Evaluation of Flemish bituminous mixtures’ performance containing RAP.
Statistical analysis and modelling

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Presentation outline:

• Asphalt recycling
• Objectives
• Materials & Methodology
• Results
• Conclusions
Asphalt Recycling

1st oil crisis (1972)
- Estimated RA content:
  - Belgium: 80%
  - France: 43%
  - Netherlands: 45%

1980s
- Asphalt recycling as common practice
- Estimated RA content:
  - Belgium: 64%
  - France: 58%
  - Netherlands: 65%

1997
- Kyoto protocol signed.
- Reduce greenhouse gas emissions
- EU Waste Framework Directive:
  - 70% Recycling target

Sources: Belgium by COPRO (2013)
France and Netherlands by EAPA (2013)
Japan and USA by NAPA (2014)
A Life Cycle Assessment (LCA) research about Flemish mixtures: significant environmental benefits when adding RA.

Note: the quality of the final mixture has to be ensured.

Performance benefits?

Objectives

- To investigate the effect of RA on manufactured mixtures
- Define the influential factors of the mechanical properties
A dataset containing information of 74 registered asphalt mixtures in Flanders was studied. The data were provided by the FRA (Flemish Road Agency).

Types of mixtures in the dataset:
- APO-A
- APO-B
- AVS-B

APO → Asphalt Concrete (AC) with performance requirements
AVS → High modulus asphalt mixtures (EME)

Max aggregate size:
A → 20 mm
B → 14 mm
Properties of the mixtures:

- Stiffness (MPa) ($E^*$)
- Fatigue ($\mu$m/m) ($\varepsilon_6$)
- Wheel tracking (%) ($P_i$)
- RA content (%)
- Total binder content (%)
- Old over new binder (O/N) (%)
- Penetration (dmm)
- Softening point (R&B) (°C)
- Air voids (VA) (%)
- Stones (%)
- Sand (%)
- Filler (%)
Methodology

Impact of using RA on mixes’ mechanical properties:

- Independent T-test or U-test

Influential factors of the mechanical properties:

- Multivariate analysis
- Multiple linear regression analysis
Results

T-test or U-test for mixtures with and without RA

Fatigue (APO-A)
\[ t(27) = -3.157, p = 0.004 \]

Wheel tracking (APO-A)
\[ U = 19, z = -2.18, p = 0.028 \]

Wheel tracking (APO-B)
\[ t(19) = 2.340, p = 0.030 \]
Multivariate analysis
Pearson’s R correlation coefficient

<table>
<thead>
<tr>
<th></th>
<th>RA (%)</th>
<th>Stones (%)</th>
<th>Sand (%)</th>
<th>VA (%)</th>
<th>O/N (%)</th>
<th>Total binder content (%)</th>
<th>Penetration (dmm)</th>
<th>Softening point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness $E^*$ (MPa)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.416</td>
<td>0.320</td>
</tr>
<tr>
<td>Fatigue $\varepsilon_6$ (µm/m)</td>
<td>-</td>
<td>0.482</td>
<td>-0.450</td>
<td>-0.417</td>
<td>-</td>
<td>0.623</td>
<td>-0.625</td>
<td>0.601</td>
</tr>
<tr>
<td>Wheel tracking $P_i$ (%)</td>
<td>-0.373</td>
<td>-0.369</td>
<td>0.365</td>
<td>-</td>
<td>-0.374</td>
<td>-</td>
<td>0.549</td>
<td>-0.574</td>
</tr>
</tbody>
</table>

**Coefficient $r$, association ($\pm$):**
- $0.1 \sim 0.3$: Small
- $0.3 \sim 0.5$: Medium
- $0.5 \sim 1.0$: Strong
Multiple linear regression

**Stiffness** = 57652.678 – 474.051 * (Stones %) – 396.196 * (Sand %) – 73.209 * (Penetration)

**Fatigue** = – 64.997 + 0.412 * (RA %) + 33.812 * (Binder content %)

**Wheel tracking** = 2.224 – 0.020 * (O/N) + 0.064 * (Penetration)

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B$</th>
<th>$SE_B$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>57652.678</td>
<td>16612.880</td>
<td>0.001</td>
</tr>
<tr>
<td>Stones</td>
<td>-474.051</td>
<td>190.789</td>
<td>0.015</td>
</tr>
<tr>
<td>Sand</td>
<td>-396.196</td>
<td>161.905</td>
<td>0.017</td>
</tr>
<tr>
<td>Penetration</td>
<td>-73.209</td>
<td>19.969</td>
<td>0.001</td>
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<tr>
<td>Intercept</td>
<td>-64.997</td>
<td>22.293</td>
<td>0.005</td>
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<tr>
<td>RA</td>
<td>0.412</td>
<td>0.114</td>
<td>0.001</td>
</tr>
<tr>
<td>Binder content</td>
<td>33.812</td>
<td>4.151</td>
<td>&lt;.0001</td>
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<td>Intercept</td>
<td>2.224</td>
<td>0.444</td>
<td>&lt;.0001</td>
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<tr>
<td>O/N</td>
<td>-0.020</td>
<td>0.0006</td>
<td>0.001</td>
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<tr>
<td>Penetration</td>
<td>0.064</td>
<td>0.012</td>
<td>0.0001</td>
</tr>
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**Results**

F(3,69)=7.339, $p=0.0002$, $R^2 = 0.210$

F(2,71)=33.293, $p<.0001$, $R^2 = 0.469$

F(2,60)=21.962, $p<.0001$, $R^2 = 0.403$
T-test/U-test analysis:

- **Fatigue of APO-A mixtures with RA was higher.**
- **Wheel rutting depth** of APO-A and APO-B mixtures was significantly **lower when RA was added.**
- For the rest, **no significant differences** were traced.

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<th>Stiffness</th>
<th>Fatigue</th>
<th>Rutting</th>
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<tr>
<td>APO-A → AC20</td>
<td>APO-A</td>
<td>N.D.</td>
<td>RA mix</td>
</tr>
<tr>
<td>APO-B → AC14</td>
<td>APO-B</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>AVS-B → EME14</td>
<td>AVS-B</td>
<td>N.D.</td>
<td>N.D.</td>
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The multivariate analysis:
• The correlations had moderate or strong association.
• Binder properties influence the mechanical properties. Since RA replaces an adequate amount of the virgin binder, an improper blend design can mislead the mix design and consequently provide mixtures with lower performance.

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Multiple linear regression analysis

- All studied mechanical properties can be influenced by RA
- The $R^2$ of the models indicate that the data are rather spread. Indicate the factors that mainly affect the mechanical properties.

**Stiffness** = $57652.678 - 474.051 \times (\text{Stones} \%) - 396.196 \times (\text{Sand} \%) - 73.209 \times (\text{Penetration} \%)
F(3,69)=7.339, p=0.0002, R^2 = 0.210

**Fatigue** = $-64.997 + 0.412 \times (\text{RA} \%) + 33.812 \times (\text{Binder content} \%)$
F(2,71)=33.293, p=<.0001, $R^2 = 0.469$

**Wheel tracking** = $2.224 - 0.020 \times (\text{O/N}) + 0.064 \times (\text{Penetration} \%)$
F(2,60)=21.962, p=<.0001, $R^2 = 0.403$
Conclusions

For the Flemish mixtures, RA can be beneficial regards:
• Rutting and fatigue (in some cases).
• No difference was traced for stiffness.

At least equal mechanical properties between groups.
Thank you for your attention

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