Using the Multiple-Stress Creep-Recovery (MSCR) Test

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Acknowledgments

- DTFH61-08-H-00030
  - Cooperative Agreement between the FHWA and the Asphalt Institute
- John A. D’Angelo
- Asphalt Binder ETG
- Member Companies of the Asphalt Institute
  - Technical Advisory Committee
Discussion

• Background
• Basics of the MSCR test
• How do MSCR results ($J_{nr}$) relate to rutting?
• How can MSCR Recovery be used and what does it indicate?
• How does the specification work?
• Educational and implementation activities
One cycle is complete...

DSR Operation: AASHTO T315
Shortcomings of G*/sin δ

• G*/sin δ as a High Temperature Parameter
  – Properties determined in Linear Viscoelastic (LVE) region
    • No damage behavior
      – Rutting is a non-linear failure
      – Polymer-modified systems engaged in non-linear region
  • Characterizes stiffness
    – Related to rutting
Effect of Phase Angle

Phase Angle, degrees

\[ \sin \delta \]

\[ 60 \quad 65 \quad 70 \quad 75 \quad 80 \quad 85 \quad 90 \]
High Temperature Testing

• Repeated Shear Creep
  – Analogous to mixture test (RSCH)
  – Performed in DSR
    • Controlled shear stress (i.e., 25 Pa or 300 Pa)
    • 100 cycles
    • 1-second load, 9-second rest per cycle
    • High test temperature (HT-?)
  – Response: permanent shear strain ($\gamma_p$) or strain slope
Repeated Shear Creep

NCHRP 9-10: PG 82 Binders
Repeated Shear Creep (70°C, 300Pa)

Perm. Shear Strain, %

Time, seconds

0 2 4 6 8 10 12 14

0 2 4 6 8 10 12 14
Repeated Shear Creep

NCHRP 9-10: PG 82 Binders
Repeated Shear Creep (70C, 300Pa)

<table>
<thead>
<tr>
<th>Time, seconds</th>
<th>Perm. Shear Strain, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
</tr>
<tr>
<td>400</td>
<td>4</td>
</tr>
<tr>
<td>600</td>
<td>6</td>
</tr>
<tr>
<td>800</td>
<td>8</td>
</tr>
<tr>
<td>1000</td>
<td>10</td>
</tr>
</tbody>
</table>

- Ox
- PE-s
- SBS-r
Multiple-Stress Creep-Recovery (MSCR) Test: AASHTO TP70

- Performed on RTFO-aged Binder
- Test Temperature
  - Environmental Temperature
  - Not Grade-Bumped
- 10 cycles per stress level
  - 1-second loading at specified shear stress
    - 0.1 kPa
    - 3.2 kPa
  - 9-second rest period
MSCR Test

• Calculate Non-recoverable Creep Compliance ($J_{nr}$)
  – Non-recoverable shear strain divided by applied shear stress
    • “J” = “compliance”
    • “nr” = “non-recoverable”

• Calculate Recovery for each Cycle, Stress
  – Difference between strain at end of recovery period and peak strain after creep loading
MSCR

- Recoverable shear strain
- Non-recoverable (permanent) shear strain
- Instantaneous shear strain

Permeability shear strain, %

Time, seconds

0 2 4 6 8 10

0 2 4 6 8 10 12 14
MSCR – Non-Recoverable Compliance ($J_{nr}$)

$$J_{nr} = \frac{\text{Unrecovered Shear Strain}}{\text{Applied Shear Stress}}$$

Cycle 1 Unrecovered (permanent) strain

Cycle 2 Unrecovered (permanent) strain

Cycle 3 Unrecovered (permanent) strain
MSCR – Non-Recoverable Compliance ($J_{nr}$)

