Evaluation of HMA Mixtures Containing Sasobit®

by

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ABSTRACT

This limited study provided a laboratory and field comparative evaluation of PG 76-22 HMA hot mix asphalt (HMA) mixture and a mixture containing the additive "Sasobit®." The fundamental material characterization testing (asphalt cement binder rheology, durability, and permanent deformation) was performed. The mixtures' durability (moisture susceptibility) and permanent deformation (rutting) was measured by the Modified Lottman and Loaded Wheel Tracking (LWT) (Hamburg type) tests. In addition, the influence of Sasobit® on compaction through roadway and laboratory density comparisons was examined. The results of the tests performed on PG 76-22 HMA and Sasobit® mixtures considered in this study showed that the use of the Sasobit® additive had no significant affect in terms of rut resistance and moisture susceptibility. The addition of Sasobit® may adversely affect the low temperature properties of the original asphalt cement binder being utilized as observed through asphalt cement binder rheology testing.

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IMPLEMENTATION STATEMENT

This was a very limited study that evaluated the laboratory and field performance of PG 76-22 HMA and the Sasobit$^{®}$ hot mix asphalt mixtures. The test factorial and number of projects evaluated was minimal; therefore, further in-depth research is necessary to fully understand and determine the affects of Sasobit$^{®}$ on long-term pavement performance before implementation of this product.

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INTRODUCTION

The use of PG 76-22M asphalt cement has helped in the prevention of rutting and resistance to moisture damage. However, the increase in asphalt cement stiffness sometimes creates compactibility issues in the field. This study utilized the Sasobit® warm mix technology to reduce compaction temperatures, which allowed HMA mix temperatures to fall between 300°F and 325°F in lieu of the 350°F typically seen.

Conventional HMA production takes place between 250°F and 325°F, not to exceed 350°F, and placement and compaction occurs between 260°F and 300°F *[1]*. Before mixing with hot liquid asphalt, fine and coarse aggregates are heated to high temperatures to drive off moisture, ease coating of the mineral aggregates with the liquid asphalt, and keep the complete mix fluid enough to be workable during placement. A number of new processes and products have become available that can reduce the temperature at which HMA is mixed and compacted.

Since the introduction of warm asphalt mixes into North America, the asphalt industry has gotten closer to producing low-emission HMA mixtures. Warm asphalt mixes are of particular interest because of their potential for reducing plant emissions, benefits in construction in the field, and reducing energy consumption in the plant. The use of warm mixes may also extend the construction season in colder weather because contractors may no longer fear the critical loss of temperature in the cold *[2]*.

The use of warm asphalt technologies was developed in Europe with the aim of reducing greenhouse gases produced by manufacturing industries *[3]*. Specifically, the European Union has agreed to reduce CO_2 emissions by 15 percent by 2010. With this goal, the European hot mix industry has begun the use of warm mix asphalt technology to construct asphalt pavements at much lower temperatures.

Three processes are currently used to produce warm mix asphalt (WMA). All three processes allow the production of WMA by reducing the viscosity of the asphalt binder at a given temperature. This reduced viscosity allows the aggregates to be fully coated at significantly lower temperatures than what is traditionally required in HMA production. The three processes are as described below *[2]*, *[4]*, and *[5]*:

1. The addition of a synthetic zeolite, which has been hydro-thermally crystallized, releases water molecules when mixed with liquid asphalt creating a foaming effect in the binder. This product is commercially called Aspha-Min. The

percentage of water held internally by the zeolite is 21 percent by mass and is released in the temperature range of 185°F-360°F. By adding Aspha-Min to the mix at the same time as the binder, a very fine water spray is created. This release of water creates a volume expansion of the binder that results in asphalt foam and allows increased workability and aggregate coating at lower temperatures.

2. A two-component binder system called WMA Foam introduces a soft and a hard foamed binder at different points during production. The soft binder component is mixed with aggregate in the first stage at approximately 230°F to achieve full aggregate coverage. The hard binder component is mixed in a second stage into the pre-coated aggregates in the form of foam. Rapid evaporation of water by injecting cold water into the heated hard binder as it is added to the mix produces a large volume of foam. The hard binder foam combines with the soft binder to achieve the required final composition and properties of the asphalt product.

3. The use of organic additives such as Sasobit® reduces the viscosity of the binder at mixing and compaction temperatures. Sasobit® is a fine crystalline, long chain aliphatic hydrocarbon produced from coal gasification using the Fischer-Tropsch (FT) process and is known as FT paraffin wax. The melting point of Sasobit® is approximately 210°F and is completely soluble in an asphalt binder at temperatures in excess of 240°F. It produces a reduction in the binder viscosity. This enables production temperatures to be reduced by 18°F – 54°F. At temperatures below its melting point, Sasobit® forms a lattice structure in the asphalt binder that is the basis for the reported stability of asphalts that contain Sasobit®. At service temperatures, Sasobit® modified asphalts are reported to display an increased resistance to rutting. In addition, it is reported that improved compactibility was observed with an increase in the degree of compaction for the same roller loading as unmodified asphalt *[6]*. It is reported that the use of Sasobit® increases the softening point, reduces penetration, and does not affect the low temperature properties of the asphalt cement binder *[7]*. Research has shown that FT synthetic waxes give outstanding results as modifiers for every kind of bitumen, whether straight-run, air-blown, or even polymer-modified bitumens (PMB). FT waxes are completely soluble in bitumen because of their structural similarity to the waxes naturally present in bitumen, in contrast to polymers. FT waxes have excellent thermal stability and

> have a lower viscosity than other constituents of bitumen. The FT wax acts as a very stable flow improver for bitumen, both during the asphalt mixing process and during laying operations. This enables asphalt mixing temperatures to be reduced, which results in energy savings during mixing and a lower level of toxic emissions. The flow improvement properties of the FT wax allow HMA mixtures to be laid satisfactorily at lower ambient temperatures when lay down operations would not normally be possible. They also greatly facilitate the laying of stiff asphalts, such as those containing PMBs. The addition of 3 to 6 percent FT wax into the bitumen or PMB results in the stiffness of the parent bitumen, independent of its penetration class, to be increased by 54°F to 72°F expressed in terms of the ring and ball softening point. The low temperature properties remain the same as for the parent bitumen. These changes are independent of the bitumen's crude oil source *[8]*.

Several field trials have been conducted in Europe to evaluate the use of WMA mixtures and their compactability and in-service performance. Those trials were carried out in Norway, the United Kingdom, and the Netherlands *[5]*. The level of emissions during construction was measured. Visual inspection after laying the trial roads and up to three years of trafficking indicated performance similar to control sections constructed using conventional asphalt. Cores from the field trials showed similar stability and adhesion characteristics to those of conventional asphalt.

