Nanotechnology for Asphalt Pavements
TYPICAL CONSTRUCTION DESIGN

SURFACE / WEARING COURSE

BINDER / BC COURSE

BASE / DBM COURSE
ZYCOSOIL FEATURES

• Chemically Reactive
• Antistripping Additive
• Asphalt Modifier
The chemistry - Theory

Hydrophilic polar aggregates get converted to non-polar Hydrophobic aggregates by nano modification, at processing temperatures of HMA.
ZYCOSOIL - THE CHEMICAL ACTION

- OH groups make surface very hydrophilic (water loving)

Particle surface

Zycooil molecule creates molecular level hydrophobic zone (water repellent)

Soil / Clay particle surface silicate structure

Newly formed Siloxane bonds

Internal Siloxane bonds

Soil / Clay surface silicate structure after Zycooil reaction
ANTISTRIPPING ADDITIVE

Zycosoil eliminates Asphalt Stripping

TSR Value (AASHTO T283) > 95 %
ASPHALT MODIFIER

Improves

- Rut Resistance
- Marshall Stability
- Flow Value
- Hveem Stability
EXISTING TECHNOLOGIES - ISSUES

Non Uniformity ➔

Good and poor quality aggregates can come from single rock formation

Aggregates Dust Coating ➔ A Reality

Causes Reverse Emulsification of asphalt binder leading to stripping

Marginal and Quartzite Aggregates ➔ Rejected for asphalt concrete
WATERPROOF DEPOSITED DIRT ON AGGREGATE
ANTISTRIPPING ADDITIVE - AMINES

1. Improve Antistripping Performance
2. Lower Rut Resistance
3. Lower Fatigue Resistance
4. Handling issue - Bad Smell
ANTISTRIPPING ADDITIVE – HYDRATED LIME

1. Reacts chemically with Si-OH of aggregates and forms calcium silicate, reduces water absorption but does not eliminate water sensitivity

2. Mechanical limitation: Needs Wet Mixing 1.5 % lime with Aggregates. In case of marinating extra 24-48 hours required. Needs additional drying

3. Improves antistripping and Rut Resistance
ZYCOSOIL USP’S / BENEFITS

Reactive anti-strip agent

Eliminates stripping (debonding)

Improves rut resistance

Improves compaction by 1 to 1.5% on the field

Glossier pavements

Does not impart any odor to the asphalt binder or asphalt mix, improved working environment

Neutral, does not cause any corrosion and skin irritation unlike lime or amines
### ASPHALT BINDER - COMPOSITION

<table>
<thead>
<tr>
<th>Component</th>
<th>Content</th>
<th>Composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphaltenes</td>
<td>Three dimensional association of polar molecules</td>
<td>5-10</td>
</tr>
<tr>
<td>Maltenes</td>
<td>Mostly Nonpolar hydrocarbon compounds</td>
<td>90-95</td>
</tr>
</tbody>
</table>

Asphalt binder contains 5-10 % Polar components
Asphalt microstructure is a continuous three-dimensional association of polar molecules “Asphaltenes”, dispersed in a fluid of non-polar molecules "Maltenes"
ASPHALT - SILANE - AGGREGATE : INTERACTION

Adhesion - Reactive Bonding

Wetting - Pinhole free surface
Improved Coverage
TYPICAL AGGREGATE

ZYCOSOIL REACTED AGGREGATE

Polar Silanol Groups

Zycosoil Additive converts Aggregate Polar silanol groups to Non-polar siloxanes

Aggregate Polar group

Aggregate Non-polar group
TYPICAL AGGREGATE-ASPHALT BINDER INTERACTION

Polar - Polar Interaction
5-10 % Asphalt Bonding

Aggregate & Asphalt binder Polar group

ZycoSoil Additive converts Aggregate Polar silanol groups to Non-polar siloxanes

Nonpolar- Nonpolar Interaction
90-95 % Asphalt Bonding

ZycoSoil Additive converts Aggregate Polar silanol groups to Non-polar siloxanes
AASHTO T182 at 60° C / ASTM 1664

