BITUMEN STABILISED MATERIALS

Recycling Technology Update

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Outline

• Developments of ISAP WG2 Cold Recycling
• Global perspective – CR research
• Application of research to improve technology
• Manuals, specifications, guidelines
• Overcoming barriers to recycling
• Future needs for research
Minutes from TRB 2010: ISAP TC
Asphalt Pavement and Environment

- WG1 on Recycling (Chantal de la Roche)

WG1
Hot Recycling-RAP (Peter Sebaaly)

WG2
Cold Recycling-RAP (Kim Jenkins)
Purpose of ISAP WG2

• Global interface for needs analysis regarding cold recycling
• Coordinate research by sharing findings and technological developments
• Promote CR technology by:
  – Coordinate publications, guidelines, specifications
  – Create a database of research/project data
  – Gather & share info on enviro & sustainability
ISAP WG2 Members

TOTAL = 32
Focus of WG2 discussions

- Research focus areas (Global)
  - Laboratory
  - Field (APT and LTPP)
- Key findings and developments
  - Mix design
  - Structural design
  - Specifications
- Publications, documents and manuals
Activities of WG2 in 2010
Meet at Conferences

- Meeting and workshop at EATA (European Asphalt Technology Association) Conference, Parma, Italy on 11th June 2010
- Regional Workshop at MRC (Malaysia Roads Conference) Kuala Lumpur, Malaysia on 9th October 2010
Programme: WG2 Regional EU Workshop in Parma

• Workshop structure with 6 presenters
  – Global perspective on Cold Recycling
  – USA: UC Davis
  – Italy: Pisa & Anconna Uni - France: LCPC
  – Asia: Chang’an Univ - SE Asia: Malaysia
  – Africa: Practitioner and Researcher

• Global representation

• Broad research perspective, projects
Programme: WG2 Regional Asian Workshop in KL

• Workshop structure with 4 presenters
  – Global perspective on Cold Recycling and feedback from Parma
  – China: RIOH (Research Inst)
  – Thailand: Road authority
  – Malaysia: Contractor HCM /R&D

• Regional representation
• More applications, less research
Use of RAP Worldwide (2005)

COUNTRY
- South Africa
- France
- Australia
- Netherlands
- USA
- Germany
- Japan

RAP in HMA
- < 5%
- 13%
- 50%
- 75%
- 70%
- 82%
- 99%
## Re-use of asphalt in Europe (2009)

<table>
<thead>
<tr>
<th>Country</th>
<th>Available RAP (ton)</th>
<th>Re-used HOT (%)</th>
<th>Re-used COLD (%)</th>
<th>%New HMA production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>$14 \times 10^6$</td>
<td>82</td>
<td>18</td>
<td>60</td>
</tr>
<tr>
<td>Spain</td>
<td>$2.25 \times 10^6$</td>
<td>8</td>
<td>4</td>
<td>3.5</td>
</tr>
<tr>
<td>Italy</td>
<td>$14 \times 10^6$</td>
<td>18</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>$6.5 \times 10^6$</td>
<td>13</td>
<td>&lt; 2</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Norway</td>
<td>$0.59 \times 10^6$</td>
<td>7</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>Netherland</td>
<td>$3 \times 10^6$</td>
<td>75</td>
<td></td>
<td>63</td>
</tr>
</tbody>
</table>

(source: Molenaar)
Changing Technologies helps Environment
Emissions at the Chimney

