Outline

- Background
- Refining
- Chemistry
- Heated Asphalt Cement
- SUPERPAVE
- Asphalt Modification
- Aging
- Rheology
- Rutting
- Fatigue Cracking
- Low Temp Cracking
- MSCR
- Additional Asphalt Cement Tests
- Grade Selection & Ontario Specifications
- Other Grading Systems
- Mixing and Compaction
- Moisture Sensitivity
- Emulsions and Cutbacks
BACKGROUND INFORMATION
Asphalt cement (along with air) occupies the space between the aggregate in an asphalt pavement mix.

It is the “glue” that holds the aggregates together and influences many of properties of a flexible asphalt pavement.

A typical asphalt mix contains 5% asphalt cement binder by weight although in practice this varies.
## Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt</td>
<td>Bitumen</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>Binder</td>
</tr>
<tr>
<td>Asphalt Binder</td>
<td>Modified Asphalt</td>
</tr>
<tr>
<td>AC or PGAC</td>
<td>Modified Binder</td>
</tr>
<tr>
<td>Aggregate</td>
<td>Stone</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>Sand</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>Gravel</td>
</tr>
<tr>
<td>Hot Mix</td>
<td>Asphalt</td>
</tr>
<tr>
<td>Warm Mix</td>
<td>Asphalt Concrete</td>
</tr>
<tr>
<td>Mix</td>
<td>Asphalt Pavement</td>
</tr>
</tbody>
</table>
Terminology Origins

• Bituminous
  – Adjective
    • Of, containing, or of the nature of bitumen
  – Origin
    • Mid 16th century: from French bitumineux, from Latin bituminosus

• Asphalt
  – Noun
    • Sticky, black and highly viscous liquid or semi-solid form of petroleum; also known as bitumen
  – Origin
    • From the Greek “asphaltos” meaning “secure”
Asphalt is **NOT** Tar

### Asphalt
- Soluble in petroleum products
- Generally produced from distillation (refining) of petroleum crude oil
- Can be naturally occurring
- Black, sticky, semisolid, highly viscous material at room temperature
- Acts as strong/durable cement with excellent adhesive and waterproofing characteristics
- Highly resistant to most acids, alkalis and salts

### Tar
- Resistant to petroleum products
- Generally a by-product of coke (from coal) production
Asphalt Has Been Used Since Ancient Times

Asphalt cement is mankind’s oldest engineering material. Its adhesive and waterproofing properties were known at the dawn of civilization.

Around 6000 B.C. it was used in the shipbuilding industry in Sumeria.

Babylon 615 BCE – first recorded use of asphalt as road building material

- First US hot mix asphalt (HMA) constructed in 1870’s
  - Used naturally occurring asphalt from surface of lake on island of Trinidad

- Two sources (natural asphalt lakes)
  - Island of Trinidad
  - Bermudez, Venezuela
  - Each lake source is very consistent
  - Used solubility test to determine source
  - Insolubles differed substantially between sources
In the early part of 20th century mankind learned how to produce asphalt by the distillation of crude petroleum. This lead to the availability of large amounts of asphalt for paving purposes.

Demand for paved roads exceeded the supply of lake asphalts in the late 1800’s. Led to the use of petroleum asphalts.

During 2014 the amount of Hot Mix Asphalt (HMA) produced and placed in the U.S. was estimated to be over 350 million tons (NAPA 2014 Asphalt Pavement Industry Survey – Info. Series 138)

In the U.S., 94% of hard surfaced roads (2.7 million miles) have asphalt surfaces (www.asphaltpavement.org)
Global Asphalt Cement Demand (2013)

- N America: 25%
- S America, C America: 7%
- Africa: 3%
- Asia & Pacific: 37%
- European Union: 17%
- Europe, Other: 11%

87 Million Tonne Annual Global Demand

US = 17.3 Million Tonne
Canada = 2.43 Million Tonne

Majority use is in paving applications (in North America approx. 25% is used in roofing and minor secondary applications)
Asphalt Cement Supply Chain

**Refiner**
- Supplies base asphalt cement binder
- Available supply of asphalt cement binder may not match government user agency specifications

**Terminal Supplier / Modifier**
- Stores & terminals asphalt cement binder from multiple refineries
- Manufactures enhanced/modified grades of asphalt cement to meet government user agency specifications

**Contractor**
- Produces and paves with asphalt mix using asphalt cement binder supplied by Terminal Supplier / Modifier
- Contractually responsible for quality
ASPHALT CEMENT REFINING
## Canadian Petroleum Crude Oil Refineries (2018)

![Map of Canada with refineries marked](image)

<table>
<thead>
<tr>
<th>Province</th>
<th>BC</th>
<th>AB</th>
<th>SK</th>
<th>ON</th>
<th>QC</th>
<th>NB</th>
<th>NL</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nº of Refineries</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>Capacity (BBL/Day)</td>
<td>66,810</td>
<td>541,725</td>
<td>235,297</td>
<td>395,011</td>
<td>402,518</td>
<td>300,394</td>
<td>115,098</td>
<td>2,056,852</td>
</tr>
</tbody>
</table>

Refinery number and capacity data from CAPP Statistical Handbook – February 2018  [www.capp.ca](http://www.capp.ca)  Does not include oil sands bitumen upgraders
2019: 135 Refineries / 18.8 Million Barrels per Calendar Day

Increased refining capacity offsetting decreasing number of refineries

Similar trends observed in US and on global basis

Transportation logistics have become critical factor for adequate supply
US Petroleum Crude Oil Refineries

- Similar trends in USA
- Number of operable refineries has decreased from 301 in 1982 to 135 in 2018
- Refining capacity ~18.6 million barrels per day in 2018
  - ~ 9 times Canadian refining capacity
## Selected Crude Oil Classifications

### API Gravity

<table>
<thead>
<tr>
<th>Classification</th>
<th>API Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>&lt;22.3° API</td>
</tr>
<tr>
<td>Medium</td>
<td>22.3° API &lt; 30.2° API</td>
</tr>
<tr>
<td>Light</td>
<td>≥30.2° API</td>
</tr>
</tbody>
</table>

Higher API Gravity = Lower Sp.Gr.

\[ ^o_{API} = \frac{141.5}{Sp.\,Gr.} - 131.5 \]

### Sulfur Content

<table>
<thead>
<tr>
<th>Type</th>
<th>Sulfur Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sour</td>
<td>&gt;0.7% Sulfur</td>
</tr>
<tr>
<td>Sweet</td>
<td>&lt;0.7% Sulfur</td>
</tr>
</tbody>
</table>

Reported cut-offs for sulfur content may vary (i.e. sour crude >1% S / sweet crude <0.5% S)
Actual asphalt yield depends on distillation temperature (may vary between ~850 – 1000°F) and whether crude yields asphaltic residuum.
## Crude Oil Assay Properties

<table>
<thead>
<tr>
<th>Crude Oil</th>
<th>°API</th>
<th>Specific Gravity</th>
<th>Wt. % Sulfur</th>
<th>Volume % Residuum (&lt; 1000 °F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Lake Blend*</td>
<td>19.7</td>
<td>0.936</td>
<td>3.8</td>
<td>36</td>
</tr>
<tr>
<td>Lloyd Blend*</td>
<td>20.8</td>
<td>0.928</td>
<td>3.5</td>
<td>41</td>
</tr>
<tr>
<td>Western Canadian Select [WCS]*</td>
<td>20.8</td>
<td>0.928</td>
<td>3.5</td>
<td>40</td>
</tr>
<tr>
<td>Maya (Mexico)</td>
<td>21.5</td>
<td>0.925</td>
<td>3.4</td>
<td>37</td>
</tr>
<tr>
<td>Bakken (US)</td>
<td>41</td>
<td>0.820</td>
<td>0.2</td>
<td>5</td>
</tr>
<tr>
<td>West Texas Intermediate [WTI] (US)</td>
<td>40.8</td>
<td>0.821</td>
<td>0.3</td>
<td>10</td>
</tr>
</tbody>
</table>

- ✓ = High quality asphaltic crude oil

*Canadian crude oil

- Crude oils suitable for asphalt distillation are typically
  - Heavy (sp.gr > 0.9) and high in sulfur (>1%)

- Western Canada has significant quantities of high quality asphaltic crudes (globally ~10% of crudes are asphaltic)
  - Refineries routinely blend asphaltic and non-asphaltic crudes and produce high quality asphalt cement
Asphalt Refining Distillation Process

**CRUDE OIL**

- Preheat
- 250-300°F

**Desalter**

- 250-300°F

**Furnace**

- 650°F

**Atmospheric Distillation**

- 650°F
- Steam
- Atmospheric Residue

**Vaccum Distillation**

- Max 750-800°F
- Vacuum Residue

**Atmospheric Residue**

- 850 - 1000°F

- (atmospheric equivalent temperature)

**Gases, Methane, Ethane, Propane, Butane...**

**Distillate Feeds For Other Refinery Units**

- Light VGO
- Heavy Vacuum Gas Oil (HVGO)

**Fuel Oil**

**Gases, Methane, Ethane, Propane, Butane...**

- Kerosene
- Gas Oil

**Asphalt Cement**
Refinery Processes Used to Produce Asphalt Cement

Atmospheric and Vacuum Distillation

Solvent Distilled Asphalt

Solvent distillation is a specialty process which produces a very hard asphalt cement by precipitating polar fractions of heavy crude oil called asphaltenes using non polar solvent (e.g. propane). This hard asphalt cement must be softened if used in paving applications.
ASPHALT CEMENT CHEMISTRY
Asphalt Cement Chemistry

• Complex chemical composition
  – Up to 1,000,000 types of molecules

• Composition varies according to
  – Crude oil source (asphalt cements produced from different crude oils may exhibit very different chemistries)
  – Age of asphalt cement (chemistry changes as asphalt cement ages)
  – Chemical modifiers which may have been used to modify properties of asphalt cement
### Elemental Analysis of Asphalt Cement

<table>
<thead>
<tr>
<th>Element</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (% by wt)</td>
<td>82.8</td>
<td>80.2–84.3</td>
</tr>
<tr>
<td>Hydrogen (% by wt)</td>
<td>10.2</td>
<td>9.8–10.8</td>
</tr>
<tr>
<td>Nitrogen (% by wt)</td>
<td>0.7</td>
<td>0.2–1.2</td>
</tr>
<tr>
<td>Sulfur (% by wt)</td>
<td>3.8</td>
<td>0.9–6.6</td>
</tr>
<tr>
<td>Oxygen (% by wt)</td>
<td>0.7</td>
<td>0.4–1.0</td>
</tr>
<tr>
<td>Atomic Ratio (H/C)</td>
<td>1.47</td>
<td>1.42–1.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel (ppm)</td>
<td>83</td>
<td>10–139</td>
</tr>
<tr>
<td>Vanadium (ppm)</td>
<td>254</td>
<td>7–1590</td>
</tr>
<tr>
<td>Iron (ppm)</td>
<td>67</td>
<td>5–147</td>
</tr>
<tr>
<td>Manganese (ppm)</td>
<td>1.1</td>
<td>0.1–3.7</td>
</tr>
<tr>
<td>Calcium (ppm)</td>
<td>118</td>
<td>1–335</td>
</tr>
<tr>
<td>Magnesium (ppm)</td>
<td>26</td>
<td>1–134</td>
</tr>
<tr>
<td>Sodium (ppm)</td>
<td>1.47</td>
<td>1.42–1.5</td>
</tr>
</tbody>
</table>

- Asphalt cement consists primarily of carbon and hydrogen (hydrocarbon) along with other heteroatoms (nitrogen, sulfur, oxygen) as well as metals.
Separating Asphalt Cement Into Broad Chemical Components – SARA Analysis

- Asphalt Cement (n-heptane precipitation)
  - Maltenes (n-heptane soluble)
  - Asphaltenes (n-heptane insoluble)
    - Filter
    - Silica gel/alumina chromatography
      - Saturates (n-heptane elution)
      - Aromatics (toluene elution)
      - Resins (toluene/methanol elution)
Asphalt Cement Chemical Fractions

