ZYCOSOIL™

Nanotechnology for
Asphalt Pavements

Paving the Way for
Nanotechnology Road to Progress

- 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 odour to the asphalt binder or asphalt mix, improved working environment
- Neutral does not cause any corrosion and skin irritation unlike lime or amines

"American roads are not good because America is rich,
but America is rich because American roads are good."

- John F. Kennedy

» Introduction

Good road construction requires that the asphalt pavement maintains its integrity without stripping (debonding of asphalt binder from aggregate surface especially when exposed to moisture or water) and provides resistance to rutting (with adequate strength), fatigue cracking and low-temperature cracking. Stripping of asphalt pavements has become a major problem in recent years. Stripping can lead to premature rutting, fatigue cracking or disintegration (potholing) of the asphalt pavement.

» Nanotechnology

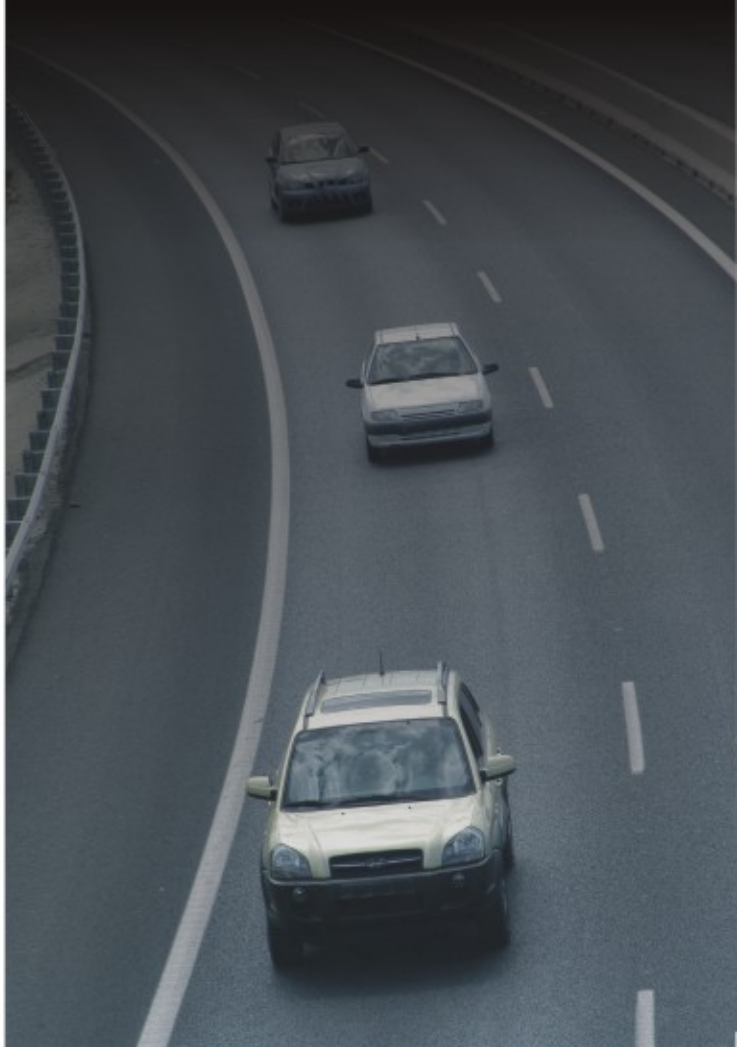
Zycosoil nanotechnology is a technological breakthrough to address stripping problems in asphalt paving mixes. Zycosoil chemically bonds with the aggregates surface and eliminates debonding of asphalt binder. Liquid amines or hydrated lime are typically used as anti-strip agents in asphalt mixes. Amines simply increase the ability of asphalt binders to coat aggregate particles in asphalt mix. Hydrated lime modifies the surface properties of aggregate particles to make it generally more compatible with asphalt binder. However, Zycosoil not only does both the functions of amines and hydrated lime but it does it chemically, by providing Mother Nature's strongest bond, which survives for centuries, which cannot be displaced by water ever.

Besides being a very effective and durable anti-strip, Zycosoil provides additional advantages which are not provided by amines or hydrated lime. Zycosoil increases the tensile strength of asphalt mix by about 15 to 20%, which has the potential to increase its fatigue life (that is, resistance to cracking under repeated traffic loading). Zycosoil also increases the Marshall stability of asphalt mixes to provide increased resistance to rutting while keeping it flexible (that is, maintaining the same flow properties). Zycosoil also improves the asphalt binder properties, in terms of lowered mixing viscosity, higher resistance to rutting, and increased elasticity. Zycosoil modified asphalt mix is easier to compact both in the laboratory and in the field. Field compaction is improved by 1 to 1.5% with the same compactive effort, resulting in construction cost savings and increased durability of asphalt pavement with reduced air voids.