Reduction of emissions

- CO
- NOx
- Dust

10-30%  60-70%  25-55%

Reduction of emissions

- CO2
- SO2
- VOC

30-40%  35%  50%

HMA  WAM
<table>
<thead>
<tr>
<th>Material procurement / Construction activity</th>
<th>Unit</th>
<th>Energy consumed (Mj)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material procurement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graded crushed stone (GCS)</td>
<td>Mj / t</td>
<td>50</td>
</tr>
<tr>
<td>HMA manufacture</td>
<td>Mj / t</td>
<td>30</td>
</tr>
<tr>
<td>Cement</td>
<td>Mj / t</td>
<td></td>
</tr>
<tr>
<td>Bitumen</td>
<td>Mj / t</td>
<td></td>
</tr>
<tr>
<td>Material haulage</td>
<td>Mj / t</td>
<td>1</td>
</tr>
<tr>
<td><strong>Construction activity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milling</td>
<td>Mj / t</td>
<td>5</td>
</tr>
<tr>
<td>In situ recycling / stabilising</td>
<td>Mj / t</td>
<td>10</td>
</tr>
<tr>
<td>Processing aggregate layer</td>
<td>Mj / t</td>
<td>66</td>
</tr>
<tr>
<td>Ditto per m² for 150mm thick layer</td>
<td>Mj / m²</td>
<td>10</td>
</tr>
<tr>
<td>Compacting and finishing layer</td>
<td>Mj / m²</td>
<td>10</td>
</tr>
<tr>
<td>HMA paving and compaction</td>
<td>Mj / t</td>
<td>20</td>
</tr>
</tbody>
</table>
Concrete and Masonry Recycling

- Re-use and recycling of e.g. concrete and masonry rubble is at embarrassing low level
- Some countries are really front runners; in the Netherlands 90% of the concrete/masonry rubble is recycled as base course for roads
- Much can be gained
Lots of talk but how much action?
Way forward of WG2
Synthesis of Global Research and Publications

FOCUS AREA
1. Research
2. Mix Design
3. Structural design
4. Construction & QC

RESPONSIBILITY
• D Jones
• K Jenkins
• G Tebaldì & F Long
• D Collings

“State of the Art”??
Is this going anywhere?

- Where are the challenges in research?
- How to manage these challenges?
So where can new tech go wrong? 
...remember 3 P’s of Innovation

- Pioneers
- Inventors
- Artists
- Hitchhikers
- Rather stolen than poorly invented
- Pirates
- Commercialise
- Passion
How to address the recycling needs (manage the process)

1. Awareness
2. Acquiring knowledge
3. Develop the tools
4. Implementation
Cold Recycler and Soil Stabilizer WR 2500 / S / SK
Worldwide distribution

- North America: 189
- West Europe: 243
- East Europe: 105
- Russia: 15
- Middle East: 31
- Asia: 104
- Africa: 13
- Latin America: 51
- Australia: 13
Cold Recycler and Soil Stabilizer
WR 2000, WR 2400, WR 2500 / S / SK - Worldwide distribution

North America: 321
West Europe: 427
East Europe: 191
Russia: 15
Asia: 163
Middle East: 83
Latin America: 187
Africa: 59
Australia: 59
1. Awareness: Issues to address

- Barriers to Cold Recycling of RA?
- Distress mechanisms (rutting, fatigue, durability)?
- Key areas for future research to address needs
  - High percentage RA
  - Appropriate tests
  - Lab versus field behaviour
- Harmonisation of mix & structural design
- Global research cooperation?
Findings - short term ageing
Pen vs. time for (80/100) foam

Field relevance??
BSM -emulsion versus -foam

Who is the custodian of strategic research?

- Emulsion: Koch/Sem, Akzo Nobel, Colas, Mead Westvaco
- Foam: Recycler suppliers (Wirtgen, Bomag etc)…who else?

ISAP WG2 Cold Recycling
2. Acquiring knowledge

- Universities and Research Institutes
- Research initiatives
  - Laboratory research
  - Accelerated Pavement Testing
  - LPTT
- International Cooperation? (WG2)
- Database of research?
Curing
Field moisture versus time

Moloto (BSM-emulsion)
Mr (field) versus cure

N7 PSPA Mr Analysis over 7 Months

- B1-B3
- B4-B6
- Poly. (B4-B6)

LAB

LTPP

APT
BSM Modulus (back analysis)

Foamed mix – Greek Highway

If it were fatigue design

Loizos et al

Τομέας ΜΣΥ-ΕΜΠ

Μάιος 2005
Pavement Analysis: stresses/strains

Critical parameters

<table>
<thead>
<tr>
<th>Mr asp</th>
<th>Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr base</td>
<td>BSM</td>
</tr>
<tr>
<td>Mr s’base</td>
<td>Cemented</td>
</tr>
<tr>
<td>Mr s/g</td>
<td>Subgrade</td>
</tr>
</tbody>
</table>

Stresses/strains:
- $\sigma_1$
- $\sigma_3$
- $\sigma_v$
- $\varepsilon$
- $\varepsilon_v$
What are others’ analyses finding?

