

Laboratory Evaluation of ZycoSoil as an Anti-Stripping Agent on Superpave Mixtures

Submitted to:

Zydex Industries India

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INTRODUCTION

Background

Moisture damage in asphalt pavements has been considered to be a widespread problem in the United States and around the world. Water that infiltrates the pavement structure can cause premature failure of hot-mix asphalt layers, primarily through loss of adhesion between the asphalt binder and the aggregate or the loss of cohesion in the asphalt binder. Loss of adhesion can lead to stripping and raveling. The stripping or raveling of asphalt films from the surface of aggregate particles results in the cause of premature failure of asphalt pavement. Moisture damage is a function of several factors. These factors include asphalt mixture characteristics, environmental factors, construction practices, etc (Hicks 1991). The important characteristics of asphalt mixtures include the type of aggregate, the chemical and physical properties of the asphalt binder, and the types of mixture. Environmental factors that accelerate pavement moisture damage are climate and traffic loading. The majority of damage occurs in extreme weather conditions, particularly freeze-thaw action, combined with heavy traffic volume. Incomplete coating of aggregates occurring during pavement construction also accelerates pavement moisture damage.

Numerous theories have been proposed to identify the root causes of moisture damage and to develop better methods for predicting moisture damage in the mix design stage. Rice (1958) classified these theories as mechanical interlocking, chemical reaction, and molecular orientation or surface energy. Chemical interactions are believed to be the best explanation of the adhesive bond (Curtis et al. 1992). Furthermore, all theories assume that the bond is influenced by the composition and surface chemistry of aggregates. In order to promote the bond between the asphalt binder and the aggregate and prevent stripping, anti-stripping agents have been commonly added to asphalt binders. Typical anti-stripping agents used today are fatty amines, fatty amido-amines, and hydrated lime. These, however, form temporary bonding with aggregates and do not work for all types of aggregates. As opposed to the typical anti-stripping agents, ZycoSoil was developed to stabilize soil by surface modification of soil particles. It is an organosilane compound which reacts with soil particles and forms hydrophobic layers on the surfaces of soil and clay particles. This makes soil particles water-insensitive and offers long-lasting protection against infiltration of water.

As requested by Zydex Industries India, a laboratory evaluation of ZycoSoil as an anti-stripping agent on Superpave binders and mixtures has been initiated. This report includes the results of the Superpave performance grading for PG 64-22 asphalt binders with/without 0.05% ZycoSoil and those of the Superpave mix design verification and the Hamburg Wheel-Tracking tests for mixtures containing the same binders with/without 0.05% ZycoSoil.

Objectives

The objectives of this research project are to:

a) identify the effects of ZycoSoil on the Superpave binders and mixtures;

b) evaluate the capability of ZycoSoil for resisting moisture damage by comparing the properties of mixture with ZycoSoil to those of mixture without ZycoSoil.

Scope

The Superpave design methodology known as the Superior Performing Asphalt Pavements (Superpave^{TM}) System developed through the Strategic Highway Research Program (SHRP) was exclusively used for the evaluation of ZycoSoil as an anti-stripping agent. In addition to the laboratory tests required in the Superpave^{TM}, the Hamburg Wheel-Tracking (HWT) tests as a complementary laboratory test was performed to evaluate moisture susceptibility of the Superpave mixtures. The work plan was developed based on the mutual agreement between the National Center for Asphalt Technology (NCAT) and Zydex Industries India as follows:

1. Superpave binder performance grading verification for PG 64-22 binder containing 0.05% ZycoSoil by weight of the binder
2. Superpave mix design verification (including AASTO T 283) for Superpave 12.5 mm NMAS asphalt mixes with the following binder/additive:
    - Georgia granite aggregate & PG 64-22 binder with no additive [control mix]
    - Georgia granite aggregate & PG 64-22 binder with 0.05% ZycoSoil [The mix has the same aggregate, same gradation, and same binder content as the control mix.]
3. Performing Hamburg Wheel-Tracking (HWT) tests for mixtures (a) and (b) at 60 °C

METHODS

The Strategic Highway Research Program (SHRP) conducted a $50 million research effort from October 1987 through March 1993 to develop performance-based test methods and specifications for asphalts and asphalt mixtures. The resulting product is a new system called Superpave™, which includes a binder specification and an asphalt mixture design method. Superpave™ is a performance based mix design and analysis process that evaluates both constituent materials and final mixture performance. The liquid asphalt binder is evaluated for performance based on the criteria of temperature, time of loading, and aging factors, while the constituent mineral aggregates are evaluated based on surface characteristics, particle shape, and gradation. Finally, once combined into an HMA mixture, this mixture is evaluated for performance under various loading and environmental field conditions.

Superpave Binder Tests

The asphalt binders are selected for a particular mix design specification based primarily on the climate that the binder will experience. Based on the climatic variation, the asphalt binders are tested and labeled according to performance. For example, an asphalt binder that is expected to perform adequately in a climate with an average 7-day maximum temperature of 64°C and a minimum pavement design temperature of -22°C would be labeled PG 64-22. The PG stands for performance grade and the numbers correspond to the high and low temperature variation. The procedures of the Superpave binder tests are described in this section.

