Effect of Mixing conditions on the Quality of Asphalt Mixtures containing RA

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Introduction
  • Asphalt Recycling and Facilities
  • Problem Statement
  • Research Objectives
  • Research Methodology
• Experiment Design
• Infrared Heat transfer video screening
• Mechanical Test Methods and Results
• Initial findings and conclusion

Junex13, x2012
Introduction

• What is RA?
• Reclaimed (recycled) Asphalt
**Initial Problem?**

- Energy
- CE Marking and performance base contracts
- Competition in price and quality
- Introducing new technology
- Warm mix asphalt demand from Market
- High usage of RA is a MUST
Asphalt Recycling (Energy)

- Hot Mix Asphalt Recycling (HMA)
- Half Warm Mix Asphalt Recycling (HWA)
- Warm Mix Asphalt Recycling (WMA)
- Cold Recycling

![Graph showing energy consumption and aggregate temperature for different recycling methods.](image-url)
Reclaimed asphalt used in the Netherlands

June 13, 2003
Research Objectives

• Developing optimum production processes
  ➢ Maximum RAP
  ➢ Lowest Temperature (Energy)

• Developing mix designs regarding with new technology

• Comparing the quality level of the ADBDM

• Simulating the actual recycling process in the lab
Problem Statement

- Using high amount of RAP
  - RAP Moisture (4%)
  - Super Hot Virgin Aggregates (500 °C)
  - CE Marking requirements
    - Asphalt Performance (Fatigue, water sensitivity, resilient modulus)
- RAP binder blending degree?
- Mix designs
Asphalt Recycling facilities

- Batch Plants
- Drum mixer
- Double drum mixers
Hot Mix Recycling facilities in Netherlands
(Partila Warming method)

- 50% RAP
- Preheating RAP 130°C
Astec Double Barrel Drum Mixer (cold RAP introducing method)
Astec Double Barrel Drum mixer

(1) + (2) → (3) → (4)
• RA: Reclaimed Asphalt (According to EN13108-8)
• ADBDM: Astec Double Barrel Drum Mixer
• PWBP: Partial Warming Batch Plant
Research Methodology

- Simulating in the lab
  - moisture handling
  - RA and virgin aggregate preheating
  - Mixture and binder short term aging (loose mixture storage)
  - Mixing time
Experiment Design

Material

Virgin
Virgin bitumen
Virgin Aggregate
Binder Extraction & Recovery
Mineral Aggregate extraction

Penetration
Softening point
Gradation analysis

Blending
Mix DesignS
Performance tests

Indirect tensile strength test
Cyclic indirect tensile resilient modulus
Indirect tensile resistance to fatigue

Results & Analysis

Conclusions
Recommendations for next experimental plan
Laboratory simulation

- Standard Method (RA=170° & virgin aggregate= 170°C)
- Partial warming (RA=130°C & virgin aggregate> 200°C)
- Upgraded Method (RA=Cold+ moisture & virgin aggregate> 300°C)
Experiment design

- Design factors
  - Mixing methods: SM, PW, UPG
  - Moisture conditions: 0% and 4%
  - RA content: 0%, 30% and 60%
  - Maximum aggregate size: 22 mm (Base Asphalt concrete)
  - Mixing time: constant 3 minutes
Preheating Temperatures

SM30
- RAI 170°C
- Virgin 170°C

PW30
- Virgin 240°C
- RAI 130°C

UPG030
- Virgin 290°C
- RAP 25°C

UPG130
- Virgin 345°C
- RAP 25°C

SM60
- Virgin 170°C
- RAI 170°C

PW60
- Virgin 330°C
- RAI 130°C

UPG060
- Virgin 430°C
- RAI 25°C

UPG160
- Virgin 515°C
- RAP 25°C
Preheating Temperatures

- Virgin preheat temp (+RAP30%)
- Virgin preheat temp (+RAP60%)
- RAP preheat temp
RA fractions

<table>
<thead>
<tr>
<th>RA</th>
<th>Virgin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2 mm</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>2-5,6 mm</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>5,6-8 mm</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>8-11 mm</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>11-16 mm</td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td>16-22 mm</td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
</tbody>
</table>
RA gradation

