CEDR Transnational Road Research Programme
Call 2012: Recycling: Road construction in a post-fossil fuel society
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AllBack2Pave
Toward a sustainable 100% recycling of reclaimed asphalt in road pavements

International workshop on Recycling: Road construction in a post-fossil fuel society

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AllBack2Pave is a research project that will evaluate the feasibility of **going towards 100% recycling of asphalt pavements into surface courses**.
Objectives

AllBack2Pave is a research project project that will evaluate the feasibility of maximizing the amount of recycling of asphalt pavements into surface courses.

The main objectives of the project are:

- To establish, through laboratory tests on binders and asphalt mixes, whether the use of high rates of RA is feasible in developing mixes with a high level of performance which do not affect the durability.

- To develop the so-called “AllBack2Pave end-user manual” on how to best produce cost-effective and quality asphalt mixes with high RA content.
Project organization

WP1: Coordination, Management, Advisory board and Dissemination

- Raw Material characterisation
- Blends design
- Mix design
- Technology Up-scaling guidelines
- Sustainability assessment methodology
- Other sustainability metrics
- LCA and LCCA
- High Content RA-Warm asphalts For wearing courses

WP2: Mix and Blend design
- Validation of Mix Design of 0%, 30%, 60%, 100% RA

WP3: Technology up-scaling at asphalt Plant
- Mixes and Binder Characterisation

WP4: Performance Assessment
- Pavement Design Life calculation

WP5: Sustainability Assessment
- Pavement DURABILITY

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Methodology

- Two typical asphalt **surface mixes of high volume** roads of Germany and Italy.

- Mix design and production following each country regulatory environment.

- Three different amounts of RA in each mix.

<table>
<thead>
<tr>
<th>Control mixes</th>
<th>30% RA</th>
<th>60% RA</th>
<th>Max% RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE: SMA 8S</td>
<td>DE30</td>
<td>DE60</td>
<td>DE60+Add.</td>
</tr>
<tr>
<td>IT: AC 16</td>
<td>IT30</td>
<td>IT60</td>
<td>IT90</td>
</tr>
</tbody>
</table>
Materials: DE

Control mixes
DE: SMA 8S
30% RA
DE30
60% RA
DE60
Max% RA
DE60+Add.

Stockpiles of virgin aggregates
Cold Feeders
Aggregates heating drum
Fibres silo
Aggregate elevator
Screen / Fractioning
Aggregate scale
Parallel heating drum for RA
Bitumen tank
RA elevator
RA Screen
Stockpiles of RA
Mix
Additive addition
Hot mix storage silo

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## Materials: DE

### Table of Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Source / Producer</th>
<th>Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed stone 8/11</td>
<td>Quarry in Gilching</td>
<td></td>
</tr>
<tr>
<td>Crushed stone 8/11</td>
<td>Quarry in Treidling</td>
<td></td>
</tr>
<tr>
<td>Crushed stone 5.6/8</td>
<td>Quarry in Gilching</td>
<td></td>
</tr>
<tr>
<td>Crushed stone 5.6/8</td>
<td>Quarry in Treidling</td>
<td></td>
</tr>
<tr>
<td>Crushed stone 2/5.6</td>
<td>Quarry in Gilching</td>
<td></td>
</tr>
<tr>
<td>Crushed stone 2/5.6</td>
<td>Quarry in Treidling</td>
<td></td>
</tr>
<tr>
<td>Sand 0/2</td>
<td>Quarry in Gilching</td>
<td>2 buckets of 15kg each</td>
</tr>
<tr>
<td>Fines</td>
<td>Quarry in Lauterhofen</td>
<td>1 bucket of 15 kg</td>
</tr>
<tr>
<td>Fibres</td>
<td>Viatop premium</td>
<td>1 bucket of 5 kg</td>
</tr>
<tr>
<td>Bitumen (PmB 25/55-55)</td>
<td>OMV</td>
<td>1 bucket of 15 Kg</td>
</tr>
<tr>
<td>Additives</td>
<td>Blend of rejuvenator and WMA</td>
<td>1 sample of 5 kg was obtained from the producer</td>
</tr>
<tr>
<td>RA</td>
<td>Reclaimed asphalt SMA 11S</td>
<td>Rehabilitation of A8 highway near Munich 10 buckets of 15 kg each. The buckets were filled with RA from 5 random locations of the stockpile</td>
</tr>
</tbody>
</table>
Materials: IT

Control mixes
IT: AC 16

30% RA
IT30

60% RA
IT60

Max% RA
IT90

Virgin minerals
Virgin bitumen
Additive
RA

Ferrara Accardi & Figli
Hot mix recycling process

Reclaim the asphalt

Process the RA

Characterize the RA

Transport and paving

Mixing

Mix design

Maintenance

End of life

Reclaim the asphalt (multiple recycling)
Reclaim the asphalt

**German RA**

- Mill out from the surface layer of a high volume road near Munich (highway A8).
- The RA was made up of a bituminous surface originally designed as a SMA with a nominal grain size of 11mm (SMA 11S) and a Polymer modified bitumen (PmB 25/55-55).
- The original mix design formulas and maintenance history of the RA were not available.

