Experimental Investigation on Double Recycling of Asphalt Mixture for Pavement Applications

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Naxos, Greece, June 13-16, 2018
Outline

- Introduction
- Materials and Experimentation
- Results and Analysis
- Summary and Conclusions
Introduction

• **Asphalt mixture** is the main road paving material

• In **Europe** and **north America** more than 90% of roads are surfaced with asphalt mixture (NAPA & EAPA, 2011)

Asphalt mixtures:
• a particulate composites that contain **aggregate particles** of various sizes and shapes randomly distributed in a matrix made of **asphalt bitumen/binder**.
Introduction

Asphalt Bitumen/Binder + Aggregates = Asphalt Mixture
Introduction

REUSE AND RECYCLING

<table>
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<th>Country</th>
<th>All available reclaimed asphalt in tonnes</th>
<th>Hot Mix Asphalt Production</th>
<th>Warm Mix Asphalt Production</th>
<th>Half Warm Mix Asphalt Production</th>
<th>Cold Recycling**</th>
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<td>98</td>
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<td>91</td>
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**Cold recycling includes stabilisation with bitumen emulsion, foamed bitumen and/or cement.
*** no data, but all recycled

EAPA (Asphalt in Figures, 2015)

Introduction

Asphalt bitumen/binders and asphalt mixtures are temperature susceptible materials. Thermal cracking is a significant distress in asphalt pavements built in cold climates.

After field aged or laboratory aged, the asphalt binders are getting harder and more stiffness; hence, the low temperature properties of asphalt mixture should be studied.
Introduction

Research Objective

Evaluate the effect of adding different amounts of re-recycled (double recycled) RAP on low temperature creep property and fracture property of asphalt mixture.

Based on:

- Bending Beam Rheometer (BBR) Test on asphalt mixture
- Semi-Circular Bending (SCB) tests
Materials and Experimentation

Materials

Table 1. Asphalt mixtures

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Recycling Level</th>
<th>Asphalt Binder</th>
<th>RAP (%)</th>
<th>Air Voids (%)</th>
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<tbody>
<tr>
<td>A</td>
<td>Virgin</td>
<td>PG 58-28</td>
<td>0</td>
<td>7</td>
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<tr>
<td>B</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Generation</td>
<td>PG 58-28</td>
<td>20</td>
<td>7</td>
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<tr>
<td>C</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Generation</td>
<td>PG 58-28</td>
<td>40</td>
<td>7</td>
</tr>
<tr>
<td>D</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Generation</td>
<td>PG 58-28</td>
<td>20</td>
<td>7</td>
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<tr>
<td>E</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Generation</td>
<td>PG 58-28</td>
<td>40</td>
<td>7</td>
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<tr>
<td>F</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Generation</td>
<td>PG 58-28</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>G</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Generation</td>
<td>PG 58-28</td>
<td>40</td>
<td>7</td>
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</table>

PG: Performance Grade
PG 58-28: the materials is suitable for the temperature between -28°C and 58 °C.
Materials and Experimentation

Bending Beam Rheometer (BBR) – creep testing
• A small asphalt mixture beams ($l=102\text{mm}$, $b=12.5\text{mm}$, and $h=6.25\text{mm}$) with the BBR equipment.
• A higher constant load $P=4,000\text{mN}$ and extend time of $t=1,000\text{s}$ were used for BBR asphalt mixture testing.

Figure 2. BBR Pro Device
Figure 3. BBR Mixture Sample
Bending Beam Rheometer (BBR) – creep testing

creep stiffness: \[ S(t) = \frac{\sigma}{\varepsilon(t)} = \frac{P l^3}{4b h^3 \delta(t)} = \frac{1}{D(t)} \]

\( \sigma \) the maximum bending stress, 
\( \varepsilon(t) \) the bending strain, 
\( P \) 4,000mN, 
\( \delta(t) \) the mid-span deflection 
\( t \) time (0~1,000 seconds).

The relaxation parameter \textit{m-value} is also computed.

\[ m(t) = \left| \frac{d \log S(t)}{d \log t} \right| \]
Bending Beam Rheometer (BBR) – creep testing

Based on the conventional Hopkins and Hammings algorithm (1967) and the CAM model (Marasteanu and Anderson, 1999), the thermal stress can be calculated:

\[
\sigma(\xi) = \int_{-\infty}^{\xi} \frac{de(\xi')}{d\xi'} \cdot E(\xi - \xi')d\xi' = \int_{-\infty}^{t} \frac{d(\alpha \Delta T)}{dt'} \cdot E(\xi(t) - \xi'(t))dt'
\]

where,

\(\xi = t / a_T\) the reduced time,

\(\alpha\) the coefficient of thermal contraction of asphalt mixture assumed to be equal to 30.28\times10^{-6}/^\circ\text{C}.$
Materials and Experimentation

Bending Beam Rheometer (BBR) – creep testing

critical cracking temperature, $T_{cr}$:

![Diagram showing the Shenoy (SAP) method for computing $T_{cr}$]

Single Asymptote Procedure (SAP): $T_{cr}$ is determined as the intersection with the x axis (temperature) of the asymptotic line to the highest stress value in the thermal stress curve.

