A Comparative Study of Three WMA Technologies in the City of Calgary

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Acknowledgements

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- Lafarge GCA Asphalt Manufacturing and Construction Divisions
- Lafarge Center of Research, Lyon – France

for their support and contribution in preparation of this paper.
Project Description

At the Plant Production
- Quality / Volumetrics - AC/Gradation, AV, VMA, Moisture
- Aggregate / AC / Mix temperature
- Water concentration
- Emissions
- Baghouse temperatures

At the Construction Site
- Temperature behind paver
- Cooling rate profile
- Thermal segregation
- Compaction profile - densities
- Texture - Visual inspection
- Cores – Stiffness, future evaluations

At the Laboratory
- Moisture susceptibility - TSR
- Rutting resistance – APA, Flow number
- Fatigue – Fatigue tests at different strain
- Low temperature – TSRST tests
- Complex Modulus
- Binder evaluation – Extracted & original
What is WMA?

- Allows a reduction in the temperatures at which asphalt mixes are produced and placed

- Reduced viscosity at lower temps
  - Complete aggregate coating

- Chemical package or binder treatment to promote coating of the aggregate
Warm Mix Asphalt (WMA)

- Hot Mix Asphalt 275-325°F (135-160°C)
- Warm Mix Asphalt 250-275°F (120-135°C)
Warm Mix Asphalt (WMA) Technologies

Technologies

- WMA additives that are added to the asphalt binder
- WMA additives that are added to the mixture during production
- Sequential mixing processes
- Plant foaming processes
ASTEC
Double Barrel® Green

GENCOR
Ultrafoam GX™

HyperTherm
Additive
Project Location
Project Location

GENCOR Foam
ASTEC DBG Foam
GENCOR HyperTherm
GENCOR Conventional
Mix Design
Plant Production
# Plant Production

<table>
<thead>
<tr>
<th></th>
<th>GENCOR Foaming</th>
<th>ASTEC DBG Foaming</th>
<th>GENCOR HyperTherm</th>
<th>GENCOR Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production Date</strong></td>
<td>Aug 31/2009</td>
<td>Sep 01/2009</td>
<td>Sep 02/2009</td>
<td>Sep 03/2009</td>
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<tr>
<td><strong>Aggregate Temperature, °C</strong></td>
<td>-</td>
<td>158</td>
<td>-</td>
<td>-</td>
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<tr>
<td><strong>Asphalt Cement Temperature, °C</strong></td>
<td>137</td>
<td>151</td>
<td>138</td>
<td>135</td>
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<tr>
<td><strong>Asphalt Mix Temperature, °C</strong></td>
<td>120</td>
<td>127</td>
<td>124</td>
<td><strong>150</strong></td>
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<tr>
<td><strong>Water Concentration, % by weight of AC</strong></td>
<td>2.0</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
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<tr>
<td><strong>Bag house inlet temperature, °C</strong></td>
<td>104</td>
<td>89</td>
<td>105</td>
<td>120</td>
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<tr>
<td><strong>Bag house outlet temperature, °C</strong></td>
<td>77</td>
<td>72</td>
<td>78</td>
<td>86</td>
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<tr>
<td><strong>Plant Production, tonnes/hour</strong></td>
<td>171</td>
<td>225</td>
<td>177</td>
<td>176</td>
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</tbody>
</table>
### Plant Produced Mix Properties

<table>
<thead>
<tr>
<th>Sieve Sizes (mm)</th>
<th>Mix Design</th>
<th>GENCOR Foam</th>
<th>ASTEC Foam</th>
<th>GENCOR HyperTherm</th>
<th>GENCOR Conventional</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100 – 100</td>
</tr>
<tr>
<td>19</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100 – 100</td>
</tr>
<tr>
<td>16</td>
<td>100</td>
<td>99.6</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>97 – 100</td>
</tr>
<tr>
<td>12.5</td>
<td>98</td>
<td>95.3</td>
<td>96.5</td>
<td>95.2</td>
<td>97.4</td>
<td>95 – 100</td>
</tr>
<tr>
<td>9.5</td>
<td>91</td>
<td>88.2</td>
<td>89.8</td>
<td>88.2</td>
<td>91.0</td>
<td>88 – 94</td>
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<tr>
<td>4.75</td>
<td>62</td>
<td>65.6</td>
<td>64.1</td>
<td>62.8</td>
<td>62.1</td>
<td>59 – 65</td>
</tr>
<tr>
<td>2.36</td>
<td>50</td>
<td>50.7</td>
<td>50.2</td>
<td>48.3</td>
<td>47.9</td>
<td>47 – 53</td>
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<tr>
<td>1.18</td>
<td>42</td>
<td>41.0</td>
<td>42.0</td>
<td>39.2</td>
<td>39.6</td>
<td>39 – 45</td>
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<tr>
<td>0.6</td>
<td>33</td>
<td>32.9</td>
<td>34.6</td>
<td>31.6</td>
<td>32.4</td>
<td>30 – 36</td>
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<tr>
<td>0.3</td>
<td>16</td>
<td>17.1</td>
<td>18.1</td>
<td>16.4</td>
<td>17.4</td>
<td>13 – 19</td>
</tr>
<tr>
<td>0.15</td>
<td>7.5</td>
<td>7.9</td>
<td>8.5</td>
<td>7.7</td>
<td>7.7</td>
<td>4.5 – 10.5</td>
</tr>
<tr>
<td>0.075</td>
<td>5.4</td>
<td>5.6</td>
<td>5.1</td>
<td>5.5</td>
<td>5.2</td>
<td>4.0 – 6.4</td>
</tr>
<tr>
<td>AC Content (%)</td>
<td>6.0</td>
<td>5.90</td>
<td>6.03</td>
<td>5.91</td>
<td>6.00</td>
<td>6.0 min.</td>
</tr>
<tr>
<td>Air Voids (%)</td>
<td>3.9</td>
<td>3.8</td>
<td>3.9</td>
<td>3.7</td>
<td>3.7</td>
<td>3.0 – 5.0</td>
</tr>
<tr>
<td>Mix Moisture</td>
<td>-</td>
<td>0.10</td>
<td>0.12</td>
<td>0.10</td>
<td>0.10</td>
<td>-</td>
</tr>
<tr>
<td>VMA</td>
<td>16.0</td>
<td>16.1</td>
<td>15.9</td>
<td>16.0</td>
<td>16.0</td>
<td>14.0 min</td>
</tr>
<tr>
<td>VFA</td>
<td>75.7</td>
<td>77.0</td>
<td>77.6</td>
<td>77.1</td>
<td>77.1</td>
<td>-</td>
</tr>
</tbody>
</table>
Temperature Discharge Silo