**Italian RA**

- Mill out from the surface layer of an urban road.
- The RA was made up of a bituminous surface originally designed as an AC with a nominal grain size of 16mm.
- The original mix design formulas and maintenance history of the RA were not available.
Reclaim the asphalt

German RA

- Mill out from the surface layer of a high volume road near Munich
- RA properly milled (i.e. layer by layer)
- Mix design formulas, material and maintenance records of RA
- Designed as a SMA with a nominal grain size of 11mm (SMA 11S) and a Polymer modified bitumen (PmB 25/55-55).
- The original mix design formulas and maintenance history of the RA were not available

Italian RA

- Mill out from the surface layer of an urban road
- RA properly milled (i.e. layer by layer)
- Mix design formulas, material and maintenance records of RA
- The original mix design formulas and maintenance history of the RA were not available
Hot mix recycling process

1. Reclaim the asphalt
2. Process the RA
3. Characterize the RA
4. Transport and paving
5. Mixing
6. Mix design
7. Maintenance
8. Rehabilitation
9. Reclaim the asphalt (multiple recycling)

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Process the RA

**German RA**
- RA crushed in the mixing plant to a maximum grain size of 22 mm
- RA stored in stockpiles without further screening
- Open air storage

**Italian RA**
- RA crushed in the mixing plant to a maximum grain size of 20 mm
- RA stored in stockpiles without further screening
- Under shelter storage
**Process the RA**

**German RA**
- RA crushed in the mixing plant to a maximum grain size of 22mm
- RA storage in stockpiles without further screening
- Open air storage
- **ra properly stored (e.g. under shelter)**
- **Fractionation of RA**

**Italian RA**
- RA crushed in the mixing plant to a maximum grain size of 20mm
- RA storage in stockpiles without further screening
- Under shelter storage
- RA properly stored (e.g. under shelter)
- **Fractionation of RA**

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Hot mix recycling process

1. Reclaim the asphalt
2. Process the RA
3. Characterize the RA
4. Transport and paving
5. Mixing
6. Mix design
7. Maintenance
8. Rehabilitation
9. Reclaim the asphalt (multiple recycling)
Characterize the RA

Binder extraction and recovery
Testing of RA aggregates
Testing of Binder

Bitumen content

Coarse fraction
Fine fraction

Coarse fraction >4.75mm
Fine fraction <4.75mm

German RA: 4.8%
Italian RA: 5.83%

4.76%
6.83%

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Characterize the RA

Binder extraction and recovery

Testing of RA aggregates

Testing of Binder

Partial blending concept

Black Aggregate

White Aggregate

Aged bitumen

Mineral

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Characterize the RA

Binder extraction and recovery

Testing of RA aggregates

Testing of Binder

Partial blending concept

Graph showing percent passing as a function of grain size with curves for Grey, White, and Black curves.
Characterize the RA

Binder extraction and recovery
Testing of RA aggregates
Testing of Binder

Grading

German RA
Italian RA

White curve
Grey curve
White curve

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Characterize the RA

Binder extraction and recovery  
Testing of RA aggregates  
Testing of Binder

PSV.

The aggregates ability to resist skidding is crucial when designing wearing course mixes.

<table>
<thead>
<tr>
<th>PSV value</th>
<th>German RA agg.</th>
<th>Italian RA agg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>51</td>
<td>48</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Characterize the RA

Binder extraction and recovery

Testing of RA aggregates

Testing of Binder

Angularity

- Aggregates without fractured faces
- Aggregate with fractured faces

<table>
<thead>
<tr>
<th></th>
<th>German RA agg.</th>
<th>Italian RA agg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>C100/0</td>
<td>95%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>0%</td>
</tr>
</tbody>
</table>