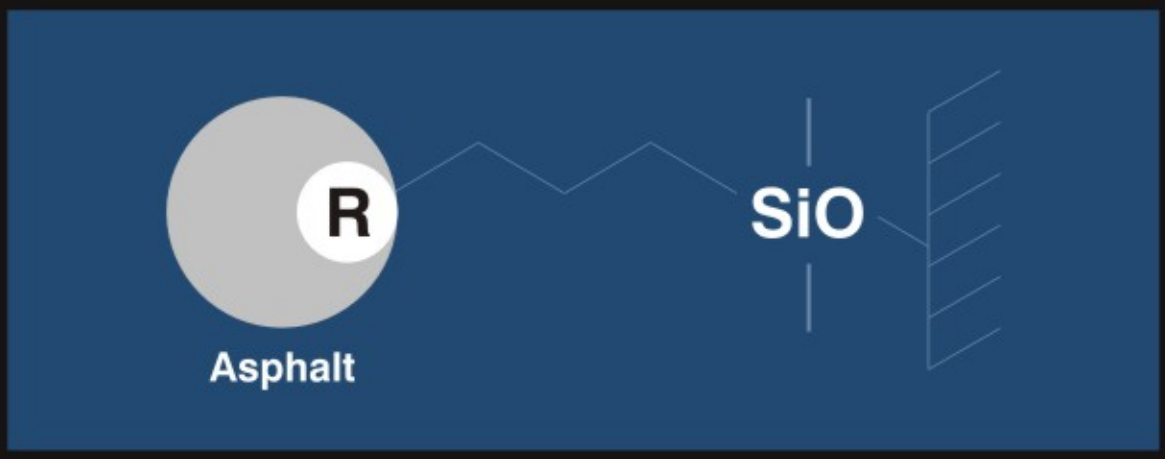
» Zycosoil Features

Zycosoil is a reactive organo-silicon compound. It forms Si-OH silanol groups upon hydrolysis. These silanols are reactive and can form Si-O-Si siloxane bonds with surface silanol groups of inorganic substrates. Zycosoil nanotechnology offers:

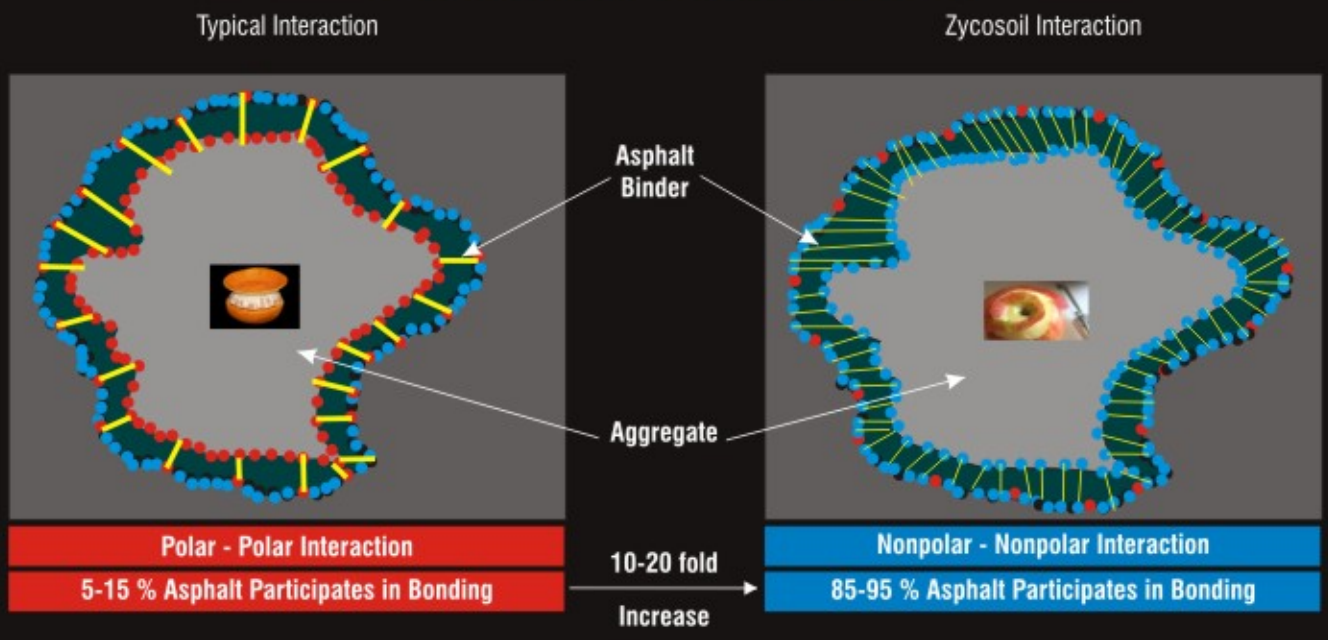
- Permanent water repellent nano layer on all types of clay, fines (stone powder) and aggregates
- Reaction leads to permanent nano siliconization of the surfaces by converting the water loving silanol groups to water repellent alkyl siloxane surfaces
- The Si-O-Si siloxane bond is Mother Nature's strongest bond which survives for centuries

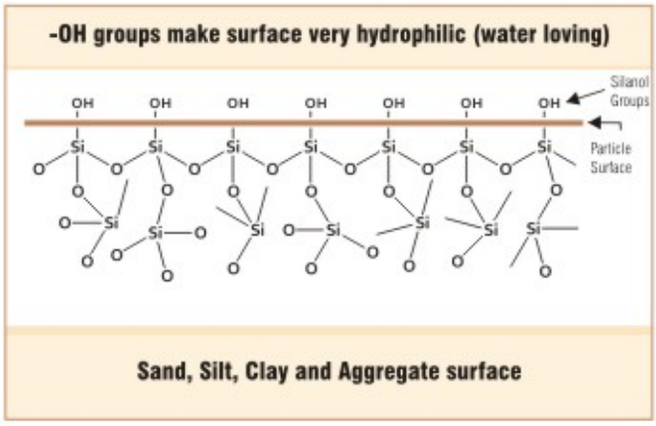


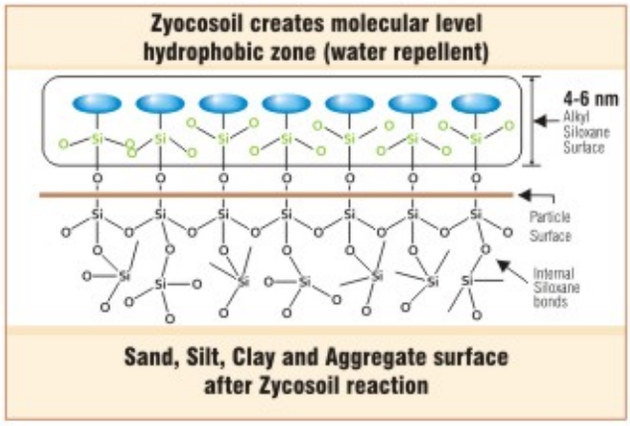
PINHOLE FREE SURFACE



AGGREGATE-ASPHALT BINDER INTERACTION







» Superior Anti-strip Performance of Zycosoil in All Types of Standard Stripping Tests

Zycosoil was evaluated by different agencies using four standard ASTM or AASHTO test methods used worldwide for determining stripping potential of asphalt mixes. The performance of Zycosoil was found to be superior compared to other anti-strip agents. The test data from these evaluations follow :

1. Tensile Strength Ratio (AASHTO T 283)

Tensile Strength Ratio (TSR) determined by AASHTO T 283, "Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage" is the most prevalent way to quantify moisture susceptibility and has been an accepted test for evaluating practically all asphalt mix designs (both Superpave and Marshall methods).

