RA activity, ageing of cold recycled mixes and multiple recycling

Sachgebiet Bau und Erhaltung von Verkehrswegen

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• Reuse or recyclability is one of the basic requirements defined in EU construction product regulation No. 305/2011.
• Concurrent paving procedures (hot recycling) claim for 100 % recyclability and even long-term storage of bitumen for post-oil era
• Questions are raised:
  - What is the role of RA in cold recycled material?
  - Can ageing and recycling process be simulated in laboratory?
  - What procedures are available for recycling of layers composed of cold recycled material
    > (Multiple) cold recycling
    > Hot recycling
Question 1: What is the role of RA in cold recycled material?

Laboratory study on the effects of various mix granulates in cold recycled material

- **3 mix granulates:**
  - Reclaimed asphalt (RA)
  - Reclaimed concrete
  - Natural aggregates (e.g. from unbound base layers)

- **Same grading**

- **Residual bitumen content: 4 %**
  - Bitumen emulsion (cationic, 60 % bitumen, 50/70)
  - Foamed bitumen 50/70;
    Foaming @ 180 °C, 5.5 bar, 4.5 % water

- **Active filler: 2 % Portland cement**

- **Mixing water content (total): 7.8 %**
## Sample mixtures (same grading)

<table>
<thead>
<tr>
<th>Mix variations</th>
<th>Reclaimed asphalt (RA)</th>
<th>Reclaimed road concrete (RRC)</th>
<th>Crushed natural aggregates (agg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100/0/0</td>
<td>100%</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>75/0/25</td>
<td>75%</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>50/25/25</td>
<td>50%</td>
<td>25%</td>
</tr>
<tr>
<td>D</td>
<td>50/0/50</td>
<td>50%</td>
<td>-</td>
</tr>
<tr>
<td>E</td>
<td>40/20/40</td>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>F</td>
<td>0/50/50</td>
<td>-</td>
<td>50%</td>
</tr>
<tr>
<td>G</td>
<td>0/25/75</td>
<td>-</td>
<td>25%</td>
</tr>
<tr>
<td>H</td>
<td>0/0/100</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Laboratory tests

- **Static compaction (30 s à 45.9 kN)**
- **Specimen curing:**
  - 1 day in mould
  - 2 days demoulded @ 20 °C, 80 % humidity
  - 25 days at room conditions
- **Tests**
  - Bulk density & void content
  - Indirect tensile strength (5 °C)
  - 7 day, 28 days, 14 days in water
  - CBR dry
Insufficient compaction (German requirement: < 15 %)
- Reasons:
  - Coarse mix, low fines
  - Low compaction energy

The higher RA content in mix granulate, the lower the void content
- At same grading, RA allows for better compaction
- Similar results for emulsion and foamed bitumen mix
The higher RA content, the higher the ITS obtained
- Reduced voids content
- Increased flexibility

RA content has stronger effect on foamed bitumen mixtures compared to bitumen emulsion mixtures

Difference between crushed concrete and crushed natural aggregates at same RA content:
- No effect for emulsion mixtures
- Higher RCC content results in higher ITS for foamed bitumen mixtures

Bitumen emulsion mixtures have higher strength compared to foamed bitumen mixtures

CoRePaSol – Dipl.-Ing. Diana Simnofske
Water susceptibility (14 days @ 40 °C)

- Applied mix design results in feasible ITSR for all samples
- Emulsion mixtures: Strength loss
- Foamed bitumen mixtures:
  Often strength increase observed
  (hydration of active binder)
CBR as parameter for bearing capacity and resistance against permanent deformation

- Increase of RA content will reduce CBR
  - Increased flexibility
  - Increased viscoplastic properties

- Foamed bitumen mixtures reach higher CBR
  - Higher friction between granulate by discontinuous bitumen bonds

<table>
<thead>
<tr>
<th>Sample</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>100%</td>
<td>75%</td>
<td>50%</td>
<td>50%</td>
<td>40%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RCC</td>
<td>-</td>
<td>-</td>
<td>25%</td>
<td>-</td>
<td>20%</td>
<td>50%</td>
<td>25%</td>
<td>-</td>
</tr>
<tr>
<td>Agg.</td>
<td>-</td>
<td>25%</td>
<td>25%</td>
<td>50%</td>
<td>40%</td>
<td>50%</td>
<td>75%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Conclusions (1) on RA activity study

• The content of RA controls the relevant parameters of CBSM. An increase of RA content at same mix composition results in:
  - Improved compactibility & decreased void content
  - Higher indirect tensile strength
  - Reduced bearing capacity and reduced resistance against permanent deformations

Foamed bitumen mixtures are more sensitive to RA content (factor 3) compared to emulsion mixtures (factor 2)

• Binder in RA shows active (beneficial) role in the properties of cold recycled materials
Recyclability of layers composed of cold recycled mixtures

The end of life characteristics of pavement materials plays an important role in life-cycle-based decisions and are therefore a basic requirement for construction works.