$J_{nr} = \frac{\text{Unrecovered Shear Strain}}{\text{Applied Shear Stress}}$

$J_{nr} = \frac{0.197}{0.1 \text{ kPa}} = 1.97 \text{ kPa}^{-1}$

Cycle 1 Unrecovered (permanent) strain

0.197
Relationship between Jnr and ALF Rutting 25.6kPa

Jnr = (4.74*Rut Depth) - 1.17
R² = 0.82
Mississippi I55: 6yr rutting

$J_{nr} \ 3.2 \ kPa$

$y = 0.2907x + 0.1297$

$R^2 = 0.7499$

<table>
<thead>
<tr>
<th>binder</th>
<th>mod</th>
<th>true grade</th>
<th>6 yr rut mm</th>
<th>Jnr 3.2 kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrapave</td>
<td>SBR</td>
<td>70-27</td>
<td>4.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Styrelf</td>
<td>SB</td>
<td>77-29</td>
<td>2</td>
<td>0.44</td>
</tr>
<tr>
<td>GTR 80</td>
<td>SBS</td>
<td>75-29</td>
<td>1.5</td>
<td>1.21</td>
</tr>
<tr>
<td>Sealoflex</td>
<td>SBS</td>
<td>82-27</td>
<td>3</td>
<td>0.19</td>
</tr>
<tr>
<td>Multigrade</td>
<td>SBS</td>
<td>72-24</td>
<td>5</td>
<td>2.13</td>
</tr>
<tr>
<td>Cryo Rubber</td>
<td>SBS</td>
<td>75-28</td>
<td>7</td>
<td>1.62</td>
</tr>
<tr>
<td>Control</td>
<td>SBS</td>
<td>70-24</td>
<td>11</td>
<td>3.5</td>
</tr>
</tbody>
</table>
MSCR: What is % Recovery?

- MSCR $J_{nr}$ addresses the high temperature rutting for both neat and modified binders – but many highway agencies require polymers for cracking and durability.

- The MSCR % Recovery measurement can identify and quantify how the polymer is working in the binder.
MSCR Recovery

3.2 kPa Shear Stress

Recovery = 100% * \( \frac{\text{Peak Strain} - \text{Unrecovered Strain}}{\text{Peak Strain}} \)

Recovery = 100% * \( \frac{0.300 - 0.197}{0.300} \) = 34.3%

Cycle 1 Unrecovered (permanent) strain
The curve stops at $J_{nr} = 2 \text{kPa}^{-1}$. $J_{nr}$ values greater than $2 \text{kPa}^{-1}$ are not required to have any minimum value of %Recovery.

Significant Delayed Elastic Response
### Minimum % Recovery for Measured $J_{nr}$ values

<table>
<thead>
<tr>
<th>$J_{nr}$ @ 3.2 kPa</th>
<th>Minimum % Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 - 1.01</td>
<td>30%</td>
</tr>
<tr>
<td>1.0 - 0.51</td>
<td>35%</td>
</tr>
<tr>
<td>0.50 - 0.251</td>
<td>45%</td>
</tr>
<tr>
<td>0.25 - 0.125</td>
<td>50%</td>
</tr>
</tbody>
</table>
Validate Polymer Modification

PG 76-22 Binders: MSCR3200

\[ y = 29.82x^{-0.39} \]
\[ R^2 = 0.54 \]

Recovery = 29.37*J_{nr}^{-0.26}
Evaluation of the MSCR Test for Canadian Asphalt Binders

The graph illustrates the relationship between Recovery (in %) and Jnr (in kPa) for different UTI values. The data points are color-coded as follows:
- UTI=86: Diamond (●)
- UTI=92: Circle (○)
- UTI=98: Triangle (△)
- UTI=104: Cross (×)

The graph shows that as the Jnr value increases, the Recovery decreases for each UTI level. The Recovery values are labeled on the graph for clarity:
- 88% at Jnr=0.5
- 84% at Jnr=1.0
- 71% at Jnr=1.5
- 0% at Jnr=3.0
- 10% at Jnr=2.0
- 59% at Jnr=2.5
- 50% at Jnr=3.0