TSR measures the combined accelerated effect of potential adhesive failure due to stripping (debonding) and cohesive failure (weakening of asphalt binder due to water absorption). Cohesive weakening is inherent property of asphalt binder depending on its chemical composition and its oxidative state along with polar asphaltene content. Most of the anti-strip additives do not comprehensively address a solution for adhesive or cohesive weakening of asphalt.

AASHTO T 283 method was followed to measure the tensile strength for original and conditioned compacted samples of asphalt mixes using Georgia (Lithia) Granite and Illinois aggregates. These aggregates were specifically studied due to their known history of moisture sensitivity (stripping).

Georgia (Lithia) Aggregates

The test data obtained by the National Center for Asphalt Technology (NCAT) are given in Table-1.

Table-1: Georgia (Lithia Springs Design) Granites with PG 64-22 Asphalt binder TSR Result (AASHTO T 283, NCAT Report)

(a) Binder with no additives

Mix	Freeze -Thaw	Saturated	Saturation	Air Voids	Tensile Strength (psi)	Average Tensile Strength (psi)	TSR
Control	0	No	0	7.2	182.43		
Control	0	No	0	7.0	153.47	165.87	
Control	0	No	0	7.3	161.72		0.82
Control	1	Yes	71.3	7.3	131.46		
Control	1	Yes	71.0	7.3	130.53	135.59	
Control	1	Yes	70.2	6.8	144.78		

(b) Mix PG 64-22 Binder with 0.05% Zycosoil additive

Mix	Freeze -Thaw	Saturated	Saturation	Air Voids	Tensile Strength (psi)	Average Tensile Strength (psi)	TSR
Zycosoil	0	No	0	7.3	170.39		
Zycosoil	0	No	0	7.0	159.41	159.99	
Zycosoil	0	No	0	7.2	150.17		0.95
Zycosoil	1	Yes	70.6	7.4	154.79		
Zycosoil	1	Yes	70.6	7.0	155.95	151.65	
Zycosoil	1	Yes	70.6	6.9	144.20		

(c) Mix PG 64-22 Binder with 0.1% Zycosoil additive

Mix	Freeze -Thaw	Saturated	Saturation	Air Voids	Tensile Strength (psi)	Average Tensile Strength (psi)	TSR
Zycosoil	0	No	0	7.5	155.95		
Zycosoil	0	No	0	6.7	170.84	167.55	
Zycosoil	0	No	0	6.7	175.87		1.00
Zycosoil	1	Yes	79.3	6.9	164.61		
Zycosoil	1	Yes	71.1	6.8	172.98	167.40	
Zycosoil	1	Yes	70.0	7.0	164.61		

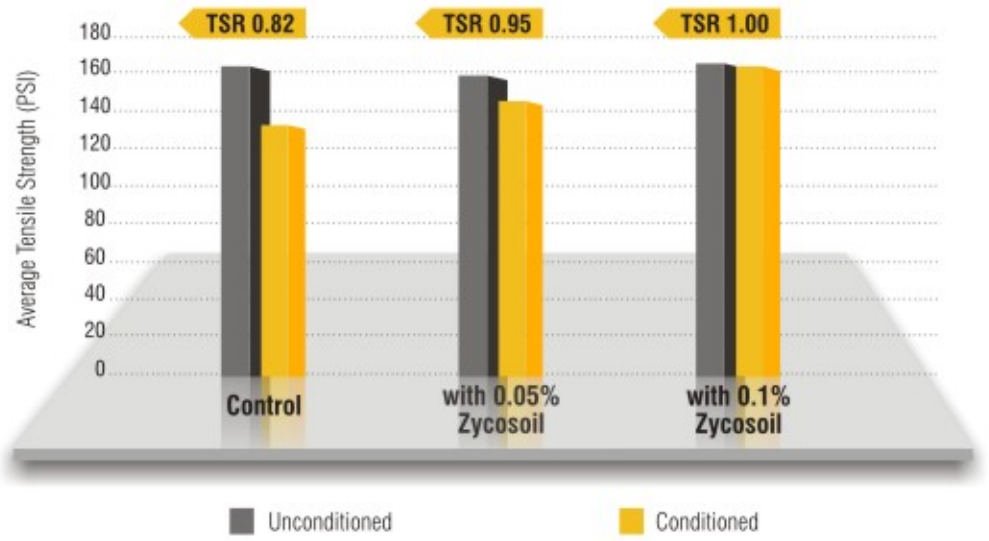


Fig. 1: TSR Test Results for Georgia (Lithia) Aggregates

The TSR's have improved from 0.82 to 0.95 and 1.0, respectively, from control to 0.05 & 0.1 % of Zycosoil added to the asphalt binder (Fig. 1) confirming its efficacy as an anti-strip additive.

Illinois Aggregates

A Superpave N70 20% recycled surface mixture containing 21% of manufactured sand with post stripping sensitivity was used with optimum content of PG 64-22 asphalt binder without additive and with 0.1% Zycosoil additive. Although the TSR's show marginal improvement but both unconditioned and conditioned samples show significant increase in mix tensile strength (Fig 2). Higher mix tensile strength tends to increase the fatigue life of a compacted mix under traffic.