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Characterize the RA

Binder extraction and recovery

Testing of RA aggregates

Testing of Binder

Conventional properties

<table>
<thead>
<tr>
<th>R&amp;B softening [°C]</th>
<th>German RA bitumen</th>
<th>Italian RA bitumen</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.5</td>
<td>71.4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Penetration [1/10mm]</th>
<th>German RA bitumen</th>
<th>Italian RA bitumen</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>8.3</td>
<td></td>
</tr>
</tbody>
</table>
Characterize the RA

- Binder extraction and recovery
- Testing of RA aggregates
- Testing of Binder

Conventional properties

**Fraass Temperature [°C]**

- German RA bitumen: -8°C
- Italian RA bitumen: 9°C

**Viscosity @135°C [mPas]**

- German RA bitumen: 1490 mPas
- Italian RA bitumen: 1827 mPas

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Characterize the RA

Binder extraction and recovery

Testing of RA aggregates

Testing of Binder

PG grade testing

Bar chart comparing Italian RA binder and German RA binder at different temperatures:

- High Tc: Italian RA binder = 87, German RA binder = 80
- Mid Tc: Italian RA binder = 33, German RA binder = 22.5
- Low Tc: Italian RA binder = -6, German RA binder = -13.5
Hot mix recycling process

1. Reclaim the asphalt
2. Process the RA
3. Characterize the RA
4. Transport and paving
5. Mixing
6. Mix design
7. Maintenance
8. Rehabilitation
9. Reclaim the asphalt (multiple recycling)
What is the maximum amount of RA that could be allowed in the mix?

Choose highest RA that satisfies both aggregate gradation and bitumen requirements

Combine aggregates to meet gradation

Combine bitumen to meet specification requirements
Mix design

The RA grading needs to be modified by addition of virgin aggregates
Mix design

German Mix

Max RA in mix: 70% - w

Italian Mix

Max RA in mix: 100% - w
What is the maximum amount of RA that could be allowed in the mix?

Choose highest RA that satisfies both aggregate gradation and bitumen requirements.

Combine aggregates to meet gradation.

Combine bitumen to meet specification requirements.

Blending charts.
Mix design

Blending charts

The charts correlate the replaced bitumen content (RBC) with the empirical properties of the blend.

By replaced bitumen content it should be understood the percentage of bitumen from the RA in the final blend.
Mix design

**GERMAN CASE:**

- *Use available RA (short term aged) and perform the design with and without rejuvenator*

- *Rejuvenator:*
  - virgin PmB 25/55-55
  - partly rejuvenator + warm mix additive (mix)
**Mix design**

**GERMAN CASE:**

- Use available RA (short term aged) and perform the design with and without rejuvenator

These charts are developed assuming that 100% of the RA binder will be mobilized and become active part of the binder in the new mix.

However, in reality it is also possible that part of the RA bitumen remain non-active resulting in a partial blending scenario.
Mix design

GERMAN CASE:

Blending charts including degree of blending between 60% and 100%
**GERMAN CASE:**

- Binder blend design based on conventional properties shows that by using the selected binder PMB 25/55-55 as a virgin binder for the selected RA-mixes (30%, 60%, and 70%), it is possible to obtain a final blend whose properties are still within the limits of Pen and SP.

<table>
<thead>
<tr>
<th>% RA in the mixture</th>
<th>Penetration (25°C) (d mm)</th>
<th>Softening Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Blend (30% RA)</td>
<td>37.3</td>
<td>61.5</td>
</tr>
<tr>
<td></td>
<td>39.7</td>
<td>61.0</td>
</tr>
<tr>
<td>Final Blend (60% RA)</td>
<td>32.3</td>
<td>62.6</td>
</tr>
<tr>
<td></td>
<td>36.6</td>
<td>61.6</td>
</tr>
<tr>
<td>Final Blend (70% RA)</td>
<td>30.8</td>
<td>63.0</td>
</tr>
<tr>
<td></td>
<td>35.7</td>
<td>61.8</td>
</tr>
<tr>
<td><strong>target</strong></td>
<td><strong>25-55</strong></td>
<td><strong>≥55</strong></td>
</tr>
</tbody>
</table>
### GERMAN CASE:

- Binder blend design based on performance-related properties shows that by using the selected binder PMB 25/55 (VB-D) as a virgin binder for the selected RA-mixes (30%, 60%, and 70%), it is possible to obtain a final blend whom properties do not differ too much from the selected Virgin binder.