Two options represent recycle strategies of highest value:

- Recycling in cold recycled mixtures
- Recycling in hot mix asphalt

For the assessment of recyclability during mix design and for research, an accelerated ageing procedure is required.
Applicability of laboratory ageing procedures on cold recycled materials

Adoption of hot-mix asphalt ageing procedure (applied during Re-Road project) and specified in TS EN 12697-54

- Oven ageing of compacted specimens at 85 °C
- Assessment of ageing effects by
  - Analyses on extracted bitumen (here $T_{R&B}$)
  - Mechanical tests on aged specimens (here: ITS)

<table>
<thead>
<tr>
<th>Type of mixture</th>
<th>A.1</th>
<th>A.2</th>
<th>B.1</th>
<th>B.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA content</td>
<td>96,4 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basalt</td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Limestone filler</td>
<td>3,6 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bituminous emulsion content</td>
<td>6,4 % (4 % residual binder)</td>
<td>-</td>
<td>6,4 % (4 % residual binder)</td>
<td>-</td>
</tr>
<tr>
<td>Foamed bitumen content</td>
<td>-</td>
<td>4 %</td>
<td>-</td>
<td>4 %</td>
</tr>
<tr>
<td>Cement content</td>
<td></td>
<td></td>
<td>2 %</td>
<td></td>
</tr>
<tr>
<td>Voids content of specimens</td>
<td>21,3±0,6</td>
<td>19,4±1,3</td>
<td>18,9±1,4</td>
<td>17,2±1,7</td>
</tr>
</tbody>
</table>
Design of ageing experiment

Type of mixture
- Cold recycled mix
- Cold mix
- RA

Binder
- A.1 emulsion
- A.2 foam
- B.1 emulsion
- B.2 foam
- No binder

Mixing, compacting and curing

Long-term aging (@ 85°C)
- 1, 3, 6, 14, 21
- 1, 3, 6, 9, 14, 21
- 1, 3, 6, 10
- 1, 3, 6, 9
- 1, 3, 6, 10

IDT
- IDT
- IDT
- IDT
- IDT

Softening point
- Softening point
- Softening point
- Softening point
- Softening point
- Softening point
Ageing effects on ITS

- Mixtures with foamed bitumen (A2 and B2) show a strong increase of ITS during ageing.
- Ageing doesn’t affect the ITS results obtained on bitumen emulsion mixtures (A1 and B1)
- No difference in ITS effects can be observed for RA or pure aggregates mixtures
Conclusions (2) on laboratory ageing procedure

- Aging procedure according to TS EN 12697-54 is applicable for cold recycling mixtures.
- Bituminous emulsion mixtures are less sensitive to aging effects compared to foamed bitumen mixtures.
- This effect is confirmed by Jenkins et al. (2008) where recovered bitumen was tested from field investigation on long term aged BSM. No clear statements to aging behavior could be given but that foamed bitumen mixes seemed to be more susceptible to aging.
End-of-life properties of cold recycled materials

- **Multiple recycling study:**
  - Bitumen stabilised material BSM (low bitumen content; no cement)
  - Bitumen-cement stabilised material BCSM (medium bitumen content; 3% cement)
  - Use of emulsion mixtures only
  - Simulation of 3 recycling cycles
Multiple recyclability of cold recycled materials

Recycling stage 1
- 1-BSM-1
  - Ageing: 9 days @ 85 °C
  - Specimen compaction
  - Crushing
  - RBSM
- 1-BCSM-1
  - Ageing: 9 days @ 85 °C
  - Specimen compaction
  - Crushing
  - RBCSM

Recycling stage 2
- 2BSM-1,-2,-3
  - Ageing: 9 days @ 85 °C
  - Specimen compaction
  - Crushing
  - RBSM2
- 2BSM-4
  - RBSMS
- 2CBSM-1,-2,-3
  - RBCSM2

Recycling stage 3
- 3BSM-1,-2,-3
  - Specimen compaction
  - Crushing
  - RBSM2
- 3BSM-4
  - RBSMS2
- 3CBSM-1,-2,-3
  - RBCSM2
Multiple recyclability of cold recycled materials

