Performance Evaluation of a 100% Recycled Asphalt Pavement Mixture using a Polymer Binder: A Pilot Study

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10th International Conference on the Bearing Capacity of Roads, Railways & Airfields
Athens, Greece – June 28-30, 2017
Introduction – Recycled Asphalt Pavement (RAP)

• Obtained from
  – Reconstruction / utility cuts
  – Millings for resurfacing
  – Plant reject

• Used in
  – HMA & WMA productions (up to ~50%)
    ▪ US (2014), > 70 million tons of RAP used in new pavements
  – Hot or cold in-place recycling (100%)
    ▪ Emulsion
    ▪ Typically requires a surface treatment or an AC overlay
Introduction

• Polymeric binder
  – G5® TechniSoil Ind. [http://www.technisoilind.com/technisoil-g5.html]
  – A polymer chemistry enabling 100% CIR of AC surface layer.
  – Liquid at room temperature

• G5-Stabilized RAP mixture
  – Mixed & compacted at room temperature
  – Cures faster than emulsion
  – Paved surface is 30 - 40°F cooler than the asphalt surface
G5 Recycling Process Flow

**Milling**
- Cold milling of pavement surface
- Additives injected at milling head
- Grindings ejected to crusher

**Crushing + Screening**
- Horizontal impact crusher
- Oversize material is screened
- Control to achieve desired gradation based on mix design

**Mixing**
- G5 binder is injected into continuous pugmill mixer
- Mixer ejects combined RAP + G5 into a windrow

**Paving + Compaction**
- Pickup machine delivers mixed RAP + G5 into paver
- Paver distributes mixture on the road surface
- Rollers compact material

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Pavement Recycling System

Pavement Grinder (Mill)

Crusher & Mixer

G5® Tank
Objective

- Evaluation of G5 for use with 100% RAP

- Conduct a laboratory evaluation
  - Measure engineering and performance properties
    - Dynamic modulus, rutting resistance, fatigue cracking resistance, thermal cracking resistance.

- Conduct a simple ME analysis
  - Estimate fatigue life of a typical pavement structure
Sample Preparation

100% passing 9.5 mm sieve crushed RAP (4.1% TWM RAP binder) Mixed with 9.5% (by dry weight of RAP) of G5®

Placed & compacted using a small roller compactor in a large slab

After curing, Cores & slabs taken to prepare test specimens
G5®-Stabilized RAP Mixture
Dynamic Modulus, E* (AASHTO TP79)

- 100mm diameter by 150mm height cored samples (12±1%)

Error bars represent the mean value plus or minus 95% confidence interval.
G5®-Stabilized RAP Mixture
E* Master Curve (AASHTO PP61) at 20°C

- G5®-stabilized RAP mixture (100% RAP)
  - **Viscoelastic** behavior.
  - **Stable** (stiffness similar to that of a typical DG asphalt mixtures).
  - Phase angle values (5 to 20 degrees) indicate **high flexibility** at low & high temperatures.
G5®-Stabilized RAP Mixture
Resistance to Rutting (AASHTO TP79)

- 100mm diameter x 150mm height cored samples (12±1%)
- Repeated pulse load of 0.1sec & rest period of 0.9sec
- Deviator stress = 600 kPa; Confinement = 0 kPa
- Test temperature = 60°C
G5®-Stabilized RAP Mixture
Resistance to Rutting (AASHTO TP79)

- G5®-stabilized RAP mixture (100% RAP) exhibited a superior & excellent resistance to rutting.
- Can successfully withstand the high & heavy traffic even in hot climates.

AASHTO TP 79 – FN Requirements for Hot-Mix Asphalt (HMA)

<table>
<thead>
<tr>
<th>Traffic Level (Million ESALs)</th>
<th>&lt; 3</th>
<th>3 to &lt; 10</th>
<th>10 to &lt; 30</th>
<th>≥ 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Flow Number (Cycles)¹</td>
<td>Testing Not Needed</td>
<td>53</td>
<td>190</td>
<td>740</td>
</tr>
</tbody>
</table>

Results: 100% RAP + G5 | No Flow after 20,000 Cycles

Permanent strain @ 60°C < 1%
G5®-Stabilized RAP Mixture
Resistance to Fatigue Cracking (AASHTO T321)

- Uncut beams long-term aged (5 days at 85°C)
- Constant strain mode of testing; 10 Hz
- Test temperature = 21.1°C