<table>
<thead>
<tr>
<th>% RA in the mixture</th>
<th>High Tc (°C)</th>
<th>Intermediate Tc (°C)</th>
<th>Low Tc (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Blend (30% RA)</td>
<td>79.5</td>
<td>19.9</td>
<td>-15.5</td>
</tr>
<tr>
<td></td>
<td>79.5</td>
<td>19.6</td>
<td>-15.7</td>
</tr>
<tr>
<td>Final Blend (60% RA)</td>
<td>79.7</td>
<td>20.6</td>
<td>-14.9</td>
</tr>
<tr>
<td></td>
<td>79.6</td>
<td>20.2</td>
<td>-15.4</td>
</tr>
<tr>
<td>Final Blend (70% RA)</td>
<td>79.8</td>
<td>20.8</td>
<td>-14.8</td>
</tr>
<tr>
<td></td>
<td>79.6</td>
<td>20.1</td>
<td>-15.3</td>
</tr>
<tr>
<td>Target (VB-D)</td>
<td>&gt;79.3</td>
<td>&lt;19.2</td>
<td>&lt;-16.0</td>
</tr>
</tbody>
</table>
Mix design

ITALIAN CASE:

- **Use available RA (long term aged) and perform the design with rejuvenator**

- **Rejuvenators:**
  - virgin bitumen 50/70
  - rejuvenator + warm mix additive (mix)

![Graphs showing penetration and softening point vs. % RVB for Rejuvenated RAP with different rejuvenators.](http://allback2pave.fehrl.org)
ITALIAN CASE:

- Binder’s blend design based on conventional properties shows that by using the selected binder Pen 50/70 as a virgin binder and RejA and RejB for the selected RA-mixes (30%, 60%, and 90%), both Pen and SP values struggle to achieve the target.

<table>
<thead>
<tr>
<th>% RA in the mixture</th>
<th>Final properties of blend with RejA</th>
<th>Final properties of blend with RejB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Penetration (25°C) (d mm)</td>
<td>Softening Point (°C)</td>
</tr>
<tr>
<td>30% RA</td>
<td>71.0</td>
<td>50.5</td>
</tr>
<tr>
<td></td>
<td>73.9</td>
<td>53.3</td>
</tr>
<tr>
<td>60% RA</td>
<td>70.4</td>
<td>53.4</td>
</tr>
<tr>
<td></td>
<td>80.3</td>
<td>59.0</td>
</tr>
<tr>
<td>90% RA</td>
<td>77.3</td>
<td>56.4</td>
</tr>
<tr>
<td></td>
<td>87.2</td>
<td>64.7</td>
</tr>
<tr>
<td>target</td>
<td>50-70</td>
<td>≥54</td>
</tr>
</tbody>
</table>

Penetration (25°C) and Softening Point (°C) values for different percentages of RA in the mixture with RejA and RejB.
ITALIAN CASE:

- Blend design based on performance-related properties shows that by using the selected binder Pen 50/70 as a virgin binder and RejA and RejB for the selected RA-mixes (30%, 60%, and 90%), it is possible to obtain a final blend with comparable properties to the target binder VB.

<table>
<thead>
<tr>
<th>Binder</th>
<th>Final properties of blend with RejA</th>
<th>Final properties of blend with RejB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Tc (°C)</td>
<td>Int Tc (°C)</td>
</tr>
<tr>
<td>RAb</td>
<td>87</td>
<td>33</td>
</tr>
<tr>
<td>Final Blend (30% RA-white100)</td>
<td>67.1</td>
<td>16.9</td>
</tr>
<tr>
<td>Final Blend (60% RA-white100)</td>
<td>68.5</td>
<td>14.8</td>
</tr>
<tr>
<td>Final Blend (90% RA-white100)</td>
<td>69.8</td>
<td>12.7</td>
</tr>
<tr>
<td>target (VB)</td>
<td>≥66</td>
<td>≤19</td>
</tr>
</tbody>
</table>
Mix design process in lab

1. Combine virgin aggregates for gradation
2. Heat virgin aggregates
3. Add RA
4. Heat RA + Virgin Aggregates
5. Add Virgin Bitumen
6. Perform conventional volumetric mix design
7. Perform performance tests

- T=180°C Time=8h
- T=120°C Time=3h
- 30%, 60%, 90%
Conclusions

• The heterogeneity of the RA aggregates plays an important role when designing asphalt mixes for wearing courses where high quality aggregates with high resistance to wear/abrasion (polishing) are needed.

• Properly milled (i.e. layer by layer) and stockpiled RA is a mandatory prerequisite in order to produce durable asphalt wearing courses with high content of RA.

• The RA must be treated as a valuable material

• In order to produce mixes with high RA content, a balanced mix design approach must be followed.

• One possible solution is to allow the use of high percentage of RA in wearing courses only if the RA material proceeds from the same location and layer where the new mix will be placed.