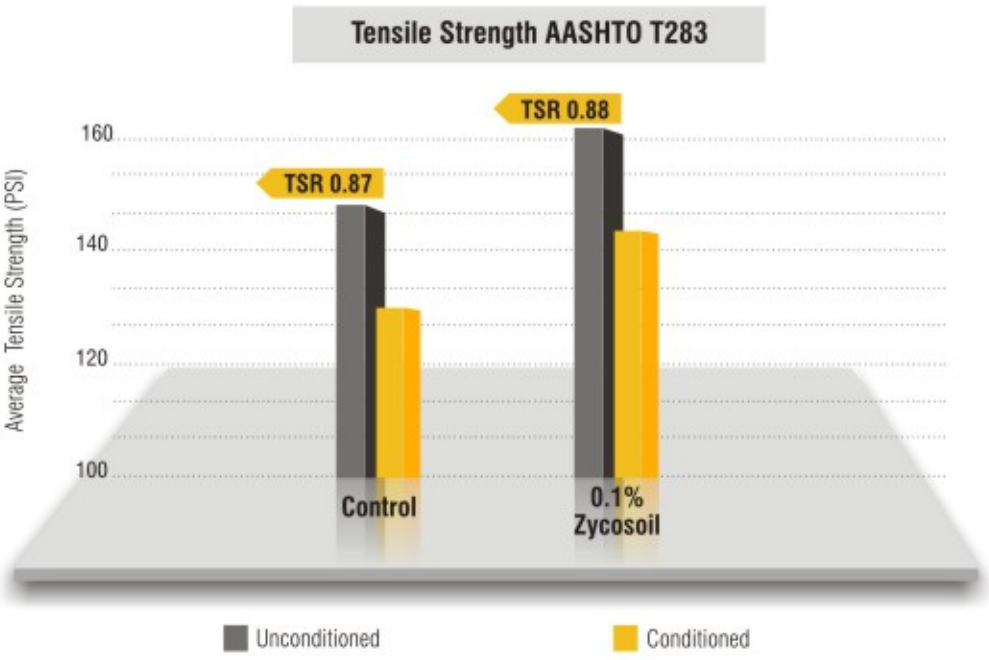


Fig. 2: TSR Test Results for Illinois Aggregates

2. Hamburg Wheel Test (AASHTO T 324), Rut Resistance

This test evaluates the moisture susceptibility (stripping) of a compacted asphalt mix by measuring the rut depth under water at 50°C using a loaded steel wheel. Moisture sensitive Maryland (USA) aggregates were chosen for the Hamburg Wheel test. A 10 mm rut depth is considered the typical cut-off limit to evaluate performance in terms of number of passes as documented by the Utah Department of Transportation. The results in Fig. 3 show a substantial improvement in the number of passes at the same rutting depth, when Zycosoil was added to the mixture.

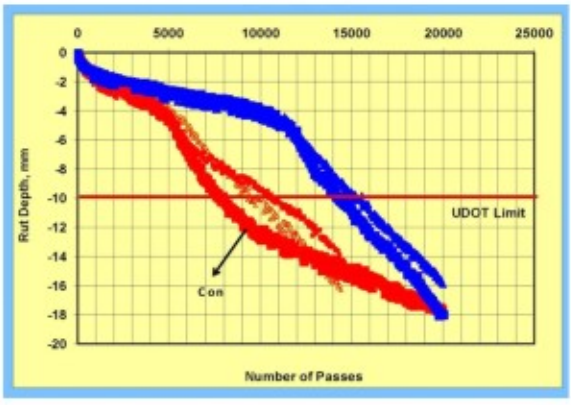


Fig. 3: Hamburg Wheel Test of PG 64-22 asphalt mix with and without Zycosoil

(Red Symbol represents control Hot Mix Asphalt and blue symbol represents Zycosoil modified Hot Mix Asphalt.)

Stripping inflection point for control mix occurred at 4,600 passes while for Zycosoil modified mix it occurred at 11,000 passes showing the latter to be highly resistant to stripping. The numbers of passes to achieve 10 mm rut depth were 9,300 for control mix and 14,300 for Zycosoil modified mix showing the superior rut resistance of the latter.

3. Boil Test (ASTM D3625)

Zycosoil was also evaluated using ASTM D3625, "Effect of Water on Bitumen- Coated Aggregate Using Boil Test". Mixes prepared as per the mix design formula were aged in the oven at 135 °C for two hours simulating the hot mix processing and silo conditioning. A normal hydrogen bonding mechanism fails around 80 °C and above.

Extended times were chosen to document point of failure of existing technology and confirm the exceptional superiority of Zycosoil chemistry.

Anti-stripping performance of a basalt aggregate with asphalt binder AC-20 (equivalent to Superpave PG 64-22 or 60/70 penetration grade or VG-30) was tested using the 6-hour boil test. The test data at different time intervals are given in Fig. 4. The near complete elimination of failure due to debonding is quite evident.