Warm asphalt is a relatively new technology in the United States. Very limited research studies have been conducted to evaluate asphalt mixtures using this technology. Earlier work on warm asphalt in the United States was conducted by the National Center of Asphalt Technology (NCAT) *[9], [10]*. NCAT evaluated the use of zeolite and Sasobit® as potential additives to produce asphalt mixtures at lower temperatures than the conventional asphalt. Improved compactability (reduction of air voids) was reported at temperatures as low as 190°F. Both additives had no effect on the resilient modulus of the asphalt mixtures. The resulting mixtures, however, showed poor resistance to moisture damage as measured by the tensile strength ratio (TSR). An adhesion failure caused by the debonding of the asphalt cement from the aggregate as a result of water presence is generally defined as stripping. Stripping was also observed when testing the mixtures in the Hamburg type LWT test. It was also reported that the addition of Sasobit® generally decreased the rutting potential, and the indirect tensile strengths for mixes containing Sasobit® were lower, in some cases, as compared to the control mixes. PRI Asphalt Technologies, Inc., tested, evaluated, and assessed the Sasobit® additive in two neat, unmodified asphalt cement binders representing different chemistries as measured by Superpave binder specifications and then retested the asphalt cement binders utilizing Superpave plus specifications. It was reported that the addition of Sasobit® at less than 3 percent may optimize performance grade enhancements of the asphalt cement binder. In addition, Sasobit® adversely affected the intermediate/ambient criteria by raising the dynamic shear rheology (DSR) value (G*Sinδ) after the rolling thin film oven test (RTFOT) and pressure aging vessel (PAV), subsequently increasing the acceptable temperature for fatigue resistance by 3^{+}°C. The m value as measured by the creep stiffness protocol also decreased as the percentage of the Sasobit® additive increased. The "Aging Index" that is a comparison of the DSR values, RTFOT/Original, indicated that the addition of Sasobit® may improve anti-aging properties as measured by this traditional comparative ratio. Also it is reported that the addition of Sasobit® resulted in the phase angle being decreased, the softening point increasing, and a reduction in viscosity at 135°C *[11]*.

OBJECTIVE

The objective of this study was to perform a laboratory and field comparative evaluation of PG 76-22 HMA mixtures and mixtures containing the additive "Sasobit®." In particular, the objectives included the following:

- Determine the fundamental material characterization (asphalt cement binder rheology and HMA mixtures).
- Evaluate the influence of Sasobit® on moisture sensitivity as measured by DOTD TR 322M/322-03 and LWT (Hamburg type) as compared to PG 76-22 HMA mixtures *[12]*.
- Examine the influence of Sasobit® on compaction through roadway and laboratory density comparisons.

SCOPE

Evaluation of the Sasobit® test section was done on an active Louisiana construction project. Two 1-inch nominal maximum size aggregate HMA binder courses were selected for evaluation in this study. The first HMA mixture utilized a PG 76-22M polymer modified asphalt cement binder course meeting Louisiana specifications, hereafter referred to as PG 76-22 HMA *[13]*. The second HMA mixture also utilized a PG 76-22M polymer modified asphalt cement binder that contained Sasobit®. The job mix formulas for each mix type considered were identical except for the asphalt cement binder type used. Siliceous limestone was the predominate aggregate used in the HMA mixture types considered.

One day's production of each mixture type was evaluated since there was only one day of production for the Sasobit® modified mixture and the PG 76-22 HMA mixture production lasted several days. Loose production mix from both mixture types and asphalt cement binders used were evaluated to determine their fundamental material characterization in terms of moisture susceptibility and durability. The influence of Sasobit® on moisture sensitivity as measured by DOTD TR 322M/322-03 and LWT (Hamburg type) as compared to the PG 76-22 HMA mixtures was evaluated *[12]*. Also, the influence of Sasobit® on field compaction was examined through roadway and laboratory density comparisons. Roadway density was evaluated at a minimum of six locations as measured by non-destructive testing, Troxler's thin-lift nuclear gauge, and field cores in accordance with DOTD TR 304-03, "Determination of Specific Gravity and Density Characteristics of Compressed Asphaltic Mixtures" *[14]*.

METHODOLOGY

Project Description

Figure 1 illustrates the project location on Route LA 1 in Lafourche Parish beginning at the south end of the Bayou Lafourche Bridge (Log Mile 0.000) and commences northward for 9.170 miles to its project ending limits (Log Mile 9.170), 1.760 miles south of junction LA 308. This project is an undivided two-lane highway with varying travel lane and shoulder widths. Eight miles of this project has 24-ft. travel lanes with two 6-ft. shoulders, whereas the remainder of the project has 20-ft. travel lanes with two 4-ft. shoulders. The contract was bid under State Project No. 064-90-0081 and was awarded to the low bidder, Barriere Construction Co., LLC. The work order date for this project was April 11, 2005. Approximately 3,159 tons of PG 76-22 HMA binder course HMA test section was placed on July 17, 2005. The Sasobit® binder course HMA test section that comprised of approximately 2,987 tons was placed on July 18, 2005.

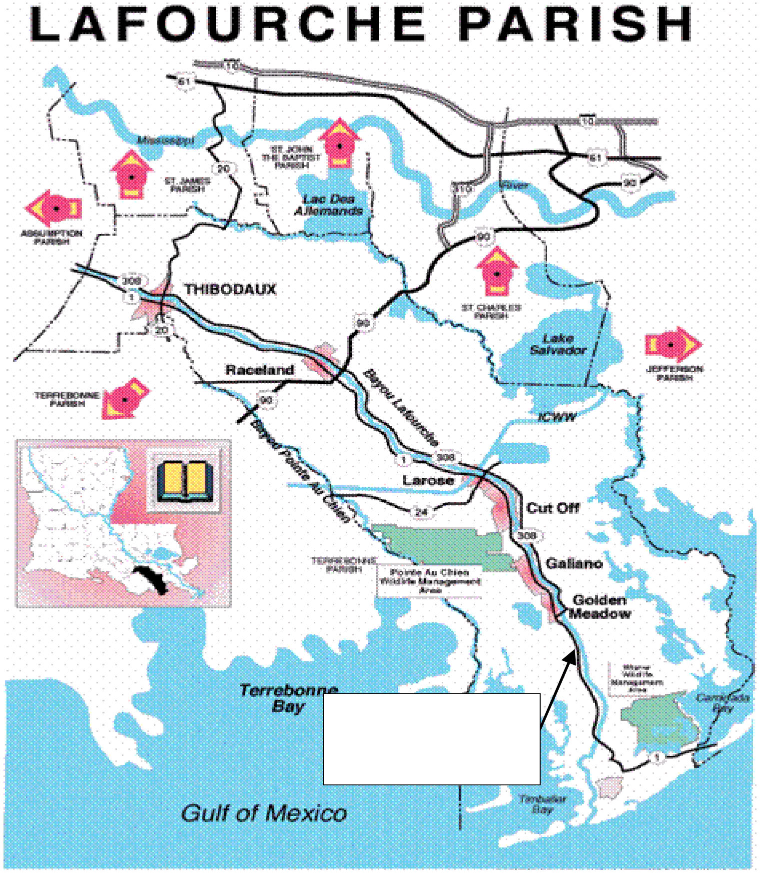

Figure 1
Project location

Material Properties and Mixture Design

Asphalt Cement

An elastomeric type of polymer modified asphalt cement was specified for this project, meeting the DOTD specification for PG 76-22M. The PG 76-22M asphalt cement was listed on QPL #41 and was supplied by Valero Marketing and Supply Company. The PG 76-22 HMA evaluated in this study contained the specified PG 76-22M asphalt cement. The Sasobit® HMA mixture used a Sasobit® modified PG 76-22M asphalt cement. The Sasobit® additive was added to the contractor's asphalt cement supply tank at the hot mix plant at the prescribed dosage, 1 percent by weight of asphalt cement, and mixed overnight while constantly being agitated with paddles.