Temperature Silos (°C)

- GENCOR Foam
- ASTEC Foam
- GENCOR Hypotherm
- GENCOR Conventional
Temperature Behind Paver

- Temperature Behind Paver (°C)

- GENCOR Foam
- ASTEC Foam
- GENCOR HyperTherm
- GENCOR Conventional
Moisture Susceptibility

<table>
<thead>
<tr>
<th></th>
<th>Dry</th>
<th>60°C Soak</th>
<th>Freez / Thaw</th>
<th>TSR (60°C)</th>
<th>TSR (Freez / Thaw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GENCOR Conventional</td>
<td>482.5</td>
<td>399.6</td>
<td>433.7</td>
<td>82.8</td>
<td>89.9</td>
</tr>
<tr>
<td>GENCOR Foam</td>
<td>416.8</td>
<td>337.5</td>
<td>408.2</td>
<td>81.0</td>
<td>97.9</td>
</tr>
<tr>
<td>GENCOR HyperTherm</td>
<td>385.5</td>
<td>397.8</td>
<td>410.2</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>ASTEC Foam</td>
<td>468.6</td>
<td>411.5</td>
<td>447.1</td>
<td>87.8</td>
<td>95.4</td>
</tr>
</tbody>
</table>

* 0.3% liquid antistrip added to all mixes

Mix Moisture (%) During Mix Manufacturing

<table>
<thead>
<tr>
<th></th>
<th>GENCOR Conventional</th>
<th>GENCOR HyperTherm</th>
<th>ASTEC Foam</th>
<th>GENCOR Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix Moisture</td>
<td>0.10</td>
<td>0.10</td>
<td>0.12</td>
<td>0.10</td>
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</tbody>
</table>
## Plant Emissions

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>GENCOR . Foaming</th>
<th>ASTEC DBG Foaming*</th>
<th>GENCOR HyperTherm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>14.85%</td>
<td>10.4%</td>
<td>13.53%</td>
</tr>
<tr>
<td>Nitrogen Oxides (NOₓ)</td>
<td>5.9%</td>
<td>8.3%</td>
<td>5.8%</td>
</tr>
<tr>
<td>SO2 (mg/m3)</td>
<td>0.0%</td>
<td>- 14.3%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>10.0%</td>
<td>10.9%</td>
<td>10.0%</td>
</tr>
</tbody>
</table>

“Lower Plant & Construction Emissions”.
Plant Emissions - Silo

- GENCOR HyperTherm
- ASTEC DBG Foam
- GENCOR Foam
- GENCOR Conventional
Construction Site
Temperature Cooling Rate

- GENCOR Foam
- ASTEC DBG Foam
- GENCOR HyperTherm
- GENCOR Conventional
Thermal Segregation

Mix Thermal Segregation, °C.
Thermal Segregation

- Standard deviation
  - GENCOR Conventional
  - GENCOR Foam
  - ASTEC DBG Foam
  - GENCOR HyperTherm

- Maximum Difference (°C)
  - GENCOR Conventional
  - GENCOR Foam
  - ASTEC DBG Foam
  - GENCOR HyperTherm
Road Compaction Profile

- GENCOR Foam
- ASTEC DBG Foam
- GENCOR HyperTherm
- GENCOR Conventional

1 Pass Vibratory Steel Roller
2 Pass Vibratory Steel Roller
Behind Paver
Final Neumatic Tire Roller

Images of road rollers and pavers.
Plant Emissions - Paving

GENCOR Foam

ASTEC DBG Foam

GENCOR HyperTherm

GENCOR Conventional
Texture

- Tight surface
- Few aggregates uncoated identified for future evaluation
Laboratory Testing
Mix Workability
Mix Workability