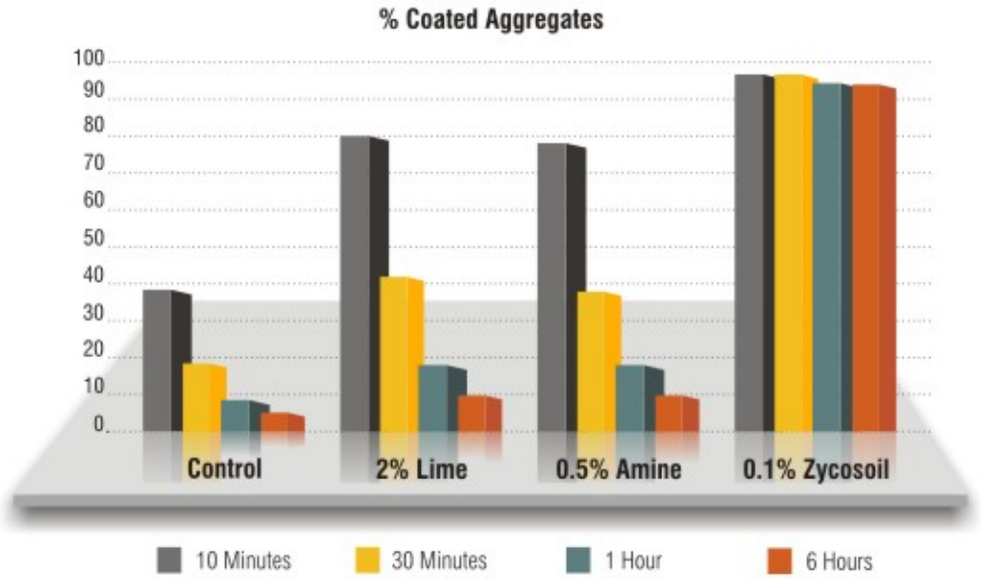
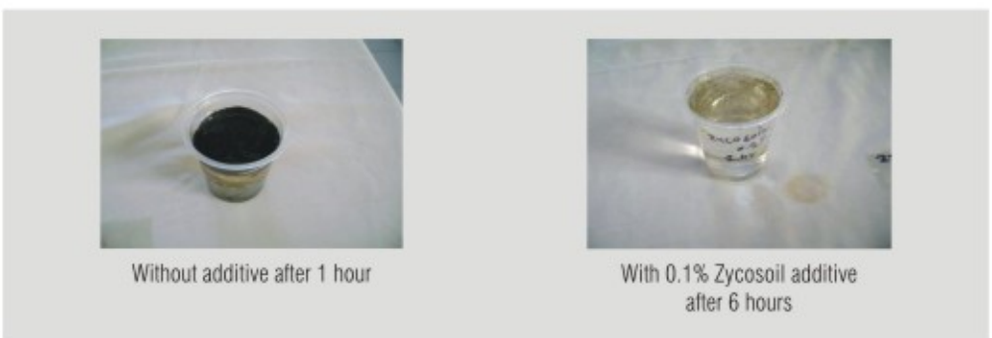


Fig. 4: Test Results of ASTM D3625 Boil Test (Basalt Aggregate)
Specified standard for 10 min. Boil Test, below 75% is considered as failure

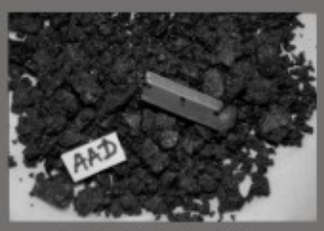


Without additive after 1 hour

With 0.1% Zycosoil additive after 6 hours

Residual Water of the One / Six Hour Boil Tests

The control samples showed significant amount of stripped asphalt binder floating in water at 1 hour. The 0.1 % Zycosoil containing asphalt binder samples showed, very little amount of stripped asphalt binder floating in water even after 6 hours of boiling.



AAD-1 Without additive

AAD-1 With 0.1%
Zycosoil additive

AAM-1 Without additive

AAM-1 With 0.1%
Zycosoil additive

A Case Study of documented moisture susceptible asphalt binder, (Strategic Highway Research Program, USA) and moisture susceptible dolomite aggregates (Keystone Quarry, Maryland, USA)

Samples of known moisture susceptible dolomite aggregates from Key Stone Quarry in Maryland, USA, were obtained to study debonding with specific asphalt binders AAM-1 & AAD-1 used in the Strategic Highway Research Program (SHRP), USA. Research had documented that AAD-1 as a binder has very poor resistance to moisture displacement while AAM-1 had an acceptable good resistance to moisture displacement.

Mixtures containing the dolomite aggregate and two SHRP asphalt binders with and without Zycosoil were subjected to ASTM D3625 test. Six-hour boil test was conducted instead of only 10 minutes in the standard test to distinguish long term resistance to debonding achievable with reactive anti-strip agent like Zycosoil . The superiority of this nanotechnology is documented below in the Table 2 which shows the percentage of uncoated aggregate particles after 6-hour boiling. Photographs of the mix with and without Zycosoil after the boil test demonstrate the difference.

Table-2 : Test Results of ASTM D3625 Boil Test
(Dolomite Aggregate, Keystone Quarry, Maryland, USA)

Test Sample	Color & Tack	Area coated on Aggreagates approx* (%)
AAD 1 + No additive	Discolored brownish mass, no tack	10-20% complete failure
AAD 1 + 0.1% Zycosoil	Black, tacky	≈ 95%
AAM 1 + No additive	Discolored brownish mass, no tack	20-30% complete failure
AAM 1 + 0.1% Zycosoil	Black, tacky	> 95%

*Specified standard for 10 min. Boil Test, below 75% is considered as failure

Improved Flexibility

4. Static Immersion Test (AASHTO T 182)

Anti-stripping performance of the same basalt aggregate used in the boil test was tested by AASHTO T 182, "Coating and Stripping of Bituminous Aggregate Mixtures". All mixes were aged at 135 °C for two hours prior to testing. Although the standard test requires immersion of the bituminous mix in distilled water at 60 °C for 16 to 18 hours only, these mixes were immersed in hot water at 60 °C for upto 360 hours, which was rather severe. The near complete elimination of failure due to debonding when Zycosoil was used even after 360 hours of conditioning is very remarkable as seen in Fig. 5.