The graph is labeled as follows:
- Y-axis: Recovery-3.2kPa @ 58°C, %
- X-axis: Jnr-3.2kPa @ 58°C, kPa⁻¹

The graph visually represents the performance of different UTI binders under varying Jnr values.
### AASHTO MP19

<table>
<thead>
<tr>
<th></th>
<th>Original Binder</th>
<th>RTFO-Aaged Binder</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PG 64</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>-10</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>-16</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>-22</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>-28</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>-34</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>-40</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DSR (T315)</strong></td>
<td><em><em>G</em>/sin δ ≥ 1.00 kPa</em>*</td>
<td><strong>64</strong></td>
</tr>
<tr>
<td><strong>MSCR (TP70)</strong></td>
<td><strong>All Grades: Jnr,Diff ≤ 75%</strong></td>
<td><strong>64</strong></td>
</tr>
<tr>
<td></td>
<td><strong>“S” Grade: Jnr-3.2 ≤ 4.0 kPa⁻¹</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>“H” Grade: Jnr-3.2 ≤ 2.0 kPa⁻¹</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>“V” Grade: Jnr-3.2 ≤ 1.0 kPa⁻¹</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>“E” Grade: Jnr-3.2 ≤ 0.5 kPa⁻¹</strong></td>
<td></td>
</tr>
</tbody>
</table>
# AASHTO MP19

<table>
<thead>
<tr>
<th></th>
<th>PG 64</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-10</td>
</tr>
</tbody>
</table>

**PAV-Aged Binder @100°C**

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Grade</th>
<th>Grade</th>
<th>Grade</th>
<th>Grade</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSR (T315) – temp @ 10 rad/s</td>
<td>31</td>
<td>28</td>
<td>25</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>“S” Grade: G*sin δ ≥ 5000 kPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“H” Grade: G*sin δ ≥ 6000 kPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“V” Grade: G*sin δ ≥ 6000 kPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“E” Grade: G*sin δ ≥ 6000 kPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBR (T313) – temp @ 60 s</td>
<td>0</td>
<td>-6</td>
<td>-12</td>
<td>-18</td>
<td>-24</td>
</tr>
<tr>
<td>All Grades:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stiffness ≤ 300 MPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m-value ≥ 0.300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Grades

- Based on Climatic Temperature
  - High and Low Pavement Temperature
- Traffic Designation
  - “S” – Standard
  - “H” – Heavy
  - “V” – Very Heavy
  - “E” – Extreme
AASHTO MP19

- Grades
  - Based on Climatic Temperature
    - High and Low Pavement Temperature
  - Traffic Designation
    - “S” – Standard < 10 Million ESAL
    - “H” – Heavy 10-30 Million ESAL
    - “V” – Very Heavy > 30 Million ESAL
    - “E” – Extreme > 30 Million ESAL and standing traffic
AASHTO MP19

• PG 64-22V asphalt binder
  – What do I need to test?
  – What are the temperatures and criteria?
PG 64-22V Asphalt Binder

- Original (Unaged) Binder
  - COC Flash Point
    - Must be ≥ 230°C
  - Rotational Viscosity @ 135°C
    - Must be ≤ 3 Pa-s
  - DSR (AASHTO T315)
    - $G^*/\sin \delta$ must be ≥ 1.00 kPa @ 64°C
PG 64-22V Asphalt Binder

- RTFO Aged Binder
  - RTFO Mass Change
    - Must be $\leq 1.00\%$
  - MSCR (AASHTO TP70)
    - $J_{nr} @ 3.2 \text{kPa} \text{ Shear Stress} \leq 1.0 \text{kPa}^{-1} @ 64°C$
    - Stress Sensitivity must be $\leq 75\%$
PG 64-22V Asphalt Binder

• PAV Aged Binder
  – DSR (AASHTO T315)
    • $G^*\sin \delta$ must be $\leq 6000$ kPa @ 25°C
  – BBR (AASHTO T313)
    • $S(60)$ must be $\leq 300$ MPa @ -12°C
    • $m(60)$ must be $\geq 0.300$ @ -12°C
Implementation