- Increase of bitumen emulsion content:
  - improved compactibility
  - Reduced void content

- Effect of multiple recycling:
  - BSM: increasing voids content
  - CBSM:
    - decreasing void content
    - Excessive increase of total binder content
Multiple recyclability of cold recycled materials

- **Increase of bitumen emulsion content on ITS:**
  - BSM: no significant effect
  - CBSM: significant increase of strength

- **Effect of multiple recycling:**
  - BSM: strength increase in 2\(^{nd}\) but decrease in 3\(^{rd}\) recycling stage
  - CBSM: increasing strength during multiple recycling
Recyclability in hot-mix asphalt

Hot-mix asphalt material: AC 16
• Design bitumen content: 4.6 %
• Addition of 0 %, 15 % and 30 % of artificially aged CBSM
  – 95 % RA sampled from stockpile, 5 % fines
  – 2 % bit. emulsion, 3 % cement
  – Marshall compaction
  – Ageing 10 days @ 85 °C
  – Manually crushing of aged specimens
• Evaluation of CBSM binder activity vs. black rock theory

<table>
<thead>
<tr>
<th>Sample Mix</th>
<th>RCBSM content</th>
<th>Content of added bitumen (50/70)</th>
<th>Content of RCBSM bitumen</th>
<th>Total bitumen content</th>
</tr>
</thead>
<tbody>
<tr>
<td>V0</td>
<td>0%</td>
<td>4.6 %</td>
<td>0 %</td>
<td>4.6 %</td>
</tr>
<tr>
<td>V1</td>
<td>15%</td>
<td>3.8 %</td>
<td>0.8 %</td>
<td>4.6 %</td>
</tr>
<tr>
<td>V2</td>
<td>30%</td>
<td>3.0 %</td>
<td>1.6 %</td>
<td>4.6 %</td>
</tr>
<tr>
<td>V3</td>
<td>30%</td>
<td>3.8 %</td>
<td>1.6 %</td>
<td>5.4 %</td>
</tr>
<tr>
<td>V4</td>
<td>30%</td>
<td>4.6 %</td>
<td>1.6 %</td>
<td>6.2 %</td>
</tr>
</tbody>
</table>
Hot recyclability: ITS (15 °C)

- Marshall-compacted specimens
- Water sensitivity – conditioning methods:
  - Dry,
  - water saturated (40 °C, 72 h),
  - Aashto T283 - Frost-Thaw cycle: (-16 °C; +60 °C)
- Results:
  - Increasing ITS\(_{\text{dry}}\) with increasing RA content
  - No significant effect of specimen conditioning (durability)
Rutting resistance: Wheel tracking tests

- Addition of 15% RA (V1) and 30% RA (V2) will reduce rutting susceptibility, when less added binder is used.
- Addition of 30% and increase of added bitumen (V3 and V4) will result in increased rutting.
- Bitumen in reclaimed CBSM can be reactivated during hot recycling.
Softening point $T_{R&B}$ of recovered bitumen

- Viscosity mixing law acc. EN 13108-8: the resulting viscosity can be calculated from the viscosity of added binder and the viscosity of the binder in RA:

$$T_{R&B \text{ mix}} = a \times T_{R&B 1} + b \times T_{R&B 2}$$

- Comparison between calculated and recovered TR&B shows applicability of mixing law

- Reclaimed BCSM can be considered as usual "RA" in HMA mix design
Conclusion (3) on recyclability of cold recycled materials

- Layers of cold recycled materials can be recycled both by **cold recycling** as well as **hot recycling**
- **For cold recycling:**
  - the resistance against permanent deformation shall be evaluated in order to avoid mixtures with excess of total bitumen content.
  - For BSM, at least 2 recycling cycles can be reached
- **For hot recycling:**
  - Sample mix design procedures applicable as for RA originating from hot mix asphalt
    > Reactivation of RA binder
    > application of mixing formula for resulting binder viscosity
  - Cement included in the cold recycling mixture doesn’t interfere with the recyclability of the bitumen.
  - Providing suitable aging properties, the bitumen “stored” in cold recycled mixtures can be recovered and reactivated again during hot recycling process.
- **For warm recycling:**
  - Applicability of warm recycling with 2 additives was shown in a lab study
Thank you very much for your attention!

COREPASOL

Activity of RA bitumen in cold-recycled mixes

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Partner 2: University College Dublin (UCD)
Partner 3: Laboratorio Nacional de Engenharia Civil, I.P. (LNEC)
Partner 4: Wirtgen GmbH

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