Understanding the Performance of Modified Asphalts in Mixtures
NCHRP 90-07, TPF 5(019)

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www.TFHRC.gov
United States National Highway System

- A $1 trillion investment/priceless national asset
- The way nearly all products move
- Inter-modal link to sea → air → rail
- Permits our high quality of life & economic growth
United States National Highway System

- NHS is over 160,000 miles of pavement
  - most over 35 years old
  - $59 billion shortfall to maintain condition
- Safety tied to pavement condition
- Customer/User expectations
  - Safer pavements
  - Smoother ride
  - Quieter pavements
  - Reduced delay & congestion
Annual HMA Investment

- $15 Billion
- 500 M tons of HMA
- 30 M tons of binder
Traffic congestion on the rise! Compared with 1970:

- Americans: Up 32%
- Drivers: Up 63%
- Vehicles: Up 90%
- Miles Traveled: Up 132%
- Ton Miles: Up 6%
- Highways: Up 400%
Following current congestion trends:

- More than 8 hours per day!
- About 80 hours per year!
- More than $250 per year per American!

- Hrs / Day When Roads are Congested
- Driver Time Lost in Rush Hour
- Cost of Congestion
Extra Vehicle Operating Cost per Year Due to Poor Pavement Condition

$41.5 Billion / year!

The Road Information Program (TRIP)
April 2001
But Things are Improving

- 2002 Report on Conditions and Performance of the NHS
  - 86.0% with acceptable ride quality
  - Up from 82.5% in 1993
  - A trend reversal
  - Most of the improvement on higher order highways
- What we are doing – we are doing better!
Materials
Structural
Construction
Get In
Stay In
Get Out
Stay Out
Outline

• Superpave® Binder ETG Direction
• Preliminary FHWA ALF Results
• Next Steps

• Goal - Right materials provide the best performance!
Production

Rutting

Fatigue Cracking

Thermal Cracking

Rutting
Fatigue Cracking
Thermal Cracking

Production

Rutting

Fatigue Cracking

Thermal Cracking

Time

No aging

RTFO - aging

PAV - aging
### Superpave® Binder Specification

**Rutting, Fatigue, and Low-Temp. Cracking**

<table>
<thead>
<tr>
<th>WHEN</th>
<th>WHAT</th>
<th>HOW</th>
<th>WHERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>Safety Pumpability</td>
<td>Flash Point Rot Visc</td>
<td>230 min 3 Pa-s max</td>
</tr>
<tr>
<td></td>
<td>Rutting</td>
<td>G* / sin δ</td>
<td>T(high)</td>
</tr>
<tr>
<td>Early</td>
<td>(RTFO)</td>
<td>Rutting</td>
<td>T(high)</td>
</tr>
<tr>
<td>Late</td>
<td>(+PAV)</td>
<td>Fatigue Low Temp</td>
<td>T(inter) T&lt;sub&gt;CR&lt;/sub&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G* sin δ BBR/DTT</td>
<td></td>
</tr>
</tbody>
</table>
Superpave® 2002

- Asphalt Binder Implementation Status

![Map of the United States with states color-coded for implementation status: Implemented, In Progress, Undetermined.]
Superpave® Plus

- Elastic recovery
- Forced ductility
- Toughness and tenacity
- Phase angle
- Method (mode and dose)
- Combinations

![Bar chart showing number of states for As is and Modified PG Grade Specifications]
Superpave® Performance Grading

High Pav. Temp.
50% Reliability

- PG 70
- PG 64
- PG 58
- PG 52
- PG 46
- PG 40
- PG <34

PG 58→

← PG 58
Adjusting Model for Performance

“Degree Days”

Frequency and Damage vs. Temperature

- Frequency
- Damage

Pavement Temperature, C

Frequency, Hours

0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
Superpave® Binder Specification
Short Term Aging - NCHRP
Superpave® Binder Specification

Rutting

\[ G^*/\sin \delta \]

