THE POTENTIAL USE OF CONSTRUCTION AND DEMOLITION WASTE IN ROAD CONSTRUCTION IN IRELAND

A. R. Woodside*
Professor, University of Ulster, UK
W. D. H. Woodward
Reader, University of Ulster, UK
J. McElhinney
University of Ulster, UK

ABSTRACT
The construction and annual maintenance of Ireland’s road network consumes large amounts of quarried virgin aggregate. The partial substitution of virgin aggregates in a 20mm Asphalt Concrete binder course with recycled construction and demolition (C&D) waste was investigated. Although this has been carried out in other countries, the use of using what would have until recently been sent to landfill is still quite novel. Whilst the part replacement of virgin aggregate with secondary materials helps reduce the burden on available landfill space it also tackles sustainability issues and helps reduce reducing the construction industry’s carbon footprint. It was found that the addition of up to 25% good quality C&D waste improved the stiffness and rutting resistance without adversely affecting mix durability.

KEY WORDS: Construction and demolition waste, asphalt.
1. INTRODUCTION
With a greater understanding of the need for sustainable development, the use of materials that would otherwise have gone to landfill has been recognized globally for its environmental and economic benefits. Road construction in Ireland has consumed large amounts of virgin aggregate and produces a large carbon footprint.

Ireland’s recent building boom along with the significant investment in infrastructure projects placed a high demand on virgin aggregates from the available quarries.

Recent studies indicate the current level of demand on virgin aggregate is putting a considerable strain on existing reserves across Ireland and the UK. A review of the Irish aggregate industry in 2006 estimated that there was approximately 17 years of reserves at 2006 output levels [1].

However, this was subject to planning permission applications being successful, with many operating quarries reporting less than 10 years reserves of aggregates left.

The need to preserve this finite source of aggregate and reduce landfill deposits such as construction and demolition (C&D) waste has encouraged the Irish road construction industry to consider C&D waste as an alternate secondary aggregate [2].

However, within Ireland there has been very little historical experience with the use of such wastes in road construction. This was the focus for the research presented in this paper i.e. could Irish C&D waste be used as a construction material to replace virgin aggregate.

The paper first considers how much potential C&D waste there is in Ireland and where it is located.

It then summarises laboratory assessment of the C&D aggregate properties. Based on the values obtained it was then decided to use the recycled C&D waste as a Virgin aggregate replacement in an AC 20 HDM mix.

The paper finishes by summarising a laboratory investigation of this mix containing 10%, 25% and 50% C&D waste.

2. CONSTRUCTION AND DEMOLITION WASTE IN IRELAND
The Irish National Waste Database defines C&D Waste as .all waste that arises from construction, renovation and demolition activities and all wastes mentioned in Chapter 17 of the European Waste Catalogue (EWC) [3]. For this paper the term C&D waste refers only to crushed concrete, bricks and blocks arising from construction activity.

The total production of C&D waste in the European Union is estimated to be about 450 - 500 million tonnes per annum. Excluding earth and excavated road materials then the amount of core C&D waste is estimated to be roughly 180 million tonnes per year [4].
Putting this into an Irish context, Figure 1 shows the location of the ten waste management regions. Figure 2 shows the regional distribution of C&D waste across its ten waste management regions. This is for the period 2003-2006 when Ireland produced in 12.6 million tonnes of C&D waste across its ten waste management regions. Figure 2 clearly shows that the greatest concentration of C&D waste produced was for Dublin, the Irish capital city and its surrounding counties.

- The setting of recycling targets for non-hazardous construction and demolition waste (70% by 2020).
- A provision which would enable the European Commission to adopt EU-wide end-of-waste criteria for specified wastes. A waste specified in this way would cease to be waste when it has undergone a recovery operation and complies with the criteria set by the Commission.
- The obligation for Member States to set up waste prevention plans within five years from the adoption of the Directive [5].
The implementation of an EU-wide end-of-waste criteria for specified wastes, may enable producers to sell the re processed C&D waste material as a new product. Therefore, this gives the construction sector the credence it requires in promoting the use of recycled materials on site.

4. ECONOMIC VIABILITY OF C&D WASTE IN IRELAND

Duarn et.al [6] used the following formula to enable a contractor to assess the most economic solution for disposal of C&D waste in Ireland. The options were to either dispose of the waste in landfill or dispose of the waste at a recycling centre.

Their formula was \[ T1 + C1 > Tr + Cr + Er \]

Where:

- \( T1 \) = Cost per tonne of transporting unsorted waste to landfill.
- \( C1 \) = Cost per tonne of disposing of unsorted waste at landfill.
- \( Tr \) = Cost per tonne of transporting waste to a recycling centre.
- \( Cr \) = Cost per tonne of bringing waste to a recycling centre.
- \( Er \) = Extra cost per tonne incurred by waste producer of bringing waste to recycling centre, i.e. segregating the waste prior to delivery to the recycling centre.