- **Asphaltenes (5-25% by mass)**
  - Highly complex and polar hydrocarbon structures with nitrogen, sulfur, oxygen heteroatoms
  - Affect rheology of asphalt cement
  - Increasing asphaltene content = harder, more viscous binder

- **Resins (+/- 20% by mass)**
  - Polar hydrocarbons with sulfur, oxygen, nitrogen atoms
  - Strongly adhesive & act as dispersing agents for asphaltenes
Asphalt Cement Chemical Fractions

• **Aromatics (40-65% by mass)**
  – Dark brown non-polar viscous liquid
  – Lower molecular weight napthene aromatics
  – Comprise majority of dispersion medium for asphaltenes
  – Aromatic rings with non-polar hydrocarbon chains
  – Able to dissolve other high molecular weight hydrocarbons

• **Saturates (5-20% by mass)**
  – White/straw brown non-polar viscous oils
  – Straight & branch aliphatic hydrocarbons with alkyl napthenes and some alkyl aromatics
HOT (HEATED) ASPHALT CEMENT
Asphalt Cement Handling

• Asphalt cement does not readily flow at ambient temp.
  – Reduce *viscosity (measure of resistance to flow)* to pump, mix, and use in production/construction of pavements

• Three solutions
  – Heat *(most prevalent)*
  – Dissolve in solvent (cut-back asphalt)
  – Disperse in water with chemicals *(asphalt emulsion)*

• Considerations – hot asphalt cement
  – Heat safely - flammability
  – Understand viscosity properties *(resistance to flow)*
Safety – Asphalt Cement Flash Point

- Specified COC Flashpoint > 230°C
  - Minimize risk of fire when heating to pumping & mixing temp. below 230°C

- Cleveland Open Cup (COC) Flashpoint
  - Asphalt cement poured into sample cup & gradually heated
  - Swivel arm with flame at end passes back & forth over sample
  - Flashpoint is temperature at which vapours above sample momentarily ignite when flame passes over sample
Viscous Flow

- Fluid layers flow past each other at molecular level
  - Layer 1 moves faster than layer 2
  - **Shear Stress** \( (\tau) \) develops between layers due to difference in relative velocity between layers (Rate of Shear Strain)
  - **Coefficient of Viscosity** \( (\mu) \) relates Shear Stress \( (\tau) \) and Rate of Shear Strain

\[
\tau = \mu \times \text{Rate of Shear Strain} = \mu \frac{d\gamma}{dt}
\]

\[
\tau = \text{Shear Stress} \\
\gamma = \text{Shear Strain} \\
\frac{d\gamma}{dt} = \text{Rate of Shear Strain} \\
\mu = \text{Coefficient of Viscosity}
\]
Viscosity ($\mu$)

- **Viscosity ($\mu$)**
  - Slope of Shear Stress ($\tau$) vs. Rate of Shear Strain graph
  - Higher viscosity = greater resistance to flow

- **Newtonian Fluids**
  - Linear relationship between Shear Stress ($\tau$) and Rate of Shear Strain
  - Viscosity ($\mu$) is constant at different Shear Strain Rates
  - Unmodified asphalt cements are typically Newtonian Fluids at high temperatures

- **Non-Newtonian Fluids**
  - Non-Linear relationship between Shear Stress ($\tau$) and Rate of Shear Strain

- **Shear Thinning**
  - Newtonian (high temp asphalt)

- **Shear Thickening**
  - Ketchup
  - Starch Solution

- **Bingham Plastic**
  - Toothpaste

Shear Thickening – Starch Solution

Bingham Plastic - Toothpaste

(Minimum Shear Stress Required to Initiate Flow)
Rotational Viscometer

- Viscosity characterizes asphalt cement flow characteristics at elevated temperatures and provides info for:
  - Pumping and mixing operations at refinery, terminal, asphalt plant
  - Mixing & compaction temperatures for laboratory asphalt mix design

Asphalt cement sample heated in temperature controlled sample chamber

Metal spindle rotates (spins)

Torque required to rotate spindle is converted into absolute viscosity

Units = Pascal-Seconds (Pa-s), Poise (P)
Asphalt Binder Viscosity Specification

- Maximum Viscosity = 3 Pa-s at 135°C
  
  3 Pa-s = 3,000 cP
  Pascal-second -> Pa-s
  Centipoise -> cP

- Specify maximum viscosity to ensure ability to properly pump/mix asphalt binder
  - Specification may be waived if binder can be properly handled at higher viscosity
SUPERPAVE
Superpave

• Superpave (Superior Performing Asphalt Pavements)
  – Final product of US Strategic Highway Research Project (SHRP)
  – $53 Million allocated to asphalt research (1987-1992)

• Asphalt Binder Specification
  • Performance Graded Asphalt Cements or PGAC

• Mix design/analysis system based on mix volumetric properties
  • Superpave Mix Design Method

• Mix performance tests and predictive models
  • Not fully completed
SHRP Asphalt Binder Specification Development

• Identify
  – Critical pavement distress modes
  – Fundamental material properties associated with critical distress modes
  – Test methods that generate fundamental material properties
    • Consider timeliness, ease, cost, suitability for specifications
  – Surrogate test method if fundamental property related to pavement distress is not suitable for specification use
    • Select another fundamental test – avoid empirical tests
Pavement Distress Modes

• Rutting
  – Permanent (plastic) deformation in upper hot-mix layers at high pavement temperatures
  – Desire stiff and elastic material at high (summer) pavement temperatures

• Low temperature cracking
  – Thermal shrinkage and fatigue cracking at low temperatures
  – Desire flexible material at low (winter) pavement temperatures

• Fatigue cracking
  – Load-associated at intermediate pavement temperatures
  – Desire strain tolerant material at intermediate (spring) pavement temperatures

• Aging
  – Asphalt cement oxidizes and stiffens as it ages
  – Ultra violet light (UV) degradation

• Moisture damage
  – Desire adhesive asphalt cement with strong bond to aggregate surface in presence of water to bond failure (stripping)
Asphalt Cement and Aggregate
Contribution to Pavement Performance

Decreasing Temperature

- Rutting
- Fatigue Cracking
- Low Temp Cracking

Asphalt Cement and Aggregate Contribution to Pavement Performance

Aggregate

Asphalt Cement
Superpave Asphalt Binder Specification

- Grading based on climatic temperature
  - High temperature rating
    - High ambient temperatures reduce stiffness of asphalt cement making it more prone to permanent deformation under traffic loads (rutting)
  - Low temperature rating
    - Low ambient temperatures increase stiffness of asphalt cement making it more prone to cracking

PG 58-28

Performance Grade -> Maximum Pavement Design Temp -> 1-day Minimum Pavement Design Temp
### Performance Grade Increments

| Average 7-Day Maximum Pavement Temperature | 46 | 52 | 58 | 64 | 70 | 76 | 82 |
| Average 1-Day Minimum Pavement Temperature | -10 | -16 | -22 | -28 | -34 | -40 | -46 |

- Increments of 6°C between Performance Grades
  - PG 58-28, PG 64-28, PG 70-28....
  - PG 64-28, PG 64-34....
## AASHTO M320 Specification for Performance Graded Asphalt Cement (PGAC)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>High PG</th>
<th>Low PG</th>
<th>PG 52</th>
<th>PG 58</th>
<th>PG 64</th>
<th>PG 70</th>
<th>PG 76</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;230 °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 3 Pa-s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Flash Point**, AASHTO T 48
- **Rotational Viscosity** @ 135° C, AASHTO T 316
ASPHALT MODIFICATION
PG Distillation Line – Signature of Crude

PGAC properties of 3 asphalt cements produced from 3 different crude oil sources

Plot of High Temp PG vs. Low Temp PG shows what grades are feasible with each crude oil

PG 58-28 possible with Crudes A and B. Crude C cannot produce PG 58-28 (blue line does not cross through PG 58-28 box)

PG 64-22 possible with all 3 crudes (lines for A, B, C all pass through PG 64-22 box)

PG 70-28 cannot be produced using crude A, B, or C. Modification of asphalt binder produced with crude A, B, or C required to produce PG 70-28 (or other grades that are above the PG line)
## Modification Requirements for PGAC

### 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>
</tr>
</thead>
<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>
</tr>
<tr>
<td>-22</td>
<td>52-22</td>
<td>58-22</td>
<td>64-22</td>
<td>70-22</td>
<td>76-22</td>
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<tr>
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<td>52-28</td>
<td>58-28</td>
<td>64-28</td>
<td>70-28</td>
<td>76-28</td>
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<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>

- **Light Blue** = Crude Oil
- **Green** = Crude Oil or Modifier Required
- **Red** = Modifier Required

### “Rule of 86”
Modification often required if spread between High Temp PG and Low Temp PG exceeds 86.
Examples of PGAC Grades Used In Ontario

- PG 58-28 (most prevalent)
- PG 64-28 (southern Ontario for higher traffic)
- PG 70-28 (southern/eastern Ontario for very high traffic)
- PG 58-34 (eastern/north eastern Ontario)
- PG 64-34 (eastern/north eastern Ontario for higher traffic)
- PG 70-34 (eastern/north eastern Ontario for very high traffic)
- PG 52-34 (northern Ontario, southern Ontario for higher RAP mixes)
- PG 52-40 (northern Ontario)
- Large number of grades – opportunity to streamline and reduce to more practical number of grades
Specifications Driving Increasing Modified Asphalt Cement Use in Ontario

Modified Asphalt Cement as Percent of Total Paving Grade Asphalt Cement Used in Canada and (1999-2018)
Based on AC Supplier Survey Information (no data available for 2009 and 2015)
General trends are depicted. Actual results may vary significantly depending on specific asphalt and modifier properties.
SBS Block Copolymer

• SBS (Styrene-Butadiene-Styrene) is one of the most if not the most prevalent asphalt modifiers

• Thermoplastic elastomer
  – Elastic at low and intermediate temperatures
  – Plastic (flows and can be moulded) when heated (thermo) to high temperatures
    • In practice, mechanical mixing/shearing is also often required
SBS Polymer Properties

- Polystyrene (PS) is a rigid and brittle polymer
  - i.e. Used to make CD cases, children’s toys
- Polybutadiene (PB)
  - Soft rubber
- Styrene-Butadiene-Styrene (SBS)
  - Properties of PS and PB combine to produce a tough, elastic polymer
SBS polymer pellets introduced into hot asphalt cement and circulated through high shear mill to produce a concentrate.

SBS softens and swells. Combination of high temperature, high shear, and time “dissolves” SBS in liquid asphalt cement.

SBS concentrate diluted to required concentration, combined with any other required additives, and often chemically stabilized to ensure the SBS does not phase separate from the asphalt cement.
Miscibility of SBS and Asphalt Cement

In practice, SBS and asphalt cement are often not miscible and will phase separate even after high shear mixing.

