Influence of viscoelastic properties of cold recycled asphalt mixtures on pavement response
Cold Recycled Asphalt Mixtures (CRAMs)

- Reclaimed Asphalt Pavement (RAP)
  - Addition of fine virgin aggregates
- Bitumen stabilization
  - Foamed asphalt
  - Asphalt emulsion
- Active filler
  - Cement
  - Hydrated lime
Cold Recycled Asphalt Mixtures (CRAMs)

- Reduced consumption of virgin aggregates
- Reduced emission of polluting gases
- Decreased transportation costs (in-situ recycling)
- Greater reclamation levels of milled aggregates

(Copeland, 2010; Lee et al., 2012)
Source: Grilli et al. (2012)
- **Granular material**
  - Higher cohesive strength
    *(Asphalt Academy, 2009)*
  - Unbound granular material with similar void content
    *(construction purposes)*
  - Confining stress dependency
    *(Fu et al., 2010; Guatimosim et al., 2018)*
Viscoelastic material

- Stiffness dependent of temperature and load frequency
  (Godenzoni et al., 2017; Nivedya et al., 2018)

- CRAMs present flatter dynamic modulus master curves than HMA
  (Ebels, 2008)
• **Test section**

  • Fernão Dias highway (BR-381)
  • 2 test sections
  • 100 m length
  • Recycled base course materials
- **Test section**

<table>
<thead>
<tr>
<th>12.5 cm</th>
<th>12.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Asphalt concrete (AC)</strong></td>
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<td><strong>Foamed Asphalt Mixture (FAM)</strong></td>
<td><strong>Asphalt Emulsion Mixture (AEM)</strong></td>
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<tr>
<td><strong>Remaining Structure</strong></td>
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<table>
<thead>
<tr>
<th>25 cm</th>
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</table>
• Test section
  
  o Instrumentation

  PT 100 temperature sensor → 13 cm depth
• Materials and test methods

Asphalt Emulsion Mixture (AEM)
- 98% RAP
- 2% Portland-limestone cement
- Curing: 3d @ 60 °C (unsealed) + 3d @ 60 °C (sealed)
- Slow-setting cationic emulsion (Pen. 50/90)
- Emulsion: 3% (62.3% binder content)
- Moisture: 5.5%

Foamed Asphalt Mixture (FAM)
- 68% RAP
- 30% fine aggregate blend
- 2% Portland-limestone cement
- Curing: 40 °C until 60% of OMC
- Foam: 3% (Pen. 85/100)
- Moisture: 6.5%
- Water for foaming: 2.6%
- Wirtgen WLB 10S
- t1/2: 7.2s
- ER: 18x
• **Materials and test methods**

  o **Material characterization**

    **Binder**: $|G^*|$ and $\delta$
    - Dynamic Shear Rheometer
    - 1 to 100 rad/s
    - 40 to 76 °C

    **Mixture**: $|E^*|$ and $\delta$
    - Dynamic modulus test
    - 25 – 10 – 5 – 1 – 0.5 – 0.1 Hz
    - 4.4 – 21.1 – 37.8 – 54 °C
- **Materials and test methods**
  - **3D Move Software Analysis 2.1**
    - **Load:**
      - Single axle dual tire
      - 20 kN/tire
      - Tire pressure: 560 kPa
      - Circular contact area: $R = 0.107$ m

- **Temperature**
  - $V = 40$ km/h
  - $W(VE) \ B(VE)$

- **Mechanical behavior**
  - $V = 40$ km/h
  - $W30 \ B20$
  - $W(VE) \ B(VE)$
  - $W(VE) \ B(EL)$

- **Asphalt concrete (AC)**
  - (ν = 0.35)

- **Asphalt Emulsion Mixture (AEM)** or **Foamed Asphalt Mixture (FAM)**
  - (ν = 0.35)

- **Remaining Structure**
  - (ν = 0.45)
• **Results and discussion**

- AEM and FAM are less thermo-sensitive than AC

- High $f_r$
  
  - AC has greater stiffness

- Low $f_r$
  
  - FAM presents greater stiffness than AEM

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**Mechanical properties dominated by aggregate gradation**

![Graph showing the relationship between reduced frequency and stiffness](image)
• Results and discussion

Asphalt Emulsion Mixture

Foamed Asphalt Mixture
• Results and discussion
• Results and discussion

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<thead>
<tr>
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<tr>
<td>10.90</td>
<td>9.12</td>
</tr>
<tr>
<td>10.11</td>
<td>7.29</td>
</tr>
<tr>
<td>9.19</td>
<td>4.13</td>
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Longitudinal strain (µε) vs Time (s)
• Results and discussion

Brown’s model:

\[
\log t = 0.5d - 0.2 - 0.94 \log v
\]

Loulizi et al. (2002)

- \( t \): Loading time (s)
- \( d \): Depth (0.124 m)
- \( v \): Vehicle speed (40 km/h)

\[ t = 0.023 \text{ s} \]

Conversion from time to frequency domain:

\[
f = \frac{1}{2\pi t} \quad \rightarrow \quad f = 7.0 \text{ Hz}
\]
• Results and discussion

<table>
<thead>
<tr>
<th>Layer</th>
<th>W20 B10 (MPa)</th>
<th>W30 B20 (MPa)</th>
</tr>
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<tbody>
<tr>
<td>AC</td>
<td>10000</td>
<td>4000</td>
</tr>
<tr>
<td>FAM</td>
<td>6000</td>
<td>5000</td>
</tr>
<tr>
<td>RM</td>
<td>118</td>
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### Results and discussion

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**Diagram:**

- **5 Hz**
  - AC
  - AEM
  - FAM

![Diagram showing moduli as a function of temperature](image-url)
• Results and discussion

Asphalt Emulsion Mixture

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<tr>
<td>Longitudinal strain (με)</td>
<td>10.90</td>
<td>24.03</td>
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Foamed Asphalt Mixture

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<td>Longitudinal strain (με)</td>
<td>4.13</td>
<td>24.96</td>
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• Conclusions

✓ AEM and FAM are thermo-sensitive materials
✓ AC’s tensile and compression strains at the bottom of the layer are sensitive to temperature variation
✓ Considering CRAMs as elastic materials underestimates its bearing capacity
THANK YOU!
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Acknowledgements: