Multi-Stress Creep and Recovery Test Method New Specification

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Problem-High Temperature Binder Criteria

- Does $G^*/\sin\delta$ reflect rutting performance of modified binders.
  - General anecdotal data says no.
High Temperature Binder Criteria

- Current spec, $G^*$ and $\delta$ are measured in the linear range.
- For viscous materials flow is linear even under high stress and high strain.
- For polymer networks the binder response is not linear for high stress and high strain.
Movement and rotation of aggregate creates very high strain in the binder.
Multi Step Creep and Recovery

Test using the DSR applying a 1 sec creep stress followed by 9 sec recovery.
Determination of $J_{nr}$

\[ J_{nr} = \frac{\gamma_u}{\tau} \]

- $\tau$ = stress applied during creep
- $\gamma_u$ = Avg. un-recovered strain
- $J_{nr}$ = non-recoverable compliance
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ CRM</td>
<td>PG 70-22 Control</td>
<td>Air Blown</td>
<td>SBS</td>
<td>TX TBCR</td>
<td>TP</td>
<td>PG 70-22</td>
<td>TP + Fibers</td>
<td>PG 70-2264-40 Blown</td>
<td>SBS</td>
<td>SBS</td>
<td>TP</td>
<td></td>
</tr>
</tbody>
</table>

**7 Asphalt Binders**
Relationship between $G*/\sin \delta$ and ALF rutting

\[ y = -7.4519x + 10.956 \]
\[ R^2 = 0.1261 \]
Relationship between Jnr and ALF rutting

25.6kPa

\[ y = 0.5011x - 0.1194 \]

\[ R^2 = 0.7577 \]
High Temperature Binder Criteria

- Linear binder tests will not correlate with high temperature mix failure test unless the binder is a viscous fluid at those temps.
- To accurately address mix failure non-linear binder properties have to be evaluated.
- Creep & Recovery testing of the binder at different stress levels is needed to describe binder properties in the non-linear range.
Hamburg Rut testing  MINN Road mixes

Jnr 12.8kPa

\[ y = 0.0398x - 0.0289 \]

\[ R^2 = 0.9646 \]
Hamburg Rutting 8 binders one mix, Jnr 12.8 kPa

$y = 0.1663x - 0.3701$

$R^2 = 0.8454$
Y = 0.031x

R^2 = 0.7453

<table>
<thead>
<tr>
<th>binder</th>
<th>mod</th>
<th>true grad</th>
<th>6 yr rut mm</th>
<th>Jnr 3.2 kPa</th>
<th>70°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrapave SBR</td>
<td>70-27</td>
<td>4.5</td>
<td>0.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Styref SB</td>
<td>77-29</td>
<td>2</td>
<td>0.044</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTR 80</td>
<td>75-29</td>
<td>1.5</td>
<td>0.121</td>
<td></td>
<td></td>
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<tr>
<td>Sealoflex SBS</td>
<td>82-27</td>
<td>3</td>
<td>0.019</td>
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<tr>
<td>Multigrade</td>
<td>72-24</td>
<td>5</td>
<td>0.213</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryo Rubber</td>
<td>75-28</td>
<td>7</td>
<td>0.162</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>70-24</td>
<td>11</td>
<td>0.35</td>
<td></td>
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</tbody>
</table>
High Temperature Binder Criteria

- Non-recoverable compliance of the binder describes the stress dependency of the binder.
- Creep and recovery testing done at multiple stress levels on one sample can be run to describe the stress dependency of the binder.
- Creep and recovery non-recoverable compliance can be correlated to mix testing done at different stress conditions and related to performance.
Affect of Jnr on Rutting

- Reducing Jnr by half typically reduced rutting by half.
- This affect is seen on ALF sections and Hamburg Rut Testing
- But most importantly this is seen on the Mississippi I 55 sections.
Determination of a Specification criteria.

- The existing binder specification works very well for neat binders.
- The grading for neat binders should not change.
- Establish new Jnr criteria based on response of neat binders at their continuous grade temp.
- Evaluate the binders near the end of their linear range. Most neat binders remain linear up to 3.2 kPa stress.
PG58-28 at multiple temperatures

Stress Pa

Jnr

58C
64C
70C
# Evaluation of Straight run binders

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Name</th>
<th>Grade</th>
<th>true grade</th>
<th>Temp</th>
<th>Jnr 3.2kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALF 6727</td>
<td>Control</td>
<td>70-22</td>
<td>72.7-74.2</td>
<td>72.7</td>
<td>0.439122</td>
</tr>
<tr>
<td>BBRS3</td>
<td>straight</td>
<td>64-22</td>
<td>66.1-27.3</td>
<td>66.1</td>
<td>0.418449</td>
</tr>
<tr>
<td>MN county rd 112</td>
<td>neat Valero</td>
<td>58-28</td>
<td>60.8-33.4</td>
<td>60.8</td>
<td>0.368445</td>
</tr>
<tr>
<td>MN county rd 112</td>
<td>neat Citgo</td>
<td>58-28</td>
<td>59.5-29.8</td>
<td>59.5</td>
<td>0.529647</td>
</tr>
<tr>
<td>MN county rd 112</td>
<td>AshlandM</td>
<td>58-28</td>
<td>60.7-31.4</td>
<td>60.7</td>
<td>0.430165</td>
</tr>
<tr>
<td>Minn Road</td>
<td>straight</td>
<td>58-28</td>
<td>61.8-30.8</td>
<td>61.8</td>
<td>0.302951</td>
</tr>
<tr>
<td>Miss I-55</td>
<td>CSL</td>
<td>67-22</td>
<td>68.3-25.1</td>
<td>68.3</td>
<td>0.266912</td>
</tr>
<tr>
<td>Shandong</td>
<td>straight</td>
<td>64-22</td>
<td>64.4-23.5</td>
<td>64.4</td>
<td>0.444057</td>
</tr>
<tr>
<td>BBRS3</td>
<td>straight</td>
<td>70-22</td>
<td>71.4-24.8</td>
<td>71.4</td>
<td>0.480855</td>
</tr>
<tr>
<td>BBRS3</td>
<td>straight</td>
<td>58-28</td>
<td>61.3-30</td>
<td>61.3</td>
<td>0.400345</td>
</tr>
<tr>
<td>MD project</td>
<td>straight</td>
<td>64-28</td>
<td>64.8-29.6</td>
<td>64.8</td>
<td>0.459335</td>
</tr>
<tr>
<td>average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.412753</td>
</tr>
</tbody>
</table>
Temp sensitivity of PG70-22 Neat

Log Jnr

0.1kPa
3.2kPa
12.8kPa

Log Temp C

\[ y = 9.9896x - 18.7 \]
\[ R^2 = 1 \]

\[ y = 9.6024x - 18.107 \]
\[ R^2 = 1 \]

\[ y = 9.3453x - 17.694 \]
\[ R^2 = 0.9999 \]
Temp sensitivity of PG70-28 Elvaloy

\[ y = 8.9053x - 17.476 \]
\[ R^2 = 0.9996 \]

\[ y = 9.7667x - 18.913 \]
\[ R^2 = 0.9999 \]

\[ y = 10.894x - 20.776 \]
\[ R^2 = 0.9995 \]
Variations in Temp sensitivity 3.2kPa

- 70-28 SBS
- 70-28 Elvaloy
- PG 58-28
- 70-28 SBS-El
- PG 70-22

Equations:
- $y = 4E^{-17}x^{8.9845}$  
  $R^2 = 0.9979$
- $y = 2E^{-22}x^{11.437}$  
  $R^2 = 1$
- $y = 6E^{-27}x^{13.808}$  
  $R^2 = 0.9999$
- $y = 1E^{-19}x^{9.7667}$  
  $R^2 = 0.9999$
- $y = 8E^{-19}x^{9.6024}$  
  $R^2 = 1$

Graph showing temperature vs. sensitivity with various polymers and their respective regression equations.
Grade bumping recommendation

- All testing should be done at the environmental grade temp. One shift factor does not work for polymer binders.
- The standard grade should be based on the Jnr value of existing neat binders 0.4.
- For high traffic, the Jnr value should be reduced by half at the grade temp to 0.2.
- For standing traffic, the Jnr value should be reduced by half again to 0.1.
New high Temp Spec

- PG 64 (Standard, Heavy, Very heavy) based on traffic.
  - PG 64S-XX $J_{nr} \leq 0.4$
  - PG 64H-XX $J_{nr} \leq 0.2$
  - PG 64V-XX $J_{nr} \leq 0.1$
## New MSCR Binder Spec

