NEW PG GRADING SYSTEM

CTEP
Annual Western Canada Pavement Workshop

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PRESENTATION OVERVIEW

• What are the desired asphalt properties
• Specification types
• PG Grading system overview
• PG Plus – reasons, additions and issues
• MSCR test and spec
• The road ahead
ASPHALT IS VISCOELASTIC

• **Viscous Materials**: all energy added is dissipated in deformation and heat
• **Elastic Materials**: all energy added is stored
• **Viscoelastic materials**: exhibit both viscous and elastic behaviour
• Fundamental principle of linear viscoelasticity is **time-temperature superposition**
  • Asphalt becomes stiffer by cooling it, or by loading it faster
  • Asphalt becomes softer by heating it, or by loading it slower
  • Time and temperature are proportional in the linear domain and one can be converted into the other
WHAT ARE THE DESIRED ASPHALT PROPERTIES?

- Wide viscoelastic region
  - Become brittle at low temp
  - Become liquid at high temp
- Low temperature susceptibility
- Good resistance to aging – short and long term
  - Low volatility of lighter ends
  - Low oxidation rate
- Good chemical compatibility with aggregate

![Graph showing the relationship between temperature and consistency, with low and high susceptibility lines. A note indicates that same consistency at 25°C does not predict performance at other temperatures. Higher viscosity provides greater stability.]

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**Diagram Note:**
- Same consistency at 25°C does not predict performance at other temperatures.
- Higher viscosity provides greater stability.
Specifications are required performance criteria for the asphalt binders:

- **Descriptive specs (recipe specs)**:
  - Ingredients and their dosage is specified (or banned)
  - Poor at predicting performance

- **Performance-related specs**:
  - Empirical Specs
  - Fundamental Specs

- **Performance-based specs**:
  - Real performance captured in service

**HOW DO WE CAPTURE THESE PROPERTIES?**
ASPHALT CEMENT SPECIFICATIONS

- Penetration Spec (ASTM D 946; AASHTO M20)
- Viscosity Spec (ASTM D3361; AASHTO M226)
- AR Specification – some US states, California
- PVN (CGSB) Spec – in-place now or until recently in BC, AB, SK, MB
- PG Specification (AASHTO M320)
  - Lots of plus specifications
- MSCR Specification (AASHTO M332)
  - Adopted as an AASHTO spec in 2014
  - Adopted by most US states
  - Adopted by QC, NB and NS in 2019
PROBLEMS WITH OLDER EMPIRICAL SPECIFICATIONS

- Penetration
  - Empirical measure of viscous and elastic effects
  - Doesn’t capture the temperature susceptibility
- Viscosity
  - Only captures viscous component
- No low temperature properties measured
- Aging either not considered; or only short-term
- Difficulty characterizing modified asphalt binders
- Tested parameters are dependent on the testing geometry and conditions
- No fundamental material parameters are measured
PG SPECIFICATION - KEYS EVENTS

- Strategic Highway Research Program (SHRP)
- 5 year, $150M program approved in 1987 – binders and mixes
- Main technical reports published in 1992-1993
- PGAC state & prov. specifications adopted in the mid to late 1990’s
- First spec built to directly address pavement distress types
- All R&D conducted on SHRP asphalts – a library of neat bitumen from the main sources and refiners in NA
  - All asphalts used during the SHRP research were neat (un-modified)
  - Timing coincided with the spread of PMB’s, especially SBS (elastic) modification
ASPHALT TEMPERATURE-LOADING SUSCEPTIBILITY

**Fatigue Cracking**
Intermediate temperature stiffness

**Thermal Cracking**
Low temperature stiffness

**Rutting**
High temperature stiffness

**Handling Production Workability**

Aging due to Oxidation during production and after being in-service

6 - 30 m

This graph illustrates the relationship between asphalt temperature and loading susceptibility, highlighting the effects of different temperatures on asphalt properties such as stiffness, thermal cracking, fatigue cracking, rutting, and handling production workability. The graph also indicates potential aging due to oxidation during production and after being in-service.
PG SPECIFICATION – OVERVIEW