• Telephone survey in 2010 and since indicate that there are barriers to state MSCR implementation
  – Inadequate DSR equipment/software
  – Lack of resources to perform transitional tests
  – Lack of guidance from suppliers and other states
  – Uncertainty about effect on binder supply and modification
Implementation: SEAUPG

- Task Force agreed to conduct survey of 14 SEAUPG states
  - Determine current capabilities to run MSCR
  - Determine need for training
  - Find out what barriers exist to testing and/or implementation
Survey Results - Barriers

9 of 14 states said biggest barrier was concerns over correlation between existing PG Plus and new MSCR criteria.

Comment:

- Satisfied with the PG 76-22 polymer modified binder performance. There is a perception that moving to MSCR test may result in lower polymer loading and reduction in binder performance.
Survey Results - Training

• 11 of 14 states said they could use some type of training
  – 8 requested classroom training
  – 9 requested laboratory training
  – Comments:
    • More important than training is keeping abreast of progress around the country
    • Internet based training would be preferred since travel is restricted
Implementation Activities

• User-Producer Groups
  – Task Force participation
  – Coordination of round-robin testing
• Conducting testing for individual user agencies
Binder AR (PG 64-22): Jnr-3.2 at 64°C
Repeatability and Reproducibility Estimates (before removal of outliers)

Jnr (3.2 kPa) @ 64°C

<table>
<thead>
<tr>
<th>ID</th>
<th>Binder</th>
<th>X-bar</th>
<th>$s_{X-bar}$</th>
<th>$s_r$</th>
<th>$s_R$</th>
<th>r</th>
<th>R</th>
<th>Repeatability</th>
<th>Reproducibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO</td>
<td>PG 64-22</td>
<td>4.73445</td>
<td>0.30437</td>
<td>0.28046</td>
<td>0.38090</td>
<td>0.78530</td>
<td>1.06651</td>
<td>5.9%</td>
<td>16.6%</td>
</tr>
<tr>
<td>BO</td>
<td>PG 76-22</td>
<td>0.31478</td>
<td>0.03366</td>
<td>0.01686</td>
<td>0.03636</td>
<td>0.04722</td>
<td>0.10182</td>
<td>5.4%</td>
<td>15.0%</td>
</tr>
<tr>
<td>CO</td>
<td>PG 70-22</td>
<td>1.09091</td>
<td>0.09018</td>
<td>0.05083</td>
<td>0.09928</td>
<td>0.14234</td>
<td>0.27797</td>
<td>4.7%</td>
<td>13.0%</td>
</tr>
<tr>
<td>AR</td>
<td>PG 64-22</td>
<td>2.16532</td>
<td>0.15582</td>
<td>0.09492</td>
<td>0.17403</td>
<td>0.26578</td>
<td>0.48729</td>
<td>4.4%</td>
<td>12.3%</td>
</tr>
<tr>
<td>BR</td>
<td>PG 76-22</td>
<td>0.13844</td>
<td>0.01514</td>
<td>0.00591</td>
<td>0.01589</td>
<td>0.01654</td>
<td>0.04448</td>
<td>4.3%</td>
<td>11.9%</td>
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<tr>
<td>CR</td>
<td>PG 70-22</td>
<td>0.42219</td>
<td>0.03845</td>
<td>0.01743</td>
<td>0.04100</td>
<td>0.04880</td>
<td>0.11479</td>
<td>4.1%</td>
<td>11.6%</td>
</tr>
</tbody>
</table>
Binder BR (PG 76-22): Rec-3.2 at 64°C
**Repeatability and Reproducibility Estimates (before removal of outliers)**

