repetitions & Rut Depth

<table>
<thead>
<tr>
<th>S. No.</th>
<th>RCA %</th>
<th>OBC %</th>
<th>Correlation equation</th>
<th>Wheel load repetitions &amp; rut depth in (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20000</td>
</tr>
<tr>
<td>1.</td>
<td>0</td>
<td>5.0</td>
<td>Y = 0.0002X + 0.7867</td>
<td>4.54</td>
</tr>
<tr>
<td>2.</td>
<td>50</td>
<td>4.8</td>
<td>Y = 0.0002X + 0.5996</td>
<td>4.03</td>
</tr>
<tr>
<td>3.</td>
<td>100</td>
<td>5.0</td>
<td>Y = 0.0002X + 0.4084</td>
<td>3.56</td>
</tr>
</tbody>
</table>

3. DISCUSSION ON RESULTS

Bituminous mixes of BC G-I were designed for its properties at Optimum Binder content. The Gradation used for this purpose was BC G-I of MORTH specification (2001) based on its mid point gradation with slight changes in the gradation. The stability of the mix was found with Marshall Mix design process with the varied binder content of 4% to 6% with 0.5% increment each time. Bulk density of 0% RCA BC G-I mix was greater than 50 & 100% RCA used in the present study. 100% RCA showed lesser Bulk Density. Voids filled with Bitumen in case of conventional bitumen mix was more when compared with the modified mixes (70%) with 100% RCA. Flow value of modified mix was less when compared to that of conventional mix with 100% RCA, indicating better quality. Both the results were within the specified limits. Better stability value was noticed in BC G-I with 100% RCA with conventional as well as modified bitumen. 100% RCA had more percentage of Volume of Voids (11.28%) with conventional bitumen 60/70 grade than Modified Bitumen SBS 70 (7.12%). The Bituminous concrete G-I mix with 0, 50, 100% RCA was compared against rutting potentiality. The Bituminous concrete G-I mix with 100% RCA has performed better than the other two percentages.

4. CONCLUSIONS

The following conclusions can be drawn based on the laboratory studies on the role of recycled aggregates in bituminous mixes.

(a) The aggregate properties of RCA are within the limits for the bituminous mix design as per the MORT&H, except for the water absorption for 100% recycled aggregate mixes.
(b) It was concluded that bulk density, voids in mineral aggregates, voids filled with binder in the compacted bitumen specimens containing RCA, were lower than those for the control mix made with natural aggregates.
(c) The Marshall Stability value for 100% RCA is more compared to 50% and 0% RCA.
(d) The Marshall Stability value for 100% RCA is more for modified bitumen (SBS70) compared to conventional bitumen grade 60/70.
(e) The stripping value for the 100% RCA is within in the limits in wet and dry conditions.
(f) Under laboratory conditions, Rutting deformation is less for 100% RCA compared with 0% RCA.

5. SCOPE FOR FUTURE STUDY

The results found in this study are encouraging. However, further investigations are required to examine the findings in this research using different percentages of recycled concrete.
aggregates in bituminous concrete and examine the field conditions for the long run performance.

REFERENCES