Basalt Aggregate (DBM): 45% 20 mm, 10% 10 mm, 45% less than 6 mm with stone dust

Asphalt Grade: AC-20 (VG-30, 60-70 penetration grade)

* Less than 85% → Fail, (as per specified standards)
BOILING TEST ASTM 3625, 2 hour conditioning at 135°C

Basalt Aggregate (DBM) : 45% 20 mm, 10% 10 mm, 45% less than 6 mm with stone dust

Asphalt Grade: AC-20 (VG-30, 60-70 penetration grade)

* Less than 85% → Fail, (as per specified standards)
All control samples showed significant amount of stripped asphalt binder floating in water
BOILING TEST
ASTM D3625

Boil test : 6 hr, Dolomite Aggregate
Keystone Quarry, Maryland, USA

<table>
<thead>
<tr>
<th>Test sample</th>
<th>Color &amp; Tack</th>
<th>Uncoated Aggregates % (approx.)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAD 1 + No additive</td>
<td>Discolored brownish mass, no tack</td>
<td>80 -90%</td>
</tr>
<tr>
<td>AAD 1 + 0.1% Zycosoil AG</td>
<td>Black, tacky</td>
<td>5%</td>
</tr>
<tr>
<td>AAM 1 + No additive</td>
<td>Discolored brownish mass, no tack</td>
<td>70 -80%</td>
</tr>
<tr>
<td>AAM 1 + 0.1% Zycosoil AG</td>
<td>Black, tacky</td>
<td>&lt; 5%</td>
</tr>
</tbody>
</table>

Asphalt Grade – resistance to moisture
AAD-1 : very poor ; AAM-1 good

* Specified Standard for 10 min. Boil Test ➔ Below 75 % considered as Fail
OH groups make surface very hydrophilic (water loving).

N70 Superpave Mix with 20% RAP (Illinois DOT approved mix)

Tensile strength AASHTO T283

Control

0.1% Zycosoil

TSR 0.87

TSR 0.88

Average Conditioned Tensile Strength

Average Unconditioned Tensile Strength

Chicago Testing Laboratory Inc.
Increased TSR values indicate significant improvement in the moisture resistance of the HMA mixtures.
HAMBURG WHEEL TEST – RUT RESISTANCE

Moisture sensitive Dolomite Aggregate Keystone Quarry under wet condition at 50 °C

Red lines → Control Hot-Mix;
Blue lines → Zycosoil Modified Hot-Mix.
HAMBURG WHEEL TEST – RUT RESISTANCE RESULTS

Moisture sensitive Dolomite Aggregate Keystone Quarry under wet condition at 50 °C

<table>
<thead>
<tr>
<th>Measure</th>
<th>Control hot mix</th>
<th>Zycosoil modified hot mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIP</td>
<td>4600</td>
<td>11000</td>
</tr>
<tr>
<td>Rut Depth 10 mm Utah DOT</td>
<td>9300</td>
<td>14300</td>
</tr>
</tbody>
</table>
HAMBURG WHEEL TEST – RUT RESISTANCE SIP VALUE

Testing under wet condition at 60 °C instead of 50 °C normally obtained

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4223</td>
</tr>
<tr>
<td>0.05 % Zycosoil</td>
<td>5692</td>
</tr>
</tbody>
</table>
Air Voids of Mix Design Asphalt Concrete (4.9 % Binder, Maryland Aggregates)
STRENGTH IMPROVEMENT

Improves Marshall Stability by 30-40 %, especially under wet condition

Improved Compaction

Improved Gloss
MARSHALL STABILITY & FLOW VALUE ASTM D1075 : AASHTO T165 at 60 °C, 24 hrs

Basalt aggregate: 45% 20mm, 10% 10mm, 45% less than 6mm with stone dust

Asphalt Concrete Marshall Strength (Kg)