![Mix Workability Graph]

- GENCORE Foam
- ASTEC DBG Foam
- GENCOR HyperTherm
- GENCOR Conventional

Mix Temperature (°C)

Maximum Load (kN)
Mix High Temperature Evaluation

Asphalt Pavement Analyzer Test (APA)

Temp: 58°C, 8,000 Cycles, 7.0 ± 0.5% AV

Flow Number Test

Stress: 600KPa, Loading Time: 0.1s, Unloading Time: 0.9s, Temp: 45°C
## Mix High Temperature Evaluation

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>APA (8.0mm Max)</th>
<th>Flow Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rut depth (mm)</td>
<td>Number of cycles</td>
</tr>
<tr>
<td>GENCOR conventional</td>
<td>6.041</td>
<td>55</td>
</tr>
<tr>
<td>GENCOR Foam</td>
<td>5.584</td>
<td>78</td>
</tr>
<tr>
<td>GENCOR HyperTherm</td>
<td>5.641</td>
<td>116</td>
</tr>
<tr>
<td>ASTEC Foam</td>
<td>6.167</td>
<td>54</td>
</tr>
</tbody>
</table>

“Similar Rutting Resistance as HMA”
Mix Fatigue Cracking

Tension compression tests on cylindrical specimens

Temperature of 10°C
Frequency of 10Hz
Strain Controlled Test
Mix Fatigue Cracking

\[ y = 7E+16 \times x^{-5.1397} \]
\[ R^2 = 0.9592 \]

\[ y = 2E+16 \times x^{-4.8941} \]
\[ R^2 = 0.9484 \]

\[ y = 1E+16 \times x^{-4.8576} \]
\[ R^2 = 0.9955 \]

\[ y = 1E+15 \times x^{-4.31} \]
\[ R^2 = 1 \]

1.E+04 1.E+05 1.E+06 1.E+07
90 140 190

Deformation (microstrains)

Nf (cycles) at 50% of initial stiffness

- Astec Foam
- Gencor Conventional
- Gencor HyperTherm
- Gencor Foam
Mix Low Temperature Cracking

Thermal Stress Restrained Specimen Test (TSRST)

Temperature (°C) drops at constant rate of 10° C/hour. Starting temperature = 5° C

Plates glued to the tested Sample and maintained At fixed position
Mix Low Temperature Cracking

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Critical Low Temperature Cracking (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GENCOR conventional</td>
<td>-33.20</td>
</tr>
<tr>
<td>GENCOR Foam</td>
<td>-35.6</td>
</tr>
<tr>
<td>GENCOR HyperTherm</td>
<td>-34.53</td>
</tr>
<tr>
<td>ASTEC Foam</td>
<td>-33.59</td>
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</tbody>
</table>

“Slightly Better Low Temperature Performance”
Mix Stiffness

Complex Modulus tests on cylindrical specimens
Mix Stiffness

“Slightly Lower Initial Stiffness”
Rheology of Recovered Binders

Dynamic Shear Rheometer

Bending Beam Rheometer
# Recovered Binder

<table>
<thead>
<tr>
<th>Tests on Recovered Asphalt Binder</th>
<th>Binders extracted from core samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>150/200 Binder Virgin - RTFOT</td>
</tr>
<tr>
<td>Dynamic Shear Rheometer</td>
<td></td>
</tr>
<tr>
<td>G*/Sin δ, KPa</td>
<td>@ 46 °C 8.770</td>
</tr>
<tr>
<td></td>
<td>&gt;=2.2 KPa 3.818</td>
</tr>
<tr>
<td></td>
<td>@ 52 °C 1.723</td>
</tr>
<tr>
<td></td>
<td>@ 64 °C -</td>
</tr>
<tr>
<td>Predicted Failure Temperature (° C)</td>
<td>56.16</td>
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<tr>
<td>Pressure Aging Vessel Residue (AASHTO R28)</td>
<td></td>
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<tr>
<td>Bending Beam Rheometer</td>
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<tr>
<td>Creep Stiffness, MPa</td>
<td>@ -18 °C 121</td>
</tr>
<tr>
<td></td>
<td>@ -24 °C 276</td>
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<tr>
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<td>@ -30 °C 586</td>
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<tr>
<td>Predicted Failure Temperature (° C)</td>
<td>-34.61</td>
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<tr>
<td>Slope, m - value, MPa</td>
<td>@ -18 °C 0.386</td>
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<td>&gt;=0.300 0.325</td>
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<tr>
<td></td>
<td>@ -30 °C 0.252</td>
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<tr>
<td>Predicted Failure Temperature (° C)</td>
<td>-36.46</td>
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<tr>
<td>Performance Grade (PG)</td>
<td>52-34</td>
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</table>

“Same PG graded” “Slightly Lower Initial Stiffness”
Follow-up Work

Stiffness evolution with age (FWD, Modulus, Coring)
Binder rheology
Pavement condition survey
Thank You!