Prior to commencement of the actual project evaluation, preliminary testing was performed on Marathon PG 76-22M asphalt cement and a modified PG 76-22M with varying percentages of the Sasobit® additive. However, the contractor chose to use asphalt cement marketed by Valero because of logistical technicalities.

Aggregates

The predominate aggregate, 74.8 percent, used in the HMA binder course mixtures was a siliceous limestone blend (#5, #7, #911, and #11) supplied by Vulcan Material Company (Source Code AA50). The remaining aggregate material was a combination of coarse sand and reclaimed asphalt pavement (RAP) at 6.2 and 19.0 percent, respectively. The aggregates used complied with the requirements set forth in Subsection 1003.06(b) of the Standard Specifications *[13]*.

Antistrip

The contractor was required to perform a modified Lottman test, DOTD TR 322M/322-03, to evaluate the mixtures' susceptibility to moisture damage. A Permatac 99 anti-strip additive from AKZO NOBEL Asphalt Applications was added at mix percentage of 0.6 by weight of asphalt cement (AC).

Mixture Design

The Superpave mix design procedure was used to determine the optimum asphalt content of the asphalt mixtures. The design criteria were set by the "Louisiana Standard Specifications for Roads and Bridges" for this project *[13]*. The final aggregate structure for the HMA mixtures was determined using the Bailey method. Table 1 shows the composition of the

HMA binder course mixtures evaluated in this study. It is shown that the optimum asphalt cement content was incorporated at a mix percent of 3.8 by weight as required by the mix design.

Table 1
Composition of mix design blends

	Percentage		
Material	**PG 76-22 HMA**	**Sasobit$^{®}$**	**Source**
#5 Limestone, FR III	34.8	34.8	Vulcan Materials
#7 Limestone, FR III	9.0	9.0	Vulcan Materials
#911 Limestone, FR III	17.4	17.4	Vulcan Materials
#11 Limestone, FR III	13.6	13.6	Vulcan Materials
Coarse Sand	6.2	6.2	TXI
RAP	19.0	19.0	Barriere Construction Company, Inc.
PG76-22M asphalt cement binder	3.8	3.8 with 1% Sasobit$^{®}$ by Weight of AC	Valero Marketing & Supply
Permatac 99 anti-strip	0.6 by Wt. of AC	0.6 by Wt. of AC	AKZO NOBEL Asphalt Applications

Table 2 presents the job mix formula (JMF) and gradation results for the PG 76-22 HMA and Sasobit$^{®}$ HMA mixtures evaluated in this study. Also shown in Table 2 are the contractor's volumetric quality control (QC) data for mixture properties and gradation analysis for the mixtures. This table shows the maximum theoretical gravity (G_{mm}), %G_{mm} at $N_{initial}$, N_{design}, and Nmax (%G_{mm}, N_i; %G_{mm}, N_d; %G_{mm}, N_{max}) for each mixture. Also, percent voids in the mineral aggregate (%VMA), percent voids filled with asphalt (%VFA), percent air voids (%V_a), and percent asphalt cement (%AC) are indicated in Table 2.

Table 2
JMF and QC volumetric, mix properties, and gradation analysis

	Binder Course			
	PG 76-22 HMA JMF	**PG 76-22 HMA QC**	**Sasobit® JMF**	**Sasobit® QC**
G_{mm}	2.515	2.515	2.515	2.509
%G_{mm}, N_i	87.1	87.2	87.1	87.7
%G_{mm}, N_d	96.5	96.0	96.5	96.3
%G_{mm}, N_{max}	96.7	—	96.7	—
%VMA	12	12.8	12	12.6
%VFA	71	68	71	71
%V_a	3.5	4.0	3.5	3.7
%AC	3.8	3.7	3.8	4.1
Sieve	**Gradation Analysis**			
1 ½”	100	100	100	100
1”	95	95	95	97
¾”	89	87	89	91
½”	76	74	76	79
3/8”	67	66	67	70
No. 4	47	46	47	50
No. 8	31	29	31	32
No. 16	23	22	23	23
No. 30	18	17	18	18
No. 50	12	11	12	11
No. 100	9	8	9	8
No. 200	6.8	6.4	6.8	6.2

Figure 2 illustrates the JMF 0.45 power curve gradation charts for the HMA binder course mixtures used in this study. It is noted that only one gradation is depicted in this figure because the JMFs for the PG 76-22 HMA and Sasobit® HMA binder course mixtures are identical. Figure 2 shows both HMA mixtures are above the maximum density line; hence, they are classified as fine mixtures.

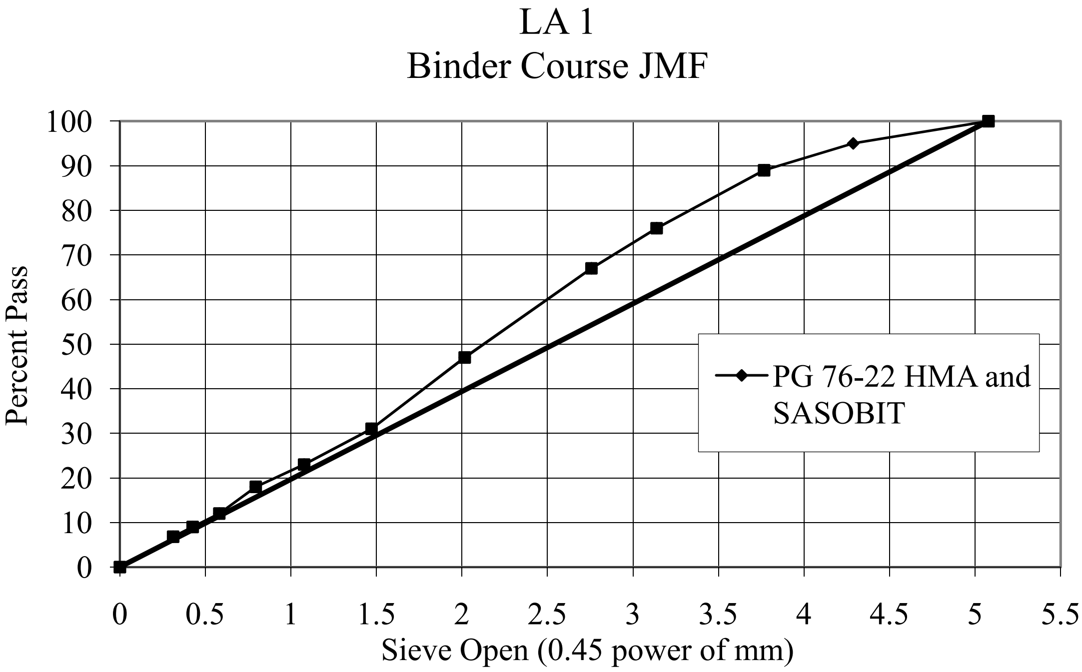

Figure 2
PG 76-22 HMA and Sasobit® JMF 0.45 power curve

Roadway Compaction

Three vibratory steel wheel rollers were used to compact the PG 76-22 HMA and Sasobit® HMA sections to required density. A PG 76-22 HMA steel wheel rolling protocol was followed, i.e., breakdown, intermediate, and then finished roller. The established rolling pattern was maintained for both mixes evaluated. The breakdown and intermediate rollers vibrated all passes for a total of seven vibratory passes. The finish steel wheel roller compacted in static mode only. The rolling speed for the compaction equipment for all steel wheel rollers was set at 3.5 mile/hour. The breakdown and intermediate rollers were set at 3,500 vibrations per minute, which equates to one impact per inch.