Figure 4. Schematic of the Shenoy (SAP) method for computing $T_{cr}$
Materials and Experimentation

Semi-Circular Bending (SCB) – fracture testing

- A semi-circular shape with a diameter of almost 150mm, a thickness of 25mm and a straight vertical central notch of 15mm in length.
- The sample is placed on a frame consisting of two fixed rollers and having a span of 120mm.

The fracture energy, $G_f$:

$$G_f = \frac{W_f}{A_{lig}}$$

where,

- $W_f$ the work of fracture,
- $A_{lig}$ the area of ligament.

Figure 5. SCB Device
Semi-Circular Bending (SCB) – fracture testing

The fracture toughness (stress intensity factor), $K_I$:

$$K_I = \sigma_0 \sqrt{\pi a} \left[ Y_{I(S_0/r)} + \frac{\Delta S_0}{r} B \right] = \sigma_0 \sqrt{\pi a} \left[ Y_{I(S_0/r)} + \left( \frac{s_a}{r} - \frac{s_0}{r} \right) B \right]$$

where,

- $K_I$ Mode I stress intensity factor, $\sigma_0 = P/(2rt)$;
- $r$ radius; $t$ thickness;
- $Y_I$ the normalized stress intensity factor (Li X. J. & Marasteanu, 2009 and 2010);
- $a$ the notch length;
- $s_a/r$ the actual span ratio;
- $s_0/r$ the nearest span ratio;
- $B$ a parameter depending on $a$ and $r$. 
Results and Analysis – BBR tests

Creep Tests

Thermal Stress

Figure 6. BBR results: (a) creep stiffness at $t=60s$; (b) $\sigma(T)$ comparison of different mixture at $20^\circ C/h$. 
Results and Analysis – BBR tests

Critical Cracking Temperature

Table 2. Critical cracking temperature, $T_{CR}$, comparison

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling Level</td>
<td>Virgin</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>RAP (%)</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>20</td>
<td>40</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>$T_{CR}$ (°C)</td>
<td>-23.06</td>
<td>-22.82</td>
<td>-22.18</td>
<td>-21.63</td>
<td>-21.32</td>
<td>-21.59</td>
<td>-21.28</td>
</tr>
</tbody>
</table>

Only slightly higher $T_{CR}$ were found in mixtures prepared with RAP compared to virgin mixtures, where a higher percentage of RAP leads to a higher $T_{CR}$.

The mixture prepare with double recycled RAP indicate a very close response to the mixtures prepared with RAP.
Results and Analysis – SCB tests

Figure 7. Load vs. LLD curves from SCB tests.

A substantial increase in the peak load and stress is found in the case of recycled asphalt mixtures of first generation (B and C), while a decreasing trend is experienced for the mixture containing RAP of second generation.
Results and Analysis – SCB tests

Table 3. SCB results comparison

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Recycling Level</th>
<th>RAP (%)</th>
<th>RAP Mixture Origin</th>
<th>$P_N$ (kN)</th>
<th>$G_F$ (kN/m)</th>
<th>$\sigma_n$ (kPa)</th>
<th>$K_f$ (MPa*m$^{0.5}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Virgin</td>
<td>0</td>
<td>-</td>
<td>3.78</td>
<td>0.411</td>
<td>988</td>
<td>1.119</td>
</tr>
<tr>
<td>B</td>
<td>1st Generation</td>
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<td>A</td>
<td>3.88</td>
<td>0.422</td>
<td>1,175</td>
<td>1.122</td>
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<td>C</td>
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<td>A</td>
<td>4.13</td>
<td>0.484</td>
<td>1,351</td>
<td>1.168</td>
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<td>D</td>
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<td>3.82</td>
<td>0.420</td>
<td>1,211</td>
<td>1.118</td>
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<td>3.75</td>
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<td>1.108</td>
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This overall trend suggests that the presence of the first generation of RAP is surprisingly improving the fracture response of the mixture. However, the fracture response of double recycled RAP is similar to the virgin mixture.
Summary and Conclusions

The effect of different amount of double recycled RAP on low temperature properties of mixture is experimentally investigated in this study.

• Low temperature creep tests indicate that mixtures prepared with double recycled RAP have similar response to that of mixtures designed with recycled RAP.

• Fracture performances tests found that the mixture prepared with double recycled RAP have similar behavior with the fresh mixture.

Important Dates
Sept. 17-18th, 2018  RILEM 252-CMB Symposium
Sept. 19-20th, 2018  RILEM Cluster F Annual Meeting

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Questions?