Rolling Thin Film Oven Test

The Rolling Thin Film Oven Test (RTFOT) serves two purposes (AASHTO T 240). One purpose is to age the asphalt binder to generally represent the aging (oxidation and volatilization) associated with production of asphalt mixtures. The RTFOT is a conditioning procedure to a binder sample that will be evaluated for physical properties. The second is to determine the mass quantity of volatiles lost from the asphalt during the process. Volatile mass loss is an indication of the aging that may occur in the asphalt during mixing and construction operations. The RTFOT continually exposes fresh films of binder to heat and air flow. The RTFOT requires an electrically-heated convection oven. An air jet blows air into each sample bottle as it circulates in a carriage. The RTFOT oven is preheated to the aging temperature, 163°C, for a minimum of 16 hours prior to use.

To prepare for RTFOT, a binder sample is heated until fluid, not exceeding 150°C. RTFOT bottles are loaded with 35 grams of binder. Eight sample bottles are required for Superpave binder testing. Two bottles are required to make the mass loss determination, and six bottles are used for further testing. After aging, the two bottles containing the mass loss samples are cooled, weighed to the nearest 0.001 grams, and the samples are discarded. The other bottles are poured into a single container to achieve homogeneity and then used for Dynamic Shear Rheometer testing and transferred into Pressure Aging Vessel pans for additional aging.

Pressure Aging Vessel

The Superpave Pressure Aging Vessel (PAV) procedure is used for simulation of long-term aging of asphalt binders over time in the pavement. According to the method (AASHTO R

28), the asphalt samples are first aged in the standard Rolling Thin Film Oven Test (RTFOT). Pans containing 50 grams of RTFOT residue are then placed in the PAV, which is pressurized with air at 2070 kPa, and aged for 20 hours. The proposed range of PAV temperature to be used is between 90 and 110°C. The PAV temperature to be used will depend on the climatic condition of the region where the binders will be used. A higher PAV temperature could be used for a warmer climatic condition, while a lower temperature could be used for a colder climatic condition.

Dynamic Shear Rheometer Test

The Dynamic Shear Rheometer (DSR) test measures the viscoelastic properties of an asphalt binder by testing it in an oscillatory mode. The general method had been used by researchers long before the SHRP researchers adopted and standardized the method for the purpose of asphalt specification. Typically, in a dynamic shear rheometer test, a sample of asphalt binder is placed between two parallel steel plates. The top plate is oscillated by a precision motor with a controlled angular velocity, while the bottom plate remains fixed. From the measured torque and angle of rotation, the shear stress and shear strain can be calculated.

SHRP standardized the dynamic shear rheometer test for use in measuring the asphalt properties at high and intermediate service temperatures for specification purposes. In the standardized test method (AASHTO T 315), the oscillation speed is specified to be 10 radians/second. The amplitude of shear strain to be used depends on the stiffness of the binder, and varies from 1% for hard materials tested at low temperatures to 13% for relatively softer materials tested at high temperatures. There are two standard sample sizes. For relatively softer materials, a sample thickness of 1 mm and a sample diameter (spindle diameter) of 25 mm are to be used. For harder materials, a sample thickness of 2 mm and a sample diameter of 8 mm are to be used. The two values to be measured from each test are the complex shear modulus, G^*, and the phase angle, δ. These two test values are then used to compute $G^*/\sin\delta$ and $G^*\sin\delta$. In the Superpave asphalt specification, permanent deformation is controlled by requiring the $G^*/\sin\delta$ of the binder at the highest anticipated pavement temperature to be greater than 1.0 kPa before aging and 2.2 kPa after the RTFOT process. Fatigue cracking is controlled by requiring that the binder after PAV aging should have a $G^*\sin\delta$ value of less than 5000 kPa at a specified intermediate pavement temperature.

Bending Beam Rheometer Test

The Bending Beam Rheometer (BBR) test (AASHTO T 313) is used to measure the stiffness of asphalts at low surface temperatures. The standard asphalt test specimen is a rectangular prism with a width of 12.5 mm, a height of 6.25 mm, and a length of 125 mm. The test specimen is to be submerged in a temperature-controlled fluid bath and to be simply supported with a distance between supports of 102 mm. For specification testing, the test samples are to be fabricated from PAV-aged asphalt binders, which simulate the field-aged binders. In the standard testing procedure, after the beam sample has been properly preconditioned, a vertical load of 100 gram-force is applied to the middle of the beam for a total of 240 seconds. The deflection of the beam at the point of load is recorded during this period, and used to compute for the creep stiffness of the asphalt binder.

For Superpave binder specification purpose, the bending beam rheometer test is to be run at 10°C above the expected minimum pavement temperature, T_{min}. The Superpave binder specification requires the stiffness at the test temperature after 60 seconds to be less than 300 MPa to control low-temperature cracking. The second parameter obtained from the BBR test result is the m-value. The m-value is the slope of the log stiffness versus log time curve at a specified time. A higher m-value would mean that the asphalt would creep at a faster rate to reduce the thermal stress and would be more desirable to reduce low-temperature cracking. The Superpave binder specification requires the m-value at 60 seconds to be greater than or equal to 0.30.

Direct Tension Test

The Direct Tension Test (DTT) measures the stress-strain characteristics of an asphalt binder in direct tension at low temperature. In this test, a small "dog bone" shaped asphalt specimen is pulled at a constant rate of 1 mm/min until it breaks. The amount of elongation at failure is used to compute the failure strain. The maximum tensile load taken by the specimen is used to compute the failure stress. The test specimen is 30 mm long and has a cross section of 6 mm by 6 mm at the middle portion. For Superpave binder specification purpose, the direct tension test is to be run on PAV-aged binders at the same test temperature as for the BBR test, which is run at 10°C above the minimum expected pavement temperature. According to the Superpave binder specification as stated in AASHTO T 314, the failure strain at this condition should not be less than 1% in order to control low temperature cracking. However, the direct tension test criterion is applicable only if an asphalt binder does not meet the bending beam rheometer stiffness requirement and has a stiffness between 300 MPa and 600 MPa.