- Control
- 2% Hydrated Lime
- 0.1 % Zycosoil
MARSHALL STABILITY & FLOW VALUE ASTM D1075: AASHTO T165 at 60 °C, 24 hrs

Basalt aggregate: 45% 20mm, 10% 10mm, 45% less than 6mm with stone dust

Zycosoil AG additive improved the Marshall Stability significantly while maintaining the flow value. The maximum gain was seen in the mix containing Crumb Rubber Modified Bitumen (CRMB)
MARSHALL STABILITY STRENGTH
ASTM D1075 : AASHTO T165 at 60 °C, 24 hrs

Basalt aggregate: 33% 20mm, 24% 10mm, 41% less than 6mm with stone dust

**Zycosoil**

Binder with 0.1 % Zycosoil
MARSHALL STABILITY STRENGTH
ASTM D1075 : AASHTO T165 at 60 °C, 24 hrs

Basalt aggregate: 33% 20mm, 24% 10mm, 41% less than 6mm with stone dust

<table>
<thead>
<tr>
<th>% Asphalt binder content</th>
<th>Strength kg</th>
<th>Flow Value Mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Modified</td>
</tr>
<tr>
<td>5.1</td>
<td>1140</td>
<td>1625</td>
</tr>
<tr>
<td>4.5</td>
<td>1467</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>1120</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>938</td>
<td></td>
</tr>
</tbody>
</table>
MARSHALL STABILITY STRENGTH ASTM D1075:
AASHTO T165 at 60 °C, 24 hrs

Basalt aggregate: 45% 20mm, 10% 10mm, 45% less than 6mm with stone dust

Stripping resistance of the Zycosoil AG modified mix in terms of retained stability ratio is significantly superior to all other additives.
Field results: Compressive Stability, Flow Value and Voids 0.1% Zycosoil added to 5.85 % Asphalt

Asphalt Grade: PG 64-22

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Bulk Specific Gravity</th>
<th>Density pcf</th>
<th>Stabililty lbs</th>
<th>Flow 0.01inch</th>
<th>Air Voids %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.455</td>
<td>152.8</td>
<td>10246</td>
<td>15</td>
<td>2.4</td>
</tr>
<tr>
<td>2</td>
<td>2.442</td>
<td>152</td>
<td>9407</td>
<td>16</td>
<td>2.9</td>
</tr>
<tr>
<td>3</td>
<td>2.443</td>
<td>152</td>
<td>9741</td>
<td>15</td>
<td>2.9</td>
</tr>
<tr>
<td>Avg</td>
<td>2.447</td>
<td>152.3</td>
<td>9798</td>
<td>15</td>
<td>2.7</td>
</tr>
</tbody>
</table>
**FIELD TEST RESULTS**

**HVEEM STABILOMETER TEST CT 304, 356**  
0.1% Zycosoil added to 5.85% Asphalt

<table>
<thead>
<tr>
<th>Briquette Number</th>
<th>Height - Inches</th>
<th>Relative Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5</td>
<td>42</td>
</tr>
<tr>
<td>2</td>
<td>2.51</td>
<td>41</td>
</tr>
<tr>
<td>3</td>
<td>2.51</td>
<td>42</td>
</tr>
<tr>
<td>Avg</td>
<td>2.51</td>
<td>42</td>
</tr>
</tbody>
</table>

- Specified Standard for California Highway → 37
Rotational Viscosity Test AASHTO T 316 at 135 °C

<table>
<thead>
<tr>
<th>Sample</th>
<th>Viscosity Pa S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.470</td>
</tr>
<tr>
<td>Zycosoil AG (0.05 %)</td>
<td>0.468</td>
</tr>
<tr>
<td>Zycosoil AG (0.1 %)</td>
<td>0.458</td>
</tr>
</tbody>
</table>

Lower Rotational viscosity values of the Zycosoil AG-containing asphalt binders are good for mixing and wetting of the aggregates with asphalt binder.