**Recovery (3.2 kPa) @ 64°C**

<table>
<thead>
<tr>
<th>ID</th>
<th>Binder</th>
<th>X-bar</th>
<th>s_{X-bar}</th>
<th>s_r</th>
<th>s_R</th>
<th>r</th>
<th>R</th>
<th>1s%</th>
<th>d2s%</th>
<th>1s%</th>
<th>d2s%</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO</td>
<td>PG 64-22</td>
<td>-0.70138</td>
<td>1.16245</td>
<td>0.27286</td>
<td>1.18361</td>
<td>0.76402</td>
<td>3.31411</td>
<td>-38.9%</td>
<td>-108.9%</td>
<td>-168.8%</td>
<td>-472.5%</td>
</tr>
<tr>
<td>BO</td>
<td>PG 76-22</td>
<td>69.86953</td>
<td>2.04476</td>
<td>0.50367</td>
<td>2.08571</td>
<td>1.41028</td>
<td>5.83998</td>
<td>0.7%</td>
<td>2.0%</td>
<td>3.0%</td>
<td>8.4%</td>
</tr>
<tr>
<td>CO</td>
<td>PG 70-22</td>
<td>35.33316</td>
<td>1.45239</td>
<td>0.89656</td>
<td>1.62644</td>
<td>2.51037</td>
<td>4.55404</td>
<td>2.5%</td>
<td>7.1%</td>
<td>4.6%</td>
<td>12.9%</td>
</tr>
<tr>
<td>AR</td>
<td>PG 64-22</td>
<td>0.85334</td>
<td>0.98338</td>
<td>0.13352</td>
<td>0.98941</td>
<td>0.37387</td>
<td>2.77035</td>
<td>15.6%</td>
<td>43.8%</td>
<td>115.9%</td>
<td>324.6%</td>
</tr>
<tr>
<td>BR</td>
<td>PG 76-22</td>
<td>75.30791</td>
<td>1.86344</td>
<td>0.46241</td>
<td>1.90130</td>
<td>1.29475</td>
<td>5.32365</td>
<td>0.6%</td>
<td>1.7%</td>
<td>2.5%</td>
<td>7.1%</td>
</tr>
<tr>
<td>CR</td>
<td>PG 70-22</td>
<td>47.66866</td>
<td>1.67845</td>
<td>0.70757</td>
<td>1.77510</td>
<td>1.98119</td>
<td>4.97028</td>
<td>1.5%</td>
<td>4.2%</td>
<td>3.7%</td>
<td>10.4%</td>
</tr>
</tbody>
</table>
Implementation Assistance

• Educational
  – FHWA Technical Brief (FHWA-HIF-11-038)
  – Asphalt Institute
    • Guidance Document, “Using the MSCR Test with the AASHTO M320 Specification”
    • www.asphaltinstitute.org
Educational Activities

• “Understanding the MSCR Test and its Use in the PG Asphalt Binder Specification”
  – Two-hour informational webinar on the MSCR test and how it is used in the specification
Implementation

Recognize that the refineries that serve your state may also serve bordering states.

This may be a good reason to work with other states to implement regionally.

Note that every Performance Grade may not equate to a distinct MSCR grade - for example, the current polymer loading in both a PG 70-22 and PG 76-22 may be high enough that both grade to a “PG 64-22 E”
Some agencies may be reluctant to implement MSCR fully, since the names by which they refer to binder types will necessarily change.

“PG 64-22 H” instead of “PG 70-22,” for a possible example

AI’s “Guidance on the Use of the MSCR Test with the AASHTO M320 Specification.”
Why MSCR?

• Why Use the MSCR Test and Spec?
  – Non-recoverable creep compliance, $J_{nr}$, is better correlated with pavement rutting than $G^*/\sin \delta$
  • The high temperature parameter is truer to the intent of the PG specification, that it be blind to method of modification
Why MSCR?

- Why Use the MSCR Test and Spec?
  - MSCR Recovery can be used to identify elastomeric modification, thereby eliminating the need for many PG-Plus tests like Elastic Recovery
    - Much quicker test
    - Not directly tied to performance
Thanks!

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