Brookfield Rotational Viscometer Test

The Superpave binder specification uses the Brookfield rotational viscometer test as specified by AASHTO T 316 for use in measuring the viscosity of binders at elevated temperatures to ensure that the binders are sufficiently fluid when being pumped and mixed at the hot mix plants. In the Brookfield rotational viscometer test, the test binder sample is held in a temperature-controlled cylindrical sample chamber, and a cylindrical spindle, which is submerged in the sample, is rotated at a specified constant speed. The torque that is required to maintain the constant rotational speed is measured and used to calculate the shear stress according to the dimensions of the sample chamber and spindle. Similarly, the rotational speed is used to calculate the shear rate of the test. Viscosity is then calculated by dividing the computed shear stress by the computed shear rate. For Superpave binder specification purpose, the rotational viscosity test is to be run on the original binder at 135°C. The maximum allowable viscosity at this condition is 3 Pa·s.

Superpave Volumetric Mix Design Method

The Hveem and Marshall methods of mix design have been used since the 1940s and 1950s. These mix design methods had performed well for many years, but with more traffic and heavier loads, a new mix design was needed in the early 1980s. At the conclusion of the SHRP Program in 1993, the resulting system, this is referred to as Superpave Volumetric Design, included consensus properties of aggregate, new mix design procedure, and mix analysis procedure. The general procedures of the Superpave Volumetric Design are described in this section. The more detailed specifications can be found in AASHTO MP 2.

Selection of Asphalt

The asphalt binder should be a PG grade asphalt meeting the requirements of AASHTO MP 1, which is appropriate for the climate and traffic condition at the project site.

Selection of Aggregate

The combined aggregate must meet the following requirements:

1. Nominal maximum aggregate size — Nominal maximum aggregate size should be 9.5 to 37.5 mm
2. Gradation control points — The gradation must pass through the control points
3. Consensus aggregate property requirements — There are four consensus aggregate property requirements. The coarse aggregate must meet the angularity requirements in terms of the minimum percentages of particles with crushed faces as measured by ASTM D 5821. The fine aggregate must meet the fine aggregate angularity requirements in terms of the minimum uncompacted void contents as measured by AASHTO T 304 Method A. The aggregate must meet the sand equivalent requirement in terms of the minimum sand contents as measured by AASHTO T 176. The aggregate must meet the requirement on the maximum allowable percentage of flat and elongated particles as measured by ASTM D 4791.

Preparation of Asphalt Mixtures

Aggregate and asphalt are mixed at the temperature at which the kinematic viscosity of the asphalt is 170 ± 20 mm^2/s. The loose asphalt mixture is then cured in a forced-draft oven at 135°C for 2 hours before compaction.

Compaction of Asphalt Mixtures

Compaction of the asphalt mixture is done in the Superpave gyratory compactor, as described in AASHTO T 312. The number of gyrations to be applied is a function of the designed traffic level. For each level of designed traffic, there are three levels of compaction, namely N_{ini} , N_{des} and N_{max} gyrations. The specimen is compacted to N_{des} gyrations, while the specimen height is recorded continuously. After compaction, the specimen is removed from the mold and its bulk specific gravity and $\%G_{mm}$ is determined. $\%G_{mm}$ is equal to 100% minus % air voids. The actual measured bulk density is compared with the calculated density based on the specimen height, and a correction factor is calculated. This correction factor and the specimen height at N_{ini} are then used to calculate the density and $\%G_{mm}$ of the specimen at N_{ini}. After the determination of the design asphalt content, duplicate samples at the design asphalt content are also compacted to N_{max} gyrations to determine the $\%G_{mm}$ of the mixture at N_{max} gyrations.

Determination of Design Asphalt Content

The design asphalt content is the asphalt content at which the asphalt mixture has an air voids content of 4% (or a $\%G_{mm}$ of 96%) when compacted to N_{des} gyrations, while all the mix design requirements are met. These mix design requirements are presented in the next section.

Superpave Mix Design Requirements

The asphalt mixture design must meet all the following requirements:

1. The asphalt mixture must have a target air void of 4% when compacted to N_{des} gyrations.
2. The VMA of the compacted mixture at N_{des} gyrations must meet the minimum VMA requirements as shown in Table 1.
3. The VFA (Voids Filled with Asphalt) of the compacted mixture at N_{des} gyrations must fall within the range as shown in Table 1.
4. The dust-to-binder ratio, which is the ratio of the weight of the mineral filler to the weight of the binder, must be between 0.6 and 1.2.
5. The $\%G_{mm}$ of the asphalt mixture compacted to N_{ini} must not exceed the limits as shown in Table 1. The $\%G_{mm}$ of the mixture compacted to N_{max} must not exceed 98%.
6. The asphalt mixture, when compacted by the Superpave gyratory compactor to 7% air voids and tested in the AASHTO T 283 must have a retained tensile-strength ratio of at least 80%.