SBS can be stabilized in asphalt cement by adjusting asphalt cement chemistry or by chemically bonding the SBS polymer molecules to reactive molecules within the asphalt cement.
SBS contains a double bond in the polybutadiene portion of the molecule which can react and allow the SBS polymer to form a chemical bond with reactive molecules within asphalt cement. Reacting or “cross-linking” SBS with asphalt cement is a means to produce a modified asphalt cement that is stable in storage.
ASPHALT CEMENT AGING CHARACTERISTICS
Asphalt Hot Mix Plant

Drum Mix Plant (Continuous Flow)
Asphalt Hot Mix Production

• Hot aggregate mixed and coated with a thin film (high surface area to volume ratio) of hot asphalt cement

• **SHORT TERM AGING** - Asphalt cement reacts with oxygen (oxidizes), loses volatiles, and stiffens

292°F = 144°C
Asphalt Pavement Construction

- Asphalt cement undergoes additional **SHORT TERM AGING** as it remains hot while it is transported to site, placed through a paver, and compacted with rollers.
Composition and Viscosity Changes During Mix Production, Placement, and Service Life

**SHORT TERM AGING**
- Significant stiffening during mixing and compaction phases
- Asphalt cement reacts with oxygen (oxidizes) as it coats aggregate as thin film (high surface area) at high temps

**LONG TERM AGING**
- Gradual oxidation & stiffening during pavement service life

**Composition changes**
- Asphaltenes ↑
- Aromatics, Resins ↓
- Increased polar asphaltene interactions produce stiffening of binder as it ages

Aging Index represents the stiffening of asphalt cement at a given time in service
SHORT TERM AGING LAB SIMULATION
Rolling Thin Film Oven (RTFO) Procedure

- Simulates short term aging experienced by binder during mix production and construction operations
  - Hot asphalt cement binder coats hot aggregates as a thin film in presence of air (oxygen)
- RTFO Procedure
  - 35 g binder poured into RTFO jar and placed horizontally into rotating carriage (15 rev/minute) in RTFO oven
  - Binder coats inside of bottle as thin film
  - Conditioned at 163°C for 85 minutes
  - 4,000 l/min air stream flows bottles as they rotate past air jet at bottom of oven
Rolling Thin Film Oven (RTFO) Procedure

• Procedure stiffens binder due to oxidation and volatiles loss
  - RTFO conditioned binder used in subsequent testing and conditioning protocols

• Mass loss measured to assess potential volatiles lost during hot mix production and paving

• Mass Loss Specification = 1% Max
LONG TERM AGING LAB SIMULATION
Pressure Aging Vessel (PAV)

• Binder conditioned under elevated temperature and pressure to simulate multi-year oxidative aging of pavement
  – Performed after short term aging RTFO procedure
• Approx. 50 g binder poured into PAV pan (~3.2 mm film depth) & conditioned under 2.1 MPa pressure for 20 hours
• Conditioning Temperatures
  – High temp PG 52 or lower conditioned at 90°C
  – High temp PG 58 or higher conditioned at 100°C
  – Binders designed for desert climate conditioned at 110°C
ASPHALT CEMENT RHEOLOGY

"PANTA REI" – "EVERYTHING FLOWS"
Motto of the Society of Rheology
Viscoelastic Response to Applied Stress or Strain

- A viscoelastic material exhibits both viscous and elastic behaviour

- Viscoelastic materials exhibit a lag between an applied stress or strain and the resulting response

- Oscillating application of stress or strain (RED) and the resulting response (BLUE) can be mathematically represented as sinusoidal waves with the same frequency and different phases
  - Phase lag describes the delayed response to an applied stress or strain
Dynamic Shear Rheometer (DSR)

- Measures rheological properties of asphalt cement binders
  - Relate to rutting (resistance to permanent deformation) and fatigue properties
- Sample positioned between parallel plates
  - Top plate oscillates back and forth
  - Bottom plate remains stationary
- Controlled stress mode
  - Apply oscillating stress & measure resulting strain
- Controlled strain mode
  - Apply oscillating strain & measure resulting stress
Complex Modulus (G*)

- **Complex (Shear Stiffness) Modulus** $G^*$
  - Ratio of **Maximum Shear Stress** ($\tau_m$) divided by **Maximum Shear Strain** ($\gamma_m$)

- Upper DSR plate oscillates back and forth
  - Measure **Angle of Rotation** ($\theta$) and applied **Torque** ($T$)
  - Determine **Shear Stress** ($\tau$) and **Shear Strain** ($\gamma$)

\[
G^* = \frac{\tau_{max}}{\gamma_{max}}
\]

\[
\tau = \frac{2T}{\pi r^3}
\]

\[
\gamma = \frac{\theta r}{h}
\]

$G^*$ = Complex (Shear Stiffness) Modulus (Pa)
$\tau_m$ = Maximum Shear Stress (Pa)
$\gamma_m$ = Maximum Shear Strain
$\theta$ = Angle of Rotation
$h$ = Sample height
$r$ = Radius of Sample/DSR plates
$T$ = Torque
Perfect Elastic and Viscous Responses

- Perfectly Elastic Solid
  - Applied Shear Stress & Resulting Shear Strain are in phase
    \[ \text{Phase Angle } \delta = 0^\circ \]
- Perfectly Viscous Fluid
  - Shear Strain lags Applied Shear Stress by 90° phase lag
    \[ \text{Phase Angle } \delta = -90^\circ \]
    \[ \text{or } -\pi/2 \text{ radians} \]
Viscoelastic Behaviour

$$\tau(t) = \tau_{\text{max}} \sin(\omega t)$$

$$\gamma(t) = \gamma_{\text{max}} \sin(\omega t - \delta)$$

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

$$\delta = \frac{2\pi \Delta t}{T}, \text{ radians}$$

$$\delta = 360 \frac{\Delta t}{T}, \text{ degrees}$$

$T = \text{Period (Cycle Time)}$
$\tau = \text{Shear Stress, Pa}$
$G^* = \text{Complex Modulus, Pa}$
$\gamma = \text{Shear Strain}$
Complex Modulus ($G^*$) May Be Resolved Into Storage Modulus ($G'$) and Loss Modulus ($G''$)

$|G^*| = \frac{\tau_m}{\gamma_m} \quad G'' = \frac{\tau_m}{\gamma_m} \sin(\delta) \quad |G^*| = (G'^2 + G''^2)^{1/2}$

$G' = \frac{\tau_m}{\gamma_m} \cos(\delta)$

**Loss Modulus ($G''$)**

Viscous (Non- Recoverable) Behaviour: Dissipated as heat upon deformation

**Storage Modulus ($G'$)**

Elastic Behaviour: Ability of Material to Store Energy and Release it Upon Deformation
RUTTING IN ASPHALT PAVEMENTS
Rutting in Upper Pavement Layers

- Accumulated plastic (permanent) deformation in mixture caused by repeated traffic loading
- Factors that influence rutting
  - Aggregate and mixture properties
  - Asphalt cement binder properties
  - Condition of base, sub-base, foundation
  - Traffic loading
  - Pavement temperature (more likely in summer)
Rutting Parameter $|G^*|/\sin\delta$

$|G^*|/\sin\delta$ on Original Binder at 10 rad/s (1.6 Hz) $\geq 1.00$ kPa

$|G^*|/\sin\delta$ on RTFO Residue at 10 rad/s (1.6 Hz) $\geq 2.20$ kPa

- Higher $|G^*|/\sin\delta$ values = Improved Rutting Resistance
  - $\uparrow |G^*|$ = Stiffer binder (resists permanent deformation)
  - $\uparrow \delta$ = More elastic binder ($G^*/\sin\delta$ increases as $\delta$ decreases)

Frequency of 10 rad/s approximates traffic at 80-100 km/hr

Note: $|G^*|$ denotes magnitude of Complex Modulus $G^*$

In the literature, the $|$ notation is commonly excluded and the rutting parameter is written as $G^*/\sin\delta$ although the proper notation is $|G^*|/\sin\delta$
Rutting Parameter $|G^*|/\sin \delta$

$|G^*|/\sin \delta$ on Original Binder at 10 rad/s (1.6 Hz) $\geq 1.00$ kPa

$|G^*|/\sin \delta$ on RTFO Residue at 10 rad/s (1.6 Hz) $\geq 2.20$ kPa

- **RTFO Residue** has undergone simulated short term aging and stiffening that binder is expected to experience when processed through asphalt plant

- Minimum requirement for **Original Binder** safeguards against over reliance on short term aging through asphalt plant (i.e. in case of low process temperature)
Rutting Parameter $|G^*|/\sin\delta$

$|G^*|/\sin\delta_{\text{ORIGINAL BINDER}} \geq 1.00 \text{ kPa}$

$|G^*|/\sin\delta_{\text{RTFO RESIDUE}} \geq 2.20 \text{ kPa}$

- Test binder at high pavement temperature for climatic region and “grade bump” for increased traffic loadings
  - One (1) Grade Bump = 6°C
  - PG 58-28 (southern Ontario) may be bumped to PG 64-28 for increased traffic loading (ESAL = Equivalent Single Axle Load of 18,000 lb / 80 kN)

<table>
<thead>
<tr>
<th>ESALS (Millions)</th>
<th>Standing Traffic</th>
<th>Slow Traffic</th>
<th>Standard Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.3 - 3</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>3 - &lt;10</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>10 - &lt;30</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>≥30</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

AASHTO M 323 Table 1
AASHTO M 320 Binder Specification

<table>
<thead>
<tr>
<th>High PG</th>
<th>PG 52</th>
<th>PG 58</th>
<th>PG 64</th>
<th>PG 70</th>
<th>PG 76</th>
</tr>
</thead>
</table>

**Original**

- **Flash Point, AASHTO T 48**
- **Rotational Viscosity @ 135°C, AASHTO T 316**
- **DSR G*/sin δ (Dynamic Shear Rheometer), AASHTO T 315**

<table>
<thead>
<tr>
<th>≥230 °C</th>
<th>52</th>
<th>58</th>
<th>64</th>
<th>70</th>
<th>76</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤3 Pa-s</td>
<td>DSR G*/sin δ (Dynamic Shear Rheometer), AASHTO T 315</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**RTFO (Rolling Thin Film Oven), AASHTO T 240**

<table>
<thead>
<tr>
<th>≤1.00%</th>
<th>52</th>
<th>58</th>
<th>64</th>
<th>70</th>
<th>76</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥2.20 kPa</td>
<td>DSR G*/sin δ (Dynamic Shear Rheometer), AASHTO T 315</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- All binders required to meet G*/sin\( \delta\)\text{ORIGINAL BINDER} ≥ 1.0 kPa and G*/sin\( \delta\)\text{RTFO RESIDUE} ≥ 2.2 kPa
  - Test PG 58-28 at 58°C, PG 64-34 at 64°C, PG 70-28 at 70°C etc.
- Flashpoint, Viscosity, & Mass Loss specifications apply to all binders.
FATIGUE CRACKING
Fatigue Cracking

• Cracking in asphalt pavement mixture caused by repeated traffic loading

• Factors that influence fatigue cracking
  – Asphalt cement content in mixes
    • Lean mixes with lower AC contents are more susceptible to cracking
  – Binder fatigue properties & traffic loading
  – Age of asphalt pavement & factors which increase oxidation of asphalt with time
    • e.g. pavements with higher air voids age faster
  – Pavement structure (thickness, strength of base, sub-base and foundation)
  – Mix gradation
    • e.g. finer mixes with higher AC content tend to have better fatigue properties than coarser mixes with lower AC content
Fatigue Cracking Parameter $|G^*| \sin \delta$

- Fundamental crack propagation properties considered too complex for specification purposes
  - Surrogate properties selected
- Dissipated energy per load related to fatigue properties of binder
- Dissipated energy in DSR test = Loss Modulus ($G''$)
- Loss Modulus $G'' = |G^*| \sin \delta$

\[ G' = \frac{\tau_m}{\gamma_m} \cos(\delta) \]

\[ G'' = \frac{\tau_m}{\gamma_m} \sin(\delta) = |G^*| \sin(\delta) \]
Fatigue Cracking Specification

\[ |G^*| \sin \delta_{\text{PAV Residue}} \leq 5,000 \text{ kPa} \]

- Fatigue testing performed on PAV residue to simulate aged pavement
  - Original Binder is SHORT TERM AGED in RTFO Oven
  - RTFO Residue subsequently LONG TERM AGED in PAV and then tested for fatigue properties
- Specification criteria remains \(|G^*| \sin \delta\) remains same for all binders and temperature at which binder is tested varies according to Performance Grade
  - Tested at mean pavement temperature + 4°C
  - PG 58-28 test temp = 19°C \(\leftarrow (58-28)/2 + 4 = 19\)
  - PG 70-34 test temp = 22°C \(\leftarrow (70-34)/2 + 4 = 22\)
AASHTO M 320 Binder Specification

- Conditioning temperature for PAV residue
  - 90°C for PG 52 climates and 100°C for higher temperature climates
  - 110°C for “desert” climates
- Temperature at which $|G^*|\sin\delta$ is evaluated using DSR

<table>
<thead>
<tr>
<th>Condition</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;230 °C</td>
<td>Flash Point, AASHTO T 48</td>
</tr>
<tr>
<td>≤ 3 Pa·s</td>
<td>Rotational Viscosity @ 135°C, AASHTO T 316</td>
</tr>
<tr>
<td>≥ 1.00 kPa</td>
<td>DSR $G^*/\sin\delta$ (Dynamic Shear Rheometer), AASHTO T 315</td>
</tr>
<tr>
<td>&lt; 1.00%</td>
<td>Mass Change</td>
</tr>
<tr>
<td>≥ 2.20 kPa</td>
<td>DSR $G^*/\sin\delta$ (Dynamic Shear Rheometer), AASHTO T 315</td>
</tr>
<tr>
<td>&lt; 5000 kPa</td>
<td>DSR $G^*\sin\delta$ (Dynamic Shear Rheometer), AASHTO T 315</td>
</tr>
</tbody>
</table>