<table>
<thead>
<tr>
<th>Property</th>
<th>G5®-stabilized RAP</th>
<th>DG-HMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average air voids</td>
<td>11.2%</td>
<td>6.7%</td>
</tr>
<tr>
<td>Average flexural stiffness</td>
<td>5,812 MPa</td>
<td>1,186 MPa</td>
</tr>
</tbody>
</table>

High Resistance to Fatigue Cracking
G5®-Stabilized RAP Mixture
Resistance to Thermal Cracking (Draft Standard)

• 57 x 140 mm cylindrical specimens (after 5 days at 85°C)
• Cooling rate of 10°C/hour from 20 to (-45)°C
### G5®-Stabilized RAP Mixture

**Resistance to Thermal Cracking (Draft Standard)**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture Temperature</td>
<td>-34.1°C</td>
</tr>
<tr>
<td>Fracture Stress</td>
<td>4,227 kPa (613 psi)</td>
</tr>
</tbody>
</table>

G5®-stabilized RAP mixture exhibited a low fracture temperature while maintaining a high fracture stress indicating a good resistance to thermal cracking in cold climates.
Simple Mechanical-Empirical (M-E) Analysis

- Bottom-up fatigue cracking Analysis Using 3D-Move analysis
  - Viscoelastic properties
  - 2 vehicle speeds (72 and 16 km/h)

<table>
<thead>
<tr>
<th>Property</th>
<th>G5 Mix</th>
<th>DG-HMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average air voids</td>
<td>11.2%</td>
<td>6.7%</td>
</tr>
<tr>
<td>$K_1$</td>
<td>4.524E-09</td>
<td>8.293E-13</td>
</tr>
<tr>
<td>$K_2$</td>
<td>4.531</td>
<td>5.293</td>
</tr>
</tbody>
</table>

$$N_f = k_1 \left( \frac{1}{\varepsilon_f} \right)^{k_2}$$

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Simple Mechanical-Empirical (M-E) Analysis (Cont’d)

G5 Mixture (Measured $E^*$)
- Crushed Aggregate Base (CAB) $E = 170$ MPa
- Subgrade $E = 55$ MPa

DG-HMA Mixture (Measured $E^*$)
- Crushed Aggregate Base (CAB) $E = 170$ MPa
- Subgrade $E = 55$ MPa
Simple Mechanical-Empirical (M-E) Analysis (Cont’d)

<table>
<thead>
<tr>
<th>Vehicle Speed</th>
<th>Surface Mixture</th>
<th>Fatigue Analysis at 21°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number of repetitions to failure, $N_f$ (million)</td>
</tr>
<tr>
<td>72 kph (45 mph)</td>
<td>G5-100%RAP</td>
<td>23.2</td>
</tr>
<tr>
<td></td>
<td>DG-HMA</td>
<td>2.9</td>
</tr>
<tr>
<td>16 kph (10 mph)</td>
<td>G5-100%RAP</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td>DG-HMA</td>
<td>1.2</td>
</tr>
</tbody>
</table>

- High resistance to fatigue cracking for G5®-stabilized RAP mixture when used as a surface layer.
Demonstration Project

• Reconstruction project: Al Wakar water station, Doha, Qatar.
  – ~60 m long by x 3 m wide stretch.

• Traffic: more than 1,000 water trucks per day, 7 days per week, each loaded with 4,000-5,000 gallons of water.

• Average high air temperature of over 38°C
  – Daily high air temperature often exceeds 43°C during summer.

• Annual rainfall ~75 mm.
Demonstration Project (Cont’d)

• ~75 mm of G5®-stabilized 100%RAP mix on top of subbase.
  – 5% G5®
  – 2 lifts compacted with 5-ton roller (3 vibratory passes)
• Average in place air voids: 10% (top lift) & 14.5% (bottom lift).
Conclusion

- The laboratory test results show that the G5®-stabilized mixture (100% RAP)
  - Is **stable** with a high stiffness.
  - Has **high resistance to rutting** at 60°C; hence, offering significantly more resistance to rutting at higher pavement temperatures.
  - Has a **high resistance to fatigue cracking** at 21°C while maintaining a high flexural stiffness.
  - Has a **cold fracture temperature** of -34°C indicating that the mixture will perform well in designated cold environment.
- The ME analysis shows that G5®-stabilized mixture (100% RAP) significantly improved fatigue life of thin pavements.
- The demonstration project had no construction-related issues & a recent visual distress survey shows no distresses in the pavement after 6 months.
THANK YOU!

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