It also results in relatively lower mix temperatures.
**Dynamic Shear Rheometer Test AASHTO T 315 at 64 °C**

<table>
<thead>
<tr>
<th>Sample</th>
<th>G* kPa</th>
<th>Phase Angle</th>
<th>G*/Sin δ kPa</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.44</td>
<td>86.4</td>
<td>1.44</td>
<td></td>
</tr>
<tr>
<td>Zycosoil AG (0.05 %)</td>
<td>1.56</td>
<td>86.4</td>
<td>1.57</td>
<td>&gt;1.00 kPa</td>
</tr>
<tr>
<td>Zycosoil AG (0.1 %)</td>
<td>1.55</td>
<td>86.4</td>
<td>1.55</td>
<td></td>
</tr>
</tbody>
</table>

The complex modulus G*, is higher while the phase angle remains same for the samples containing Zycosoil AG.

Zycosoil AG improves binder stiffness with the same visco elastic response (phase angle).
### Zycosoil AG Containing Asphalt Binders Show Increase in G* Value with Similar Phase Angle

The increase in G*/sin δ indicates improved rut resistance properties of the asphalt mix at the time of construction unlike amines, which always reduce the rut resistance.

<table>
<thead>
<tr>
<th>Sample</th>
<th>G* kPa</th>
<th>Phase Angle</th>
<th>G*/sin δ kPa</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.44</td>
<td>82.7</td>
<td>3.47</td>
<td></td>
</tr>
<tr>
<td>Zycosoil AG (0.05 %)</td>
<td>3.75</td>
<td>82.8</td>
<td>3.78</td>
<td>≥2.20 kPa</td>
</tr>
<tr>
<td>Zycosoil AG (0.1 %)</td>
<td>4.00</td>
<td>82.7</td>
<td>4.02</td>
<td></td>
</tr>
</tbody>
</table>

**Rolling Thin Film Oven Test (RTFOT)** AASHTO T 240,

**Dynamic Shear Rheometer** AASHTO T 315 at 64 °C
Pressure Aging Vessel (PAV) TEST AASHTO R 28
Dynamic Shear Rheometer AASHTO T 315 at 25 °C

<table>
<thead>
<tr>
<th>Sample</th>
<th>G* kPa</th>
<th>Phase Angle</th>
<th>G*sin δ kPa</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6373</td>
<td>43.3</td>
<td>4368</td>
<td>&lt; 5000 kPa</td>
</tr>
<tr>
<td>Zycosoil AG (0.05 %)</td>
<td>6001</td>
<td>44.1</td>
<td>4173</td>
<td></td>
</tr>
<tr>
<td>Zycosoil AG (0.10%)</td>
<td>6628</td>
<td>44.8</td>
<td>4668</td>
<td></td>
</tr>
</tbody>
</table>

PAV aged Zycosoil AG asphalt binders residue showed higher phase angle, which means increased elasticity compared to control.
Bending Beam Rheometer (BBR) Test
AASHTO T 313 at -12 °C

<table>
<thead>
<tr>
<th>Sample</th>
<th>Stiffness mPa</th>
<th>Specification</th>
<th>M Value</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>201</td>
<td>&lt; 300</td>
<td>0.312</td>
<td>&gt; 0.300 mPa</td>
</tr>
<tr>
<td>Zycosoil AG (0.05 %)</td>
<td>202</td>
<td></td>
<td>0.317</td>
<td></td>
</tr>
<tr>
<td>Zycosoil AG (0.1 %)</td>
<td>186</td>
<td></td>
<td>0.314</td>
<td></td>
</tr>
</tbody>
</table>

The low temperature properties of Zycosoil AG modified asphalt binder were either equal or better than those of the unmodified binder.