**SHORT TERM AGING**

**LONG TERM AGING**
Double Edged Notched Tension Test (DENT)

- PAV Residue (after RTFO and PAV conditioning) poured into moulds
  - 3 samples each with different ligament length (5, 10, 15 mm)
  - Pulled at 50 mm/min and 15°C in water bath equipped to measure force and displacement

- Output is Crack Tip Opening Displacement (CTOD)

- “Made in Ontario Test” (Queen’s University / MTO)
  - MTO Test Method LS-299

- Some concerns with reproducibility of test results between different laboratories
• Specific Total Work of Fracture
  – Area under Force (Load) vs. Displacement Curves divided by vertical cross sectional area of ligament

• Specific Essential Work of Fracture
  – Y-intercept of Specific Total Work of Fracture plotted against sample ligament length (i.e. Specific Total Work of Fracture at “0” ligament length)

• Crack Tip Opening Displacement (CTOD)
  – Specific Essential Work of Fracture divided by Net Section Stress of smallest sample (L = 5mm) as ‘approximation’ to net section stress at L = 0 mm
  – Net Section Stress = Peak load divided by vertical cross sectional area of ligament for L = 5mm ligament width sample

• Higher CTOD values meant to imply more strain tolerance and better fatigue
LOW TEMPERATURE CRACKING
Low Temperature (Thermal) Cracking

- Caused by low (cold) pavement temperatures
  - Asphalt binder contracts in volume to greater extent than aggregate as temperature drops
  - Asphalt cement stiffens and becomes more susceptible to cracking as temperature drops
  - Thermal cracking occurs when stress exceeds tensile strength of binder
- Single event crack
  - Temperature drops to below critical cracking temperature of binder
  - Transverse crack in road (perpendicular to direction of traffic and often across width of road from one edge to the other)
- Thermal fatigue cracking
  - Repeated temperature cycling at temperatures somewhat above critical cracking temperature
Measurement of Low Temperature Cracking Properties

• Fundamental crack propagation properties considered too complex for specification purposes
  – Surrogate properties selected

• High stiffness of asphalt binders at low temperatures ($10^7$ – $10^8$ Pa) not suitable for evaluation with DSR
  – Stiffness of PAV binder tested with DSR is $\sim$1 to $5\times10^3$ Pa)
  – High stiffness = small deformations resulting in measurement and reproducibility problems

• Bending Beam Rheometer (BBR)
  • Stiffness and relaxation properties of asphalt binders at low temperatures
Bending Beam Rheometer (BBR)

- Low temperature Creep Stiffness and relaxation properties measured at constant temperature and under constant load
  - 3-point bending beam test
- Performed on PAV residue after conditioning in simulated aging RTFO and PAV procedures
  - Rolling Thin Film Oven (RTFO) procedure simulates aging binder undergoes when mixed with aggregate during hot mix asphalt production
  - Pressure Aging Vessel (PAV) simulates oxidative aging after several years of service in the field
- Performed at temperatures related to the lowest anticipated temperature that pavement is expected to reach
Bending Beam Rheometer (BBR)

- Simply supported asphalt cement beam conditioned in low temperature fluid bath
  - Blunt nose shaft applies load of 0.98N (100g) to midpoint of beam
  - Accurately measures deflection over 240 seconds
  - Low loading level does not stress beam to ultimate strength
  - Elementary Beam Theory used to calculate Creep Stiffness and rate of change of Creep Stiffness with loading time
Time-Temperature Superposition

- Asphalt properties are a function of **Loading Time** and **Temperature**

- **Time-Temperature Superposition**
  - Time and Temperature are interchangeable
  - Higher temperature and shorter time = Lower temperature and longer time

In the above illustration the flow of asphalt cement at 60°C for 1 hr is equal to the flow at 25°C after 10 hours. This is the principle of time-temperature superposition.
BBR Test Temperature

- BBR temperature = +10°C above low temperature Performance Grade of Binder
  - PG 58-28 test temp = -18°C
  - PG 64-34 test temp= -24°C
- Time-Temperature Superposition
  - Desired Creep Stiffness obtained after 2 hours of loading at minimum pavement design temperature
    - Desired PG 58-34 Creep Stiffness obtained after 2 hr at -34°C
  - Concept of Time-Temperature allows same creep stiffness to be obtained after 60 seconds at 10°C above minimum design temperature
    - PG 58-34 Creep Stiffness at -24°C and 60 s ≈ Creep Stiffness -34°C and 2 hr
- Time-temperature superposition utilized for practical reasons to reduce testing time from 2 hr+ to a few minutes
  - Underlying assumption is that time-temperature superposition holds valid for binders tested with BBR utilizing this principle
Deflection $\delta(t)$ measured as function of time and value at 60s used to calculation Creep Stiffness ($S$) using elementary beam theory mechanics.

Creep stiffness calculated over range of 8 to 240s using above equation
Log Creep Stiffness ($S$) vs Time ($t$) plotted on graph and second order polynomial fitted to data using least squares regression

$$\log S(t) = A + B\log(t) + C[\log(t)]^2$$

m-value [$m(t)$] defined as rate of change of log creep stiffness versus time. Differentiate above equation to determine m-value

$$|m(t)| = \left| \frac{d[\log S(t)]}{d[\log t]} \right| = |B + 2C\log(t)|$$
Creep Stiffness at 60s loading:  $S(60) \leq 300 \text{ MPa}$

$m$-value at 60s loading:  $m(60) \geq 0.300$

- Creep Stiffness and $m$-value specifications remain the same for all binders
  - Test temperature varies according to grade

- Test at Low Temperature Performance Grade + 10°C
  - e.g. Test PG 58-28 @ -18°C & PG 70-34 @ -24°C

- Maximum 300 MPa Creep Stiffness spec. limits stiffness of binder at low temp to prevent cracking
World’s Longest Running Experiment

- Pitch Drop Experiment (began in 1927)
  - Prof. Thomas Parnell
  - University of Queensland, Australia
  - Although “pitch” appears solid at room temperature (can be shattered with hammer) – it is actually highly viscous liquid (230 billion times as viscous as water)
- 9 drops have fallen since experiment began
  - Nobody saw the first 8 drops fall
  - Prof. Parnell passed away in 1948 after two drops had fallen and Prof. John Mainstone who became the experiment’s custodian passed away in 2013 without seeing a drop fall
    - Missed one drop after camping out over weekend at university (drop fell after Prof. Mainstone went home tired), another missed when left for cup of tea, and most recent when power outage caused video camera to fail
  - April 17, 2014 – 9th touched 8th drop but still attached to funnel
  - April 24, 2014 – Attempt to replace beaker holding previous 8 drops caused 9th drop to ‘snap’ off
- Make history – watch the next drop fall www.theninthwatch.com

Pitch can be shattered with hammer yet flows over long period of time
Understanding m-value

- **m-value** is the absolute value of the slope of the log Creep Stiffness curve vs. log time at 60s.
  - Represents the ability of the binder to relax and reduce stress build up in the binder.

- **m-value** is the absolute value of the slope of the log Creep Stiffness curve vs. log time at 60s.
  - Higher **m-value** = greater ability of the binder to relax and reduce stress build up in the binder (note that stress decreases with time).
  - Therefore, an increase in m-value = an increase in the absolute value of the slope.

  - If you pull a strand of plasticine apart very quickly it will quickly break.
  - If you pull it slowly you can stretch it to a longer length because the plasticine has time to relax internal stress build up.
  - Also think of the pitch drop experiment (shatters when hit with a hammer yet flows slowly over time).
AASHTO M 320 Specification

<table>
<thead>
<tr>
<th></th>
<th>PG 52</th>
<th>PG 58</th>
<th>PG 64</th>
<th>PG 70</th>
<th>PG 76</th>
</tr>
</thead>
<tbody>
<tr>
<td>High PG</td>
<td></td>
<td></td>
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</table>

**Original**

- **Flash Point, AASHTO T 48**
- **Rotational Viscosity @ 135°C, AASHTO T 316**
- **DSR G*/sin δ (Dynamic Shear Rheometer), AASHTO T 315**
  - 52
  - 58
  - 64
  - 70
  - 76

**RTFO (Rolling Thin Film Oven), AASHTO T 240**

- **Mass Change**
  - 1.00%
  - ≥ 2.20 kPa
  - DSR G*/sin δ (Dynamic Shear Rheometer), AASHTO T 315
    - 52
    - 58
    - 64
    - 70
    - 76

**PAV (Pressure Aging Vessel), AASHTO R28**

- **Intermediate Temp. = [(High PG + Low PG)/2] + 4**
- **BBR S (creep stiffness) & m-value (Bending Beam Rheometer), AASHTO T 313**
  - S ≤ 300 MPa
  - m ≥ 0.300

- **BBR Testing is on PAV Residue**

**Notes:**
- If BBR m-value ≥ 0.300 and creep stiffness is between 300 and 600, the Direct Tension failure strain requirement of ≥ 1.00% can be used in lieu of the creep stiffness requirement.
- Binder shall be homogeneous, free from water, contain no deleterious materials, be at least 99.0% soluble and contain no particles larger than 250 μm.
Direct Tension Test (DTT)

- Supplementary low temperature cracking test
  - BBR creep stiffness specification limits asphalt binders to 300 MPa maximum creep stiffness
  - Some binders exhibit high creep stiffness but can stretch (exhibit low temp ductility) considerably before breaking
- Direct Tension measures pulls dog-bone shaped sample of asphalt cement binder at low temperatures and determines creep strain at failure
  - Binders with Creep Stiffness 300 – 600 MPa (fail BBR specification) but that have 1% or greater creep strain at failure in Direct Tension test deemed acceptable
Direct Tension Test Reproducibility Issues

- Simple concept but sophisticated measurement device
  - Measures very small strains at low temperatures which requires high degree of precision and accuracy
  - Failure tests in which asphalt binder breaks are impart an inherent degree of variation in test results
  - In practice test was found to be very irreproducible despite significant research efforts to reduce testing variation

- Direct Tension Test has not been widely adopted because the inherent variation in test results make it difficult to implement as part of a specification
# AASHTO M 320 Specification

<table>
<thead>
<tr>
<th>High PG</th>
<th>PG 52</th>
<th>PG 58</th>
<th>PG 64</th>
<th>PG 70</th>
<th>PG 76</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low PG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Original

| >230 °C | Flash Point, AASHTO T 48 |
|< 3 Pa-s | Rotational Viscosity @ 135 °C, AASHTO T 316 |
| ≥ 1.00 kPa | DSR G*/sin δ (Dynamic Shear Rheometer), AASHTO T 315 |
|          | 52 | 58 | 64 | 70 | 76 |

### RTTO (Rolling Thin Film Oven), AASHTO T 240

| ≤ 1.00% | Mass Change |
|≥ 2.20 kPa | DSR G*/sin δ (Dynamic Shear Rheometer), AASHTO T 315 |
|          | 52 | 58 | 64 | 70 | 76 |

### PAV (Pressure Aging Vessel), AASHTO R28

| ≤ 5000 kPa | BBR S (creep stiffness) & m-value (Bending Beam Rheometer), AASHTO T 313 |
| S ≤ 300 MPa | m > 0.300 |
| Intermediate Temp. = [(High PG + Low PG)/2] + 4 |

- If BBR m-value ≥ 0.300 and creep stiffness is between 300 and 600, the Direct Tension failure strain requirement of ≥ 1.00% can be used in lieu of the creep stiffness requirement.
- Binder shall be homogeneous, free from water, contain no deleterious materials, be at least 99.0% soluble and contain no particles larger than 250 μm.