Theyse
New LTPP Sections

• Very limited background info
  – Mix designs?
  – As built details?
• BSM-emulsion all on CTSBs
• BSM-foam all on granular
• Some new LTPP sections planned
  – Same materials, subgrade, climate
  – Cement, emulsion, foam binders
3. Develop the Tools

Level 1 – Mix Design Tests

100mm φ

ITS

BSM2

Min ITS$_{dry}$

Min ITS$_{wet}$

Min BC

BSM Binder Content

$\text{ITS}^\text{dry}$

$\text{ITS}^\text{wet}$
Vibratory Compaction Hammer

To prepare specimens

Kelfkens

Rear View of Frame

Vibrating Hammer
Mould
## Compaction time (vibratory)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>ITS</td>
<td>ITS</td>
<td>UCS</td>
</tr>
<tr>
<td>Foot φ</td>
<td>100mm</td>
<td>150mm</td>
<td>150mm</td>
</tr>
<tr>
<td>Height</td>
<td>65mm</td>
<td>95mm</td>
<td>125mm</td>
</tr>
<tr>
<td>Layers</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Surchg</td>
<td>5 kg</td>
<td>10 kg</td>
<td>10 kg</td>
</tr>
<tr>
<td>Foam</td>
<td>10 sec</td>
<td>25 sec</td>
<td>25 sec</td>
</tr>
<tr>
<td>Emuls</td>
<td>10 sec</td>
<td>15 sec</td>
<td>15 sec</td>
</tr>
</tbody>
</table>
Influence of Active Filler

Strength and flexibility

Cement < 1%

C1 to C4

Foamed bitumen, Strain
Cement, Strain*
Foamed bitumen, UCS
Cement, UCS*

Unconfined Compressive Strength (kPa)

Strain-at-break

Cement : Foamed Bitumen Ratio

CSIR
Triaxial Testing
Effect of using BSM

Shear stress

Effect of Binder

C = Cohesion

BSM

Unbound

φ Friction angle

Higher Cohesion

σ Normal stress
New “Simple triaxial”
Research Triaxial Test RTT versus Simple Triaxial Test STT

BSM Crushed Hornfels with 3.3% Emulsion

$\sigma_3 = 50 \text{ kPa and } 1\% \text{ Cement}$

$\sigma_3 = 200 \text{ kPa and } 0\% \text{ Cem}$
## BSM Classification into Shear Properties

<table>
<thead>
<tr>
<th>Equivalent BSM Class</th>
<th>Angle of Internal Friction (°)</th>
<th>Cohesion (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM 1</td>
<td>&gt; 40</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>BSM 2</td>
<td>30 to 40</td>
<td>100 – 250</td>
</tr>
<tr>
<td>BSM 3</td>
<td>&lt; 30</td>
<td>50 – 100</td>
</tr>
</tbody>
</table>
Fatigue?
Fatigue: Crushed stone + 25% RAP

![Fatigue Graph](image)

- **HMA Base 2000MPa**
HVS Tests: CIPR with Foamed Bitumen in Cape Town

Water induction into 2.3% foamed bitumen stabilised base
From HVS Testing

After 10 million 80kN axle load repetitions

- 18mm Novachip surfacing
- 35mm HMA binder layer
- 250mm foamed bitumen stabilised base
- 150mm crushed stone subbase
- Sand subgrade

No cracking
6mm rutting

Effective modulus

Steady stiffness
Constant stiffness

No water ingress
Water ingress

Time, traffic
Durability: New, Improved Tests
- Untreated Material Properties
- Moisture sensitivity tests
Effect of moisture

Shear stress

Cohesion

Lower Cohesion

Effect of Moisture

Normal stress

\( \tau \)

\( \sigma \)

\( \phi \) Friction angle
# BSM Classification into Moisture Resistance

<table>
<thead>
<tr>
<th>Equivalent BSM Class</th>
<th>Retained Cohesion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM 1</td>
<td>&gt; 75</td>
</tr>
<tr>
<td>BSM 2</td>
<td>60 – 75</td>
</tr>
<tr>
<td>BSM 3</td>
<td>50 – 60</td>
</tr>
<tr>
<td>Unsuitable</td>
<td>&lt; 50</td>
</tr>
</tbody>
</table>