Using current industry pricing schedules the authors applied this formula to the scenario of recycling C&D waste in the Dublin region and established the following results.
T1 = 90 Euro / 20 Tonne Load = 4.50 euro per tonne.
C1 = 160 Euro to dispose of unsorted waste at landfill.
Tr = 90 Euro / 20 Tonne Load = 4.50 euro per tonne.
Cr = 4.50 Euro per tonne gate fee.
Er = 6 Euro (Cost of one man and 20t machine to sort one tonne of C&D waste, at a sorting rate of 10 tonne per hour)

This equates as: €4.50 + €160 > €4.50 + €4.50 + €6.0
= €164.50 > €15.0

Therefore by segregating the C&D waste on site and disposing of it at a suitable recycling centre the contractor is able to save an average of €149.50 per tonne.

5. PROPERTY REQUIREMENTS FOR AGGREGATE IN ASPHALT PAVEMENTS

With the introduction of the new EU legislation, the Irish construction industry is under pressure to find alternate use for C&D waste to reduce waste to landfill and promote the sustainable approach of cradle to cradle construction.

The introduction of European Standards (EN) has had a positive effect on the use of secondary materials in road construction. They cover aggregates from natural, recycled and manufactured materials, focusing on fitness for purpose and not discriminating between different sources [5]. Aggregates should meet the requirements specified in NRA DMRB 900 SERIES [7].

6. AGGREGATE ANALYSIS

Virgin Carboniferous limestone and recycled C&D waste were sourced from Roadstone Wood Quarry, Belgard. The recycled C&D aggregate consisted of oversized pieces of crushed concrete, blocks, bricks and stone which were then crushed in the laboratory to produce 20mm, 14mm, 10mm, 6mm and dust sizes. The following values were obtained for the recycled aggregate i.e. Los Angeles value 27.5%, Wet micro-Deval 17.5% and Water absorption 4.0%.

Based on these results for the crushed C&D waste it was decided to blend it with virgin aggregate to make a higher value asphalt mix rather than simply using it as a subbase aggregate.

7. LABORATORY TESTS FOR BITUMINOUS BOUND RECYCLED AGGREGATES

It was decided to blend the crushed C&D waste with virgin Carboniferous limestone to make a AC 20 HDM Binder 160/220 asphalt mix in accordance with IS EN 13108-1 & SR 28. Table 1 shows the grading requirements of this material.
Table 1 Sieve analysis

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>Target Composition % passing</th>
<th>FPC Tolerance %</th>
<th>Conformity Specification % passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.5</td>
<td>100</td>
<td>-2</td>
<td>98-100</td>
</tr>
<tr>
<td>20</td>
<td>99</td>
<td>-9 +5</td>
<td>90-100</td>
</tr>
<tr>
<td>10</td>
<td>62</td>
<td>±9</td>
<td>53-71</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>±7</td>
<td>23-37</td>
</tr>
<tr>
<td>0.25</td>
<td>12</td>
<td>±5</td>
<td>7-17</td>
</tr>
<tr>
<td>0.063</td>
<td>8.0</td>
<td>±3.0</td>
<td>5.0-11.0</td>
</tr>
</tbody>
</table>

Test specimens were prepared for determination of Stiffness Modulus, Moisture Sensitivity, resistance to permanent deformation and Cantabro. Four blends of C&D and virgin aggregate were prepared. Two sizes of test specimen were prepared using gyratory compaction i.e. 100 and 150mm diameter. Tables 2 and 3 detail the composition of each blend. The mixes were blended as follows:

- Mix A containing 100% virgin aggregate, was used as a control
- Mix B containing 50% recycled aggregate and 50% virgin aggregate
- Mix C containing 25% recycled aggregate and 75% virgin aggregate
- Mix D containing 10% recycled aggregate and 90% virgin aggregate.

Table 2 Blend details for 100mm diameter sample mixes

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Virgin Aggregate (g)</th>
<th>Recycled Aggregate (g)</th>
<th>Virgin Aggregate (g)</th>
<th>Recycled Aggregate (g)</th>
<th>Virgin Aggregate (g)</th>
<th>Recycled Aggregate (g)</th>
<th>Virgin Aggregate (g)</th>
<th>Recycled Aggregate (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.5</td>
<td>418</td>
<td>209</td>
<td>209</td>
<td>104</td>
<td>314</td>
<td>42</td>
<td>376</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>352</td>
<td>176</td>
<td>176</td>
<td>88</td>
<td>264</td>
<td>35</td>
<td>317</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>198</td>
<td>99</td>
<td>99</td>
<td>50</td>
<td>148</td>
<td>20</td>
<td>178</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>44</td>
<td>22</td>
<td>22</td>
<td>11</td>
<td>33</td>
<td>4</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>88</td>
<td>44</td>
<td>44</td>
<td>22</td>
<td>66</td>
<td>9</td>
<td>79</td>
<td></td>
</tr>
</tbody>
</table>
Table 3 Blend details for 150mm diameter sample mixes

