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- Council for Scientific and Industrial Research: Parliamentary Grant funding
Asphalt Mix Characterisation

- **Application**: standard South African wearing course mix
- **Asphalt mix type**: sand skeleton- medium continuously-graded (NMPS 9.5 mm)
- **Aggregate blend**: granite and andesite
- **Binder**: 50/70 penetration grade
- **Filler**: plant filler
- **Aggregate replacement**: (granite crusher dust): 15% recycled crushed glass (MPS 5 mm)
Moisture Susceptibility Evaluation: Aggregate Properties

AGGREGATE MINERALOGICAL COMPOSITION

- marble
- limestone
- basalt
- dolomite
- sandstone
- granite
- quartzite

ADEHESIVE FAILURE IN ACIDIC AGGREGATES

- Chemical Adhesion: poor adherents to bitumen polar groups
- Physical Adhesion: negative surface charge

Zeta Potential, mV

Andesite
Recycled crushed glass

Crushed Glass Particles
50/70 PG Binder
Granite Crusher Sand
Moisture Susceptibility Evaluation: Aggregate Properties

ADEHESIVE FAILURE IN ACIDIC AGGREGATES

- Mechanical Adhesion: smooth surface texture, reduced porosity

Bond strength per unit of surface area > reduced stripping
Bond strength per unit of aggregate mass > increased stripping

Cheng et al. (2002)

Surface Texture of Crushed Glass Particle as per ISO 25178
Surface Texture Parameters
“Bond strength (ergs/cm²) between water and aggregate (both siliceous and calcareous) is approximately 30% higher than between bitumen and the same aggregates” - Cheng et al. (2002)

**ANTISTRIPPING ADDITIVES** — modify the *physical* and *chemical* properties of the aggregate and bitumen and thereby improving the durability and strength of the interfacial bond between the two surfaces

- **Hydrated Lime** — widely specified for siliceous aggregates
- **Liquid Additive: Wet-Fix BE**

<table>
<thead>
<tr>
<th>Asphalt Mix 1</th>
<th>Asphalt Mix 2</th>
<th>Asphalt Mix 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrated Lime 1% by mass of aggregate</td>
<td>Wet-Fix BE 0.5% by volume of binder</td>
<td>No additive</td>
</tr>
</tbody>
</table>
Moisture Susceptibility Evaluation: AASHTO T324

Hamburg Wheel Tracking Test (AASHTO T324) – standard test used in South Africa to evaluate the combined effects of moisture damage and rutting potential

POST COMPACTION PHASE: densification of the mix under wheel load

CREEP PHASE: permanent deformation of the mix under loading

STRIPPING PHASE: contribution mainly from stripping as well as further rutting under loading
Moisture Susceptibility Evaluation: AASHTO T324

AASHTO T324 Requirements

- Creep Slope
- Stripping Slope
- Stripping Inflection Point

Determination of “first portion” and “second portion” is not standardised in AASHTO T324

\[ SIP = \frac{\text{Intercept (second portion)} - \text{Intercept (first portion)}}{\text{Slope (first portion)} - \text{Slope (second portion)}} \] 
\,(AASHTO T324, 2017)
Moisture Susceptibility Evaluation: Proposed New Method

1. 6-Degree Polynomial Function

\[ RD_N = aN^6 + bN^5 + cN^4 + dN^3 + eN^2 + fN + C \]

Where:

- \( RD_N \) = Rut depth after N wheel passes (mm)
- \( N \) = Number of wheel passes
- \( a, b, c, d, e, f \) and \( C \) = 6-degree polynomial coefficients