![Graph showing RA gradation with various lines and data points.]
RA fraction properties

Mass percentage of each fraction in RA

- 0-2: 22%
- 2-5: 21%
- 5-8: 14%
- 8-11: 18%
- 11-16: 16%
- 16-22: 8%

Coarse RAP (5-22mm): 57%
Fine RAP (0-5mm): 43%

Binder Percentage in RA

- 0-2: 32%
- 2-5: 25%
- 5-8: 11%
- 8-11: 13%
- 11-16: 13%
- 16-22: 5%

Fine RAP (0-5mm): 58%
Coarse RAP (5-22mm): 42%

Filler Percentage in RA

- 0-2: 38%
- 2-5: 26%
- 5-8: 11%
- 8-11: 12%
- 11-16: 10%
- 16-22: 4%

Fine RAP (0-5mm): 64%
Coarse RAP (5-22mm): 36%
Video of UPG mixing with RA (+4% moisture)
Infrared thermography

- Infrared Heat Transfer screening
Infrared Mix Screening
Indirect tensile Resilient modulus

- Indirect tensile test (Dynamic): EN 12697-26
- Frequencies: 1, 2, 4, 8 Hz
- Temperatures: 5, 10, 15, 23
Stiffness values at 8Hz

![Stiffness values graph](image-url)
Stiffness Mastercurve

Log reduced frequency (HZ)

Mr (Mpa)

shifted values to 15°C

@5, 10, 15, 23, 35°C

SM0 Model
Stiffness Master curve

- Shift factor calculation at T(ref):

\[
S_{mix} = a_0 \left\{ 1 - e^{-\left( f_{\text{red}} \right)^{a_2}} \right\}
\]

\[
\alpha_T = e^{\frac{\Delta H}{R} \left( \frac{1}{T} - \frac{1}{T_{\text{ref}}} \right)}
\]

Log shift factor vs temperature at T(ref)=15°C

\[
y = -0.124x + 1.912
R^2 = 0.899
\]

 TU Delft

Gebr. van der Lee
Effect of mixing method on stiffness

![Graph showing the effect of mixing method on stiffness](image-url)

- Reference Mix
- SM60
- PW60
- UPG0-60
- UPG4-60
Effect of RA moisture on Stiffness

Graph 1: Effect of RA moisture on MR

Graph 2: Effect of RA moisture on MR
Indirect Tensile Strength

**ITS at 5°C**

<table>
<thead>
<tr>
<th>Mixing method</th>
<th>RA content</th>
<th>PW</th>
<th>UPG_4%</th>
<th>UPG_0%</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>0.0</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>30%</td>
<td>5.0</td>
<td>5.1</td>
<td>5.9</td>
<td>6.1</td>
<td>6.0</td>
</tr>
<tr>
<td>60%</td>
<td>5.5</td>
<td>5.6</td>
<td>5.8</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>UPG_0%</td>
<td>3.9</td>
<td>4.0</td>
<td>4.2</td>
<td>4.4</td>
<td>4.5</td>
</tr>
<tr>
<td>UPG_4%</td>
<td>3.9</td>
<td>4.0</td>
<td>4.2</td>
<td>4.4</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**ITS (MPa)**
Fatigue life at 20°C

- Prediction of fatigue life based on Mechanistic Models
- Indirect Tensile Fatigue test (dry)
- Indirect Tensile Fatigue test (in water)
Fatigue life prediction

- Molenaar and Medani (2001)

\[
m = \frac{d(\log S_m)}{d(\log t)}
\]

\[
n_{\text{max}} = \frac{2}{m}
\]

\[
n = \frac{n_{\text{max}}}{CF}
\]

\[
CF = 0.541 + 0.173n_{\text{max}} - 0.03524V_a
\]

\[
\log k_i = 6.589 - 3.762n + \frac{3209}{S_m} + 2.332\log V_b + 0.149\frac{V_b}{V_a} + 0.928\cdot PI - 0.0721\cdot T_{R&F}
\]
Fatigue life results (Model)