Roadway density was evaluated at a minimum of six locations for the PG 76-22 HMA and Sasobit® test sections. During compaction of the HMA mixtures, quality control for density was performed using a Troxler type thin-lift nuclear gauge. Field cores were then obtained from the previously tested locations, and densities were determined in accordance with DOTD TR 304-03 test procedures *[14]*.

The average haul time from the contractor's HMA plant facility to the roadway construction site was approximately 1.5 hours. The HMA mixture plant temperature was elevated because of the haul time for both mixtures evaluated. The average HMA plant temperature was 330°F for both mix types evaluated except for location 6 of the Sasobit® test section. During compaction of the Sasobit® test section, tenderness marked by wave-like action in front of the breakdown roller was noted. The plant temperature was subsequently lowered to 300°F for location 6 of the Sasobit® test section. The initial roadway compaction temperature for the PG 76-22 HMA and Sasobit® test sections was approximately 315°F, except for location 6 of the Sasobit® test section which was approximately 290°F.

Fundamental Material Characterization

The following section outlines the test methodology used for fundamental material characterization of the asphalt cement binders and the HMA mixtures.

Asphalt binders, PG 76-22M and Sasobit® modified PG 76-22M, were tested and characterized. LWT and Modified Lottman (DOTD TR 322M/322-03) tests were conducted to define the permanent deformation and moisture susceptibility of the HMA mixtures considered, respectively.

Triplicate samples were used for each test except for the LWT test.

Asphalt Cement Binder Rheology

Asphalt Cement Binder Tests. Asphalt binders, PG 76-22M and Sasobit® modified PG 76-22M, were tested and characterized according to AASHTO PP6, “Practice for Grading or Verifying the Performance Grade of an Asphalt Binder” in order to determine the effect of Sasobit® on asphalt cements considered in this study. In addition, the following standard asphalt cement binder tests were performed:

- AASHTO T 49, “Standard Test Method for Penetration of Bituminous Materials”
- AASHTO T 53, “Standard Method of Test for Softening Point of Bitumen (Ring-and-Ball Apparatus)”
- AASHTO T 314, “Standard Method of Test for Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)”
- AASHTO T 300, “Standard Method of Test for Force Ductility Test of Asphalt Materials”
- AASHTO T 301, “Standard Method of Test for Elastic Recovery Test of Asphalt Materials by Means of a Ductilometer”
- AASHTO T 228, “Standard Method of Test for Specific Gravity of Semi-Solid Bituminous Materials”

- AASHTO T 202, “Standard Method of Test for Viscosity of Asphalts by Vacuum Capillary Viscometer”

Laboratory Mixture Characterization

Fabrication of Mixture Specimens. Laboratory mix specimens were prepared according to the specific requirements of each individual test. According to the test factorials described, cylindrical and rectangular beam samples were fabricated. The Superpave gyratory compactor (SGC) was used to compact all cylindrical specimens. A kneading compactor was used to compact LWT (Hamburg type) beam specimens.

Laboratory Tests. Specimens fabricated through various methods at the target air voids (7 ± 1%) were used to conduct laboratory mixture performance tests as outlined in Table 3. A brief description of each test is provided below.

Table 3
Mixture performance tests

Performance Characteristics	Test	Specimen	Test Temp.	Protocol
Durability & Permanent Deformation	LWT	320 x 260 x 80 mm	50ºC	AASHTO T324-04
Moisture Susceptibility	Modified Lottman	150 x 95 mm diameter	25ºC	DOTD TR 322M/322-03

*Hamburg type LWT test will be used to evaluate both stripping and rutting.

Loaded Wheel Tracking (Hamburg type) Test. One of the major distresses in asphalt pavements is its inability to resist permanent deformation due to traffic loading. To determine the rutting characteristics of the HMA mixtures considered in this study, a loaded wheel tracking test was conducted in accordance with AASHTO T 324-04, “Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA).” In this test, specimens are subjected to a steel wheel weighing 703 N (158 lb.) that is repeatedly rolled across the specimens’ surface while being submerged in water at 50°C. The test completion time is predicated upon test specimens being subjected to a maximum of 20,000 cycles or attainment of 20 mm deformation, whichever is reached first. Upon completion of the test, the average rut depth for the samples tested is recorded.

The Hamburg type LWT manufactured by PMW, Inc. of Salina, Kansas was used in this study (Figure 3). The Hamburg LWT can test two specimens simultaneously. The test specimens are subjected to two reciprocating solid-steel wheels of 203.5 mm (8 in.) in diameter and 47 mm (1.85 in.) in width while being submerged in water at the specified temperature of 50°C. Before actual testing of the laboratory specimens, they were conditioned at 50°C for 90 minutes. After conditioning a fixed load of 703 N (158 lb.) with a rolling speed of 1.1 km/h (0.68 mi/h) at the rate of 56 passes per minute was implied, each wheel rolled 230 mm (9.1 in.) before reversing direction.

In order to accurately measure permanent deformation, two Linear Variable Displacement Transducers (LVDT's) were utilized and the subsequent test results (rut depths, number of passes, and water bath temperature) were collected and recorded in an automated data recording system associated with the Hamburg type LWT device. Figure 4 represents a typical LWT test result output.