Table 1. Superpave Mix Design Requirements

20-yr Traffic Loading (in millions of ESALs)	Required Density			Minimum VMA					VFA
				Nominal Maximum Aggregate Size					
	N_{ini}	N_{des}	N_{max}	9.5 mm	12.5 mm	19.0 mm	25.0 mm	37.5 mm	
< 0.3	≤91.5	96.0	≤98.0	15.0	14.0	13.0	12.0	11.0	70 - 80
0.3 to < 3	≤90.5								65 - 78
3 to < 10	≤89.0								65 - 75

Hamburg Wheel-Track (HWT) Test

AASHTO T 324 is the standard test procedure for the Hamburg Wheel-Track testing of compacted asphalt mixtures. The Hamburg Wheel-Tracking device measures the combined effects of rutting and moisture damage by rolling a steel wheel across the surface of an asphalt concrete sample immersed in hot water (Figure 2). The samples are prepared and are submerged in a water bath of 40 to 50°C for testing. An electrically powered machine capable of moving a steel wheel with dimensions of 203.5 mm in diameter and 47 mm in width loads each sample with a fixed load of 705 ± 22 N at a rate of 50 passes per minute. The impression is measured using a Linear Variable Differential Transformer (LVDT) device capable of measuring the depth of impression of the wheel. As shown in Figure 2, the point in the plot of the rut depth versus number of passes noted at the significant change in slope is called a Stripping Inflection Point (SIP). The SIP represents the number of wheel passes at which a sudden increase in rut depth occurs due to stripping of the binder from the aggregates. Therefore, in the test, it is required for calculation of the SIP using Equation (1).

Figure 1. Hamburg Wheel-Tracking Test

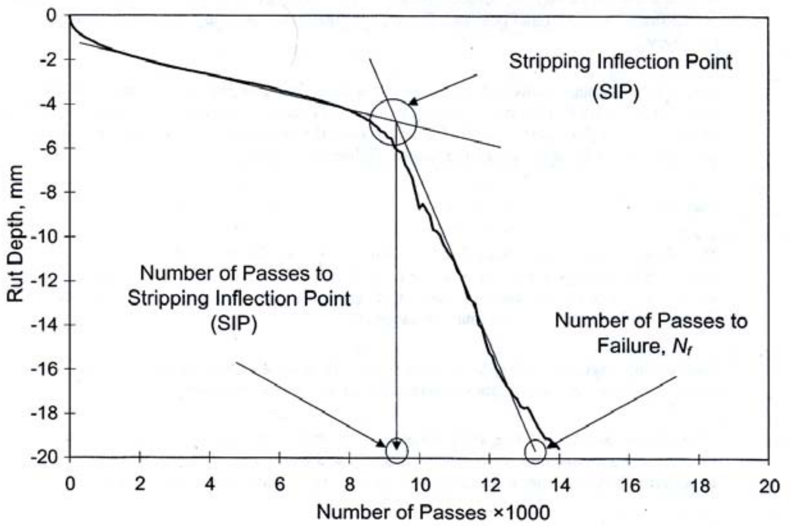


Figure 2. HWT Curve with Test Parameters

$$\text{Stripping Inflection Point (SIP)} = \frac{\text{Intercept (second portion) - intercept (first portion)}}{\text{Slope (first portion) - Slope (second portion)}} \quad (1)$$

TEST RESULTS

Binder Test Results

The binder performance grading test results are shown in Table 2. A PG 64-22 binder that had 0.05% ZycoSoil by weight of the binder was prepared for the binder performance grading tests. The DSR tests were run on the control and RTFOT-aged binders at the maximum pavement design temperature. The minimum required values of G*/sinδ at this temperature are 1.0 kPa and 2.2 kPa for the control and RTFOT-aged binders, respectively. These requirements are intended to control pavement rutting. DSR tests were also run on PAV-aged binders at an intermediate temperature, which is equal to 4°C plus the mean of the maximum and minimum pavement design temperatures. For a PG 64−22 grade, the intermediate temperature is 25°C. The maximum allowable value of G*sinδ at this condition is 5000 kPa. This requirement is intended to control pavement fatigue cracking. The BBR tests were run on PAV-aged binders at a temperature which is 10°C above the minimum pavement design temperature. For a PG 64-22, the test temperature is -12°C. At a loading time of 60 seconds, the stiffness is required to be no greater than 300 MPa, and the m-value is required to be no less than 0.3. The DDT was not performed because the asphalt binder did meet the BBR stiffness requirement (between 300 MPa and 600 MPa). All the test results met the requirements of PG 64-22. The same binder tests were performed at upper and lower temperatures. If the binder meets the requirements above at those temperatures, it would be graded as PG 70-28. As shown in Table 2, any value does not meet the requirements of PG 70-28.

In order to identify any changes in binder properties, the previous binder test results performed on the same binder (hereafter, referred to as a "control binder") were compared to those measured from the binder with 0.05% ZycoSoil (Table 3). Any significant differences between the test results of the two binders were not observed. This indicates that ZycoSoil does not significantly affect the original binder properties. Therefore, the PG 64-22 binder with 0.05% ZycoSoil can be graded as PG 64-22.

According to past experience, most amine-based liquid antistripping agents tend to lower the viscosity (analogous to reducing $G^*/\sin\delta$) of the neat (control) binder, which has been a concern of the user agencies. However, it is encouraging to note in Table 3 that the addition of 0.05% ZycoSoil has actually increased $G^*/\sin\delta$ of both neat and RTFO residue of PG 64-22, thereby increasing its resistance to rutting. Also, the ZycoSoil has significantly increased the fatigue resistance of neat PG 64-22 as is evident in Table 3 from the test values of $G^*\sin\delta$, which decreased from 4368 kPa to 4173 kPa. Therefore, the preceding changes in the neat binder are positive for binder properties in terms of both rutting and fatigue resistance.