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Virgin Aggregate (g)</th>
<th>Recycled Aggregate (g)</th>
<th>Virgin Aggregate (g)</th>
<th>Recycled Aggregate (g)</th>
<th>Virgin Aggregate (g)</th>
<th>Recycled Aggregate (g)</th>
<th>Virgin Aggregate (g)</th>
<th>Recycled Aggregate (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.5</td>
<td>760</td>
<td>380</td>
<td>380</td>
<td>190</td>
<td>570</td>
<td>76</td>
<td>684</td>
<td></td>
</tr>
<tr>
<td>20.0</td>
<td>640</td>
<td>320</td>
<td>320</td>
<td>160</td>
<td>480</td>
<td>64</td>
<td>576</td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td>360</td>
<td>180</td>
<td>180</td>
<td>90</td>
<td>270</td>
<td>36</td>
<td>324</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>80</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>60</td>
<td>8</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>160</td>
<td>80</td>
<td>80</td>
<td>40</td>
<td>120</td>
<td>16</td>
<td>144</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3 Test samples containing C&D being tested for Stiffness using the Nottingham Asphalt Tester
Stiffness was assessed using the 100mm diameter test specimens. Figure 3 shows the test specimens being assessed in the Nottingham Asphalt Tester. The test samples were assessed dry and then after soaking in water for 3 and 7 days. The results are summarized in Figure 4.

This shows that the addition of C&D waste increased Stiffness of the AC 20 HDM mix. The optimum appears to be 25% addition C&D. The effect of soaking the test samples in water did not have a significant effect on stiffness i.e. the test specimens had good moisture sensitivity.
Figure 5 Summary of Cantabro test data

The Cantabro test was carried out in accordance with BSEN 12697-17 on the 100mm diameter test specimens to determine whether the addition of C&D waste detrimentally affected the cohesive strength of the AC mix. Testing was carried out on dry samples and those that had been soaked in water for 7 days.

Testing was stopped after 300 rotations and the % mass loss determined. The results are plotted in Figure 5. The wet test specimens after 300 rotations are shown in Figure 6.

The results show that the addition of up to 25% C&D waste had little impact on the integrity of the test specimens even after soaking in water. This agrees with the findings of the wet stiffness testing.

Figure 6 Cantabro test specimens after 300 revolutions that had been soaked in water for 7 days prior to testing

The 150mm diameter test specimens were assessed for permanent deformation using the Wessex wheel tracker. Testing was carried out at 45°C for 45 minutes. Figure 7 shows the 150mm diameter test sample being tested in the Wessex equipment.
The results are plotted in Figure 8 and show that all of the samples are within the $<4$mm tolerance for bituminous binder course after testing as outlined in BS EN 12697-22.

Figure 7 A 150mm diameter test sample being tested in the Wessex equipment.

Figure 8 Summary of wheel tracking data at $45^\circ$C
8. DISCUSSION
The laboratory testing evaluated the potential of blending a good quality C&D waste in a bituminous binder layer.

The Los Angeles and wet Micro Deval data carried out on the crushed C&D aggregate showed that its toughness and abrasion resistance were within the parameters of LA30 which is recommended for coated materials and surface treatments. However, the water absorption test showed it had a high absorption value.

The tests on the blended AC mixes found that the use of the C&D waste improved the test data. For example, Stiffness testing indicated that the dry samples containing recycled C&D performed better than the samples with 100% virgin limestone aggregate.

The greater amount of C&D in the blend, the greater the improvement in stiffness. The data suggests that the addition of 25% C&D gave optimum results. Even after the samples were immersed in water for three and seven days the test specimens containing C&D out-performed the 100% virgin aggregate test specimens.

This optimum of 25% C&D was also found for the Cantabro testing. Although the effect of C&D addition was less apparent in the wheel track testing, all of the test specimens were considered to have good resistance to rutting at 45°C.

9. CONCLUSION
This paper has identified the quantity and location of C&D waste produced in Ireland. In order to meet legislative requirements implemented to deal with waste in a sustainable manner, calculations have shown that it is financially feasible to recycle C&D waste in larger urban areas of Ireland such as Dublin.

A laboratory investigation of good quality C&D found the aggregate properties to meet the requirements for sub-base use.

Therefore, it was decided to up-value use of the C&D waste in an AC 20 HDM asphalt binder course. The results clearly showed that up to 25% good quality C&D could be added to virgin Carboniferous aggregate without detrimentally affecting its performance.

This conclusion indicates that recycled quality C&D materials will help Ireland meet its waste reduction requirements under EU and domestic legislation and promote the construction of more sustainable highways.

In these days of economic turmoil with a stringent renewed interest in the industry’s CO₂ emissions and the effects of climate change, here is a product which will reduce industry carbon emissions, which makes financial sense and which out performs mixes containing 100% virgin aggregate.

This product directly promotes sustainability within the industry, by incorporating an industry recognized QA system the recycled C&D waste can be successfully promoted and used as a replacement secondary aggregate in road construction.
REFERENCES