ANALYSIS OF BINDER AGEING BY MICROMECHANICAL & MULTISCALE MODELING

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- Damage assessment

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- Numerical methods

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- Traffic & Road Planning
- Road Operation
- Maintenance Management
Outline

- Multiscale Model for Asphalt Mixes
- Bitumen Composition and Microstructure
- Micromechanical Modeling of Binder (Ageing)
- Conclusions and Outlook
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Motivation for Multiscale Modeling

- **macroscopic material models**
  identified material parameters applicable to *one* specific mixture consisting of *one* specific bitumen (e.g., B50/70), *one* specific filler (e.g., limestone dust) and *one* specific aggregate

- **(bottom-up) multiscale models**
  material parameters as functions of composition (mix design), morphology, and the properties of the material phases (e.g., bitumen, filler, ...)

  ➔ applicable to several asphalt mixes
  ➔ consideration of changes in material behavior at respective scale of observation
Multiscale Model for Asphalt

Five Scales of observation:

- **Volumetric** composition
- Identification of **mechanical properties** and **morphology**
- Phase **interaction** (Mori Tanaka)
- **Homogenization** and **Upscaling** (Viscoelasticity – Transformation to Laplace Carson Space)
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Bitumen Composition - SARA

- Common concept to identify constituents of bitumen = **SARA**
- **Asphaltenes** → n-heptane non soluble
- **Maltenes** → n-heptane soluble
- Further separation of Maltenes by chromatographic separation → Saturates, Aromatics, Resins
Bitumen Microstructure

- Imaging Methods to detect microstructure
  - Environmental Scanning Electron Microscopy (ESEM)
  - Atomic Force Microscopy (AFM)
  - Confocal Laser Scanning Microscopy (CLSM)
  - …

- Micelle structures embedded within a matrix – different thesis

Source: Sayeda Nahar, TU Delft
Microstructural model of bitumen

- Matrix (Maltenes)
- Micelles (Asphaltene core + shell of highly polar resins)
  - strongly contributing to stiffness
  - shell to balance polarity gap between maltene phase and asphaltene - homogeneous dispersion
Bitumen Microstructure

- Micelle
- Matrix
- Saturates
- Resins & Aromatics

Asphaltenes
Shell

Polarity with asphaltenes
Distance from micelle center

Polar density
Outline

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Micromechanical Modelling of Binder Ageing

- **Set-up** of micromechanical model
- **Identification** of mechanical behavior of material phases
  - Maltenes
  - Asphaltenes + Shell
- **Validation** of model for un-aged binder
- Mechanical behavior of **lab-aged binder** (RTFOT+PAV)
- **Validation** of model for lab-aged binders
Micromechanical Model

Microstructural Model

Interaction between Resin shells
Asphaltenes
Resins and Aromatics
Saturates

Resin shells
Asphaltenes
Resins and Aromatics
Saturates

\[ J(t) = J_0 + J_a \left( \frac{t}{\tau} \right)^k \]
Identification experiments

- Binder: 70/100 pen

<table>
<thead>
<tr>
<th>Parameter</th>
<th>70/100 pen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration [1/10 mm]</td>
<td>90.9</td>
</tr>
<tr>
<td>Softening Point Ring &amp; Ball [°C]</td>
<td>46.7</td>
</tr>
<tr>
<td>SHRP PG [°C]</td>
<td>58-22</td>
</tr>
</tbody>
</table>

- Artificial bitumens with varying asphaltene contents

- Creep-Recovery tests at different temperatures
### Experimental Layout

**Identification Maltenes**
- Effect of Temperature (Arrhenius)

**Identification Asphaltenes**

**Identification Interaction Shell**

**Validation**

<table>
<thead>
<tr>
<th>Asphaltene content</th>
<th>0 vol-%</th>
<th>4.18 vol-%</th>
<th>7.77 vol-%</th>
<th>12.32 vol-%</th>
<th>17.36 vol-%</th>
<th>26.71 vol-%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 wt. %</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>5 wt. %</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>10 wt. %</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>15 wt. %</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>20 wt. %</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>30 wt. %</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>
Identification Maltenes

![Graph showing the relationship between stress intensity (J) and time (t) with a linear fit and R^2 = 0.99.]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>-5 °C</th>
<th>+5 °C</th>
<th>+15 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>J_{0,malt} [1/MPa]</td>
<td>0.0980</td>
<td>0.2652</td>
<td>2.433</td>
</tr>
<tr>
<td>J_{a,malt} [1/MPa]</td>
<td>0.0076</td>
<td>0.0766</td>
<td>1.205</td>
</tr>
<tr>
<td>k_{malt} [-]</td>
<td>0.8124</td>
<td>0.9386</td>
<td>1.027</td>
</tr>
<tr>
<td>R^2</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Identification Asphaltenes + Shell

- 0% Asphaltenes
- 4.18% Asphaltenes
- 7.77% Asphaltenes
- 12.32% Asphaltenes
- 17.36% Asphaltenes
- 26.71% Asphaltenes

Graph showing stiffness gain with increasing asphaltenes content.

Abrupt stiffness gain
Identification Asphaltenes + Shell

\[ y = 0.4037 \exp(0.2559x) \]
Model Validation

![Graph showing model validation results.](image)
Mechanical Behavior of Lab-aged Binders

<table>
<thead>
<tr>
<th>Asphaltene content</th>
<th>Test temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-5 °C</td>
</tr>
<tr>
<td>0 %</td>
<td>○/○</td>
</tr>
<tr>
<td>4.18 %</td>
<td>○/○</td>
</tr>
<tr>
<td>7.77 %</td>
<td>●/○</td>
</tr>
<tr>
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<td></td>
</tr>
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<td>26.71 %</td>
<td></td>
</tr>
</tbody>
</table>

tumen, ○ ... tests on aged bitumen
Conclusion

- **Power-law model** describes viscoelastic behavior of bitumen constituents well.
- **Identification** of mechanical behavior of maltenes, asphaltenes and interaction of micelle shells **successfully**.
- Abrupt gain in stiffness with addition of asphaltenes to maltene phase → **Micelle-Matrix Model including interacting shells**.
- **Correlation** between interaction of micelle shells (needles) and asphaltene content.

- No difference between un-aged and lab-aged binder:
  - in maltene/asphaltene behavior
  - in interaction of micelle shells
- **Change in asphaltene content sufficient** to explain change in mechanical behavior due to **ageing**.
Outlook

- Verification for at least two other unmodified binders

- Direct identification of mechanical behavior of aromatics and resins

- Expansion for SBS-modified binders

More info:

- Eberhardsteiner L. et al. (2014): Influence of asphaltene content on bitumen behavior – Experimental investigation and micromechanical modeling

- Eberhardsteiner L. et al. (2014): Towards a microstructural model of bitumen ageing behavior
Thank you very much for your attention!