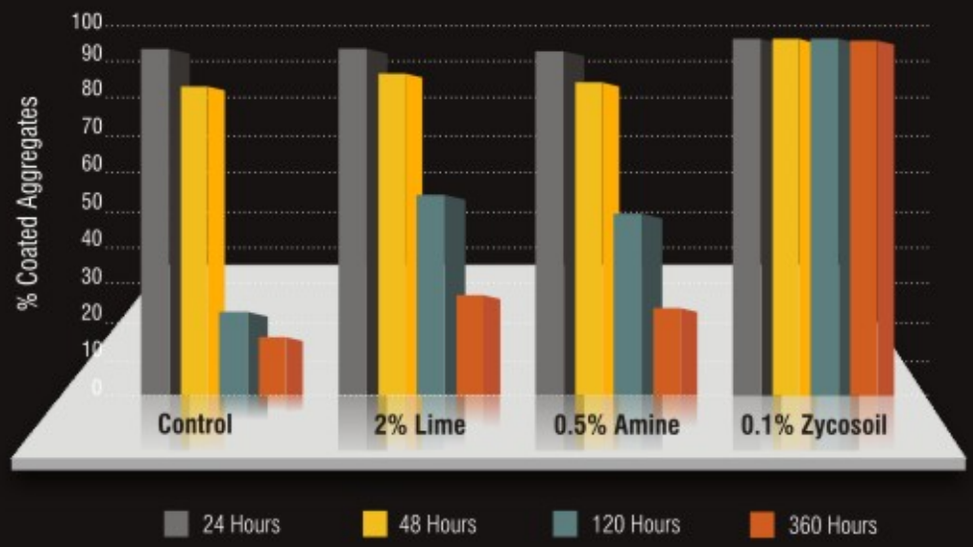


Fig. 5: Test Results of AASHTO T 182 / ASTM D1664 at 60 °C (Basalt Aggregate)
Specified standard for 24 Hours at 60 °C, Less than 95% coating is considered as failure

» Zycosoil Increases Asphalt Mix Strength

Tensile Strength

Tensile strength test data in Fig. 1 and 2 above, for Lithia and Illinois aggregates show that Zycosoil increased both the dry and wet tensile strengths of the asphalt mix. Higher tensile strengths can be linked to improved fatigue life in thick pavement structures.

Marshall Stability and Flow Value

Marshall Method was used to measure the semi-confined compressive strength and flow value of two different asphalt mixes. Specimens were compacted with 75 blows on each side. Zycosoil improved Marshall Stability while maintaining flow properties as seen in Table-3.

Table-3: Test results of ASTM D1075 / AASHTO T 165 wet conditioning at 60 °C, 24 hrs and 2 hrs at room temperature (Basalt Aggregates)

Asphalt Binder	Test Sample	Stability Strength in kg			Flow Value in mm	
		Dry	Wet	Ratio %	Dry	Wet
AC-20 (VG-30, 60-70)	Control	2086	1410	67.59	2.6	2.7
AC-20 (VG-30, 60-70)	Hydrated Lime (2%)	2056	1721	83.71	2.62	2.8
AC-20 (VG-30, 60-70)	Amine (0.5%)	2374	1765	73.4	2.61	2.86
AC-20 (VG-30, 60-70)	Zycosoil (0.1%)	2512	2461	97.97	2.79	2.95
CRMB 60	Control	2152	1794	83.36	2.94	3.18
CRMB 60	Zycosoil (0.1%)	3002	2988	99.53	3.01	3.14
PMB	Control	2442	2346	96.07	2.89	3.05
PMB	Zycosoil (0.1%)	2608	2535	97.20	2.92	3.09

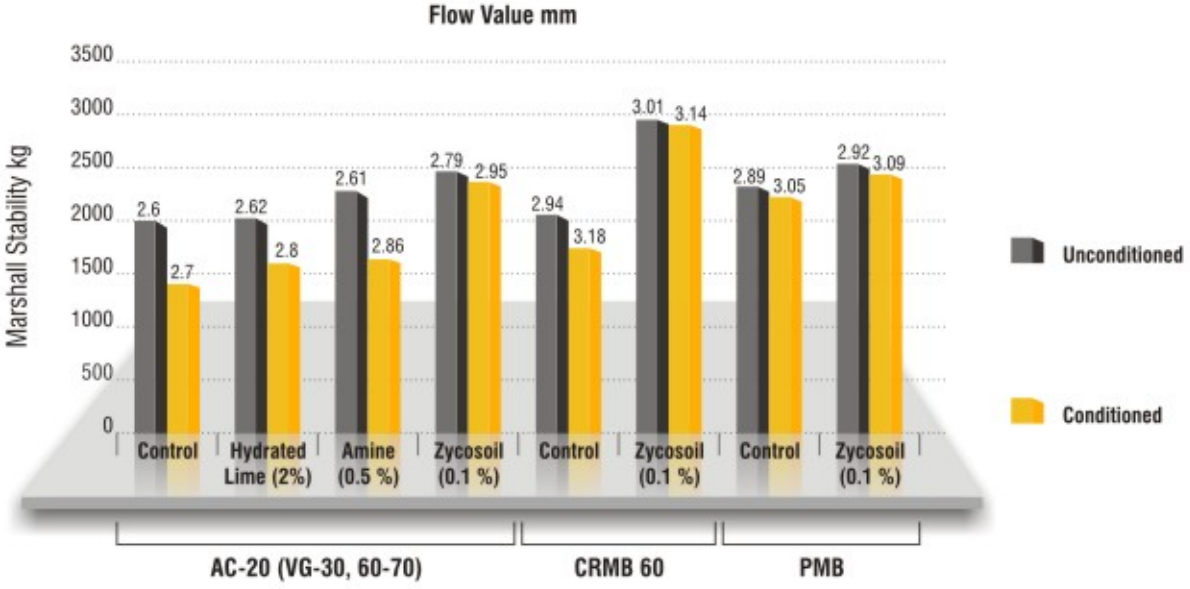


Fig. 6: Marshall Stability and Flow Value test results as per ASTM D1075 / AASHTO T 165 at 60 °C

Fig. 6 indicates that Zycosoil 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) with Zycosoil 0.1%.