CONSTRUCTION

RUTTING

FATIGUE CRACKING

LOW TEMP CRACKING

RV

DSR

BBR

RTFO

Short Term Aging

No aging

PAV

Long Term Aging

No aging

RTFO

(-18°C)
DYNAMIC SHEAR RHEOMETER (DSR)

- Used to measure high temperature (rutting) and intermediate temp (fatigue)
- Parallel plate geometry
- Measures complex shear modulus ($G^*$) and phase angle ($\delta$)
- Angular Velocity=10 rad/s; variable strains
- $G^*/\sin(\delta)$ - parameter selected for rutting
- $G^* \cdot \sin(\delta)$ - parameter selected for fatigue
- Loading is in oscillatory mode

Figure 3.4 Dynamic Shear Rheometer Operation

Figure 3.6 Asphalt Sample Configuration in DSR
BENDING BEAM RHEOMETER (BBR)

- Creep load on a aged asphalt beam; simulates thermal stress
- Tested at T+10 & 60 sec (instead of T & hours)
- **Creep Stiffness**
- m-value - capability of an AC to relieve thermal stresses through internal flow
- Beam conditioning time is critical (**1 hour**), due to isothermal hardening effects
CRITICAL CRACKING TEMPERATURE
PG SPECIFICATION OVERVIEW - TODAY

**Rotational Viscosity**

- **Temperature (°C):**
  - Original Residue: 135
  - Short-Term Aged: 58
  - Long-Term Aged: 19
  - Thermal Cracking: -18

- **Pumping, handling & workability**
  - Rotational Viscometer

- **Rutting**
  - |G*|/sin(δ)

- **Fatigue Cracking**
  - Intermediate temperature stiffness
  - G*sin(δ)

- **Thermal Cracking**
  - Low temperature stiffness
  - S(60) & m(60)

- **Rutting & Workability**
  - Dynamic Shear Rheometer
  - Bending Beam Rheometer

- **Bending & Workability**
  - Rotational Viscometer

**Testing Methods:***
- S(60) & m(60)
- |G*|/sin(δ)
- G*sin(δ)
PERFORMANCE GRADE DETERMINATION

- Grading system based on climate (LTPP)

- Developed from Air Temperatures
  - 6500 weather stations in US and Canada
  - Adjustment using SHRP function converting air temperature to:
    - High pavement TEMP (20mm below surface)
    - Low pavement TEMP (at surface)
### APPROXIMATE PEN-PG EQUIVALENCE

<table>
<thead>
<tr>
<th>Range</th>
<th>Approximate PEN-PG Equivalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>60/70</td>
<td>PG 64-22, PG 58-22, PG 58-28, HK 64-28*</td>
</tr>
<tr>
<td>85/100</td>
<td>PG 64-22, PG 58-22, PG 58-28, PG 58-28*</td>
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<tr>
<td>120/150</td>
<td>PG 58-28, PG 52-28, PG 52-28, PG 58-28*</td>
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<tr>
<td>150/200</td>
<td>PG 58-28, PG 52-28, PG 52-34, PG 58-34*</td>
</tr>
<tr>
<td>200/300</td>
<td>PG 52-34, PG 52-28, PG 46-34</td>
</tr>
<tr>
<td>300/400</td>
<td>PG 46-34</td>
</tr>
</tbody>
</table>

* - Very selective crudes only
PGAC VERIFICATION AND GRADING

• **Grade verification** – a PGAC is tested against a specified PG grade (ex. PG 58-28)

• **PG Grading** (or grade determination) – AC is tested for two (passing and failing) temperatures for top and bottom (standard PG temperatures are increments of 6°C)
  
  o Continuous PG grade is calculated by logarithmic interpolation (ex. PG 68.7 – 32.6)
  
  o Determination of the continuous grade is essential for PGAC blending and for mixes with high RAP content

• **PG Spread or UTI** – sum of the PG top and bottom
  
  o An indication of the temperature susceptibility of the ACC
## ADJUST TO TRAFFIC LOADING (GRADE BUMPING)

<table>
<thead>
<tr>
<th>Highway Type</th>
<th>Increase from Standard</th>
<th>Optional Additional Grade Increase (Note 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Freeway</td>
<td>2 Grades</td>
<td>N/A</td>
</tr>
<tr>
<td>Rural Freeway</td>
<td>1 Grade</td>
<td>1 Grade</td>
</tr>
<tr>
<td>Rural Arterial</td>
<td>Consider increasing by 1 grade if heavy truck traffic is greater than 20% of AADT</td>
<td>1 Grade</td>
</tr>
<tr>
<td>Rural Collector</td>
<td>No Change</td>
<td>1 or 2 Grades</td>
</tr>
<tr>
<td>Rural Local Urban/Suburban Collector</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:

A. Upgrading of the high temperature grade is recommended for use in both surface and top binder courses, i.e., top 80 to 100 mm of hot mix.

