Performance Grading of Bitumen

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Outline

• Background on Transport
• Targets of Bitumen Specifications
• Traditional Specifications
• Performance grade Specifications
  – Why we need to learn about them
  – Test methods necessary
  – The Superpave Bitumen grading system
## Transport Network

#### 2.6 Transport network comparison between EU 25, USA, Japan, Russia and China - 2001 (thousand km)

<table>
<thead>
<tr>
<th></th>
<th>EU 25</th>
<th>USA</th>
<th>Japan</th>
<th>China</th>
<th>Russia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road network</td>
<td>4,801</td>
<td>7,173</td>
<td>1,172</td>
<td>1,701</td>
<td>585</td>
</tr>
<tr>
<td>Motorway network</td>
<td>55.6</td>
<td>90</td>
<td>6.9</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>Railway network</td>
<td>299.9</td>
<td>315.3</td>
<td>40.2</td>
<td>88.8</td>
<td>126.4</td>
</tr>
</tbody>
</table>

Source: European Commission.
How much is spent on Roads?

3.2 Allocation of EU Structural Funds, 2000-2006

Allocation of EU Structural Funds to transport infrastructures, 2000-2006

- Roads 64%
- Urban transport 11%
- Multimodal transport 12%
- Railways 5%
- Maritime transport 3%
- Others 4%
- Airports 1%

Source: CEDEX
## 1.1 Economic Importance of Road transport in EU 15 - 2003*

<table>
<thead>
<tr>
<th>Automotive manufacturing</th>
<th>Turnover (EUR billion)</th>
<th>Turnover (% EU GDP)**</th>
<th>Employment (million people)</th>
<th>Employment (% of total)**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>452</td>
<td>4.86</td>
<td>1.90</td>
<td>1.12</td>
</tr>
<tr>
<td>Manufacture of Powered</td>
<td>1.5</td>
<td>0.02</td>
<td>0.23</td>
<td>0.14</td>
</tr>
<tr>
<td>Two Wheelers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor parts Manufacturing, Motor Trade, Maintenance, Services, and Aftermarket***</td>
<td>607</td>
<td>6.52</td>
<td>3.02</td>
<td>1.77</td>
</tr>
<tr>
<td>Fuell Refining &amp; distribution</td>
<td>243</td>
<td>2.6</td>
<td>0.54</td>
<td>0.29</td>
</tr>
<tr>
<td>Fuel Retail</td>
<td>250</td>
<td>2.7</td>
<td>0.44</td>
<td>0.26</td>
</tr>
<tr>
<td>Road Transport, Own Account, Public Transport</td>
<td>195</td>
<td>2.01</td>
<td>6.30</td>
<td>3.70</td>
</tr>
<tr>
<td>Road Construction and Maintenance</td>
<td>98</td>
<td>1.06</td>
<td>3.22</td>
<td>1.89</td>
</tr>
<tr>
<td>Motorway Operators</td>
<td>15</td>
<td>0.16</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Total Road Sector</td>
<td>1,861.5</td>
<td>19.93</td>
<td>15.71</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Source: ERF, Industry.
Common Targets for Bitumen Specifications

• Constructability

• Performance

• Durability
Historical Specifications

Consistency (pen or vis) hard

Temperature, °C: -15, 25, 60, 135

Penetration: 0 sec, 5 sec

Vacuum

A, B, C are same grade!

A, B, C
Conventional Bitumen Grades

Penetration Grades

Viscosity, 60°C (140°F)

AC 40
AC 20
AC 10
AC 5
AC 2.5

AR 16000
AR 8000
AR 4000
AR 2000
AR 1000
Asphalt Behavior

- **Hard**: Lower Temp, Shorter loading time (High Traffic Speed)
- **Soft**: Higher Temp, Longer loading time, Slower Traffic Speed
- **Elastic**: Lower Temp
- **Viscous**: Higher Temp
Effects of Time and Temperature

Flows rapidly at high temperatures

60 °C

1 hour

Flows slowly with time at lower temperatures

25 °C

1 hour

10 hours
Effects of Visco-Elasticity

Elastic

Viscous

Before Load

During Load

After Load

Before Load

During Load

After Load

Tire Load

Recoverable Deformation

Tire Load

Non-Recoverable Deformation

Effects of Visco-Elasticity
Performance Grading Should:

- Include measures describing stress-strain relationships under field loading.
- Consider the pavement conditions
  - Temperature, traffic speed, traffic volume, and pavement structure.
- Include acceptance limits derived from experience and factual field performance.
Variables that affects Binder Selection

• **Geographic Area:**
  – Air Temperature, solar radiation
  – Pavement Temperature: Max & Min

• **Traffic volume:** High, Medium, Low

• **Traffic speed:** Fast, Slow

• **Pavement Structure:** Strong, Weak
  – Stress and strain
Selection of Grades by Pavement Temperature

Maximum: @ 20-mm below surface
(approximately 18 C higher)

Minimum: @ surface
(approximately 8 C higher)
Important Considerations

**Traffic and Pavement Structure**

- Effect of traffic Volume & Speed
  - ESALS !, Speed limits!

- Pavement Damage
  - Weak vs. Strong base!
Performance Grading – PG system

Thermal Cracking

Fatigue Cracking

Rutting

Production

Pavement Temperature, C

-20 20 60 135
Performance Grading of Asphalt Binder- The Superpave System

- **Workability** at Construction Temperatures
  - Rotational Viscometer (RV) – $\eta$ at 135 C - unaged
- **Rutting** at High Pavement Temperature
  - Dynamic Shear Rheometer (DSR) - $G^*/\sin \delta$ (unaged & RTFO)
- **Fatigue** at Average Pavement Temperature
  - (DSR) - $G^*.\sin \delta$ (PAV aged)
- **Thermal cracking** at Low Pavement Temperature
  - Bending Beam Rheometer (BBR) - S(60), m(60) (PAV aged)
  - Direct Tension Tester (DTT) - Strain at failure
- **Durability** Properties - short term and long term
  - rolling thin film oven (RTFO), pressure aging vessel (PAV)
Rotational Viscometer

- Evaluates
  - handling and pumping properties
- ASTM D 4402
- Other Names: Brookfield viscometer, rotational coaxial cylinder viscometer
- Output
  - viscosity at 135 C
  - viscosity temperature chart for mix design
What are our problems?

1. Rutting in Asphalt Layer

![Diagram of rutting in asphalt layer]

- Original profile
- Weak asphalt layer
- Shear plane
Dynamic Shear Rheometer

• Evaluates
  – elastic and viscous properties
  – time and temperature effects

• Other Names
  – oscillatory shear rheometers
  – dynamic rheometers

• Output
  – complex shear modulus ($G^*$)
  – phase angle ($\delta$)
Asphalt

 Applied Stress or Strain

 Oscillating Plate

 Asphalt

 Fixed Plate

 Test at Pavement Temperature

 Dynamic Shear Rheometer

 Applied Stress or Strain

 Oscillating Plate

 Asphalt

 Fixed Plate

 Test at Pavement Temperature

 $\tau_{\text{max}}$

 Applied Shear Stress

 $\gamma_{\text{max}}$

 Resulting Shear Strain

 $G^* = \frac{\tau_{\text{max}}}{\gamma_{\text{max}}}$

 $\delta = \text{time lag}/w$

 Measures hardness

 Measures elasticity

 $\delta = \text{time lag}/w$
2. Fatigue of Pavements

“alligator” cracking
3. Low Temperature Cracking
Bending Beam Rheometer

- Evaluates
  - low temperature stiffness properties
- Output
  - creep stiffness
  - m-value
Results of the Bending Beam Rheometer

Log Creep Stiffness, $S$

$S(60)$

Thermal Stress build up

Log Loading Time

slope = m-value

$m(60)$

Thermal Stress relaxation

8 15 30 60 sec 120 240
Direct Tension Tester

- Evaluates
  - low temperature ability to stretch
- Output
  - tensile strain at failure before test

[Diagram showing the testing process with labels for load, length, and before test]
Direct Tension Testing