Figure 3
Hamburg type LWT device

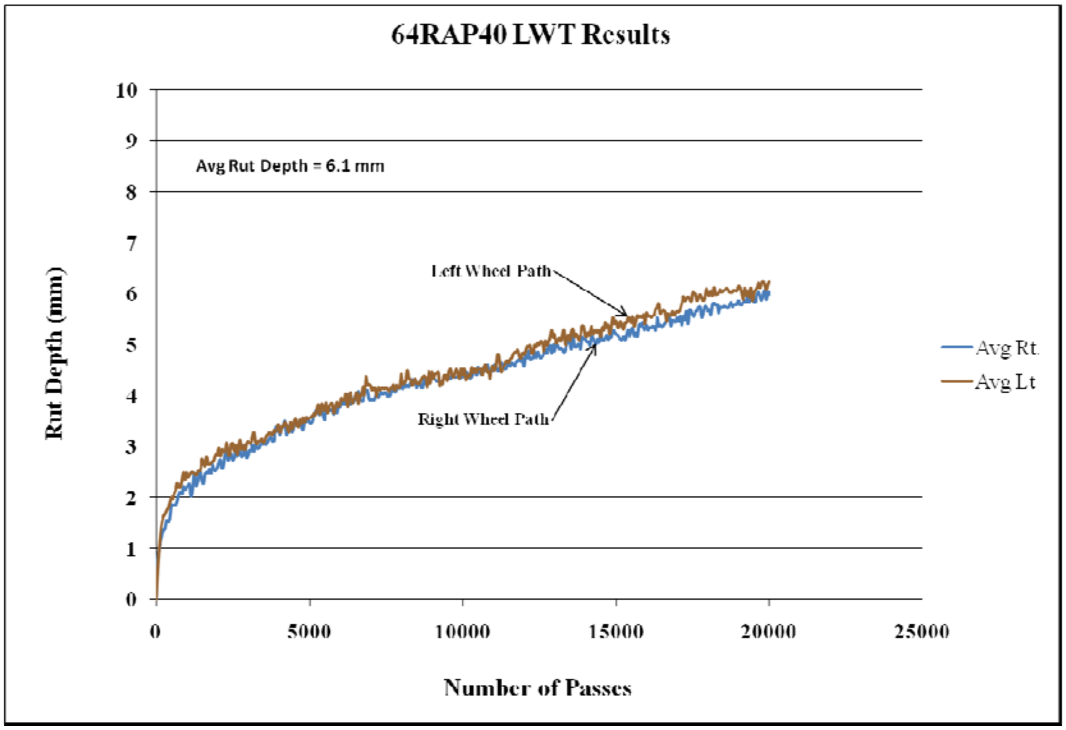

Figure 4
Typical LWT test output

Moisture Susceptibility. The moisture susceptibility of mixtures considered in this study was evaluated in accordance with DOTD TR 322M/322-03, "Method of Test for Determining the Effect of Moisture on Asphaltic Concrete Paving Mixtures." Laboratory specimens were fabricated at the target air voids of 7 ± 1 percent for moisture evaluation. Louisiana requires that the minimum tensile strength ratio (TSR) be 80 percent *[13]*.

This test is a measure of the effect of moisture on the tensile strength of HMA mixture compacted specimens. The potential for moisture damage is indicated by the tensile strength ratio (TSR) of a moisture-conditioned set of specimens to an unconditioned set of specimens. Two sets of 150 mm in diameter by 95 mm high moisture-conditioned and unconditioned specimens were prepared for moisture susceptibility testing. Moisture-conditioned specimens were completely submerged in a vacuum chamber at room temperature and then a partial vacuum was applied to saturate the specimens between a 55 and 80 percent saturation level. After saturation, each sample was placed in a leak-proof plastic bag with a predetermined amount of water and then placed in a freezer for 16 hours at a temperature of -18 ± 3°C. After freezing for the required time period, the moisture-conditioned specimens were then placed in a water bath at 60 ± 1°C for 24 hours. After this time period, the specimens were placed in another water bath for 2 hours at 25 ± 1°C. The moisture-conditioned specimens were then ready for testing.

The 150 mm in diameter by 95 mm high moisture-conditioned and unconditioned specimens were loaded to failure at a deformation rate of 50.8 mm/min. The load and deformations were recorded and indirect tensile strength was computed and used in the analysis to determine the TSR.

Conduct Data Analysis

Laboratory test data were statistically analyzed using the analysis of variance (ANOVA) procedure provided in the Statistical Analysis System (SAS) program from SAS Institute, Inc. A multiple comparison procedure with a risk level of 5 percent was performed on the means. The groupings will represent the mean for the test results reported by mixture type. The results of the statistical grouping were reported with the letters A, B, C, D, and so forth. The letter A was assigned to the highest mean followed by the other letters in appropriate order. Different letter groupings indicate a significant difference in the means. A double (or more) letter designation, such as A/B (or A/B/C), will indicate that in the analysis the difference in the means is not clear-cut and that the mean is close to either group.

DISCUSSION OF RESULTS

Asphalt Cement Binder Rheology

Table 4 indicates the asphalt binder rheology for both asphalt cement binders evaluated in this study. From this table, the following observations are made:

- The original PG 76-22M asphalt cement binder actually graded as a PG 82-22.
- The 1 percent Sasobit® modified PG 76-22M asphalt cement binder graded as a PG 82-16.
- The 1 percent Sasobit® modified asphalt cement binder failed to meet the following DOTD specifications for PG 76-22M:
    - force ductility specification
    - Bending Beam Rheometer (BBR) m-value @ -12°C (Testing protocol requires that the test temperature be 10°C warmer than the low temperature specification requirement, i.e., -12°C.)
- There was no difference in the rotational viscosity values at the three temperatures (120°C, 135°C, and 165°C) tested between the original PG 76-22M and 1 percent Sasobit® modified asphalt cement binders evaluated.
- The addition of 1 percent Sasobit® to the PG 76-22M original asphalt cement binder increased the absolute viscosity at 60 °C by 81 percent.
- The addition of 1 percent Sasobit® increased the Pen and Softening Point of the original PG 76-22M asphalt cement binder.
- There was no change in the specific gravities between asphalt cements evaluated, which was expected due to the small percentage (1 percent) of the Sasobit® additive.
- It is shown that there was a reduction in elastic recovery with the use of 1 percent Sasobit®, although it is noted that the final result was still well within the required specification.
- The Rolling Thin Film Oven (RTFO) Pressure Aging Vessel (PAV) dynamic shear values at 25°C were similar for both asphalt cement binders evaluated.

- The shear modulus at 4°C showed a higher G*Sin δ parameter for the Sasobit® mix. This indicates that the Sasobit® mix is more brittle than the PG 76-22 HMA mix, which was also reflected in the failure of the Sasobit® modified PG 76-22M to meet the force ductility specification.

- Both the 1 percent Sasobit® modified and original PG 76-22M asphalt cement binders failed the Direct Tension (DT) test. Although this test was not required by the performance graded specification protocol, the test was run for informational purposes.

Table 5 represents the Rolling Thin Film Oven Test (RTFOT) aging index. This ratio compares the RTFOT DSR value to the original DSR value. This table indicates that the addition of Sasobit® may provide a possible benefit in the anti-aging properties. Also, it is noted that as the test temperature increased, the original PG 76-22M asphalt cement binder's aging index also increased, whereas the 1 percent Sasobit® modified asphalt cement binder's index was similar. Table 5 also shows the aging index computed with only the G* component of the RTFOT and original DSR values for the asphalt cement binders studied.

Table 6 shows the PAV aging index computed for G*(sinδ) tested at 25°C. This ratio compares the PAV aged material to the unaged asphalt cement binder. This table also indicates that the addition of Sasobit® may provide a possible benefit in the anti-aging properties.