B. Alternatively, Multiple Stress Creep Recovery (MSCR) graded PGAC acceptance criteria, according to Appendix B and Appendix Table A-3, can be used.

1. Consideration should be given to an increase in the high temperature grade for roadways which experience a high percentage of heavy truck or bus traffic at slow operating speeds, frequent stops and starts, and historical concerns with instability rutting.
## MODIFICATION REQUIREMENTS

### High Temperature Performance Grade

<table>
<thead>
<tr>
<th>Low Temperature Performance Grade</th>
<th>52</th>
<th>58</th>
<th>64</th>
<th>70</th>
<th>76</th>
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<tbody>
<tr>
<td>-16</td>
<td>52-16</td>
<td>58-16</td>
<td>64-16</td>
<td>70-16</td>
<td>76-16</td>
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<td>58-28</td>
<td>64-28</td>
<td>70-28</td>
<td>76-28</td>
</tr>
<tr>
<td>-34</td>
<td>52-34</td>
<td>58-34</td>
<td>64-34</td>
<td>70-34</td>
<td>76-34</td>
</tr>
<tr>
<td>-40</td>
<td>52-40</td>
<td>58-40</td>
<td>64-40</td>
<td>70-40</td>
<td>76-40</td>
</tr>
</tbody>
</table>

- Regular Crude Oil
- High Quality Crude Oil
- Very High Quality Crude Oil or Modification Required
- Modification Required
EFFECT OF ELASTIC MODIFIERS

- More flexible at lower temperatures
- More resistant to fatigue
- Lower production and placement temperatures
- Stiffer for better rutting resistant

Temperature (°C)

Stiffness

Unmodified
Modified
MAIN TYPES OF « PG PLUS » SPECIFICATIONS

PG PLUS TO SPECIFY ELASTOMERS

ELASTIC RECOVERY BY DUCTILOMETER
- Various versions, speeds, temperatures, aging -

FORCE-DISPLACEMENT TYPE TESTS
- Force ductility -
- Toughness & tenacity -

MAXIMUM DSR PHASE ANGLE
EVOLUTION OF FATIGUE PARAMETERS

- $G^*\sin(\delta)$ – poor field correlation in neat and modified asphalts
  - Parameter elimination was considered but kept in the end, for lack of a better one

- Several other parameters were developed to try to address fatigue contribution of the binder
  - Linear Amplitude Sweep (LAS) test
  - Double Edge Notched Tension (DENT) test
  - Glower-Rowe (G-R) parameter
  - Binder Yield Energy test (BYET)
  - Delta Tc
DOUBLE EDGE NOTCHED TENSION (DENT)

- Developed and specified in Ontario
- Tested on PAV residue, 15°C
- Measures essential work of ductile fracture; strain tolerance using a force-ductility concept
- Difficult to pass if bitumen is not modified
- Relatively poor reproducibility

**DENT at Intermediate Temperatures**

![Diagram of DENT test setup]

- L = 5, 10 and 15 mm
- 80 mm
- 30 mm

**Notes:**
- Difficult to pass if bitumen is not modified
- Relatively poor reproducibility
GLOVER-ROWE PARAMETER (G-R)

- Rheological parameter that correlates with ductility
- Captures an asphalt's likeliness to experience non-load related cracking
- \( \frac{G'}{\eta'/G'} \equiv G^* \cdot (\cos \delta)^2 / \sin \delta \) tested at 15°C, 0.005 rad/s
- Because of the low testing frequency, parameter needs to be derived from mastercurves
- Proposed < 180 kPa spec limit
  - > 450 kPa onset of significant cracking