Model fatigue at 200

<table>
<thead>
<tr>
<th></th>
<th>SM0</th>
<th>SM30</th>
<th>SM60</th>
<th>PW30</th>
<th>PW60</th>
<th>UPG030</th>
<th>UPG060</th>
<th>UPG430</th>
<th>UPG460</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>5.5</td>
<td>5.7</td>
<td>5.8</td>
<td>5.5</td>
<td>5.8</td>
<td>5.7</td>
<td>5.9</td>
<td>5.8</td>
<td>5.9</td>
</tr>
</tbody>
</table>
Indirect Tensile Fatigue test

- Continuous Haversine loading
- Constant load 220 kPa
- Temperature 20°C
IT Fatigue test: failure models dry

SM0  SM30  SM60
PW30  PW60  UPG030
UPG060  UPG430  UPG460
Results: vertical displacement till failure (dry)

Displacement (mm)

- SM0
- SM30
- SM60
- PW60
- UPG030
- UPG060
- UPG430
- UPG460

Cycle

1,000.000 1,000.000 1,000.000 1,000.000

TU Delft
Fatigue Results (dry)

<table>
<thead>
<tr>
<th>Material</th>
<th>Dry IT fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM0</td>
<td>4.9</td>
</tr>
<tr>
<td>SM30</td>
<td>6.0</td>
</tr>
<tr>
<td>SM60</td>
<td>5.1</td>
</tr>
<tr>
<td>PW30</td>
<td>5.1</td>
</tr>
<tr>
<td>PW60</td>
<td>5.6</td>
</tr>
<tr>
<td>UPG030</td>
<td>5.3</td>
</tr>
<tr>
<td>UPG060</td>
<td>5.7</td>
</tr>
<tr>
<td>UPG430</td>
<td>5.5</td>
</tr>
<tr>
<td>UPG460</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Saturated IT fatigue test

- Saturated and immersed in water
- Continuous loading
- Constant load 220 kPa
- Temperature 20°C
Failure models (saturated)
Fatigue results (saturated)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Saturated IT fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM0</td>
<td>5.1</td>
</tr>
<tr>
<td>SM80</td>
<td>5.9</td>
</tr>
<tr>
<td>SM60</td>
<td>5.3</td>
</tr>
<tr>
<td>PW80</td>
<td>5.3</td>
</tr>
<tr>
<td>PW60</td>
<td>6.1</td>
</tr>
<tr>
<td>LPG030</td>
<td>5.5</td>
</tr>
<tr>
<td>LPG060</td>
<td>5.7</td>
</tr>
<tr>
<td>LPG430</td>
<td>5.8</td>
</tr>
<tr>
<td>LPG460</td>
<td>6.1</td>
</tr>
</tbody>
</table>
## Comparing Fatigue results

<table>
<thead>
<tr>
<th></th>
<th>SM0</th>
<th>SM30</th>
<th>SM60</th>
<th>PW30</th>
<th>PW60</th>
<th>UPG030</th>
<th>UPG060</th>
<th>UPG430</th>
<th>UPG460</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dry IT fatigue</strong></td>
<td>4.9</td>
<td>6.0</td>
<td>5.1</td>
<td>5.1</td>
<td>5.6</td>
<td>5.3</td>
<td>5.7</td>
<td>5.5</td>
<td>6.0</td>
</tr>
<tr>
<td><strong>Saturated IT fatigue</strong></td>
<td>5.1</td>
<td>5.9</td>
<td>5.3</td>
<td>5.3</td>
<td>6.1</td>
<td>5.5</td>
<td>5.7</td>
<td>5.8</td>
<td>6.1</td>
</tr>
</tbody>
</table>
Analysis of fatigue results

- UPG method with 4% moisture doesn’t have negative effect on the fatigue life in the laboratory simulations.
- Fatigue life get improved by using high amount of RA in all mixing method except SM
- Saturating conditioning doesn’t have negative effect on the fatigue life
Conclusion & Initial findings

• RA and virgin binder blending degrees are different due to the process and it affects the final mixture performance in some degrees.
• Moisture and temperature simulation in lab seems to be quite different from actual plant practice.
• log- pen rule may not be always applicable in UPG.
Conclusion and initial findings

• UPG method in the LAB compared to PW and SM shows reasonable:
  • Fatigue life
  • Stiffness
  • Indirect tensile strength
  • Water sensitivity

3 minutes of mixing in the Lab!