DTT
Extended BBR

• “Made in Ontario Test” (Queen’s University / MTO)
  – MTO Test Method LS-308

• Outputs
  – Low Temperature Limiting Grade (LTLG)
    • Low temperature BBR grade after BBR beams have been conditioned for 72 hr at low temperature prior to testing
  – Grade Loss
    • Difference between BBR grade after 1 hr of low temperature conditioning and BBR grade after 72 hr of conditioning
      – e.g. 72 hr BBR grade = -29°C and 1 hr BBR grade = -33°C then LTLG = -29°C and Grade Loss = 4°C

• Beam Conditioning
  – BBR beams conditioned for 1 hr, 24 hr, and 72 hr at T+10°C and T+20°C
    • Where T = Low Temperature Grade of Asphalt Cement
    • i.e. T= -28°C for PG 64-28
  – Exact grade required to be determined at each conditioning time & temp
  – Numerous samples and a lot of time required to obtain Extended BBR result
Extended BBR

• Based on premise that materials physically harden when held at isothermal (constant temperature)
• Generally referred to as Physical Hardening in asphalt cement and Physical Aging in other materials
• Phenomenon is common and occurs in many materials such as plastics and other polymers, ceramics, glasses...
• Phenomenon is reversible and effects can be erased if material is warmed up or if subjected to stress (stress relaxation)
• Scientists have known about physical hardening in asphalt cement for many decades and was also studied as part of the SHRP research program
  – i.e. penetration of asphalt cement at 25°C will be lower if sample tested after 24 hr is compared to sample results after 1 hr
  – Accounted for in other tests by limiting conditioning times (i.e. the ASTM D5 test method for penetration specifies maximum permissible conditioning times prior to testing)
MSCR TEST
How well does $G^*/\sin\delta$ correlate to rutting in the field?

I-80 Highway in Nevada
Two asphalt mixes: same aggregate gradation but different asphalt binder

- PG 63-22 polymer modified
  No rutting
- PG 67-22 neat (unmodified)
  15mm rutting

- PG 67-22 should have performed better than PG 63-22
  - High temperature rutting parameter $G^*/\sin\delta$ does fully capture ability of polymer modified asphalt cements to resist permanent deformation (rutting)
  - $G^*/\sin\delta$ appears to work better for unmodified binders

Danny Gierhart, PE – Asphalt Institute SEAUPG MSCR Task Group Web Meeting August 25, 2011
Rutting results in extensive deformation (strain) which is in the non-linear region for \( G^* \) and \( \delta \) (i.e. \( G^* \) and \( \delta \) are not constant with respect to strain at these strain levels).

- High temperature rutting parameter \( G^*/\sin\delta \) assumes a linear viscoelastic material
  - i.e. assumes \( G^* \) and \( \delta \) do not depend on strain for the low strain levels used in the test

- Reality is that rutted pavements experience high strain levels beyond the linear viscoelastic range for polymer modified asphalts
  - Low strains used when measuring \( G^*/\sin\delta \) do not give polymer chains in polymer modified asphalt cement a chance to “stretch” enough for them to “show their stuff” and distinguish themselves from an unmodified asphalt cement with a similar stiffness
Multiple Stress Creep Recovery Test (MSCR)

- Performed using DSR applying stress in unidirectional motion
  - DSR does not oscillate
  - Moves in 1 direction
  - **High strain levels are beyond linear viscoelastic region**
- Apply 1s Creep Stress (load) at 0.1 kPa followed by 9s rest period
  - Material creeps under stress and then partially recovers during rest period
- Repeat 10x at 0.1 kPa Creep Stress level
- Increase to 3.2 kPa Creep Stress level and repeat 10x
MSCR Creep Strain Response

- MSCR test measures non-recoverable shear strain
  - Expressed as non-recoverable creep compliance ($J_{nr}$)
- MSCR test measures recoverable shear strain
  - Expressed as % Recovery
Non-Recoverable Creep Compliance ($J_{nr}$)

- Modulus = Stress / Strain
- Compliance = Strain / Stress (reciprocal of modulus)
- $J_{nr}$ = Non-Recoverable Creep Compliance
Calculating $J_{nr}$ in MSCR Test

- $J_{nr}$ calculated for each of 10 cycles at 0.1 kPa shear stress and average $J_{nr \ 0.1kPa}$ reported
- $J_{nr}$ calculated for each of 10 cycles at 3.2 kPa shear stress and average $J_{nr \ 3.2kPa}$ reported
Calculating % Recovery in MSCR Test

% Recovery calculated for each of 10 cycles at 3.2 kPa shear stress and average % Recovery is reported.
Asphalt cement binders are viscoelastic materials with “built-in” elastic recovery properties.

- Inherent % recovery increases as binder becomes stiffer (i.e. as $J_{nr}$ decreases)

Required % Recovery must be $\geq 29.371(J_{nr})^{-0.2633}$ for binder to be considered as significantly modified with elastomeric modifier.

% Recovery criteria is not relevant for $J_{nr} > 2$ kPa$^{-1}$ (binder is likely unmodified)

Binders with % Recovery values above the curve are considered to have significant elastic recovery properties.

Binders with % Recovery values below the curve are not considered to have significant elastic recovery properties.
MSCR Test Identifies Differences in Polymer Network

- SBS polymer modified PG 64-22 asphalt cement (refined from Saudi Light Crude by Lion Oil)
  - SBS is compatible with this asphalt cement and does not separate for a long time
- LC 4 – 4% Linear SBS – discrete polymer particles
  - Highest $J_{nr}$ and lowest % recovery
  - Adding 0.5% Polyphosphoric Acid (PPA) causes polymer strands to develop in LC4 P - $J_{nr}$ decreases and % recovery increases
- LOP 4 – 4% Radial SBS diluted from 15% concentrate down to 4% SBS content
  - More uniform dispersion than LC4 and some bulking – lower $J_{nr}$ and higher % recovery
  - Adding 0.5% PPA causes even more uniform dispersion in LOP 4P – $J_{nr}$ decreases and % recovery increases

John D’Angelo – Transportation Research Board TRB E-C147 Developments in Asphalt Specifications - 2010
AASHTO M332 MSCR Specifications

- Test RTFO residue at **climatic temperature (LTPPBind High Temperature)** for region and adjust the specified value of $J_{nr \_3.2}$ (at 3.2 kPa$^{-1}$) to account for traffic loading
  - Cutting $J_{nr}$ in half approximately reduces rutting by half
- Example PG 58 Region: 58°C is designated as the maximum design pavement temperature
  - PG 58S-xx $J_{nr \_3.2} < 4.5$ $S =$ Standard <10 Million ESAL and and standard traffic loading
  - PG 58H-xx $J_{nr \_3.2} < 2$ $H =$ Heavy 10-30 Million ESAL or slow moving traffic
  - PG 58V-xx $J_{nr \_3.2} < 1$ $V =$ Very heavy >30 Million ESAL or standing traffic
  - PG 58E-xx $J_{nr \_3.2}<0.5$ $E =$ Extreme >30 Million ESAL & standing traffic
MSCR % Recovery Requirement

If elastomeric modifier is required:

\[
\% \text{ Recovery} \geq 29.371 \left( J_{nr} \right)^{-0.2633}
\]
AASHTO M332 MSCR Specifications

• If elastomeric modifier is required:
  \[ \% \text{Recovery} \geq 29.371 \left( J_{nr} \right)^{-0.2633} \text{ on RTFO Residue} \]

• \( G^* \sin \delta \) on PAV Residue \( \leq 6,000 \) kPa
  - Tested at intermediate temperature for base grade
    • i.e. for “S” grade
  - Test temperature does not get adjusted if upgrade to H, V, E grades
    • i.e. test temperature for 58S-28 is 19°C
    • 58H-28, 58V-28, and 58E-28 also all tested at 19°C
ADDITIONAL ASPHALT CEMENT TESTS
Consistency Test - Penetration

- Empirical test to measure asphalt consistency
  - Usually run at 25°C, 100 g load, for 5 seconds
  - Asphalt cement sample poured into penetration cup and conditioned at test temperature in temperature controlled water bath
  - Standardized needle loaded with 100 g weight and allowed to penetrate asphalt standardized conditions (i.e. 25°C, 100g, 5 s)
  - Penetration depth measured in units of 0.1 mm (dmm) and reported as penetration units
    - e.g. if needs penetrates 8.5 mm (i.e. 85 dmm) then the penetration is 85
  - Sometimes run at 4°C to provide information on low temp properties of asphalt cement

![Diagram of Penetration Test](image)
Solubility, Ash Content, Water Content - Purity Tests

- **Solubility Test (ASTM D2042)**
  - Refined asphalt cement consists of almost pure bitumen
    - Entirely soluble in carbon disulfide (by definition)
    - Only little amounts of impurities generally present in refined asphalt cements
  - Asphalt cement sample of known weight dissolved in trichloroethylene (TCE) and filtered through glass fibre pad
    - Insoluble material (constitutes impurity) is washed, dried, and weighed
  - Specifications generally require minimum 99.0% solubility in TCE

- **Ash Content (ASTM D2939)**
  - Asphalt cement sample (50 g in 30 cm³ crucible) incinerated at 1110°F (600°C) in muffle furnace
  - Remaining ‘ash’ content represents impurities
  - Ontario Specifications currently vary from minimum 1.0% ash down to minimum 0.6% ash content permitted
    - Reduced maximum ash content requirement limits non-organic modifiers or modifiers (i.e. REOB) with non-organic components such as metals

- **Moisture Content**
  - Desirable that the asphalt is free of moisture because it can cause the asphalt to foam when it is heated above 100°C
Consistency Tests - Viscosity

- Viscosity = resistance to flow of a fluid

- Absolute viscosity
  - Applied shear stress divided by shear rate per second
  - Basic unit of viscosity is the Pascal second (Pa.s)
    - (6.895 psi = 1 kilopascal or 1 kPa)
  - Viscosity grading of asphalt cements based on absolute viscosity at 60°C

- Kinematic viscosity of asphalt cement usually measured at 135°C with units of mm²/sec

- Absolute viscosity = Kinematic viscosity x specific gravity of asphalt cement
Consistency Tests - Softening Point

• Softening Point is measured by the ring and ball method (ASTM D36)
  • Temperature at which the asphalt cement cannot support the weight of a steel ball and starts flowing
  • Purpose is to determine the temperature at which a phase change occurs in asphalt cement

• Used more extensively in Europe to specify paving grade asphalts
• In North America, mostly used to specify roofing asphalts, crack sealants, some emulsion residues
Ductility and Elastic Recovery

• **Ductility Test (ASTM D113)**
  - Ductility measured by the distance to which asphalt cement will elongate before breaking when the two ends of a briquette specimen are pulled apart
    - Typically tested at 25°C and 5 cm/min pull rate
  - Originally introduced to identify asphalt cements with high wax contents, since these materials had poor ductility
  - Utility of this test is limited due to its empirical nature and poor reproducibility.

• **Elastic Recovery Test (ASTM D6084)**
  - Measured by the recoverable strain determined after severing an elongated briquet specimen
  - Specimens pulled to a specified distance at a specified speed (5 cm/min) and at a specified temperature (25°C)
  - Quebec (MTQ) test varies – conducted at 15°C
Specific Gravity

- Specific Gravity (ASTM D70)
  - Ratio of mass of material at given temperature to mass of equal volume of water at same temperature
    - Measured using pycnometer
  - Specific gravity of asphalt cement changes with temperature
  - Specific gravity at 15.6°C (60°F) used for asphalt cement purchases/sales
    - Measured volume at given temperature corrected to volume at 15.6°C (60°F).
    - Specific gravity used to convert volume to mass (e.g. tonne)
  - Typical asphalt cement specific gravity at 15.6°C (60°F) = 1.03
Aging Test – Thin Film Oven Test

- Thin Film Oven Test (TFO) simulates substantial short-term aging (hardening) asphalts undergo when they are mixed with hot mineral aggregates in a HMA facility.

- Thin Film Oven Test
  - 50 gm is placed in a flat bottom pan to a depth of 1/8 in
  - Material is then heated at 163 ºC for 5 hours
  - Penetration or viscosity is then measured as well as loss or gain.