Source: Rowe et al., The Influence of Asphalt Rheology on the Cracking of Asphalt Mixes on Airport and Highway Projects
DELTA Tc (ΔTc)

• Is essentially a fatigue parameter, even if derived from the BBR data tested at cold temperature
• \( \Delta Tc = T(S_{\text{critical}}) - T(m_{\text{critical}}) \)
  - More positive – bitumen stiffness controls behaviour
  - More negative – relaxation properties control behaviour
• Proposed PG specifications will limit \( \Delta Tc \) to a minimum (-2.0 and -5.0 are discussed)
• ON and QC are collecting \( \Delta Tc \) “for info only” during 2020
• Recent data: \( \Delta Tc \) might be incorrectly trending elastomeric modified asphalts
PHYSICAL (ISOTHERMAL) HARDENING

- Reversible hardening of bitumen around the Tg
- Degree of physical hardening depends on bitumen source
- Arguably a behaviour that leads to thermal cracking
- Behaviour not captured in the PGAC specification
- Extended BBR – specified in ON
  - BBR test with a 72h conditioning time
    - Test data collected at 1, 24, 72 h
  - Two parameters captured
    - Low temp limiting grade
    - Grade loss over 72h
  - Any bitumen with a grade loss over 6 degrees is deemed unsuitable for cold climate pavements
- Research is ongoing for replacing the EBBR test in ON (high duration and cost)
  - PAV phase angle at a fixed shear modulus correlates well with EBBR
AGING

• Rolling Thin Film Oven (RTFO) - short term
  o Higher modified bitumen age less because they roll less in the bottle (higher viscosity)
  o Higher modified PMB usually RTFO controlled

• Pressure Aging Vessel (PAV) – long term
  o General belief is that the PAV at 20 hrs underpredicts aging in the field
  o 40 hrs PAV aging becomes more common
  o 20 hrs PAV aging in thin film

• Could the more severe field aging be an artifact of the SUPERPAVE mixes???
MULTIPLE STRESS CREEP RECOVERY (MSCR)

- Rutting correlation for modified asphalts

- A different rutting approach was needed, to capture polymer contribution in rutting
- MSCR test developed, validated and adopted

\[ \frac{|G^*|}{\sin(\delta)}, \text{kPa} \]

\( R^2 = 0.126 \)

\( R^2 = 0.817 \)
MULTIPLE STRESS CREEP AND RECOVERY (MSCR)

• DSR test using a different loading
• Creeps and relaxes binder in the DSR
• Tested only on RTFO residue
• Measures two parameters
  o $J_{nr}$ – non-recovered creep compliance
  o Recovery, in %
• $J_{nr}$ is a rutting parameter (compliance)
• Recovery relates to temperature and strains seen in pavements
MSCR – RECOVERY = f(J_{nr})
MSCR TEST VS. MSCR SPEC

• MSCR Test (AASHTO T350) – a load and recovery test
  o Can be added to regular PG spec as a Plus test
  o Currently a Plus test in AB, BC, MB (Recovery) and ON (Recovery & Jnr)
  o Done at environmental temperature – **NO GRADE BUMPING!**
  o RTFO DSR and RTFO MSCR need to be done at different temperatures for some grades.

• MSCR Spec (AASHTO M332)
  o Adopted in Quebec, NB, NS in 2019; in effect across most US states
  
  • **“S”** Standard  Jnr < 4.5  PG 58S-28; PG 52S-34
  • **“H”** High  Jnr < 2  PG 58H-34; PG 58H-28
  • **“V”** Very High  Jnr < 1  PG 52V-40; PG 64V-22
  • **“E”** Extremely High  Jnr < 0.5  PG 58E-34; PG 58E-28
PG GRADING SYSTEM – SHORTCOMINGS TO DATE

RUTTING
- So-so correlation of DSR parameter
- Fails to capture PMA contribution
- MSCR test/spec developed as response

FATIGUE
- Poor correlation of DSR parameter
- Numerous other alternatives tried
  - DENT
  - G-R
  - LAS
  - Delta Tc
- Attempt to capture bitumen relaxation
  - R-Value

PHYSICAL HARDENING
- Not captured by existing PG spec
- Extended BBR test
  - Week-long testing protocol
- PAV DSR Phase angle is studied as a replacement