Table 4
Asphalt binder rheology

	Spec	PG 76-22M		1% Sasobit® modified PG 76-22M	
Test on Original Binder		**Results**	**Pass/Fail**	**Results**	**Pass/Fail**
Dynamic Shear, G*/Sin(δ), (kPa)	1.00^{+} @ 76°C	2.09	Pass	2.57	Pass
Dynamic Shear, G*/Sin(δ), (kPa)	1.00^{+} @ 82°C	1.06	Pass	1.49	Pass
Dynamic Shear, G*/Sin(δ), (kPa)	1.00^{+} @ 85°C	—	—	1.15	Pass
Dynamic Shear, G*/Sin(δ), (kPa)	1.00^{+} @ 86°C	—	—	0.99	Fail
Dynamic Shear, @ 25°C, G*Sin(δ), (kPa)	—	97	—	413	—
Force Ductility Ratio, f_2/f_1, 4°C @ 30 cm elongation	0.30^{+}	0.60	Pass	Broke[1]	Fail
Rotational Viscosity @ 120°C (Pa·S^2)	—	4.3	—	4.3	—
Rotational Viscosity @ 135°C (Pa·S^2)	3.0	1.6	Pass	1.6	Pass
Rotational Viscosity @ 165°C (Pa·S^2)	—	0.4	—	0.4	—
Viscosity @ 60°C (Pa·s), AASHTO T 202	—	3400	—	6160	—
Penetration @ 25 °C, (dmm), AASHTO T 49	—	43	—	32	—
Softening Point, °C AASHTO T 53	—	63.8	—	71.4	—
Specific Gravity AASHTO T 228	—	1.029	—	1.029	—
Tests on RTFO					
Dynamic Shear, G*/Sin(δ), (kPa)	2.20^{+} @ 76°C	5.01	Pass	4.83	Pass
Dynamic Shear, G*/Sin(δ), (kPa)	2.20^{+} @ 82°C	3.07	Pass	2.82	Pass
Dynamic Shear, G*/Sin(δ), (kPa)	2.20^{+} @ 85°C	2.30	Pass	2.14	Fail
Elastic Recovery @ 25°C, %	60^{+}	77.5	Pass	70.0	Pass
Tests on (RTFO+ PAV)					
Dynamic Shear, @ 25°C, G*Sin(δ), (kPa)	5000^{-}	3576	Pass	3503	Pass
Dynamic Shear, @ 4°C, G*Sin(δ), (kPa)	—	16467	—	22576	—
Bending Beam Creep Stiffness @ -12°C, (MPa)	300^{-}	146	Pass	169	Pass
Bending Beam m-value@ -12°C	0.300^{+}	0.309	Pass	0.282	Fail
Bending Beam Creep Stiffness @ -6°C, (MPa)	300^{-}	68	Pass	81	Pass
Bending Beam m-value@ -6°C	0.300^{+}	0.366	Pass	0.328	Pass
Direct Tension Test @ -12°C, (% Strain)	1.000^{+}	0.935	Fail	0.840	Fail
Actual PG Grading		**PG 82 - 22**		**PG 82 - 16**	

[1] 4 out of 5 samples tested broke before 30 cm elongation, 26.2 cm average elongation. Sample 5 broke at 30 cm elongation with force ductility ratio of 0.50.

Note: "—" indicates the test was not run at that temperature.

Table 5
Traditional aging index

Test Temperature	PG 76-22M		1% Sasobit® modified PG 76-22M	
	G*/sinδ	G*	G*/sinδ	G*
76°C	2.40	2.30	1.88	1.81
82°C	2.90	2.79	1.89	1.83
85°C	—	—	1.86	1.81

Note: "—" indicates the test was not run at that temperature.

Table 6
PAV aging index

Test Temperature	PG 76-22M	1% Sasobit® modified
	G*(sinδ)	G*(sinδ)
25°C	36.72	8.47

HMA Mixture Characterization

Moisture Susceptibility

Table 7 represents the Modified Lottman test results for both mix types evaluated in this study. The indirect tensile strength (ITS) for the conditioned specimens of both HMA mixtures evaluated was slightly higher than the unconditioned specimens. Such that the %TSR for the PG 76-22 HMA and Sasobit® modified HMA specimens were 106.0 percent and 100.6 percent, respectively. It is noted that the %TSR for the Sasobit® modified HMA was lower than the PG 76-22 HMA. This may have resulted from the waxy component of the Sasobit® as well as the high wax content of the neat asphalt binder cement (Mayan crude) used to manufacture the polymer modified asphalt cement.

Table 7
Modified Lottman test results

PG 76-22 HMA Mix Type			Sasobit® Mix Type		
Sample No.	Tensile Strength (PSI)		Sample No.	Tensile Strength (PSI)	
	Unconditioned	Moisture Conditioned		Unconditioned	Moisture Conditioned
1	209.0	249.4	1	207.6	202.2
2	220.9	230.8	2	172.3	202.1
3	231.3	220.4	3	184.6	163.3
Average	220.4	233.5	**Average**	188.2	189.2
Stdev	11.2	14.7	**Stdev**	17.9	18.3
CV	5.1	6.3	**CV**	9.5	9.6
%TSR	106.0		**%TSR**	100.6	

Loaded Wheel Tracking (Hamburg type) Test

Table 8 shows the rut measurements taken from the Precision Machine and Welding version of the LWT test. The LWT test evaluates mixtures for rutting properties and moisture susceptibility. Samples pass if they attain no more than 6.0 mm of rutting after 20,000 passes of the LWT test. Also, the LWT test will stop the measurement process if the samples have attained more than 20.0 mm at 20,000 passes. Two samples each from the PG 76-22 HMA mixture and Sasobit® mixture were subjected to testing. Tests were conducted at 50ºC. Both sets of samples were tested at 56 passes per minute. Prior to testing, the samples were submerged for 90 minutes at the required testing temperature. Table 8 indicates that the Sasobit® binder course performed slightly better than the PG 76-22 HMA mixture. The lower total rut depth may be attributable to the lower air voids of the fabricated Sasobit® test samples. There was a difference of approximately 1.1 percent air voids between the PG 76-22 HMA and Sasobit® test samples. The PG 76-22 HMA mix had an average air void content of 7.5 percent and a rut depth average of 4.3 mm. The Sasobit® mix had an average air void content of 6.4 percent with an average rut depth of 3.0 mm. The rut depths shown in Table 8 are an average of the center five of eleven points taken from each sample. It is noted that both binder course mixture types, PG 76-22 HMA and Sasobit®, were well within the maximum allowable rut depth criteria of 6 mm for attaining passing results. In addition, there was no moisture susceptibility observed for the HMA mixtures evaluated.

Figure 5 illustrates the average sample deformation under loading vs. the number of passes for the PG 76-22 HMA and Sasobit® mixtures as tested in the LWT test, respectively.

Table 8
Rut measurements from LWT device

PG 76-22 HMA Binder Course				Sasobit® Modified Binder Course			
Sample Type		Compacted Beams		Sample Type		Compacted Beams	
Sample ID		LA 1 Barriere		Sample ID		LA 1 Barriere	
Test Condition		50°C Wet @ 56 PPM		Test Condition		50°C Wet @ 56 PPM	
Avg. Rut Depth @ 20,000		4.3 mm		Avg. Rut Depth @ 20,000		3.0 mm	
Left Sample		Right Sample		Left Sample		Right Sample	
Pass No.	Rut (mm)	Pass No.	Rut (mm)	Pass No.	Rut (mm)	Pass No.	Rut (mm)
500	1.4	500	1.1	500	0.5	500	0.7
1000	2.1	1000	1.4	1000	0.9	1000	0.9
2500	2.5	2500	2.2	2500	1.3	2500	1.1
5000	2.7	5000	2.8	5000	1.7	5000	1.5
10000	3.5	10000	3.4	10000	2.3	10000	1.7
15000	3.9	15000	3.8	15000	3.1	15000	2.2
20000	4.4	20000	4.2	20000	3.6	20000	2.4
Left Sample had 7.3% voids. Right sample had 7.6% air voids.				Left Sample had 6.4% voids. Right sample had 6.3% air voids.			

