Early Findings for EBBR and DENT Implementation and Prospects for Simplification

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Superpave™ Performance Graded Asphalt Cement

RTFO → 3 → DSR → 4 → PAV → 6 → BBR → PG XX-II-YY
Shell Qualagon™ (1980s)

Adhesion
- Retained Marshall
- Exudation Droplet Test

Oxidation Stability
- HMA Storage \( \Delta \) R & B
- Field Trials \( \Delta \) R & B

Paraffinic Demixing
- Low Temp Ductility

Volatility
- TBP – GLC 450°C
- TBP – GLC 600°C

Oxidation Stability
- RTFO \( \Delta \) R & B
- RTFO Retained Pen

Van Gooswilligen et al., Eurobitumen, Madrid, 1989
Identical PG 64-34 Grades, Timmins
(Constructed 2003, Photographs 2008)

655-1 Sol-type: Low physical/oxidative hardening, R-value, S-controlled, and high CTOD. **Little or no cracking.**

655-4 Gel-type: High physical/oxidative hardening, R-value, m-controlled. **Major cracking and moisture damage.**

Stable RET + PPA

Unstable SBS + REOB
Modus Operandi for Municipalities

1. Control or ban what we can:
   • REOB, paraffin oils, etc.
   • Waste bio industry oil, vegetable oils, etc.
   • RAP, RAS, waxes, cracked/oxidized residues, etc.

2. Test extracted and recovered AC for what we cannot predict or imagine:
   • LS-228 Modified Pressure Aging Vessel (2012)
   • LS-299 Double-Edge-Notched Tension Test (2006)
   • LS-308 Extended Bending Beam Rheometer Test (2005)

3. As materials change so will the test methods and acceptance criteria.
AASHTO Adopted LS-308 EBBR as Provisional Standard TP 122-16

Standard Method of Test for

Determination of Performance Grade of Physically Aged Asphalt Binder Using Extended Bending Beam Rheometer (BBR) Method

AASHTO Designation: TP 122-16
Thermoreversible Aging of “Gel-Type” Structures in Asphalt Cement

AFM of Waxes + Saturates
Pauli et al., IJPE, 2011

ESEM of Resins + Asphaltenes
Lamont C-SHRP Cracking Correlations (2006)

M 320 (1 h) MTQ Results (blue) vs T(m=0.35, 72 h) Queen’s Results (green)

\[ y = 12x + 460 \quad R^2 = 0.73 \]

\[ y = 4.7x + 140 \quad R^2 = 0.996 \]

30°C Error!

Gavin et al., CTAA, 2003 and Zhao and Hesp, IJPE, 2006
Phase Contrast and Fluorescence Microscopy on Asphalt Cement (2007)

Lamont RR-7L Cold Lake

False Blue = Phase Contrast
False Green = Fluorescence

Stable 300/400 pen Cold Lake binder from Section 7 in Lamont never cracked for 22 years until trial site was reconstructed:

- Little or no phase separation;
- Low physical hardening;
- Low oxidative hardening;
- Low R-value;
- S-controlled; and
- high CTOD

Hesp et al., Energy and Fuels, 2007
Recovered Grading by EBBR (MTO LS-308)

106 Contract Samples (-28 and -34 zones)

Acceptable: 26  29  32
Borderline:  5  0  2
Failed:      6  5  1

Ding et al., CTAA, Regina, 2018
AASHTO Adopted DENT as Provisional Standard TP 113-15

Standard Method of Test for

Determination of Asphalt Binder Resistance to Ductile Failure Using Double-Edge-Notched Tension (DENT) Test

AASHTO Designation: TP 113-15
Recovered Grading by DENT (TP 113-15)
106 Contract Samples (-28 and -34 zones)

Acceptable: 29 29 33
Borderline: 2 2 1
Failed: 6 3 1

Limits
20 mm
14 mm

Ding et al., CTAA, Regina, 2018
Corrélations entre la fissuration et les caractéristiques des bitumes (1998)
(Correlation of Cracking Distress with Bitumen Properties)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Field Cracking (7 Years)</th>
<th>Change Field/Unaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T(\delta=27^\circ, 7.8 \text{ Hz})$</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>$T(\delta=45^\circ, 7.8 \text{ Hz})$</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>$T(S=300 \text{ MPa})$</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>$m$-value</td>
<td>****</td>
<td>***</td>
</tr>
<tr>
<td>$T(m=0.300)$</td>
<td>*****</td>
<td>*****</td>
</tr>
</tbody>
</table>

Migliori et al., Eurobitumen, Luxembourg, 1998 *(LCPC, Colas, Shell, Mobil, BP, Esso)* (this followed earlier papers in Europe, USA and Canada on phase angle measurements to study/mitigate cracking).
Correlation of Cracking Distress with Asphalt Cement Phase Angle (2009)

Contracts from Eastern Ontario (20 samples)

\[
\tan \delta = 0.54 \rightarrow \delta = 28^\circ
\]

Soleimani et al., JTRB, 2009
Limiting Phase Angle vs M320 or LS-308
2011 Implementation Contracts (60+ samples, 2018-2019)

R² = 0.67-0.71

Ding et al., CTAA, Regina, 2018 and Lill et al., CTAA, Montreal, 2019
## Performance Graded AC Testing Correlation Program of MTO (2015)