Table 2. Superpave Asphalt Binder Grading Summary

Binder: PG 64-22 with 0.05% ZycoSoil				
Test, Method			**Test Results**	**Specification**
Rotational Viscosity @ 135°C, AASHTO T 316, PaS			0.468	≤ 3 Pa·s
Dynamic Shear Rheometer AASHTO T 315				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* / sinδ, kPa	
64	1.56	86.4	1.57	≥ 1.00 kPa
70	0.74	87.4	0.75	
Rolling Thin Film (RTFO) Aged Binder, AASHTO T 240				
Mass Change, %			-0.019	≤ 1.00%
Dynamic Shear Rheometer AASHTO T 315				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* / sinδ, kPa	
64	3.75	82.8	3.78	≥ 2.20 kPa
70	1.76	84.6	1.77	
Pressure Aging Vessel (PAV) Aged Binder, AASHTO R28				
Dynamic Shear Rheometer AASHTO T 315				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* sinδ, kPa	
25	6001	44.1	4173	≤ 5,000 kPa
22	9040	41.1	5945	
Bending Beam Rheometer (BBR) AASHTO T 313				
Test Temperature, °C				
-12	Stiffness, MPa		202	≤ 300 MPa
	m-value		0.317	≥ 0.300
-18	Stiffness, MPa		379	
	m-value		0.252	
True Grade	67.7-23.6			
PG Grade	64 - 22			
1. DSR Original: T_{max}				
Temperature at which G*/sinδ = 1.00 kPa		67.7		
2. DSR RTFO: T_{max}				
Temperature at which G*/sinδ = 2.20 kPa		68.3		
3. DSR PAV: T_{int}				
Temperature at which G*sinδ = 5,000 kPa		23.5		
4. BBR PAV: T_{min}				
Temperature at which S(t) = 300 MPa		-25.3		
Temperature at which m = 0.300		-23.6		

Table 3. Control versus Binder with 0.05% ZycoSoil

Binder: PG 64-22 with 0.05% ZycoSoil			
Rotational Viscosity @ 135oC, AASHTO T 316, PaS		Test Results	
0.05% ZycoSoil		0.468	
Control		0.470	
Dynamic Shear Rheometer AASHTO T 315			
Test Temperature, 64 oC	G*, kPa	Phase Angle	G* / sinδ, kPa
0.05% ZycoSoil	1.56	86.4	1.57
Control	1.44	86.4	1.44
Dynamic Shear Rheometer AASHTO T 315			
Test Temperature, 64 oC	G*, kPa	Phase Angle	G* / sinδ, kPa
0.05% ZycoSoil	3.75	82.8	3.78
Control	3.44	82.7	3.47
Pressure Aging Vessel (PAV) Aged Binder, AASHTO R28			
Dynamic Shear Rheometer AASHTO T 315			
Test Temperature, 25 oC	G*, kPa	Phase Angle	G* sinδ, kPa
0.05% ZycoSoil	6001	44.1	4173
Control	6373	43.3	4368
Bending Beam Rheometer (BBR) AASHTO T 313			
Test Temperature, -12 oC	Stiffness, MPa		m-value
0.05% ZycoSoil	202		0.317
Control	201		0.312
PG Grade	64 -22		

Mixture Test Results

The Lithonia Georgia granite was selected because it had been reported that field pavements constructed by use of the aggregates showed stripping problems in the state of Georgia. The aggregates, however, met all the criteria for the consensus and source properties that aimed to prevent the use of substandard aggregates in producing asphalt mixtures.

The Superpave mix design procedure bases its selection for asphalt content on a set of criteria, which are the volumetric properties of the mixture such as VMA, VFA, etc. at 4% air voids. A densely graded asphalt mixture that has a nominal aggregate size of 12.5 mm and the binder graded as PG 64-22, meeting the Superpave mix design criteria was designed for testing and evaluation (hereafter, referred to as a "control mixture"). Figure 3 shows a designed gradation of the mixture. For ZycoSoil, a mixture that had the same aggregate, gradation, and asphalt content as the original mixture, but with the binder which included 0.05% ZycoSoil by weight of the PG 64-22 binder was prepared for testing and evaluation.