- Rolling Thin Film Oven Test (RFTO)
  - Covered previously in this presentation
  - Part of PGAC grading system
  - Used more extensively than TFO
ASPHALT CEMENT GRADE SELECTION AND ONTARIO SPECIFICATIONS
Ontario PGAC Zones

• Ontario divided into PGAC zones in 1990’s
  – Zone 1 = 52-34
  – Zone 2 = 58-34
  – Zone 3 = 58-28

• Zone borders
  – Zone 1 and 2 from Georgian Bay, east along French River, Lake Nipissing, Mattawa River to the Ottawa River
  – Zone 2 and 3 from Honey Harbour, south-easterly through Longford, Taylor Corners, Caven, Cambellford, and Mallorytown
LTPPBind Pavement Design Temperatures

• **LTPPBind v3.1 available online**
  – Outputs High and Low Temperature Performance Grades at different reliability levels based on historical weather station data for a particular location

• **High Temp PG based on high temperature damage algorithm**
  – 20-Year Degree Days > 10°C
  – Rut depth (2-13 mm / select nominal 10 mm)
  – Standard Traffic
    • ≤3 Million Equivalent Single Axle Loads (ESAL)
    • High Speed

• **Average 1-Day Minimum Pavement Temperature (T_{Low})**
  – Pavement temperature at surface of pavement layer
Ottawa – LTTPBind Output – PG 58-34 Region

<table>
<thead>
<tr>
<th>Station ID</th>
<th>County / District</th>
<th>Last Year Data Avail.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6105976</td>
<td>E. Ontario Counties</td>
<td>1996</td>
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</table>

<table>
<thead>
<tr>
<th>State/Province</th>
<th>ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather Station</td>
<td>OTTAWA CDA</td>
</tr>
</tbody>
</table>

| Depth from Pavement Surface to Top of Layer, mm | 0 |

<table>
<thead>
<tr>
<th>Air Temperature</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Min</th>
<th>Max</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>High 7-day Air Temp., Deg. C</td>
<td>30.6</td>
<td>1.8</td>
<td>27.0</td>
<td>35.5</td>
<td>101</td>
</tr>
<tr>
<td>Low Air Temperature, Deg. C</td>
<td>-31.6</td>
<td>3.0</td>
<td>-38.9</td>
<td>-23.9</td>
<td>104</td>
</tr>
<tr>
<td>Low Air Temp. Drop, Deg. C</td>
<td>16.7</td>
<td>6.5</td>
<td>6.1</td>
<td>31.7</td>
<td>103</td>
</tr>
<tr>
<td>Degree Days over 30 Deg. C</td>
<td>27</td>
<td>24</td>
<td>0</td>
<td>109</td>
<td>101</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pavement Temperature and PG</th>
<th>HIGH</th>
<th>LOW</th>
<th>High Rel</th>
<th>Low Rel</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% Reliability Pvt Temp., C</td>
<td>48.0</td>
<td>-23.8</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>&gt;50% Reliability PG</td>
<td>52</td>
<td>-28</td>
<td>88</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>58</td>
<td>-28</td>
<td>98</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>58</td>
<td>-34</td>
<td>98</td>
<td>98</td>
</tr>
</tbody>
</table>

PG 58-34 at 98% reliability
## Comparing Ontario Zones to LTPPBind
### Low Temp PG Requirement at 98% Reliability

<table>
<thead>
<tr>
<th>Location</th>
<th>Ontario Zone Classification</th>
<th>LTPPBind Low Temp PG Requirement at 98% Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timmins</td>
<td>PG 52-34 (Zone 1)</td>
<td>-40</td>
</tr>
<tr>
<td>Ottawa</td>
<td>PG 58-34 (Zone 2)</td>
<td>-34</td>
</tr>
<tr>
<td>Barrie (wpcc)</td>
<td>PG 58-28 (Zone 3)</td>
<td>-34*</td>
</tr>
<tr>
<td>Richmond Hill</td>
<td>PG 58-28 (Zone 3)</td>
<td>-28</td>
</tr>
<tr>
<td>Toronto</td>
<td>PG 58-28 (Zone 3)</td>
<td>-28</td>
</tr>
<tr>
<td>Windsor</td>
<td>PG 58-28 (Zone 3)</td>
<td>-22</td>
</tr>
</tbody>
</table>

*Note: PG XX-28 binder for Barrie (wpcc) has a 96% low temp design reliability*
Low Temperature Reliability Changes Moving from South to North of Kingston

- PG XX-28 = 50% Reliability
- PG XX-34 = 98% Reliability
- PG XX-22 = 50% Reliability
- PG XX-28 = 98% Reliability
Selecting Low Temperature Design Reliability

- Based on a statistical interpretation of the weather data
  - Choose a level of reliability based on the tolerance for risk on the part of the agency
  
  “An important question is what level of reliability should be used when selecting binders. Engineers and technicians should keep in mind that if a PG binder is selected at a 50% reliability level, there is a 50-50 chance in any year that the high and/or low pavement temperature will exceed those for which the binder has been developed. That is, a pavement made using a binder selected at a 50% reliability level is likely to exhibit rutting and/or low-temperature cracking within a few years. Therefore, high reliability levels should be used when selecting binders. For lightly travelled rural and residential roads, reliability levels of at least 90% should be used. For interstate highways and other major construction projects, reliability levels of at least 95% should be used when selecting performance-graded binders.”

- Selecting low temp design reliability of 95% still means that there is a 5% chance in any year that low temp rating of the binder will exceeded
  - What is the risk tolerance of the government owner agency?
Ontario Provincial MTO Guidelines for Upgrading High Temp PGAC Grade Based on Roadway Classification and Traffic Conditions


<table>
<thead>
<tr>
<th>Highway Type</th>
<th>Increase From Standard (1)</th>
<th>Optional Additional Increase (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Freeway</td>
<td>2 Grades</td>
<td>N/A</td>
</tr>
<tr>
<td>Rural Freeway Urban Arterial</td>
<td>1 Grade</td>
<td>1 Grade</td>
</tr>
<tr>
<td>Rural Arterial Urban Collector</td>
<td>Consider 1 Grade if Heavy Truck Traffic &gt; 20% of AADT</td>
<td>1 Grade</td>
</tr>
<tr>
<td>Rural Collector Urban/Suburban Collector</td>
<td>No Change</td>
<td>1 or 2 Grades</td>
</tr>
</tbody>
</table>

- Note 1: Upgrading high temp grade recommended for surface & top binder courses
  - Top 80 to 100 mm of hot mix

- Note 2: Consider increase in high temp grade for roadways experiencing high % heavy truck or bus traffic at slow speeds, frequent stop/starts, and historical concerns with instability rutting
Ontario Municipal Guidelines for Upgrading High Temp PGAC Grade Based on Roadway Classification and Traffic Conditions

- OPSS.MUNI 1101 Material Specification for Performance Graded Asphalt Cement November 2016 (Non-Mandatory Appendix 1101-A)

<table>
<thead>
<tr>
<th>Highway Type</th>
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<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></td>
</tr>
<tr>
<td>Urban Arterial</td>
<td>1 Grade</td>
<td>1 Grade</td>
</tr>
<tr>
<td>Rural Arterial</td>
<td>Consider 1 Grade if Heavy Truck Traffic &gt; 20% of AADT</td>
<td>1 Grade</td>
</tr>
<tr>
<td>Urban Collector</td>
<td>No Change</td>
<td>1 or 2 Grades</td>
</tr>
<tr>
<td>Rural Collector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural Local Collector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban/Suburban Collector</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Upgrading high temp grade recommended for surface & top binder courses
  - Top 80 to 100 mm of hot mix

- Note 1: Consider increase in high temp grade for roadways experiencing high % heavy truck or bus traffic at slow speeds, frequent stop/starts, and historical concerns with instability rutting
### Ontario Municipal Guidelines for Selecting MSCR Grade Based on Roadway Classification and Traffic Conditions

- **OPSS.MUNI 1101 Material Specification for Performance Graded Asphalt Cement November 2016 (Non-Mandatory Appendix 1101-B)**

<table>
<thead>
<tr>
<th>Highway Type</th>
<th>MSCR Grade</th>
<th>Optional Additional Increase (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Freeway</td>
<td>XXV-YY</td>
<td>N/A</td>
</tr>
<tr>
<td>Rural Freeway</td>
<td>XXH-YY</td>
<td>XXV-YY</td>
</tr>
<tr>
<td>Urban Arterial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural Arterial</td>
<td>XXH-YY</td>
<td>XXV-YY</td>
</tr>
<tr>
<td>Urban Collector</td>
<td>Consider XXH-YY if heavy truck traffic &gt;20% of AADT</td>
<td>XXV-YY</td>
</tr>
<tr>
<td>Rural Collector</td>
<td>XXS-YY</td>
<td>XXH-YY or XXV-YY</td>
</tr>
<tr>
<td>Rural Local</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban/Suburban Collector</td>
<td>XXS-YY</td>
<td>XXH-YY or XXV-YY</td>
</tr>
<tr>
<td>Toll Plaza</td>
<td>XXE-YY</td>
<td>N/A</td>
</tr>
<tr>
<td>Port Facility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dedicated Transitways</td>
<td>XXE-YY</td>
<td></td>
</tr>
<tr>
<td>Truck Marshaling Yards (standing traffic)</td>
<td></td>
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</tr>
</tbody>
</table>

- MSCR graded asphalt cement recommended for surface & top binder courses
  - Top 80 to 100 mm of hot mix

- Note 1: Consider increase in high temp grade for roadways experiencing high % heavy truck or bus traffic at slow speeds, frequent stop/starts, and historical concerns with rutting
AASHTO M323 Binder Selection on Basis of Traffic Speed and Traffic Level

- AASHTO M323 Superpave Volumetric Mix Design – Table 1

<table>
<thead>
<tr>
<th>Design ESALS over 20 Year Period (Millions)</th>
<th>Standing Traffic (Avg &lt;20 km/hr)</th>
<th>Slow Traffic (Avg 20-70 km/hr)</th>
<th>Standard Traffic (Avg &gt;70 km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.3 - 3</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>3 - &lt;10</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>10 - &lt;30</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>≥30</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

(ESAL = Equivalent Single Axle Load of 18,000 lb / 80 kN)
Ontario Provincial Asphalt Cement Specifications

• Specifications
  – OPSS.PROV 1101 Material Specification for Performance Graded Asphalt Cement
  – SSP 111 F09 – Amendment to OPSS.PROV 1101

• Requirements
  – AASHTO M320 (PGAC)
  – Additional Requirements
    • Restrictions on Polyphosphoric Acid (PPA) Modifier
    • Ash Content Limits
    • MSCR % Recovery
    • DENT
    • Extended BBR
Ontario Municipal Asphalt Cement Specifications

- Specifications
  - OPSS.MUNI 1101 Material Specification for Performance Graded Asphalt Cement
  - Numerous municipalities have their own specific specifications
    - Potential to consolidate under OPSS.MUNI 1101 which underwent major revisions in November 2016

- Requirements
  - AASHTO M320 (PGAC)
  - Additional Requirements
    - Restrictions on asphalt cement modifiers
    - Ash Content Limits
    - MSCR % Recovery
    - DENT
    - Extended BBR
  - Optional Appendix to specify full MSCR (AASHTO M332) requirements
OTHER ASPHALT CEMENT GRADING SYSTEMS
Other Asphalt Cement Grading Systems

• Penetration Grading System
  • Penetration of asphalt cement at 25 °C is primary criteria
  • Six typical paving penetration grades: 40-50, 60-70, 85-100, 120-150, 150-200 and 200-300
  • Penetration grade 300-400 and softer may also be specified or used for non-paving applications (i.e. roofing flux)

• Viscosity Grading System
  • Absolute Viscosity of asphalt cement at 60 °C is basis for specification
  • Six grades commonly specified are AC-2.5, AC-5, AC-10, AC-20, AC-30 and AC-40
    • e.g. AC-10 requires absolute viscosity of asphalt cement at 60°C be 1000±200 poise

• AR Viscosity Grading System
  • Based on absolute viscosity of aged residue after aging in rolling thin film oven
  • Five grades commonly specified are AR-1000, AR-2000, AR-4000, and AR-8000 and AR-16000
    • e.g. AR-1000 has aged viscosity requirement of 1000 ± 250 poise at 60 °C
Comparison of Penetration and Viscosity Spec Systems

Penetration Grades

- AC 40
- AC 20
- AC 10
- AC 5
- AC 2.5

Viscosity, 60°C (140°F)

- AR 16000
- AR 8000
- AR 4000
- AR 2000
- AR 1000
Penetration-Viscosity Spec System (A, B, C Grades)

- Penetration-Viscosity Spec System
  - Based on CAN/CGSB-16-3-M90 “Asphalt Cements for Road Purposes” (specification has been withdrawn)
  - Still used by some western Canadian Provinces

<table>
<thead>
<tr>
<th>Penetration</th>
<th>Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 - 70</td>
<td>150 - 200</td>
</tr>
<tr>
<td>80 - 100</td>
<td>200 - 300</td>
</tr>
<tr>
<td>120 - 150</td>
<td>300 - 400</td>
</tr>
</tbody>
</table>

In addition, three Groups of asphalt cements are defined in accordance with their temperature susceptibility properties. Temperature susceptibility is defined as the change in consistency (viscosity or penetration) that an asphalt cement undergoes for a given change in temperature. Thus the temperature susceptibility properties, by Group, are:

- **Group A** - asphalt cements that have a high viscosity at 60°C (or 135°C), for a given penetration at 25°C (low temperature susceptibility).