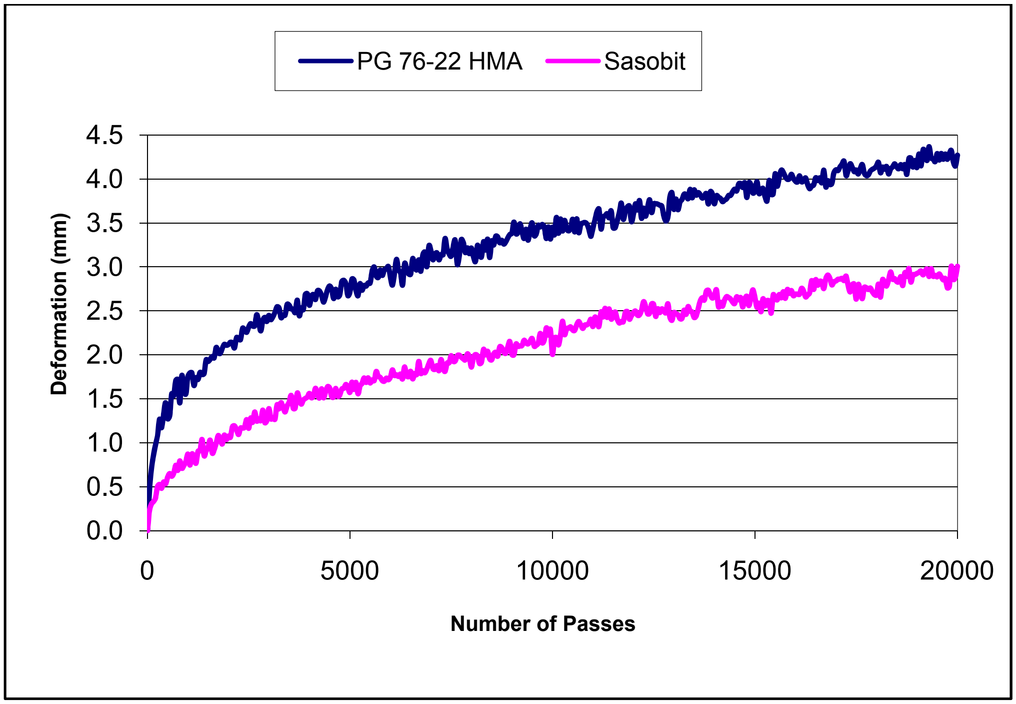

Figure 5
LWT sample deformation under loading vs. number of passes

Roadway Compaction

Table 9 represents the density comparison at seven locations of the nuclear gauge readings versus field cores of the PG 76-22 HMA binder course mixture that was evaluated. This table indicates that the final average density reading for the nuclear gauge of all test locations was 93.0 percent, while the average roadway core density was 94.5 percent. This represents a difference of 1.5 percent between measuring protocols. It is noted in Table 9 that the average nuclear gauge density directly behind the screed was 75.2 percent. It is shown that the standard deviations for the final average roadway densities as measured by the nuclear gauge and field cores were 0.525 and 0.906, respectively.

Table 10 illustrates the density comparison of the nuclear gauge readings versus field cores of the Sasobit® modified HMA binder course mixture evaluated. This table indicates that the final average density reading for the nuclear gauge of the six test locations was 93.3 percent, whereas the average roadway core density was 95.4 percent. This is a 2.1 percent difference between measuring protocols. Also in Table 10, it is noted that the average nuclear gauge density directly behind the screed was 78.7 percent. The standard deviations as shown for the final average roadway densities as measured by the nuclear gauge and field cores were 0.881 and 0.872, respectively. Table 10 shows that the final nuclear gauge density reading for location 6, which had a lower initial compaction temperature, had similar density readings as the other locations with elevated compaction temperatures. Also, the core density for location 6 was approximately 0.9 percent lower than the average density of the other locations. It is noted that the core density for location 6 was well above the minimum density requirement of 92.0 percent, as required by specification. The lower temperature at location 6 produced a similar density as the PG 76-22 HMA thus presenting energy efficiency and fuel savings albeit for one sample.

Table 11 compares the differences in the final average density values of all test sections for the nuclear gauge and field cores for the PG 76-22 HMA and Sasobit® modified HMA mixtures evaluated in this study. It is shown that the roadway density directly behind the screed was 3.5 percent higher for the Sasobit® HMA mixture than for the PG 76-22 HMA mix type as measured by the nuclear gauge. Also, Table 11 indicates an increase in roadway density of 0.9 percent for the Sasobit® modified HMA binder course. The increase in roadway density may be attributable to the increased asphalt content of 0.4 percent observed in the Sasobit® modified HMA mixture over the PG 76-22 HMA mix type.

Table 9
PG 76-22 HMA, nuclear gauge, and field core density comparison

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**		
Lane Location	**Left**	**Left**	**Left**	**Left**	**Left**	**Left**	**Left**	**Avg. Density**	**Std. Dev.**
Station #	**458+00**	**420+25**	**410+00**	**365+75**	**340+00**	**320+90**	**307+00**		
Nuclear Gauge Readings									
Directly Behind Screed	74.2	76.7	71.5	79.5	78.8	72.6	72.9	75.2	3.174
Roller 1-Pass 1	84.6	86.4	85.1	85.7	86.4	85.7	85.0	85.6	0.676
Roller 1-Pass 2	88.0	89.3	89.6	89.9	89.9	87.7	88.0	88.9	0.985
Roller 1-Pass 3	88.4	91.6	90.7	90.7	91.2	88.9	89.1	90.1	1.258
Roller 1-Pass 4	91.4	91.2	—	92.7	—	—	90.1	91.3	1.086
Roller 2-Pass 1	91.3	92.1	90.3	93.1	90.9	89.7	90.4	91.1	1.188
Roller 2-Pass 2	91.9	92.4	91.88	93.2	92.1	90.2	91.3	91.9	0.931
Roller 2-Pass 3	92.0	92.6	91.3	93.5	91.4	90.7	91.5	91.9	0.939
Roller 2-Pass 4	92.6	93.0	—	93.7	92.4	91.1	91.2	92.3	1.020
Roller 3-Pass 1	93.2	92.7	91.5	93.3	92.9	91.3	91.5	92.3	0.906
Roller 3-Pass 2	93.9	92.3	92.7	93.6	93.0	91.7	92.6	92.8	0.729
Roller 3-Pass 3	90.8	92.9	93.4	92.1	92.7	91.6	91.9	92.2	0.863
Roller 3-Pass 4	93.3	94.0	—	92.6	92.9	92.6	92.8	93.0	0.557
Final Reading	93.3	94.0	93.4	92.6	92.9	92.6	92.8	93.0	0.525
Roadway Core									
Average	94.2	93.8	93.9	95.9	94.0	94.1	95.8	94.5	0.906
Difference	0.9	-0.2	0.5	3.3	1.1	1.5	3.0	1.5	1.287