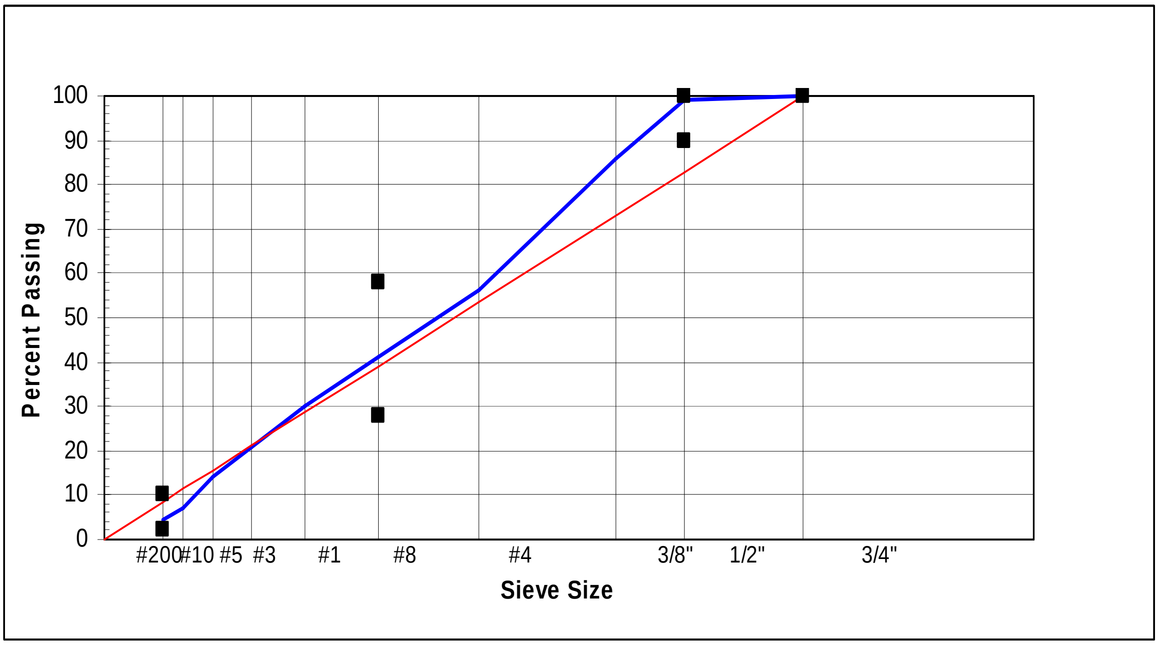


Figure 3. Gradation

The Superpave design method for compacted asphalt mixtures specifies the number of gyrations to which a sample must be compacted with the Superpave gyratory compactor.

The dense graded asphalt mixture was compacted at the number of gyrations of 65 applicable to all traffic levels as specified by the Georgia Department of Transportation (GDOT). A trial blend sheet, attached in Appendix A, was prepared based on the Job Mix Formula (JMF) for the aggregates. The mixing temperature of 310 ± 5°F, which is commonly used for mixing aggregates with unmodified binders, was used. The aggregates were then removed from the oven and mixed until the aggregates were well coated with asphalt binder. The mixed samples were spread out in pans and heated in an oven for 2 hours for short-term oven aging. After short-term oven aging, the samples were then removed and quickly compacted using the Superpave Gyratory Compactor (SGC). The samples were compacted with a ram pressure of 600 kPa at a gyratory angle of 1.16°. The compaction data of the samples were used in determining the design asphalt content. That is, volumetric properties of the mixture such as air voids (VTM), voids in mineral aggregates (VMA), and voids filled with asphalt (VFA) were calculated at these asphalt contents and then each was plotted as a function of asphalt content at N_{des}. The design asphalt content was obtained by interpolating the air void versus asphalt content curve to obtain asphalt content at 4%. A summary of the volumetric properties obtained at the optimum asphalt content, meeting all the Superpave standards is shown in Table 4.

Evaluation of a mixture's moisture sensitivity is currently the final step in the Superpave volumetric mix design process. The Superpave mix design system has adopted AASHTO T 283 as the basis for assessing moisture susceptibility in a proposed mix. Six specimens were compacted to 6-8 percent air void content. Group 1 of three specimens was used as an unconditioned group. Group 2 specimens were vacuum saturated (70 to 80% saturation) with water, and then subjected to one freeze-thaw cycle. All specimens were tested for the Indirect Tensile Strength (ITS) at 25°C using a loading rate of 50 mm/min, and the Tensile Strength Ratio (TSR) was determined, as shown in Table 5.

A value of TSR, which is a ratio in strength loss determined by comparing indirect tensile strengths of the unconditioned group to those of the conditioned samples, is used to evaluate the moisture susceptibility of asphalt mixtures. According to AASHTO T 283, if the average retained strength of the conditioned group strength is less than eighty percent of the unconditioned group strength, then the mix is considered to be moisture susceptible. The TSR value of the mixture with 0.05% ZycoSoil was 0.95 while that of the mixture without ZycoSoil was 0.85, indicating that ZycoSoil had improved the moisture resistance of the given mixture. In order to confirm the values of TSR, an additional Superpave mixture (Lithia Springs), used in another research project, was used for repeating the same mixture tests as described above. Table 5 also includes the TSR values obtained from the second mixtures.

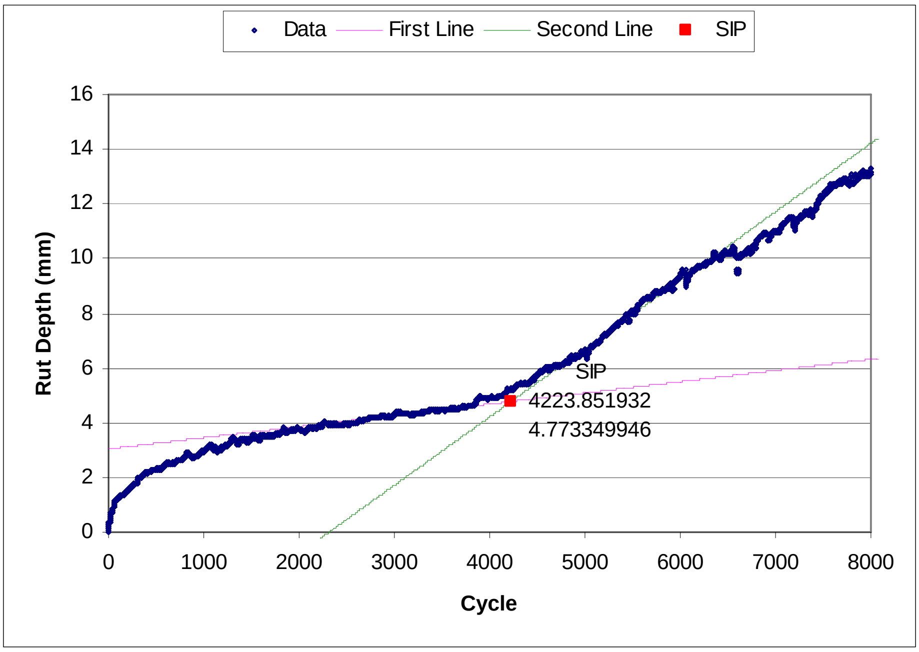
Table 4. Volumetric Properties

Design Summary		Requirement
Nominal Max	12.5 mm	
Design Gyrations	65	
Binder	PG 64-22	
Opt Pb	5.30%	
VMA	15.2	>14
VFA	72.9	65 - 78
Dust / Asphalt	0.90	0.6 - 1.2