Mix Fitted HWTT Curve Equation

<table>
<thead>
<tr>
<th>Mix</th>
<th>Fitted HWTT Curve Equation</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA 1</td>
<td>( RD = 3.9E-25N^6 + 8.3E-20N^5 + 3.2E-15N^4 + 5.3E-11N^3 - 4.7E-07N^2 + 2.6E-03N + 0.4 )</td>
<td>0.999</td>
</tr>
<tr>
<td>GA 2</td>
<td>( RD = -1.2E-22N^6 + 5.7E-18N^5 - 1.0E-13N^4 + 8.5E-10N^3 - 3.6E-06N^2 + 7.8E-03N + 2.5 )</td>
<td>0.993</td>
</tr>
<tr>
<td>GA 3</td>
<td>( RD = -4.7E-23N^6 + 2.4E-18N^5 - 4.6E-14N^4 + 4.3E-10N^3 - 2.0E-06N^2 + 5.2E-03N + 0.8 )</td>
<td>0.999</td>
</tr>
</tbody>
</table>
2. Curvature Change from Positive to Negative

\[
\frac{d^2 RD}{dN^2} = 30aN^4 + 20bN^3 + 12cN^2 + 6dN + 2e = 0
\]

Where:
RD = Rut depth
N = Number of wheel passes

Moisture Susceptibility Evaluation of GA Mix 1 Using SIPNew

Automated code for best fit function, SIP\textsubscript{New} and SIP\textsubscript{AASHTO T324} determination
Moisture Susceptibility Evaluation: Comparative Analysis

Min. SIP criteria (South Africa) = **10 000 cycles** (*Sabita Manual 35/TRH 8, 2016*)

<table>
<thead>
<tr>
<th>Asphalt Mix</th>
<th><strong>SIPAASHTO T324</strong></th>
<th><strong>SIPNew</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>GA Mix 1</td>
<td>13 864</td>
<td>10 636</td>
</tr>
<tr>
<td>GA Mix 2</td>
<td>10 893</td>
<td>10 101</td>
</tr>
<tr>
<td>GA Mix 3</td>
<td>11 976</td>
<td>9 731</td>
</tr>
</tbody>
</table>

- Treated with Hydrated Lime
- Treated with **Liquid Anti-Stripping Additive**
- No Anti-Stripping Additive
Moisture Susceptibility Evaluation: ASTM D4867M

Modified Lottman Test

<table>
<thead>
<tr>
<th>Indirect Tensile Strength (kPa)</th>
<th>Wet Strength</th>
<th>Dry Strength</th>
<th>TSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA Mix 1</td>
<td>1106</td>
<td>982</td>
<td>0.89</td>
</tr>
<tr>
<td>GA Mix 2</td>
<td>867</td>
<td>692</td>
<td>0.80</td>
</tr>
<tr>
<td>GA Mix 3</td>
<td>950</td>
<td>722</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Tensile Strength Ratio

Without Additive

Hydrated Lime

Wetfix

BE
Moisture Susceptibility Evaluation: Microscopic Image Analysis

<table>
<thead>
<tr>
<th>Methodology</th>
<th>GA Mix 1</th>
<th>GA Mix 2</th>
<th>GA Mix 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Original image</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Original image for GA Mix 1" /></td>
<td><img src="image2" alt="Original image for GA Mix 2" /></td>
<td><img src="image3" alt="Original image for GA Mix 3" /></td>
<td></td>
</tr>
<tr>
<td>2. 8-bit greyscale image conversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image4" alt="8-bit greyscale for GA Mix 1" /></td>
<td><img src="image5" alt="8-bit greyscale for GA Mix 2" /></td>
<td><img src="image6" alt="8-bit greyscale for GA Mix 3" /></td>
<td></td>
</tr>
</tbody>
</table>
### Moisture Susceptibility Evaluation: Microscopic Image Analysis

**Unconditioned sample reflecting glass particles**

<table>
<thead>
<tr>
<th>3. Binary image conversion (with reflecting glass particles)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. Elimination of reflecting particles ≤ 0.15 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>
5. Stripping and sample surface area determination