<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>RTFOT</th>
<th>PAV</th>
</tr>
</thead>
<tbody>
<tr>
<td><em><em>DSR G</em>/sinδ</em>*</td>
<td><strong>Min 1.0</strong></td>
<td><strong>64</strong></td>
<td><strong>28</strong></td>
</tr>
<tr>
<td><strong>H &amp; V grade</strong></td>
<td><strong>Min 5000</strong></td>
<td></td>
<td><strong>Min 6000</strong></td>
</tr>
<tr>
<td><strong>64 Standard</strong></td>
<td><strong>MSCR &lt;0.4</strong></td>
<td><strong>64</strong></td>
<td><strong>H &amp; V grade</strong></td>
</tr>
<tr>
<td><strong>MSCR &lt;0.2</strong></td>
<td><strong>64</strong></td>
<td><strong>64</strong></td>
<td><strong>H &amp; V grade</strong></td>
</tr>
<tr>
<td><strong>64 Very heavy</strong></td>
<td><strong>MSCR &lt;0.1</strong></td>
<td><strong>64</strong></td>
<td><strong>H &amp; V grade</strong></td>
</tr>
</tbody>
</table>

Low temp BBR and DTT remain unchanged.
Effect of blending and formulation on one base one polymer content different blending process.
Polymer network effects response

- LC P4 70C
- LOP 4P 70C
- LC 4 70C
- LOP 4 70C
**MSGR does a far better job of distinguishing between binders**

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Continuous Grade</th>
<th>Polymer</th>
<th>Acid</th>
<th>Temp C</th>
<th>$J_{nr}$ 3.2kPa</th>
<th>ER</th>
<th>% Recovery 3.2kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC</td>
<td>66.7-24.1</td>
<td>0</td>
<td>64C</td>
<td>0.312</td>
<td>5</td>
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<td>LC 4</td>
<td>75.7-22.3</td>
<td>4% SBS</td>
<td>0</td>
<td>70C</td>
<td>0.185</td>
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<td>19.2</td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td>76C</td>
<td>0.455</td>
<td>73.8</td>
<td>5.96</td>
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<tr>
<td>LC P4</td>
<td>81.2-22.2</td>
<td>4% SBS</td>
<td>0.50%</td>
<td>70C</td>
<td>0.106</td>
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<td>28.4</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>76C</td>
<td>0.24</td>
<td>93.8</td>
<td>20.55</td>
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<tr>
<td>LOP 4</td>
<td>76.6-25.2</td>
<td>4% SBS from Concentrate</td>
<td>0</td>
<td>70C</td>
<td>0.118</td>
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<td>40.3</td>
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<tr>
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<td>76C</td>
<td>0.235</td>
<td>86</td>
<td>37.02</td>
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<td>LOP 4P</td>
<td>81.6-24.5</td>
<td>4% SBS from Concentrate</td>
<td>0.50%</td>
<td>70C</td>
<td>0.067</td>
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<td>52.05</td>
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<tr>
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<td></td>
<td>76C</td>
<td>0.138</td>
<td>83</td>
<td>42.52</td>
</tr>
</tbody>
</table>
Effect of X-linking on ER

![Graph showing the effect of X-linking on ER temperature]
MinnRoad Study

![Graph showing MSCR % Recovery vs. MSCR Jnr for two curves labeled 58-40 and 58-34.](image)
New MSCR Binder Grade

- Note For H and V grades MSCR % recovery can be added to validate polymer modification
  - H grade 25% Recovery
  - V grade 35% Recovery
64-34 has 95% recovery
76-22 has 75% recovery
Both have the same Jrn 0.006
The new specification should be based on the non-recoverable compliance on the binder.

All testing should be done at the pavement environmental grade temp to reflect response at actual operating temperatures.

The test should be run at two stress levels 0.1 and 3.2 kPa ten cycles at each level. A comparison would be made to check how stress sensitive the binder is.

Grade bumping should be done by halving the Jnr value.
Conclusions

- MSCR can identify how the polymer, binder and processing will affect performance in one simple test.

- The use of PPA and x-linker seem to work together to improve the performance properties of the binder as opposed to being used individually.
Continued Work

- Does % recovery in the MSCR relate to durability and fatigue?
Thank You