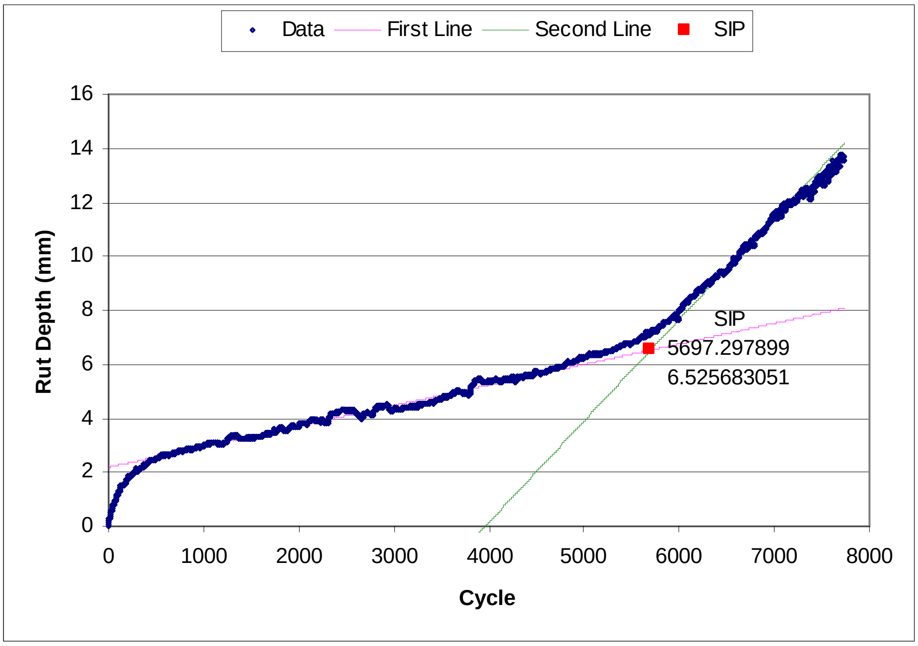
Table 5. TSR Test Results

	Tensile Strength Ratio (TSR)	
Mixture	Control Mixture	Mixture with 0.05% ZycoSoil
Lithonia	0.85	0.95
Lithia Springs	0.82	0.95

Another test used to evaluate the moisture damage of asphalt mixtures is the Hamburg Wheel-Tracking test. This test is useful for identifying the performance of a mixture which is intended to be evaluated for its resisting water damage (in this study, the mixture with 0.05% ZycoSoil) against that of a mixture with general volumetric properties (the control mixture).



(a)



(b)

Figure 4. Hamburg Wheel-Tracking Test Results with SIP: a) Control Mixture; b) Mixture with 0.05% ZycoSoil

Per Zydex Industries India's request, the Hamburg Wheel-Tracking test was performed at 60°C. A temperature of 40°C or 50°C was recommended when this test was developed in Hamburg, Germany considering relatively colder climate there. Many states in the US use a 50°C test temperature. However, some asphalt paving technologists believe the test temperature should be 60°C in the regions where PG 64 grade is used, considering the average 7-day maximum pavement temperature in those regions can be as high as 64°C. The fact that 60°C test temperature is much more severe than 50°C test temperature, should be kept in mind while reviewing the Hamburg test data in this report. The other testing conditions were the same as those described in AASHTO T 324.

Two replicates of each mixture were compacted using the Superpave Gyratory Compactor (SGC) in the laboratory, and the second method for compacting SGC specimens described in AASHTO T 324 was used. The Stripping Inflection Points (SIPs) were clearly observed from four samples of two mixtures. The SIPs estimated from the averaged deflections of each mixture are shown in Figure 4.

The results clearly showed that the SIP estimated from the mixture with ZycoSoil was higher than that from the control mixture. The SIP values of the ZycoSoil mixture and the control mixture were 5697 and 4224, respectively. This indicates that ZycoSoil has a potential for minimizing water damage, and it also implies that ZycoSoil would be an effective anti-striping agent capable of improving the resistance of asphalt mixtures to water damage.

SUMMARY AND CONCLUSIONS

As requested by Zydex Industries India, a laboratory evaluation of ZycoSoil as an anti-stripping agent on Superpave binders and mixtures was performed at the National Center for Asphalt Technology. This report includes the Superpave binder and mixture test results performed on the Superpave mixtures with/without ZycoSoil.

The Superpave binder performance grading tests were performed on the PG 64-22 binder containing 0.05% ZycoSoil by weight of the binder. The test results showed that ZycoSoil did not affect the original binder properties, and the binder with 0.05% ZycoSoil met all the requirements of PG 64-22. Accordingly, it was concluded that the PG 64-22 binder with 0.05% ZycoSoil is graded as PG 64-22. Although the grade of PG 64-22 did not change, it was noted that the rutting resistance (in terms of $G^*/\sin\delta$) and the fatigue resistance (in terms of $G^* \sin\delta$) were enhanced when 0.05% ZycoSoil was added to the neat binder.