COMPOSITION
- Does not prevent the use of substandard modifiers
- Some specs restrict modifiers
  - REOB
  - Acids
  - Waxes
  - Oils (incl. bio)
PG SPECIFICATIONS IN WESTERN CANADA TODAY

• PG Specification (AASHTO M320)
  o One intermediate low grade (PG XX-37) – captures climatic conditions and local binders
  o Modified low temperature acceptance for PG 58-28 (minimum -30)
  o Usage of REOB as a softener is not allowed
  o MSCR % Recovery is a requirement for modified grades (tested at 58°C)

<table>
<thead>
<tr>
<th>PGAC Grade</th>
<th>Minimum $R_{3.2@58^\circ C}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>58-34, 64-28</td>
<td>25%</td>
</tr>
<tr>
<td>58-37, 58-40, 64-34, 70-28</td>
<td>40%</td>
</tr>
<tr>
<td>64-37, 76-28</td>
<td>55%</td>
</tr>
</tbody>
</table>
### Table 4: Selection of Asphalt Binder Grades for New Construction

<table>
<thead>
<tr>
<th>Temperature Zone</th>
<th>Design ESAL (millions)</th>
<th>1st Stage</th>
<th>Final</th>
<th>1st Stage</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1.0</td>
<td>1.0 to &lt;3.0</td>
<td>3.0 to &lt;6.0</td>
<td>6.0 to &lt;20</td>
<td>≥20.0³</td>
</tr>
<tr>
<td>1</td>
<td>PG 52-34</td>
<td>PG 58-34</td>
<td>PG 58-34</td>
<td>PG 58-34</td>
<td>PG 64-34</td>
</tr>
<tr>
<td>2</td>
<td>PG 52-34</td>
<td>PG 52-34</td>
<td>PG 58-34</td>
<td>PG 58-34</td>
<td>PG 64-34</td>
</tr>
<tr>
<td>3</td>
<td>PG 46-34</td>
<td>PG 52-34</td>
<td>PG 58-34</td>
<td>PG 58-34</td>
<td>PG 64-34</td>
</tr>
<tr>
<td></td>
<td>PG 52-34</td>
<td>PG 52-34</td>
<td>PG 58-34</td>
<td>PG 58-37²</td>
<td>PG 64-34</td>
</tr>
</tbody>
</table>

**Note:**

1. Use M1 mix type.
2. For non-staged new construction or thick pavement structures use a PG xx-37 in the upper 100 mm and a PG xx-34 for material greater than 100 mm in depth from pavement surface.
3. In certain special applications where resistance to wheel path rutting is paramount use a PG 70-28 in all lifts as per Section 3.3 Special Applications.
SUPERPAVE - CANADIAN USAGE 2020

British Columbia
- PG + MSCR Rec
- CGSB still allowed
- SP mix - limited

Alberta
- PG + MSCR Rec
- CGSB still allowed
- SP mix
  - Calgary - limited
  - Edmonton - yes
  - AT - abandoned

Saskatchewan
- PG spec - no
- SP mix - no

Manitoba
- PG + MSCR Rec
- SP mix - no

Ontario
- PG +++
- SP mix - yes

Quebec
- MSCR Spec
- SP mix - own version

Newfoundland & Labrador
- PG spec - yes
- SP mix - no

P.E.I
- PG spec - yes
- SP mix - yes

Nova Scotia
- MSCR Spec
- SP mix - yes

New Brunswick
- PG spec - yes
- SP mix - yes
CLOSING REMARKS

• PG Grading system is designed to accommodate all climates and traffic levels
• Specification proliferation is a major problem in our industry in Canada
• Specs are often used to indirectly address recipe issues
• Western provinces are using all the same approach for PG and PMA adoption
• Owners are currently looking at PG Grading on extracted and recovered binders
• Superpave mixes are also undergoing an evolution process
• HMA performance specs are the ultimate goal
  o Various solutions are being explored for improving the Superpave mixes
    ▪ Balance mix design, regression method for binder and lower gyrations
    ▪ Superpave5 – French inspired mix-design approach
    ▪ Higher density, thicker AC films, less permeability, lower aging rates
THANK YOU

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