Load

failure stress = \( \frac{\text{Load at break}}{\text{area}} \)

failure strain = \( \frac{\text{elongation}}{\text{length before test}} \)
Failure Properties
Strength and Strain Tolerance

stress vs. strain

brittle
brittle-ductile
ductile
Asphalt Aging Behavior

• Asphalt Reacts with Oxygen and hardens

• During Construction - Short Term
  – hot mixing, placing, and compaction

• In Service - Long Term
  – hot climate worse than cool climate
  – So What?
  – *Pavement layer is brittle >> cracking*
Rolling Thin Film Oven
Short Term aging

controls
fan

empty bottle before
coated bottle after

air jet
bottle carriage
The Pressure Aging Vessel

- Pressure vessel
- Sample rack
- Sample pan
- Asphalt
- Air pressure
- Temperature probe
Superpave Binder Specifications

- Modulus
  - $S = 300\,\text{MPa}$
  - $m > 0.3$
  - $G\sin\delta = 5\,\text{MPa}$
  - $G*/\sin\delta = 0.001, 0.0022\,\text{MPa}$

- Temperature
  - Tmin
  - Tavg
  - Tmax
  - 135°C

- RTFO
  - η = 3.0 pa-s

- PAV-aged

- Unaged
Asphalt Binder Selection

• Performance Based
  – permanent deformation
  – fatigue cracking
  – low temperature cracking

• Physical Properties
  – criteria remain the same
  – temperature at which criteria achieved varies
  – measured on aged binder
Grade is First Selected from Pavement Temperatures

<table>
<thead>
<tr>
<th>Max Pave Temperature (HT)</th>
<th>PG 58 -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Pav Temperature (LT)</td>
<td>-16 -22 -28 -34 -40</td>
</tr>
<tr>
<td>Viscosity at 135 C</td>
<td>@ 135 C &lt; 3.0 Pa-s</td>
</tr>
<tr>
<td>G*/sin d (ungaed)</td>
<td>@ HT &gt; 1.0 Kpa</td>
</tr>
<tr>
<td>G*/sin d (RTFO-aged)</td>
<td>@ HT &gt;2.2 Kpa</td>
</tr>
<tr>
<td>G*.sin d (RTfO+PAV-aged)</td>
<td>@ IT &lt;5000 Kpa</td>
</tr>
<tr>
<td>S(60) (RTfO+PAV-aged)</td>
<td>@ LT &lt;300,000 Kpa</td>
</tr>
<tr>
<td>M(60) (RTfO+PAV-aged)</td>
<td>@ LT &gt;0.300</td>
</tr>
<tr>
<td>Strain @ failure (RTFO+PAV)</td>
<td>@ LT &gt;1.0 %</td>
</tr>
</tbody>
</table>
Grading System

PG 64-22

- Performance Grade
- Average 7-day max pavement design temp
- Min pavement design temp
Binder PG Grades (AASHTO) PG HT- LT

Modified Bitumen

Unmodified Bitumen
Map for Production of PG Grades

- High-Temp Grade (HT)
- Low-Temp Grade (LT)

- Modified Bitumen
- Best Crude
- Standard Crude

PG HT-LT

-52 -46 -40 -34 -28 -22 -16 -10 -4
Methods of Selection

• Select base grade based upon:
  – Geographic Area
  – Air Temperature
  – Pavement Temperature

• Adjust base grade based upon:
  – Traffic Speed
  – Traffic Volume
Considering traffic volume and speed - adjustment to PG Grade

<table>
<thead>
<tr>
<th>Traffic Volume ESALs</th>
<th>Traffic Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standing</td>
</tr>
<tr>
<td>&lt;0.3</td>
<td>(~ +1)</td>
</tr>
<tr>
<td>0.3 to &lt; 3</td>
<td>+2</td>
</tr>
<tr>
<td>3 to &lt; 10</td>
<td>+2</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
<td>+2</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>+2</td>
</tr>
</tbody>
</table>

+1 : Increase PG grade by 6 degrees; e.g. PG 64-22 to PG 70-22
Effect of Traffic Speed and Volume on Binder Selection

- Examples
- Base Grade PG 58 -22
  - for toll road
    - (high Volume) PG 64-22
  - for toll booth
    - (high volume and slow traffic) PG 70-22
  - for rest area
    - (high volume and standing traffic) PG 76-22
Thank You for your attention

Questions!