- **Group B** - asphalt cements that have a medium viscosity at 60°C (or 135°C) for a given penetration at 25°C (medium temperature susceptibility).

- **Group C** - asphalt cements that have a low viscosity at 60°C (or 135°C) for a given penetration at 25°C (high temperature susceptibility).

A matrix of eighteen candidate asphalt cements exists, as a function of penetration grade and temperature susceptibility Group.

NOTE: THERE ARE NO MAXIMUM VISCOSITY LIMITS FOR "A" GRADE ASPHALT CEMENTS
LABORATORY MIXING AND COMPACTION TEMPERATURES
Temperature-Viscosity charts used to predict mixing and compaction temperatures for laboratory (not in the field) mix designs based on equi-viscous temperature ranges

- Applicable to unmodified binders (required temperatures for polymer modified binders often over-predicted by using this methodology)
- AC Viscosity very sensitive to temperature (Temperature ↑ = Viscosity ↓)
Laboratory Mixing and Compaction Temperatures

- New specifications are increasing content of polymer modifiers in asphalt cement
- Suspect laboratory compaction influenced by lubricity (polymers increase lubricity?) and viscosity
- NCHRP 648 – Mixing and Compaction Temperatures in HMA
  - DSR Steady Shear Flow Viscosity
  - DSR Phase Angle Method
- Other methods
  - High shear rate viscosity, zero shear viscosity, mixture workability/compaction

Required laboratory mixing and compaction temperatures for modified asphalt cements are lower than predicted by Equiviscous Temperature Method which may predict temperatures that are too high. Currently no universally accepted standard method to determine mixing/compaction temperatures for modified binders.
MOISTURE SENSITIVITY
Moisture Damage

- Poor adhesion between the asphalt cement binder and aggregate may lead to stripping (delamination of the binder from the aggregate surface) in the presence of water.
- Leads to pavement failure (ravelling, potholes, rutting)

Asphalt cement has stripped from aggregate after conditioning in presence of water.
Asphalt briquette prior to conditioning in presence of water in order to evaluate potential moisture damage.
Pavement with Stripping Failure

Left Side of Asphalt Pavement Experiencing Stripping Problems

Right Side of Asphalt Pavement Performing Well
Moisture Damage

- Ability of asphalt binder to coat and remain adhered to aggregate depends on:
  - Chemical compatibility between asphalt cement and aggregate surface
    - Aggregate surfaces have a greater affinity for water than they do for asphalt cement
  - Porosity and surface texture of aggregate surface
    - Asphalt cement may have more difficulty adhering to smooth low absorbing aggregates (granite, quartzite)
  - Aggregates with a high dust content
    - Asphalt binder coats dust but not the coarse aggregate particle surrounded by the dust
  - Processing Conditions
    - Freshly crushed aggregates may have poorer adhesion properties than weathered aggregates (issue with high silica content agg.)
    - Failing to properly dry/remove the water from aggregates during the hot mix production process can lead to stripping issues
Asphalt – Aggregate Surface Chemistry

• Aggregates sometimes described as basic or acidic
  – Basic (Limestone, Marble – low silica content)
  – Acidic (Granite, Quartzite – high silica content)
  – Very simplified model (aggregates actually contain combination of basic and acidic groups)

• Asphalt cement is acidic in nature
  – Napthenic acids have carboxylic acid (-COOH) functional group
    • Simplified model (asphalt cement has acidic and basic components but is more acidic than basic)

• Acidic groups in asphalt cement:
  – React with and adhere better to basic aggregates (limestone) with low silica contents (“Opposites Attract”)
  – Exhibit poorer bonding to acidic aggregates (granite, quartzite) with high silica contents (“Likes Repel”)

Anti-Stripping Agents Improve Adhesion

- Asphalt cement modified with anti-stripping agents
  - Amine based chemistries are most common
  - Polar head is hydrophilic and is attracted to aggregate surface
  - Lipophilic tail is attracted to asphalt cement
  - Acts as bridge to bond asphalt cement and aggregate

Akzo-Nobel – Asphalt Institute Meeting – Spring 2002
Options to Improve Asphalt Aggregate Adhesion

• Liquid anti-stripping agents
• Treat aggregate with hydrated lime slurry
  – Theory is that hydrated lime (basic) reacts with napthenic acids in asphalt cement to improve adhesion to aggregates with higher silica contents (granite, quartzite...)
• Allow freshly crushed aggregate time to weather
  – Theory is that crushing imparts electrostatic charges onto aggregate surface and/or opens fresh reaction sites which repel asphalt cement
  – Charges dissipate over time and/or reaction sites partially react with substances in environment
• Other
  – Latex or silane treatment of aggregate
• Deep topic – we have looked at simplified view
BONUS/REFERENCE MATERIALS
(EMULSIONS AND CUTBACKS WILL BE COVERED IN ANOTHER COURSE)

ASPHALT EMULSIONS AND CUTBACKS

OIL

WATER

OIL IN WATER EMULSION
Asphalt Emulsions - Oil and Water Do Mix

- An emulsion is a stable dispersion of two immiscible fluids
  - A dispersion of small droplets of one liquid in another liquid

- Asphalt emulsion is asphalt dispersed in water and chemically stabilized.

- Emulsifiers are chemicals that are used to stabilize a suspension of asphalt in water.

Asphalt Emulsion Under the Microscope
Why emulsify asphalt?

- Asphalt cement is not very fluid at ambient temperatures
- In order to move it around we must reduce the asphalt’s viscosity
  1. Increase temperature
  2. ‘Cut’ with solvent (cutback asphalt)
  3. Disperse in **water** (emulsify)
- Emulsions may be used with unheated and wet aggregates
Asphalt Emulsion Composition

- Asphalt Cement ~40 to 70% (~62% typical value for some grades)
- Water (often softened) ~ 30 to 50% (~35% typical value)
- Chemicals (emulsifiers) ~ 0.2 to 2.5%
- Solvent (sometimes) ~ 0 to 30%
- Polymers (sometimes) ~ 0 to 4%
- Other Additives ~ 0 to 1%
Asphalt Emulsion Manufacturing

- Emulsions are made by mixing hot asphalt with water

- Using sufficient energy to break the asphalt up into droplets *(Mechanical Energy)*

- In the presence of emulsifying chemicals that keep the asphalt droplets dispersed in the water *(Chemical Energy)*
Mechanical Energy

• Mechanical energy
  – Divides asphalt cement (or bitumen if you happen to be in Europe) into fine particles

• COLLOID MILL provides mechanical energy
Colloid Mill Shears
Asphalt Cement Into Microscopic Droplets
Colloid Asphalt Emulsion Mill

- **a)** Soap pumped into mill
- **b)** Asphalt pumped into mill
- **c)** Rotor & Stator mill asphalt into microscopic droplets which are dispersed in soap
- **d)** Emulsion exits mill
Typical asphalt emulsion droplet particle size distribution

Asphalt Emulsion Particle Size Distribution
Chemical Energy – The Emulsifier Molecule

- **ANIONIC**—hydrophilic head has a negative charge
  - e.g. \[ \text{R(tall oil)} - \text{COO}^- \text{ Na}^+ \]

- **CATIONIC**—hydrophilic head has a positive charge
  - e.g. \[ \text{R(tallow)} - \text{N}^+(\text{CH}_3)_3 \text{ Cl}^- \]

- **NON-IONIC** - no charge

Source: Akzo-Nobel
Anionic Asphalt Emulsions

• Anionic asphalt emulsions
  • Emulsifiers are often fatty acid derivatives from wood products.
  • e.g. Tall oil can be reacted with caustic to form an emulsifying agent [RCOO\(^{-}\) Na\(^{+}\)]
• Break by evaporation of water to form a continuous film of asphalt on the aggregate.
Cationic Asphalt Emulsions

• Cationic asphalt emulsions
  • Emulsifiers are often fatty amines derived from animal fat (tallow)
  • Fatty amine is usually reacted with hydrochloric (muriatic) acid to form the emulsifying agent $[\text{RNH}_3^+\text{Na}^+]$
  • Break primarily by electro-chemical process and most effective with aggregates that have net negative charge (e.g. siliceous gravel).

1. Contact of emulsion with aggregates
2. Adsorption of free emulsifier
3. Electrophoresis of droplets to surface
4. Coagulation / spreading over surface

Source: Akzo-Nobel
Emulsion Stability

- **Anionic emulsion**
  - Emulsifier (also called Surfactant or “Soap” if you work in a real emulsion plant) provides negatively charged surface around asphalt droplets
  - Electrostatic repulsion keeps asphalt droplets dispersed in water

- **Cationic emulsifiers** (positively charged) also provide electrostatic stabilization

- **Non-ionic emulsifiers** are not charged and use steric stabilization
The Soap Opera

- Emulsifier **tail** *likes asphalt* (lipophilic) and **hates water** (hydrophobic)
  - Embeds itself into asphalt droplet
- Emulsifier **head** *hates asphalt* (lipophobic) and **likes water** (hydrophilic)
  - Stays in water and surrounds surface of asphalt droplet
- Emulsifier heads do not like each other (electrostatic or steric repulsion)
  - Surfactants (surface-active-agents) prevent asphalt droplets from coming in close proximity and keep them dispersed in water phase
Asphalt Emulsion Plant Schematic

Emulsion tanks are tall and skinny. This minimizes surface area exposed to air and helps prevent ‘skinning’ of emulsion surface.

Source: Akzo-Nobel
Emulsion Types

- Oil in Water Emulsion (e.g. HF-150S)
- Water in Oil Emulsion (e.g. VLW)
- Multiple Emulsion (i.e. Water In Oil – In Water)
Three States of Emulsions

**Stable Emulsion (Emulsion Droplets)**

Close approach between droplets prevented by charge on droplet surface.

**Flocculation**

Close approach of droplets leads to adhesion between droplets.

**Coalescence**

Water drains between droplets. Surfactant film breaks down. Droplets fuse.

