Advances in performance evaluation of asphalt binders

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Outline

> Performance grading (PG) background
> PG plus in USA
> New Concept: Damage Resistance Characterization

- Rutting Resistance
  - Multiple Stress Creep and Recovery
- Fatigue Resistance
  - Binder Yield Energy Test
  - Linear Amplitude Sweep
- Bond strength - cohesion and adhesion
- Fracture Testing
Performance Grading and Modified (Engineered) Bitumen

- Cold Temp. Cracking
- Fatigue Cracking
- Rutting

Temperature

Stiffness, $G^*$

Typical Asphalt

Ideal (modified) Asphalt

PMB

PMB w/ WMA

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Superpave Bitumen Tests

Related to Performance!
- Climate -- PG HT-LT
- Traffic Speed – DSR
- Traffic Volume – PG shift

- Traffic loading – NA
- Pavement Structure – NA
- Assumption: Bitumen in Linear VE range

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The focus on Linear Visco-elasticity: $G^*$, $\delta$

Low SBS %
- No polymer network
- Viscous above 60°C
- Reasonably workable

High SBS %
- Polymer network
- Elastic during compaction
- Workability problem

Courtesy of Nynas
Performance Grading –Redefined (2001)

> Linear VE is not sufficient (NCHRP 9-10)
> Bitumen damage resistance is very important
> Modified bitumen are best in damage resistance
Evolution of PG Bitumen Specification

- Performance Indicators: S, m, Tg, Fracture Energy, Nf, Adhesion

- Temperature: Tmin, Tavg, Tmax, 135 C, 160 C

- Viscosity: η= 3.0 pa-s, η= 6.0 pa-s
Can only give total energy:

\[ Total \ W = \pi \cdot \tau_i^2 \cdot \sin \delta / G^* \]

\[ = W_{\text{elastic}} + W_{\text{delayed elastic}} + W_{\text{viscous}} \]
The new tests: Creep and Recovery (MSCR)
Binders with same $G^*/\sin\delta$ but different recovery

Strain vs. Time (s)

- PG82-Oxidized (1 cycle)
- PG82-Oxidized (100 cycle)
- PG82-PEs (1 cycle)
- PG82-PEs (100 cycle)
- PG82-SBSr (1 cycle)
- PG82-SBr (100 cycle)
Binder Rutting Parameter

> The creep compliance, \( J(t) \), in terms of its elastic component \( (J_e) \), the delayed-elastic \( (J_{de}) \), and the viscous component \( (J_{nr}) \):

\[
J(t) = J_e + J_{de} + J_{nr}
\]

> Calculate the viscous compliance \( (J_{nr}) \).
Binder Fatigue Data

**Time Sweep - 5% Applied Strain**

- **ALF Control**
- **ALF CR-TB**
- **ALF Terpolymer**
- **ALF SBS-LG**
- **TPF Control A**
- **TPF PG64-34 A**
- **TPF PG76-22 A**
- **TPF PPA A**
- **TPF Latex A**

Dynamic Shear Modulus [Pa]

Time (Cycles/Frequency) [sec]
AASHTO Standard for Binder Yield Energy (BYE)

\[ \text{Yield Energy} = A_{i-1} + \sum_{i=1}^{N} \left( \frac{\tau_i + \tau_{i-1}}{2} \right) (\gamma_i - \gamma_{i-1}) \]

Binder Yield Energy Test

Shear Stress [Pa]

Shear Strain [%]

1. AASHTO
   1.1.

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Yield Energy Evaluation of different binders

![Graph showing yield energy evaluation of different binders.]