» Effect of Zycosoil on Asphalt Binder Properties

Zycosoil when added to asphalt binder was tested by the National Center for Asphalt Technology (NCAT) for all the properties of Superpave Performance Grade (PG) binder specification. The suggested dosage levels of 0.05 to 0.1% by weight of asphalt binder were found not to affect the PG grading of the Superpave binder. The various properties of a PG 64-22 asphalt binder with and without Zycosoil are given in Tables 4 through 8.

Table-4: Rotational Viscosity Test AASHTO T 316 at 135°C

Sample	Viscosity PaS
PG 64-22 Binder	0.470
PG 64-22 Binder with 0.05 % Zycosoil	0.468
PG 64-22 Binder with 0.1 % Zycosoil	0.458

The Rotational viscosity values of the Zycosoil containing asphalt binders are lower, which is good for mixing and wetting of the aggregates with asphalt binder. This would also result in relatively lower mix temperatures.

Table-5: Dynamic Shear Rheometer Test AASHTO T 315 at 64°C

Sample	G*,kPa	Phase Angle	G*/Sin δ, kPa	Specification
Control	1.44	86.4	1.44	
Zycosoil (0.05 %)	1.56	86.4	1.57	≥ 1.00 kPa
Zycosoil (0.1 %)	1.55	86.4	1.55	

The complex modulus G* is higher while the phase angle remains same for the samples containing Zycosoil. The addition of Zycosoil improves binder stiffness with the same viscoelastic response (phase angle).

Table-6: Rolling Thin Film Oven Test (RTFOT) AASHTO T 240, Dynamic Shear Rheometer AASHTO T 315 at 64°C

Sample	G*,kPa	Phase Angle	G*/Sin δ, kPa	Specification
Control	3.44	82.7	3.47	
Zycosoil (0.05 %)	3.75	82.8	3.78	≥ 2.20 kPa
Zycosoil (0.1 %)	4.00	82.7	4.02	

The Zycosoil 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 in general always reduce the rut resistance.

Table-7: Pressure Aging Vessel (PAV) TEST AASHTO R 28
Dynamic Shear Rheometer AASHTO T 315 at 25°C

Sample	G*,kPa	Phase Angle	G*/Sin δ, kPa	Specification
Control	6373	43.3	4368	≤ 5000 kPa
Zycosoil (0.05 %)	6001	44.1	4173	
Zycosoil (0.1 %)	6628	44.8	4668	

PAV aged Zycosoil asphalt binders residue showed higher phase angle, which means increased elasticity compared to control

Table-8: Bending Beam Rheometer (BBR) Test AASHTO T 313 at –12°C

Sample	Stiffness MPa	Specification	m-Value	Specification
Control	201	≤ 300 MPa	0.312	≥ 0.300
Zycosoil (0.05 %)	202		0.317	
Zycosoil (0.1 %)	186		0.314	

The test data in Table-8 show that the low temperature properties of Zycosoil 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.

» Zycosoil Improves Compaction of Asphalt Mix

Zycosoil improves compaction of asphalt mix. Zycosoil additive in asphalt leads to glossier hot mix asphalt which is silky and easy to flow. This ensures improved workability and easy flow in storage / surge silos, dumper trucks and pavers.

Asphalt mixes are typically designed at a specified number of Marshall blows or Gyratory cycles simulating the compaction effort applied in the field. The optimum asphalt binder content is selected at 4% voids. Air voids at the time of field compaction typically range from 6 to 8%.

Zycosoil helps to improve compaction both in the laboratory (during mix design) as well as in the field at the time of construction compared to normal mix either modified with amine, lime or with any additive at the same mechanical compaction effort.

The Zycosoil modified binder improved compaction resulting in lower air void content. Table-9 and Fig. 7 show air void content results in a mix design at optimum binder content at same number of Marshall Blows.

Table-9: Laboratory Air Voids Data

Sample ID	Mix type	Specific Gravity	Binder Content	No. of Gyrations	Air voids
NS 4.9 A 50	No Zycosoil	2.507	4.9%	50	6.1
NS 4.9 A 100				100	3.2
NS 4.9 A 50	0.1% Zycosoil			50	5.5
NS 4.9 A 100				100	2.9

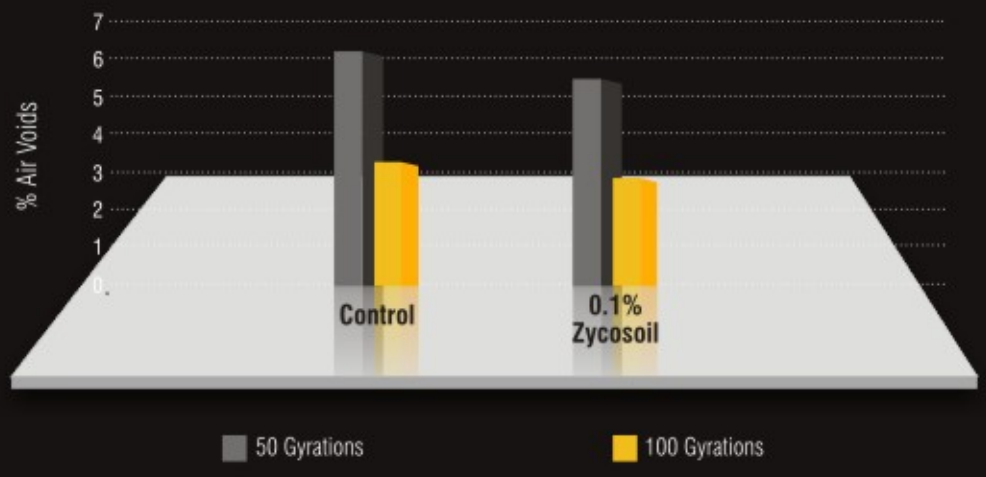


Fig. 7: 4.9% Asphalt Binder, Maryland Aggregates, USA Air Voids Data

It has been observed in all the field trials where Zycosoil was added to asphalt binder, the compacted material density values measured by nuclear density gauge were consistently higher by 1 to 1.5%. Compaction is a significant property to build longer lasting and better pavements. The improved workability will also ensure better compaction at lower temperature. This will improve the latitude of working in the field particularly in cold climate.