Table 10
Sasobit® HMA, nuclear gauge, and field core density comparison

Location	**1**	**2**	**3**	**4**	**5**	**6**		
Lane Location	**Right**	**Right**	**Right**	**Right**	**Right**	**Right**	**Avg. Density**	**Std. Dev.**
Station #	**458+40**	**436+00**	**394+00**	**360+75**	**320+00**	**285+00**		
Nuclear Gauge Readings								
Directly Behind Screed	78.1	79.6	77.7	79.9	76.6	80.6	78.7	1.515
Roller 1-Pass 1	86.6	88.5	86.6	87.4	85.6	87.1	87.0	0.970
Roller 1-Pass 2	88.0	90.4	89.9	89.9	88.7	89.4	89.4	0.889
Roller 1-Pass 3	89.4	91.0	90.2	89.0	90.2	90.4	90.0	0.715
Roller 1-Pass 4	89.5	91.7	—	92.8	—	—	91.3	1.695
Roller 2-Pass 1	89.8	92.3	91.6	92.6	91.0	92.4	91.6	1.057
Roller 2-Pass 2	91.2	91.3	92.0	93.3	93.3	93.1	92.4	0.971
Roller 2-Pass 3	90.9	92.3	93.2	93.9	91.4	92.8	92.4	1.138
Roller 2-Pass 4	82.7	93.2	—	94.7	93.4	93.1	93.4	0.778
Roller 3-Pass 1	91.3	93.3	92.5	94.6	92.9	93.1	92.9	1.081
Roller 3-Pass 2	91.6	93.2	93.7	92.8	93.1	93.4	93.0	0.748
Roller 3-Pass 3	91.7	—	93.9	94.2	93.1	93.8	93.3	0.993
Roller 3-Pass 4	91.7	93.1	—	94.3	93.2	93.5	93.2	0.924
Final Reading	91.7	93.1	93.9	94.3	93.2	93.5	93.3	0.881
Roadway Core								
Average	94.3	95.5	96.6	96.3	95.2	94.7	95.4	0.872
Difference	2.6	2.4	2.7	2.0	2.0	1.2	2.1	0.553

Table 11
PG 76-22 HMA/Sasobit® nuclear gauge and field core density comparison

Average Nuclear Gauge Density Readings			
	Sasobit®	**PG 76-22 HMA**	**Difference**
Directly Behind Screed	78.7	75.2	3.5
Roller 1-Pass 1	87.0	85.6	1.4
Roller 1-Pass 2	89.4	88.9	0.5
Roller 1-Pass 3	90.0	90.1	-0.1
Roller 1-Pass 4	91.3	91.3	0.0
Roller 2-Pass 1	91.6	91.1	0.5
Roller 2-Pass 2	92.4	91.9	0.5
Roller 2-Pass 3	92.5	91.9	0.6
Roller 2-Pass 4	93.4	92.3	1.1
Roller 3-Pass 1	92.9	92.3	0.6
Roller 3-Pass 2	93.0	92.8	0.2
Roller 3-Pass 3	93.3	92.2	1.1
Roller 3-Pass 4	93.2	93.0	0.2
Final Reading	93.3	93.0	0.3
Roadway Core			
Average	95.4	94.5	0.9
Difference	2.1	1.4	0.7

Table 12 shows the statistical comparisons of the volumetric parameters, asphalt content, and roadway densities of the HMA mixtures studied. Although the population is limited in this study, it is shown that there was no statistical difference between mix types evaluated for G_{mm}, %V_a, %VMA, %VFA, and %AC. As indicated in Table 12, there is a statistical difference between the Sasobit® modified HMA and the PG 76-22 HMA binder course mixtures as measured by the average final roadway core densities.

Table 12
Statistical analysis, volumetric parameters, asphalt content, and roadway density

				SAS	
Plant	**PG 76-22 HMA**	**Sasobit®**	**Difference**	**PG 76-22 HMA**	**Sasobit®**
G_{mm}	2.515	2.509	0.006	A	A
%V_a	4.0	3.7	0.3	A	A
%VFA	68	71	3	A	A
%VMA	12.8	12.6	0.2	A	A
%AC	3.7	4.1	0.4	A	A
Roadway Avg. Core Density	94.5	95.4	0.9	B	A

CONCLUSIONS

This study provided a laboratory and field evaluation of PG 76-22 HMA mixtures and mixtures containing the additive "Sasobit®." The testing factorial included the Modified Lottman test, Loaded Wheel Tracking (LWT) test, asphalt binder cement rheology characterization, and field density analysis. The tests were performed on PG 76-22 HMA and Sasobit® mixes.

The following conclusions are made based on the findings of this study:

- The binder rheology testing showed that the PG 76-22M binder graded as a PG82-22, whereas the Sasobit® modified PG 76-22M binder graded as an 82-16. The Sasobit® binder failed to meet the DOTD PG 76-22M specifications. Also, the addition of Sasobit® may have adversely affected the low end temperature properties of the original asphalt cement binder due to the waxy component of this material.

- The RTFOT aging index increased for the PG 76-22M as temperature increased, but it remained the same for the Sasobit® modified PG 76-22M.

- It is shown that the addition of Sasobit® may provide a possible benefit in the anti-aging properties as measured by the RTFOT aging index and the PAV aging index.

- The density results showed better compactability for the Sasobit® mix. The Sasobit® mix achieved a final average roadway core density of 95.4 percent, while the PG 76-22 HMA mix final density was 94.5 percent. This represents an increase in roadway density of 0.9 percent for the Sasobit® mix. The increase in roadway density may be attributed to the increased asphalt content of 0.4 percent observed in the Sasobit® mix over the PG 76-22 HMA mix. The lower temperature at location 6 produced a similar density as the PG 76-22 HMA thus presenting energy efficiency and fuel savings albeit for one sample.

- The moisture susceptibility as measured by the Modified Lottman for both mixtures considered in this study passed the minimum percent TSR requirement.

- The LWT test indicated some differences between the PG 76-22 HMA and the Sasobit® mixes in terms of the permanent deformation, 4.3 mm and 3.0 mm, respectively. This difference may be attributable to the higher average air void content of the PG 76-22 HMA test specimens, 7.5 percent versus 6.4 percent, respectively.

RECOMMENDATIONS

The following is recommended based on the limited laboratory and field comparative evaluation of PG 76-22 HMA mixtures and mixtures containing the additive Sasobit®:

- Since this was a limited study, further in-depth laboratory and field evaluation is required to determine the affects of pavement performance utilizing Sasobit® type additives.

- The performance grading of the Sasobit® modified asphalt cement binder should be confirmed and should meet all DOTD specification requirements before HMA placement.

- It is purported that the use of Sasobit® additives can lower HMA temperatures at the HMA production facility. Therefore, further investigation of moisture sensitivity is needed as DOTD moves toward warm mix technology.

ACRONYMS, ABBREVIATIONS, & SYMBOLS

AC	asphalt dement
ANOVA	Analysis of Variance
BBR	Bending Beam Rheometer
°C	degree Celsius
°F	degree Fahrenheit
DT	direct tension
DSR	Dynamic Shear Rheometer
ft.	foot
FT	Fischer-Tropsch
HMA	hot mix asphalt
in.	inch
ITS	indirect tensile strength
JMF	job mix formula
lb.	pound
LWT	Loaded Wheel Tracking
LVDT	Linear Variable Displacement Transducers
mm	millimeter
mm/min.	millimeter per minute
NCAT	National Center for Asphalt Technology
PAV	pressure aging vessel
%AC	percent asphalt cement
%VFA	percent voids filled with asphalt
%VMA	percent voids in the mineral aggregate
%TSR	percent tensile strength ratio
psi	pounds per square inch
PMB	polymer-modified bitumens
QC	quality control
RAP	recycled asphalt pavement
RTFOT	rolling thin film oven test
SAS	statistical analysis system
SGC	Superpave gyratory compactor
TSR	tensile strength ratio
WMA	warm mix asphalt

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