This is important for asphalt projects located in cold climate regions.
MARSHALL STABILITY STRENGTH ASTM D1075; AASHTO T165 at 60 °C, 24 hrs

<table>
<thead>
<tr>
<th>Test Sample 5.1% asphalt binder on weight of mix</th>
<th>Stability in kg</th>
<th>Ratio %</th>
<th>Flow value in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
<td>Dry</td>
</tr>
<tr>
<td>Unaged binder Control</td>
<td>2265</td>
<td>2015</td>
<td>89.0</td>
</tr>
<tr>
<td>Unaged binder – Zycosoil AG (0.1%)</td>
<td>2485</td>
<td>2320</td>
<td>93.4</td>
</tr>
<tr>
<td>Aged binder 15 days – Control</td>
<td>2235</td>
<td>2011</td>
<td>90.0</td>
</tr>
<tr>
<td>Aged binder 15 days – Zycosoil AG (0.1%)</td>
<td>2652</td>
<td>2445</td>
<td>92.2</td>
</tr>
</tbody>
</table>

Zycosoil AG was added in asphalt binder and aged at 150 °C for 15 days

Efficacy of Zycosoil AG does not diminish when the hot binder modified with it, is stored for a long period of 15 days
ADDITIONAL APPLICATIONS

Substantial improvement in strength and Resistance to Moisture in

OGFC design mix

Micro-surfacing formulation

Slurry Seal mixtures
POROUS PAVEMENT (OPEN GRADED ASPHALT FRICTION COURSE)

Porous pavements undergo severe hydraulic scouring by vehicle tire movement, pushing the water through the porous pavements at high pressure and speed.

Strengthening and improving stiffness of the asphalt due to Zycosoil AG additive, will also contribute to improvement of the structural strength of the pavement.
SLURRY SEAL AND MICRO-SURFACING

Zycosoil AG can be used in Slurry Seal and Micro Surfacing formulations to improve their anti-stripping performance

Dilute 1 part of Zycosoil AG in 100 parts of water

Add 7 parts of the above diluted Zycosoil solution in 113 parts of water and mix. Add this mixed solution to 880 parts of aggregate mix

Spray the solution on aggregates first to allow it to mix & react with aggregates
SLURRY SEAL AND MICRO-SURFACING

Add 120 gms of cationic asphalt emulsion to the wet mix

For aggregates with high moisture sensitivity add 14 parts of the diluted Zycosoil solution
The mixes were prepared with and without Zycosoil and dried at room temperature and conditioned at 80 °C for 12 hrs & then subjected to Boil test at 100 °C.

<table>
<thead>
<tr>
<th>Regular</th>
<th>With Zycosoil AG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates 880 gm</td>
<td>Aggregates 880 gm Aggregates 880 gm</td>
</tr>
<tr>
<td>Water 120 gm</td>
<td>Diluted Zycosoil AG 7 gm Diluted</td>
</tr>
<tr>
<td>Asphalt emulsion</td>
<td>120 gm (cationic) Water 113 gm Water</td>
</tr>
<tr>
<td></td>
<td>Asphalt emulsion 120 gm (cationic)</td>
</tr>
</tbody>
</table>

Then, the samples were subjected to 1hr and 3hr boil test. The standard procedure was followed to conduct boil test (ASTM 3625) of prepared samples.
## BOIL TEST RESULTS

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Material</th>
<th>% Coated Aggregate</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Time 1 hr</td>
<td>Time 3 hr</td>
</tr>
<tr>
<td>1</td>
<td>Aggregates Basalt</td>
<td>40%</td>
<td>Total failure</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>98%</td>
<td>90%</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>98%</td>
<td>96%</td>
</tr>
</tbody>
</table>
GREEN PERPETUAL PAVEMENTS

Substantial improved life

Improved Asphalt content in RAP

Technology can quicken the move towards Warm Asphalt Mix (WAM)

→ Reduced CO₂ generation
→ Decrease in Oxidation
→ Improved working condition during compaction
ECONOMICS

$ 0.9 per ton (US ton = 2000 lb) Asphalt Mix
and
$ 1 per MT Asphalt Mix
THANK YOU