User Friendly

Odour

Zycosoil is almost odour free and does not impart any odour to the asphalt binder or asphalt mix resulting in a substantially improved working environment in hot mix production facility as well as on paving site.

Handling

Zycosoil is Non Flammable and safe to handle in HMA plants unlike amines and lime, which are known to cause skin irritation and are not user friendly.

Corrosion

Zycosoil is neutral and does not cause any corrosion unlike lime or certain amines.

Terminal / Bulk Tank Addition

Zycosoil was added in asphalt binder and aged at 150 °C for 15 days and then subjected to Marshall Stability and Flow tests. The test data in Table 10 show that the efficacy of Zycosoil does not diminish when the hot binder is stored for a long period such as 15 days. Therefore, Zycosoil can be added directly to the asphalt binder terminal.

Table-10: Aged Binder Marshall Stability and Flow Values
ASTM D1075 / AASHTO T 165 at 60 °C, 24 hrs (Basalt Aggregates)

Test Sample 5.1% asphalt binder on weight of mix	Stability Strength in kg		Ratio %	Flow value in mm	
	Dry	Wet		Dry	Wet
Unaged binder Control	2265	2015	89.0	2.7	2.9
Unaged binder – Zycosoil (0.1%)	2485	2320	93.4	2.8	3.1
Aged binder 15 days – Control	2235	2011	90.0	2.8	3.2
Aged binder 15 days – Zycosoil (0.1%)	2652	2445	92.2	2.77	3.14

» In-plant Blending

Blending of Zycosoil in asphalt binder is shown in the Fig. 8.

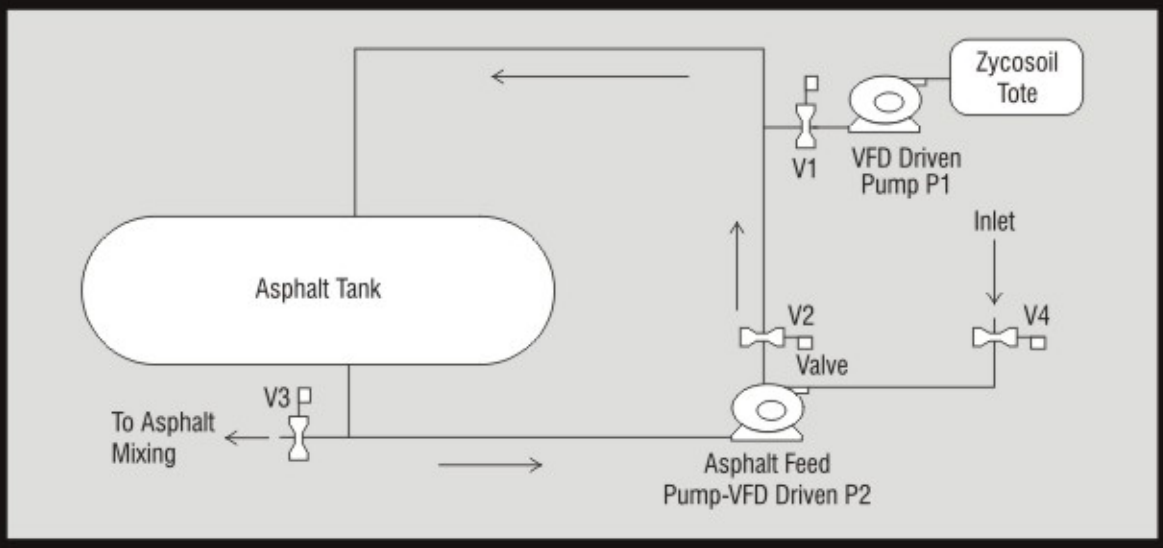


Fig. 8: Process Flow Diagram

- Connect Asphalt tanker outlet pipe with the inlet of Asphalt storage tank.
- Open valve V4 and start unloading asphalt binder to the storage tank through pump P2. Simultaneously open valve V1 to inject Zycosoil from Zycosoil Tote in the line through progressive cavity pump P1.
- Shut valve V1& V4 and Pump P1 after completion of asphalt binder unloading from tanker.
- Circulate the Zycosoil mixed hot molten asphalt binder by pump P2 for 1-2 hr (depending on the pump flow rate) to ensure at least one full circulation.
- Now Zycosoil mixed asphalt can be taken in line for asphalt concreting.

If VFD driven progressive cavity pump P1 is not available then start circulating pump and slowly add Zycosoil from top hole of the storage tank. Keep circulating hot Zycosoil mixed asphalt binder through circulating pump for 1-2 hr (depending on the pump flow rate). Ensure at least one full circulation. (Do not add Zycosoil under static condition of hot asphalt)

» Technical Specifications

Color	:	Clear to pale yellow
Solid Content	:	41 ± 2%
Flash Point	:	80 °C
Viscosity (25°C)	:	200 – 800 cps
Solubility	:	Soluble in asphalt

» Packaging

Available in 20 kg Carboy.

» Storage

Store under shaded area, away from direct sunlight. Recommended storage temperature is 5 °C to 45 °C. Keep away from heat, ignition /sparks source and from rain / standing water.

Keep the container tightly closed after the first withdrawal (product can start reacting with moisture in the ambient air) when not in use, in a dry and cool place.

» Shelf Life

24 months when stored as recommended.

ZYCOSOIL™

Nanotechnology for
Asphalt Pavements

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