Shear Stress, kPa

Shear Stain, mm/mm
Superpave® Binder Specification

Fatigue

\[ G^* \sin \delta \]

\[ \gamma_{\text{max}} \]

\[ \tau_{\text{max}} \]
Superpave® Binder Specification

Long Term Aging

Little Research Using Microwave Technology
Superpave® Binder Specification

Low Temperature Cracking (Thermal Fatigue)
**Superpave® II**

**PG based on Degree Days**

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<td>Safety</td>
<td>Flash Point Rot Visc ( f' (G^* \delta) )</td>
<td>230 min 3 Pa-s max T(high)</td>
</tr>
<tr>
<td></td>
<td>Pumpability</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rutting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>Rutting</td>
<td>( f' (G^* \delta) )</td>
<td>T(high)</td>
</tr>
<tr>
<td>(GRF, TX)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late</td>
<td>Fatigue</td>
<td>( f''(G^*\delta)DT ) DT ABCD</td>
<td>T(inter) T&lt;sub&gt;CR&lt;/sub&gt;</td>
</tr>
<tr>
<td>(PAV)</td>
<td>Low Temp</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Technical Working Group (TWG) Meeting December 5-6, 2002
(17 States, 29 Industry Partners/Collaborative Researchers)
## Final Test Matrix

<table>
<thead>
<tr>
<th></th>
<th>AZ</th>
<th>CRM</th>
<th>PG 70-22</th>
<th>Air Blown</th>
<th>SBS</th>
<th>TX</th>
<th>T-P</th>
<th>PG 70-22</th>
<th>SBS</th>
<th>Air Blown</th>
<th>SBS</th>
<th>T-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

The table above shows various combinations of materials and conditions tested in the final test matrix, including different types of PG and SBS materials, as well as air blown conditions and T-P fibers.
Mix Designs

**Superpave**
12.5mm NMS
Coarse Graded
Pb = 5.3%
PG 74-28
Ndes = 75

**Arizona CRM**
12.5mm NMS
Coarse Graded
Pb = 7.1%
PG 58-22 with
17% CRM
**ALF Testing Status**

*Initial Strain Measurements: 100% Complete
*Rutting Tests: Shakedown Tests Complete (5, 9)
*Rutting Tests: 5 of 12 Lanes Complete
*Fatigue Tests: Shakedown Test Complete (1)
ALF - Laboratory

Preliminary Results
Preliminary ALF Results

ALF Rutting after 40,000 Passes at 64°C, (mm)

<table>
<thead>
<tr>
<th>Asphalt Binder</th>
<th>ALF Rutting</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ CR</td>
<td>12.7</td>
</tr>
<tr>
<td>E-T</td>
<td>11.8</td>
</tr>
<tr>
<td>TBCR</td>
<td>8.8</td>
</tr>
<tr>
<td>PG 70-22</td>
<td>15.7</td>
</tr>
<tr>
<td>Air Blown</td>
<td>15.7</td>
</tr>
<tr>
<td>SBS 64-40</td>
<td>19.5</td>
</tr>
</tbody>
</table>
TBCR: $y = 0.1529x - 1.1525$, $R^2 = 0.98$
SBS 64-40: $y = 0.3037x - 1.513$, $R^2 = 0.98$
SBS 64-40: $y = 0.2927x - 1.4978$, $R^2 = 0.98$
Air Blown: $y = 0.2366x - 1.3018$, $R^2 = 0.99$
T-Polymer: $y = 0.157x - 1.0456$, $R^2 = 1.00$
Control: $y = 0.1794x - 1.0318$, $R^2 = 0.99$
AZ CR: $y = 0.1695x - 1.0816$, $R^2 = 0.99$
Preliminary ALF Data

\[ R^2 = 0.17 \]

French PRT, Rut Depth at 60,000 / 74°C, mm

ALF Rut Depth at 40,000 Passes, 64°C
Preliminary ALF Data

Ham burg, Wheel Passes to 20 mm at 64°C

ALF Rut Depth at 40,000 Passes, 64°C

R^2 = 0.23

- TBCR
- AB
- AZ CR
- E-T
- PG 70-22
- SBS 64-40
Preliminary ALF Data

R\(^2\) = 0.76

ALF Rut Depth at 40,000 Passes, 64°C

R\(SCH\), G\(^*\) at 10 Hz / 74°C, MPa

- TBCR
- AB
- E-T
- PG 70-22
- SBS 64-40
- AZ CR

20,000 25,000 30,000 35,000 40,000 45,000 50,000 55,000 60,000

0.0 5.0 10.0 15.0 20.0 25.0
Preliminary ALF Results

$R^2 = 0.86$

ALF Rut Depth at 40,000 Passes, 64°C

RSCH Cycles to 2% CPSS, 74°C

- TB CR
- AZ CR
- PG 70-22
- AB
- SBS 64-40

AZ CR
Significance

- Superpave Shear Tester
  Repeated Shear at Constant Height to 2% Cumulative Permanent Shear Strain