Source: Akzo-Nobel
Emulsion Nomenclature

Most emulsions are named using a few simple conventions:

- C or K refers to CATIONIC. If neither is in the name it is usually and ANIONIC grade.
- RS means “Rapid Set”
- MS means “Medium Set”
- SS means “Slow Set”
- QS means “quick set” (slurry mixing grades)
- S at end means “spray grade”
- M at end means “mixing grade”
- HF means High Float
- P means Polymer Modified
- 1 means low viscosity
- 2 means high viscosity
- H means harder asphalt used
- V means Very
- L means Little
- W means Water
## Emulsion Grades

### ANIONIC
- **RS-1**  
  rapid setting low viscosity
- **RS-2**  
  rapid setting high viscosity
- **SS-1**  
  slow setting low viscosity
- **SS-1H**  
  slow setting hard asphalt
- **HF-150S**  
  high float spray grade
- **HFRS-2**  
  high float rapid set high viscosity
- **HFMS-2**  
  high float medium set high viscosity
- **HFMS-2P**  
  high float medium set high viscosity polymer modified
- **VLW**  
  Very Little Water

### CATIONIC
- **CRS-1 / RS-1K**  
  cationic rapid set low viscosity
- **CRS-2 / RS-2K**  
  cationic rapid set high viscosity
- **CRS-2P**  
  cationic rapid set high viscosity polymer modified
- **CQS-1H**  
  cationic quick set hard asphalt
- **CQS-1HP**  
  cationic quick set hard asphalt polymer modified
General Uses for Asphalt Emulsions

• Rapid Setting Emulsions
  • Designed to react quickly with aggregate and revert from the emulsion state to asphalt
  • Used for spray applications (chip seals, surface treatments, etc.)
  • RS-2 and CRS-2 have high viscosities to prevent runoff

• Medium Setting Emulsions
  • Designed for mixing with coarse aggregate
  • Do not break immediately upon contact with aggregate and mixes remain workable for several minutes

• Slow Setting Emulsions
  • Designed for maximum mixing stabilities
  • Used with high fines content, dense graded aggregates
  • May be diluted up to 50% with water to produce tack coat for hot mix applications
  • Industrial applications (coating, waterproofing, roofing...
Handling Related Tests

How the *emulsion handles* before and during application

- **Viscosity** – the emulsion should be of a consistency such that it can be easily sprayed or mixed but will not be so fluid that it runs all over the place.

- **Storage Stability / Settlement** – the emulsion should be stable enough so that it does not separate in storage.

- **Sieve Test** – there should not be any large particulate material (shot) to clog nozzles.

- **Particle Charge** – identifies whether the emulsion is anionic or cationic.

- **Demulsibility** – measures the rate of set (or stability) – high Demulsibility = rapid setting.
Residue Related Tests

How the residue behaves after application

• **% Residue** – measures the amount of residual material (solids)

• **Penetration** – measures the hardness of the residue

• **Apparent Viscosity** – measures residue viscosity

• **Float Test** – measures viscosity (later)

• Elastic recovery, force ductility, softening point, toughness & tenacity – residue Rheology
Viscosity – the emulsion should be of a consistency such that it can be easily sprayed or mixed but will not be so fluid that it runs all over the place.
% Residue – measures the amount of residual material (solids)

Distillation procedure also quantifies oil content in emulsion and recovers emulsion residue (free of water) for subsequent property testing
**The Float Test**

- High Float emulsions are those that pass the Float Test
  - Emulsion residue has been CHEMICALLY MODIFIED by the emulsifier so that it has a GEL structure
- HF residues are NON-NEWTONIAN in their rheological behavior
  - They will not flow until the minimum yield stress is experienced (normal asphalt will always flow) even when they are very soft
Emulsion sprayed on prepared granular base or existing pavement (HF-150S, HFMS-2, RS-2, CRS-2 and polymer versions)

Aggregate is applied and rolled

FINISHED SURFACE TREATMENT
Assuring Successful Surface Treatments with High Float Emulsions

- HF residues are less likely to bleed / flush (creep up on the road) in high temperatures
- HF residues are less brittle at low temperatures so they hold stone better
- Both of those properties are affected by application rate, so HF emulsions are more forgiving and thus USER FRIENDLY
High Float Emulsion Types

- **Standard** Ontario HF’s are *PEN* graded, e.g.
  - HF-100S has a residue pen of 80-150
  - HF-150S has a residue pen of 150-250
  - HF-250S has a residue pen of 250-350
  - Fairly slow setting and are used with graded aggregates (MTO Class 2/“Granular A” meeting Class 2). Because of the high fines content (and thus high surface area), the emulsion needs to be stable to penetrate the aggregate

- **Newer** Ontario HF’s are graded by SETTING TIME:
  - HFRS-2 is a rapid setting high float (pen 100-200) used with clean one size aggregate (MTO Class 1/ “9.5mm clear chip” meeting Class 1 )
  - HFMS-2 is a medium setting high float (pen 90-200) used with dusty chips (MTO Class 6 “HL3 Stone”)

- Mixing grade HF’s are used for cold mixes (and cold in place recycling) and are designated such with an “M” e.g. HF-150M, HF-150MP
Surface Treatment

• **Dense Graded**
  • Aggregate - Granular “A” (i.e. that meets MTO Class 2)
  • Emulsion - HF 150/250S or polymer version
  • Application Rates
    • Aggregate - 19 kg/m² ; Emulsion - 1.6 L/m²

• **Where/Why**
  • Usually northern secondary highways with traffic counts < 2000 VPD
  • Areas where crusher run Granular “A” is in abundance and is used on secondary region/county roads (e.g. Muskoka/Haliburton)
  • Cost effective process providing a bituminous wearing course.
Surface Treatment (con’t)

• Aggregate – 9.5 mm (3/8”) clear washed/unwashed
• Emulsion – CRS-2 or CRS-2P
• Application Rates
  • Aggregate - 16 kg/m² ; Emulsion - 1.8 L/m²

• Where/Why
  • Rural/Suburban area
  • 2,000 – 5,000 VPD traffic counts
  • Areas where 9.5 mm clear chip is economically produced, e.g. South/Southwestern/Southeastern regions.
Tack Coat

• Emulsion is sprayed prior to next lift of pavement so that lifts are bonded and behave as single structure with adequate strength
  – Unbonded lifts may behave independently and may not be able to withstand traffic induced bending stresses
    • Delamination, Longitudinal wheel path cracking, fatigue cracking, potholes....

• Typical Emulsion: SS-1 (diluted)
  – Also RS-1 (full strength), and non-track tack coat (SS-1HH)
Cold In Place Recycling

• Existing road surface and sub grade are milled up and mixed with asphalt emulsion and re-laid in one pass.

• Typical emulsions:
  – HF-150M
  – HF-150MP
Cold In-Pace Recycling (con’t)

- Recycling depth - 60 mm to 100 mm
- Maximum Recycled particle Size - 37 mm
- Emulsion - HF 150M, HF-150MP
- Emulsion rate - 1.75% (determined by mix design)

Alternate Technology
- Cold In Place Recycling with Expanded Asphalt Mix (CIREAM)
- Asphalt cement binder (58-28 in southern Ontario and 52-34/58-34 in northern regions) replaces emulsion
- Hot asphalt cement injected into mix with water causing the binder to foam and “spot-weld” RAP/aggregate together

Where/Why
- Suburban/rural roads, 6000<VPD>2000
- 100% recycling of existing bituminous pavement
- Remediation of deformations to granular base
- Provides improved (repaired) base coarse
Slurry Seal / Micro-surfacing

- Emulsion is mixed in a truck with graded aggregate, water, mineral filler (usually cement) and laid as a thin surface course.
- Typical Emulsions: CQS-1H (slurry), CQS-1HP (Micro-surfacing)
Micro-surfacing

- **Aggregate**
  - Type 2 (6.5 mm) and Type 3 (9.5 mm) limestone screenings (other mineral types possible)
  - Mineral additive (hydrated lime, cement, other...)

- **Emulsion**
  - CQS-1HP (also referred to as CSS-1H with quick set functionality)
    - Polymer (Latex) modified “quick set” emulsion type emulsion

- **Set up/Curing of Micro-surfacing**
  - Chemical break (emulsion interacting with aggregate/mineral additive)
    and evaporation of water

- **Thickness**
  - Up to 20 mm (multiple layers of aggregates)

- **Where/Why**
  - Preventative maintenance measure for non recyclable pavements
  - Leveling of rutted pavements
  - Retardation of surface deformations
  - Provides skid resistant surface (wearing) course
  - Buys time for alternative (permanent) rehabilitation measures
Slurry Seal

• Aggregate
  • Combination of Type 1 (3.25 mm) and Type 2 (6.5 mm) limestone screenings
  • Mineral additive (hydrated lime and other)

• Emulsion
  • CQS-1H (also referred to as CSS-1H with quick set functionality)
  • May also be latex modified

• Application Rates
  • Aggregate - 7 kg/m² and Emulsion - 1.0 - 1.5 L/m²

• Set Up/Curing of Slurry Seal
  • Chemical break (emulsion interacting with mineral additive and aggregate) and evaporation of water

• Thickness
  • Thickness of one aggregate layer

• Where/Why
  • Cost effective way to restore riding surface coarse
  • Safety. Improved skid resistance
  • Retard water intrusion through smaller cracks

Akzo-Nobel technical bulletin
Cold Mix

- Emulsion is mixed in a hot mix plant with sand and stone to make cold patching material that is stockpiled for later use.
- Typical Emulsions: HF-1000M, VLW
Paver Laid Cold Mix

- Emulsion is mixed with sand and stone in place on road or in plant and laid using paver (e.g. Midland Mix Paver)
- Emulsion
  - Typically HF-150M, CMS-2 (also possible with SS-1, CSS-1, MS-2)
- Aggregate
  - 9.5 mm (3/8”mm) clear washed
- Application Rates
  - Aggregate – 130 kg/m² and Emulsion – 6.7 L/m²
- Where/Why
  - Low volume roads susceptible to freeze/thaw movement (inadequate base stabilization)
  - Cost effective temporary solution vs. total base reconstruction
  - Typically done near lake areas (e.g. Muskoka, Simcoe, Haliburton regions)
Cutback Asphalts

• Manufactured by adding (cutting back) petroleum solvents (also called cutter stock or diluent) to asphalt cements
  • Solvent reduces asphalt viscosity so asphalt cutback flows and can be used at lower application temperatures than hot asphalt cement temperatures
• Solvent evaporates when cutback is applied to aggregate or pavement leaving asphalt cement on surface
• Three classes according to relative evaporation rates:
  • Rapid Curing (RC), Medium Curing (MC), & Slow Curing (SC)
• Consistency
  • Kinematic viscosity (mm²/s) at 60°C
    • Zeitfuchs Cross-Arm Viscometer
  • Viscosity grades are 30, 70, 250, 800 and 3000
    • e.g. MC 250 is a medium curing cutback asphalt with a viscosity between 250 and 500 mm²/s
General Uses for Cutback Asphalts

• Rapid-Curing Asphalt (RC)
  • Light diluent of high volatility (generally gasoline or naphtha) added to asphalt cement.
  • Historically used for granular sealing, tack coat, surface treatments
• Medium Curing (MC)
  • Medium diluent (generally kerosene) added to asphalt cement.
  • Generally used for prime coat, stockpile patching mixtures and road-mixing operations.
• Slow-Curing (SC)
  • Low volatility oils (generally diesel or other gas oils) added to asphalt cement
  • Also called road oils and have been used for prime coat, stock pile patching mixtures, and dust pallatives
Cutback Asphalt Uses

- Granular sealing, cold mix/patch...
- Non-road building and specialty applications
  - Waterproofing (roofing, foundations, metal/automotive), coatings, industrial glues/mortars...
- Emulsions have replaced cutbacks in many applications (cold mix paving, prime coat, seal coat, tack coat...)

Production of High Performance Cold Patch (cutback binder, adhesion promoter, unheated/wet aggregate)
Ontario Asphalt Emulsion and Cutback Specifications

- **OPSS 1102** – Liquid Asphalt Used in Spraying, Sealing, and Priming Applications
  - Cutback asphalt specifications
  - Provincial and Municipal versions
- **OPSS 1103** – Material Specification for Emulsified Asphalt
  - Provincial and Municipal versions
- **SSP 115S05** – Amendment to OPSS 1103
  - Includes specification for SS-1HH
    - Intended for use as “trackless” tack coat
  - Includes specification for solvent-free emulsified asphalt
    - Intended for use in priming/granular sealing applications
Low VOC Future?

- Environment Canada Code of Practice for Reduction of Volatile Organic Compound Emissions from the Use of Cutback and Emulsified Asphalt
  - Voluntary Code Effective 2017

- Asphalt Emulsion and Cutback Asphalt Use in Canada in 2010
  - 255,850 tonne emulsified asphalt (85%)
  - 45,150 tonne cutback asphalt (15%)
  - 301,000 tonne TOTAL

- Associated VOC Emissions
  - 3,600 tonne emulsified asphalt (41%)
  - 5,200 tonne cutback asphalt (59%)
  - 8,800 tonne TOTAL

- 5 year objective = 55% reduction in VOC emissions from sector
QUESTIONS & DISCUSSION

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