*Develop Tools ☻☻☻☻*
Implementation

Keep your eyes on the road
# Materials Classification BSMs - Similar to granular

## Test Limits for Material Class

<table>
<thead>
<tr>
<th>Test or Indicator</th>
<th>Samples</th>
<th>BSM1</th>
<th>BSM2</th>
<th>BSM3</th>
<th>BSM1</th>
<th>BSM2</th>
<th>BSM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCP Penetration</td>
<td>12</td>
<td>0.13</td>
<td>0.29</td>
<td>0.06</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWD Stiffness</td>
<td>67</td>
<td>0.26</td>
<td>0.32</td>
<td>0.11</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grading Analysis</td>
<td>3</td>
<td>0.37</td>
<td>0.34</td>
<td>0.11</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Passing 0.075</td>
<td>3</td>
<td>0.43</td>
<td>0.37</td>
<td>0.11</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasticity Index</td>
<td>5</td>
<td>0.46</td>
<td>0.47</td>
<td>0.11</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>California Bearing Ratio</td>
<td>2</td>
<td>0.49</td>
<td>0.54</td>
<td>0.16</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Moisture Content</td>
<td>4</td>
<td>0.52</td>
<td>0.57</td>
<td>0.19</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Outcome:

Material is most likely a **G5** design equivalent

## Confidence:

Confidence of the assessment is **medium**. For structural rehabilitation, it is recommended that the sample size and number of test indicators be increased.
Materials Classification

Example: ITS

Not suitable < 95

DE-BSM3 95 to 135

DE-BSM2 135 to 175

DE-BSM1 > 175

Area = Relative certainty that material is a DE-BSM3 based on this test

10th Percentile Value = 80

Median Value = 120

90th Percentile Value = 190

Certainty that falls in class

| 0.15 | 0.48 | 0.32 | 0.06 |

Adjusted for test certainty factor
## Cumulative Certainty

<table>
<thead>
<tr>
<th>Test</th>
<th>No</th>
<th>BSM1</th>
<th>BSM2</th>
<th>BSM3</th>
<th>NSuit</th>
<th>Cumulative Certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCP</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0      0.07 0.03  -</td>
</tr>
<tr>
<td>P0.075</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.15     0.07 0.03  -</td>
</tr>
<tr>
<td>FWD</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.23     0.26 0.03  -</td>
</tr>
<tr>
<td>PI</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.23     0.26 0.06  0.21</td>
</tr>
<tr>
<td>Moisture</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.27     0.29 0.06  0.021</td>
</tr>
<tr>
<td>Grading</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.27     0.33 0.34  0.25</td>
</tr>
<tr>
<td>Cohesion</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.27     0.49 0.38  0.26</td>
</tr>
<tr>
<td>Friction</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.30     0.60 0.4   0.26</td>
</tr>
<tr>
<td>Ret. Coh.</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.30     0.62 0.43  0.37</td>
</tr>
</tbody>
</table>
### Design: Pavement Number

<table>
<thead>
<tr>
<th>Material Classes</th>
<th>5. Assign modular ratio’s and max stiffness</th>
<th>6. Calculate Layer ELTS Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 mm BSM2</td>
<td>MR = 2, ( E_{\text{Max}} = 450 )</td>
<td>ELTS = 450</td>
</tr>
<tr>
<td>200 mm C4</td>
<td>MR = 3, ( E_{\text{Max}} = 400 )</td>
<td>BCF = 0.7</td>
</tr>
<tr>
<td>180 mm G6</td>
<td>MR = 1.8, ( E_{\text{Max}} = 180 )</td>
<td>ELTS = 400</td>
</tr>
<tr>
<td>150 mm G7</td>
<td></td>
<td>Thickness Adj = 0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ELTS = \min(212, 180)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ELTS = 180</td>
</tr>
</tbody>
</table>

1. Material Classes
2. Determine subgrade stiffness (140 MPa)
3. Adjust for climate (126 MPa)
4. Adjust for cover (118 MPa)
5. Assign modular ratio’s and max stiffness
6. ELTS = \( \min(E_{\text{support}} \times MR, E_{\text{max}}) \)
7. Layer PN = thickness \( \times \) ELTS
8. \( \text{PN} = \sum \text{layer PN} \)

www.bitstab.roadrehab.com
Design Guides

Wirtgen Cold Recycling Technology

Technical Guideline:
Bitumen Stabilised Materials

Implementation ☺ ☻ ☾
Research needs Perseverance!!