Tracks ALF Rutting Performance
Superpave Performance Tests

- Dynamic Modulus, $|E^*|$
- Flow Time
- Flow Number – Repeated Creep
- Ongoing Testing...
Binder Specification
Parameters
Preliminary Results
High Temperature Parameters

- $|G^*|/\sin \delta \ @ 10 \text{ radians} \ \ \ \ \ (\text{Superpave})$
- $|G^*|/(1-(1/\tan \delta \ \sin \delta)) \ @ 0.25 \text{ radians} \ \ (Shenoy)$
- $\% Y_{acc} \ \ \text{Repeated Creep} @ 300 \text{ Pa} \ \ \ (Bahia)$
- $\eta' \ @ 0.01 \text{ radians/s, LSV} \ \ (Dongre'/D'Angelo)$
- $\eta_0 \ @ \sim 0 \text{ radians/s, ZSV} \ \ (Rowe)$
- $\text{MVR, 1.225kg load, cc/10min} \ \ \ \ (Shenoy)$
High Spec. Temperature, $T_{HS}$

- $|G^*|/\sin \delta = 2200 \text{ Pa}$ (Superpave)
- $|G^*|/(1-(1/\tan\delta \sin\delta)) = 50 \text{ Pa}$ (Shenoy)
- $\% \gamma_{acc} \text{ No Criterion}$ (Bahia)
- $\eta' = 250 \text{ Pa-s, LSV}$ (Dongre’/D’Angelo)
- $\eta_0 = 250 \text{ Pa-s, ZSV}$ (Rowe)
- $MRV = 50 \text{ cc/10min}$ (Shenoy)
High-Temperature Performance
I-80, Nevada
Same gradation - different binders.

PG 63-22 modified
No rutting

PG 67-22 unmodified
15mm of rutting
High Temperature (Rutting) Repeated Creep Recovery Test

- PG 67-22 Neat AC
- PG 63-22 Modified

Graph showing Strain (%) vs. Time (seconds) for different asphalt types.
Repeated Creep Test Results
Two binders of Same PG-Grade

B 6281 (PG74-28)
B 6289 (PG74-31)

Limited Recovery, AB ALF, 15.7mm, s=0.24

Higher recovery, T-P ALF, 8.8mm, s=0.15
Repeated Creep Test Results
Two binders of Different PG-Grades

<table>
<thead>
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<th>Strain (mm/mm)</th>
<th>Time (s)</th>
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<tbody>
<tr>
<td>1.70</td>
<td>487</td>
</tr>
<tr>
<td>1.90</td>
<td>492</td>
</tr>
<tr>
<td>2.10</td>
<td>497</td>
</tr>
<tr>
<td>2.30</td>
<td>502</td>
</tr>
<tr>
<td>2.50</td>
<td>507</td>
</tr>
<tr>
<td>2.70</td>
<td>512</td>
</tr>
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- B 6280 (PG71-38)
- B 6286 (PG79-28)

SBS ALF, 19.5mm, s=0.30
TBCR ALF, 8.8mm, s=0.15
Summary of Findings To Date

Preliminary Results

- Current specification does not adequately identify the benefits of modifiers

- RSCH tracks ALF rutting performance

- A wide range of high specification temperature parameters are being evaluated
What’s Next

- Fatigue Testing
  - Two Temperatures
- Rutting Testing
  - 7 Lanes
- Additional Sections
  - TBD
- Superpave SPT
  - $|E^*|$, Creep
- Beam Fatigue
- Low-Temp Study
  - ABCD, DT, $T_{CR}$
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<td>$f'' (G^* \delta)DT DT A B C D$</td>
<td>T(inter)  $T_{CR}$</td>
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Binder Specification
Direction

- To better handle neat asphalts
- To address modifiers
- To do it faster, better, and more economical!

*** RULES ***

Tests need to be:
- Easy to set up
- Easy to perform
- Easy to analyze
Smooth Roads Ahead