6. Percentage Stripping Computation
Moisture Susceptibility Evaluation: Microscopic Image Analysis

<table>
<thead>
<tr>
<th>GA Mix 1</th>
<th>GA Mix 2</th>
<th>GA Mix 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Area of white pixels = 3.6 mm²</td>
<td>Area of white pixels = 2.1 mm²</td>
<td>Area of white pixels = 10.4 mm²</td>
</tr>
<tr>
<td>Area of stripping = 1.1%</td>
<td>Area of stripping = 0.6%</td>
<td>Area of stripping = 3.2%</td>
</tr>
<tr>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Area of white pixels = 1.9 mm²</td>
<td>Area of white pixels = 5.2 mm²</td>
<td>Area of white pixels = 18.3 mm²</td>
</tr>
<tr>
<td>Area of stripping = 0.6%</td>
<td>Area of stripping = 1.6%</td>
<td>Area of stripping = 5.7%</td>
</tr>
<tr>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Area of white pixels = 5.1 mm²</td>
<td>Area of white pixels = 13.3 mm²</td>
<td>Area of white pixels = 30.9 mm²</td>
</tr>
<tr>
<td>Area of stripping = 1.6%</td>
<td>Area of stripping = 4.1%</td>
<td>Area of stripping = 9.6%</td>
</tr>
</tbody>
</table>

Area of white pixels = 3.6 mm²
Area of stripping = 1.1%

Area of white pixels = 2.1 mm²
Area of stripping = 0.6%

Area of white pixels = 10.4 mm²
Area of stripping = 3.2%

Area of white pixels = 1.9 mm²
Area of stripping = 0.6%

Area of white pixels = 5.2 mm²
Area of stripping = 1.6%

Area of white pixels = 18.3 mm²
Area of stripping = 5.7%

Area of white pixels = 5.1 mm²
Area of stripping = 1.6%

Area of white pixels = 13.3 mm²
Area of stripping = 4.1%

Area of white pixels = 30.9 mm²
Area of stripping = 9.6%

Total Area of Stripping:
6.2%  9.9%  46.4%
Moisture Susceptibility Evaluation: Summary of Results

<table>
<thead>
<tr>
<th>Asphalt Mix</th>
<th>TSR (^1)</th>
<th>Microscopic Image Analysis</th>
<th>SIP(_{AASHTO \text{T324}}) (^2)</th>
<th>SIP(_{\text{New}}) (^2)</th>
<th>Performance Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA Mix 1 (HL)</td>
<td>0.89 (1)</td>
<td>6.2% (1)</td>
<td>13 864 (1)</td>
<td>10 636 (1)</td>
<td>1</td>
</tr>
<tr>
<td>GA Mix 2 (LAA)</td>
<td>0.80 (2)</td>
<td>9.9% (2)</td>
<td>10 893 (3)</td>
<td>10 101 (2)</td>
<td>2</td>
</tr>
<tr>
<td>GA Mix 3 (None)</td>
<td>0.76 (3)</td>
<td>46.4% (3)</td>
<td>11 976 (2)</td>
<td>9 731 (3)</td>
<td>3</td>
</tr>
</tbody>
</table>

1 Min. TSR criteria (South Africa) = 0.8
2 Min. SIP criteria (South Africa) = 10 000 passes
Conclusions

- **Hydrated lime is most effect** in alleviating stripping in highly siliceous aggregates.
- **Liquid antistripping additive**, which is known to be commonly used in HMA production in South Africa, may not be as effective in, **while also reducing the strength of the mix.**
- **Proposed new method to determine the SIP parameter** is more effective in evaluating mix moisture susceptibility **than the standard method of evaluation** which demonstrates inconsistency in the calculated SIP value.
- **Microscopic imaging techniques** conducted to evaluate mix moisture susceptibility is capable of providing an accurate representation of the degree of stripping and furthermore eliminates visual judgment and biased interpretation associated with the current standard of visual inspection and reporting.
Way Forward

- Future research into the **correlation between the proposed new method for SIP determination and the SIP compliance criterion** with asphalt pavements of known stripping performance is recommended.

- Expected levels of moisture-related performance based on the **stripping inflection point should not be assessed in isolation** but rather in **conjunction with the rutting criterion** (i.e. the minimum number of passes to reach a prescribed rut depth).
THANK YOU