Binder:
- PG52-28
- PG64-22
- PG64-22 PMA
- PG70-22
- PG70-28
- PG70-28 (LSSB)
- PG70-28 (Teta)
- PG76-28 (Blown)
- PG76-28 (CR)

Yield Energy (Pa):
- 0
- 500,000
- 1,000,000
- 1,500,000
- 2,000,000
- 2,500,000
- 3,000,000
Linear Amplitude Sweep (LAS)
Need 2 tests for VECD analysis

Stress Relaxation Test Results

Amplitude Sweep Loading Scheme

Relaxation /freq Sweep

Amplitude Sweep

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Standard Method of Test for

Estimating Fatigue Resistance of Asphalt Binders
Using the Linear Amplitude Sweep

AASHTO Designation: T XXX-09

1. SCOPE

1.1. This test method covers the indication of asphalt binders’ resistance to fatigue damage by means of cyclic loading employing a linearly ramping amplitude sweep test. The amplitude sweep is conducted using the Dynamic Shear Rheometer at the continuous intermediate temperature performance grade (PG Grade) of the asphalt binder. The test method can be used with material aged using AASHTO T 240 (RTFOT) and/or AASHTO R 28 (PAV) to simulate the estimated aging for in-service asphalt pavements.
VECD Analysis of LAS – Damage Curve

Damage equation following Yong-Rak Kim & D. Little work (2006):

\[
D(t) \equiv \sum_{i=1}^{N} \left[ \pi \cdot I_D \cdot \gamma_0^2 \left( |G^*| \sin \delta_{i-1} - |G^*| \sin \delta_i \right) \right]^{\frac{\alpha}{1+\alpha}} \left( t_i - t_{i-1} \right)^{\frac{1}{1+\alpha}}
\]
VECD Fatigue Prediction Model

With the VECD curve fit to a simple numeric equation:

\[ |G \ast| \sin \delta = C_0 - C_1 (D)^{C_2} \]

Fatigue life can be predicted using:

\[
N_f = \frac{f(D_f)^k}{k \left( \pi \frac{I_D}{|G^\ast|} C_1 C_2 \right)^\alpha |G^\ast|^{-\alpha (\gamma_{max})^{-2\alpha}}}
\]

\[
k = 1 + (1 - C_2) \alpha
\]
Simulated Fatigue

Fatigue Law: $N_f = A(\gamma_0)^B$

- $A$
- $B$

**Graph:**
- X-axis: Applied Shear Strain [%] [Pavement Structure Indicator]
- Y-axis: $N_f / ESAL's$ [Traffic Volume Indicator]

**Equation:**
$N_f = A(\gamma_0)^B$
Binder Qualification Example
Effects of Traffic and Pavement Structure

> For unmodified PG70-22 binder, \( N_f = A \times (\gamma_0)^B \)

- A: \( 3.89 \times 10^6 \)
- B: -5.277

<table>
<thead>
<tr>
<th>Traffic [ESAL’s]</th>
<th>Pavement Structure:</th>
<th>Nf/ESAL’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S) 1,000,000</td>
<td>Weak (400(\mu\varepsilon))</td>
<td>0.10</td>
</tr>
<tr>
<td>(H) 3,000,000</td>
<td>Strong (200(\mu\varepsilon))</td>
<td>3.86</td>
</tr>
<tr>
<td>(VH) 10,000,000</td>
<td>PG70-22 H</td>
<td>0.39</td>
</tr>
</tbody>
</table>
Modified BBR to Test for Fracture
FEM simulations of two different geometries

New BBR Geometry:

=> Continuity of stresses

=> Plane sections remain plane after bending
SENNB Example Results

![Graph showing Load vs. Displacement for different samples and materials.](image)

**Binder**
- Sample 1 (green)
- Sample 2 (magenta)
- Sample 3 (orange)
- Sample 4 (blue)

**Mastic**
- Limestone
- Granite

**Legend**
- PPS = 252 pulses/step = 2

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Bitumen Adhesion

Source: Gerrie Van Zyl – RSA

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Bitumen Bond Strength Testing Apparatus

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Example of Test Results

Cohesive Failure

Adhesive Failure
Results and Analysis:

Effect of Conditioning Time in Tap Water

Granite

Limestone
BBS Relationship to Performance

Tensile Strength > 125 psi yield <10% chip loss. Curing time ~ 6 hours.
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Questions

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