The Lithonia Georgia granite, which had been reported to have stripping problems in the state of Georgia, was selected to evaluate the effectiveness of ZycoSoil as an anti-stripping agent. A densely graded asphalt mixture that has a nominal aggregate size of 12.5 mm and the binder graded as PG 64-22, meeting the Superpave mix design criteria was designed for testing and evaluation. For ZycoSoil, a mixture with the same aggregate, gradation, and asphalt content as the original mixture, except for the binder which included 0.05% ZycoSoil by weight of the binder, was prepared.

The value of TSR, which is a ratio in strength loss required in the Superpave mix design, was used to evaluate the moisture susceptibility of the given asphalt mixtures. The TSR value of the mixture with 0.05% ZycoSoil was 0.95 while that of the mixture without ZycoSoil was 0.85. The Hamburg Wheel-Tracking test, which has been used for evaluating the moisture susceptibility of asphalt mixtures, was also performed on the given asphalt mixtures. The SIP values of the mixture with 0.05% ZycoSoil and that of the control mixture without ZycoSoil were 5697 and 4224, respectively. It should be noted that the Hamburg Wheel-Tracking test was conducted at a test temperature of 60°C in this study, which is much more severe than the test temperature of 50°C normally used in some states in the US. All the mixture test results indicated that ZycoSoil had improved the moisture resistance of the given mixture. Consequently, the conclusion was drawn that ZycoSoil has a potential for minimizing water damage occurring in asphalt mixtures and could be used as an effective anti-stripping agent capable of improving the resistance of asphalt mixtures to water damage. It is however recommend that quantitative binder and mixture tests be performed in the near future to draw a stronger conclusion of the effectiveness and suitable use of ZycoSoil as an anti-striping agent.

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APPENDIX

Trial Mix Design

Project:	Zycosoil - Design No Zycosoil			Aggregate Type: Lithonia Granite	Date
AC Sp. Gr. (Gb) = 1.03	App. Sp. Gr. (Gsa) 2.643	Eff. Sp. Gr. (Gse): 2.642	Bulk Sp. Gr. (Gsb): 2.612	Trial Blend: 1 NMAS: 12.5 mm Compactive Effort: 65 Gyration	

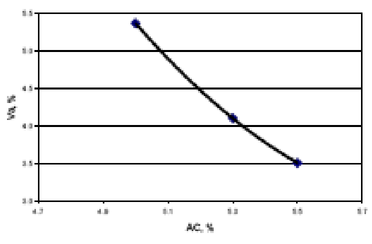
Specimen Number	Asphalt Content	Masses: In Air (g)	In Water (g)	SSD (g)	Specific Gravities: Bulk (Gmb)	TMD (Gmm)	Gse	Voids: Va, %	VMA, %	VFA, %	Pba	Pbe	Dust/Binder Ratio
1	5.0	4845.9	2760.4	4850.9	2.318	2.451	2.643	5.4	15.7	65	0.46	4.56	0.96
2	5.0	4834.6	2765.6	4848.9	2.321	2.451	2.643	5.3	15.6	66	0.46	4.56	0.96
Avg.					2.319	2.451	2.643	5.4	15.6	66	0.46	4.56	0.96
1	5.5	4844.6	2784.0	4847.7	2.348	2.433	2.642	3.5	15.1	77	0.46	5.07	0.87
2	5.5	4854.2	2788.0	4855.6	2.348	2.433	2.642	3.5	15.1	77	0.46	5.07	0.87
Avg.					2.348	2.433	2.642	3.5	15.1	77	0.46	5.07	0.87
1	5.3	4851.8	2778.0	4854.7	2.336	2.440	2.642	4.2	15.3	72	0.45	4.87	0.90
2	5.3	4847.4	2780.5	4849.0	2.343	2.440	2.642	4.0	15.0	74	0.45	4.87	0.90
Avg.					2.340	2.440	2.642	4.1	15.2	73	0.45	4.87	0.90
1													
2													
Avg.													
Input By:	Jason R. Moore						Checked By:						

SSD = Saturated Surface Dry
TMD = Theoretical Maximum Density
AC = Asphalt Cement
g = grams
Va = Voids in Total Mix
VMA = Voids in Mineral Aggregate
VFA = Voids Filled With Asphalt Cement
Pba = absorbed binder
Pbe = effective binder

% AC	VTM	VMA	VFA	Pba	Pbe	DP
5.0	5.4	15.6	65.7	0.46	4.56	0.96
5.5	3.5	15.1	76.7	0.46	5.07	0.87
5.3	4.1	15.2	72.9	0.45	4.87	0.90

Combined Gsb of Aggregates			Combined Gsa of Aggregates		
Stockpile	Gsb	% Blend		Gsa	% Blend
Fine	2.615	56.7	Fine	2.640	56.7
Coarse	2.608	43.3	Coarse	2.648	43.3

Opt Pb



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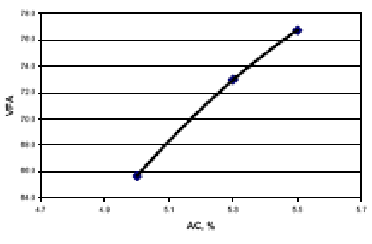
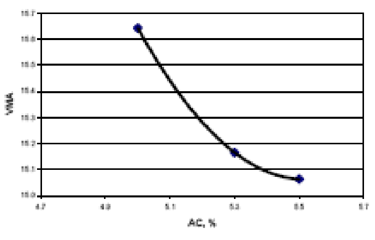


VMA



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