<table>
<thead>
<tr>
<th>Test</th>
<th>Parameter</th>
<th>COV</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSR&lt;sub&gt;Unaged&lt;/sub&gt;</td>
<td>Complex Modulus, G*</td>
<td>0.042</td>
</tr>
<tr>
<td></td>
<td>Phase Angle, δ</td>
<td>0.005</td>
</tr>
<tr>
<td>DSR&lt;sub&gt;RTFO&lt;/sub&gt;</td>
<td>Complex Modulus, G*</td>
<td>0.064</td>
</tr>
<tr>
<td></td>
<td>Phase Angle, δ</td>
<td>0.007</td>
</tr>
<tr>
<td>DSR&lt;sub&gt;PAV&lt;/sub&gt;</td>
<td>Complex Modulus, G*</td>
<td>0.110</td>
</tr>
<tr>
<td></td>
<td>Phase Angle, δ</td>
<td>0.017</td>
</tr>
<tr>
<td>BBR&lt;sub&gt;PAV&lt;/sub&gt;</td>
<td>Creep Stiffness, S</td>
<td>0.060</td>
</tr>
<tr>
<td></td>
<td>Creep Rate, m</td>
<td>0.021</td>
</tr>
</tbody>
</table>
M320 and LS-308 vs Phase Angle

2011 Implementation Contracts (60+ samples, 2019)

<table>
<thead>
<tr>
<th></th>
<th>BBR</th>
<th>EBBR</th>
<th>Phase Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>-43</td>
<td>-39</td>
<td>-17</td>
</tr>
<tr>
<td>High</td>
<td>-26</td>
<td>-14</td>
<td>13</td>
</tr>
</tbody>
</table>
Effect of Cold Conditioning on $\Delta T_c$ BBR

Contracts from Eastern Ontario (20 samples, 2009)

Hesp and Subramani, MAIREPAV6, Turin, Italy, 2009
AASHTO M 320 and MTO LS-308 vs LS-228 Modified PAV

655 Trial Sections + Alberta Binders (11 samples, 2012)

Erskine et al., Eurobitumen, Istanbul, Turkey, 2012
Rheological Type Determination with $\Delta T_c$ BBR

2011 Implementation Contracts (42 samples, 2018)

$\Delta T_c$ (BBR, 1 h), °C

EBBR Grade Loss, °C

$R^2 = 0.09$

$\Delta T_c$ (EBBR, 72 h), °C

EBBR Grade Loss, °C

$R^2 = 0.69$

Ding et al., JCBM, 2018
655 Black Space Diagram (15 Years, 2018)

655-1 (Best ●) vs 655-4 (Worst ●)

$T(\delta_{30^\circ}) = 0^\circ C$

$T(G^*_{100 \text{ MPa}}) = -6^\circ C$

$\Delta T_{cd} = +6^\circ C$

$T(\delta_{30^\circ}) = +26^\circ C$

$T(G^*_{100 \text{ MPa}}) = 1^\circ C$

$\Delta T_{cd} = +25^\circ C$
Limiting Phase Angle and Stiffness (2018)

Recovered Binder

User A

User B

User C

Recovered Binder

User A

User B

User C

Recovered Binder

• Effect of 10, 20 and 30 % RAP on PG 58-28 A & B
• Effect of 10, 20 and 30 % RAS on PG 58-28 A & B
• Effect of 4, 8, 12 and 16 % REOB on PG 58-28 C
• Effect of binder source and grade on G*
• Effect of PAV aging time
• Effect of PAV film thickness
Effect of RAP/RAS on PG 58-28 A

RAP/RAS Content, %

G*, MPa

T(δ=30), °C
Effect of RAP/RAS on PG 58-28 B

![Graph showing the effect of RAP/RAS content on T(δ=30) and G* values.](image)

**Graph 1:**
- **T(δ=30), °C**
  - RAP 7: 1.8
  - RAP 11: 2.1
  - RAP 403: 4.3
  - RAS: 5.2

**Graph 2:**
- **G*, MPa**
  - RAP 7: 50
  - RAP 11: 49
  - RAP 403: 41
  - RAS: 41

**Legend:**
- Blue: RAP 7
- Red: RAP 11
- Green: RAP 403
- Yellow: RAS

**RAP/RAS Content, %**
- 0%
- 10%
- 20%
- 30%

**T(δ=30), °C**
- 0
- 10
- 20
- 30

**G*, MPa**
- 0
- 10
- 20
- 30

---

This graph illustrates the effect of RAP/RAS content on the T(δ=30) and G* values for PG 58-28 B. The data shows how the incorporation of RAP/RAS affects the performance of asphalt mixtures at different percentages.
Effect of REOB on PG 58-28 C

- Upper graph: $T(\delta=30)$, °C
  - REOB Content, %: 0, 4, 8, 12, 16
  - Values: 3, 1, 0, 1, -2

- Lower graph: $G^*$, MPa
  - REOB Content, %: 0, 4, 8, 12, 16
  - Values: 81, 66, 55, 38, 38
CTOD vs Flexibility Index-B

R² = 0.97
CTOD vs Butt Joint Failure Strain ($D_f$)

R² = 0.90
MTO NER PG 52-40

Unstable binder showing excessive degree of paraffinic demixing (REOB > 30%):

\[
T(\delta = 30^\circ) = 28^\circ C \\
T(G^* = 100 \text{ MPa}) = -16^\circ C \\
\Delta T_{cd} = 44^\circ C \ldots
\]

40-46°C grading error !?

False Blue = Phase Contrast
False Green = Fluorescence

Hesp et al., Energy and Fuels, 2007
Summary and Conclusions

• EBBR and DENT tests are highly sensitive indicators for AC quality and durability and for that reason are being implemented by user agencies.

• PAV protocol needs to be improved or replaced.

• Phase angle and complex modulus need more study but show promise to replace EBBR test.

• Fatigue index and pull-off strain at failure need more study but show promise to replace the DENT test.

• It is important to test recovered AC!
Thank you!

Questions?

Chemistry Department
25 faculty, 100 graduate students & 1000+ undergraduate students

Queen's University
1,000 faculty, 4,000 graduate students & 20,000 undergraduate students