

**FIELD PERFORMANCE OF WARM MIX ASPHALT AT THE NCAT TEST
TRACK**

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ABSTRACT

Warm Mix Asphalt (WMA) mixes produced using an emulsion process were evaluated under accelerated loading in three sections of the NCAT Test Track and used as the surface mix for two of the sections. The Evotherm® was incorporated into mix designs used previously on the track. In-place densities of the WMA surface layers were equal to or better than the HMA surface layers even when compaction temperatures were reduced by 8 to 42 °C (15 to 75 °F). Laboratory rutting susceptibility tests conducted in the APA indicated similar performance for the WMA and HMA surface mixes using the PG 67-22 base asphalt. Laboratory tests indicated increased potential for moisture damage with the WMA mixes. The two WMA sections and HMA section showed excellent field performance in terms of rutting after the application of 515,333 ESALs in a 43 day period. One of the WMA sections was also evaluated for quick turn over to traffic and showed good performance.

INTRODUCTION

NCAT Test Track

An experimental asphalt pavement test track was constructed in Opelika, Alabama (near Auburn University) in 2000. The test track is a 2.7 km (1.7 mile) oval track consisting of 45 different flexible pavement sections (25 in tangents and 20 in curves). External sponsors, most commonly U. S. DOT's, cooperatively funded experimental sections on the test track with subsequent operation and research managed by the National Center for Asphalt Technology. Each test section is approximately 61 m (200 feet) in length. Traffic loading is provided by 4 semi-trailers, specifically loaded to provide 10.362 equivalent single axle loads (ESALs) per pass. Each tractor pulls 3 fully loaded trailers resulting in a total load per truck of approximately 68,100 kg (150,000 lbs). The sections will receive 10 million ESALs in a 2-year period.

In 2003, the test track was rehabilitated. Some sponsors elected to continue traffic on the section they constructed in 2000. Some sponsors elected to conduct rutting studies on new mixes placed as inlays. The underlying pavement structure is the same for each of these sections and is designed to carry 30 million equivalent 18-kip single axle loads (ESALs). However, in 2003 track eight sections on the North tangent were dedicated to a structural study to provide performance data for mechanistic-empirical pavement design models. Sections were constructed with three thicknesses of hot mix asphalt (HMA); 5 (2 sections), 7 (4 sections) and 9 (2 sections) inches. The 5 and 7 inch thick sections were designed to fail at approximately one third and two-thirds of the planned 10 million ESALs, respectively. A complete description of the structural experiment is provided in (1). The two 5-inch thick sections, N1 and N2, failed after approximately 1.7 million ESALs. This failure created the opportunity to place additional experimental mixes to rehabilitate the sections. An initial rehabilitation was performed in both sections during the winter of 2005 using a proprietary product. This rehabilitation failed rapidly creating the opportunity for a second rehabilitation. The second rehabilitation was conducted using Warm Mix Asphalt. Due to delays in the

contractor's schedule, the rehabilitation was not conducted until the fall of 2005, near the end of the loading cycle.

Warm Mix Asphalt

Several new processes have been developed to reduce the mixing and compaction temperature of hot mix asphalt, improve compaction or both. Three processes were initially developed in Europe, Aspha-min® zeolite, Sasobit®, and WAM Foam®. A fourth process, Evotherm®, was developed in the United States. All of these processes work by reducing viscosity at mixing and compaction temperatures. Laboratory studies were conducted to evaluate the effect of three of these products: Aspha-min® zeolite, Sasobit®, and Evotherm®, on mixture performance and evaluate their suitability for U.S. paving practices (2-4). The laboratory studies generally indicated the following (5):

- The processes evaluated increased density in the Superpave gyratory compactor (SGC) and in a vibratory compactor to temperatures as low as 88 °C (190 °F),
- The Warm Mix Asphalt processes did not affect the measured resilient modulus,
- There was a tendency for increased rutting potential for samples tested in the Asphalt Pavement Analyzer (APA) as the mixing and compaction temperatures decreased for both the control and WMA mixes. This increase in rutting is believed to be related to decreased aging of the binder during production. Some of the WMA processes partially mitigated this effect,
- The lower compaction temperature used when producing WMA with any Warm Mix Asphalt additive may increase the potential for moisture damage. The lower mixing and compaction temperatures can result in incomplete drying of the aggregate. The resulting water trapped in the coated aggregate may cause moisture damage.

An emulsion based WMA process was used in the rehabilitation of sections N1 and N2. In addition, a mill and inlay was placed in section E9. The developer of the product paid for the construction costs for the three repaired sections.

Emulsion Based WMA Process

The emulsion-based technology used in this test track project was developed by MeadWestvaco Asphalt Innovations and is known as Evotherm®. In certain ways, the Evotherm® Warm Mix Asphalt emulsion displays properties currently found in asphalt emulsions used widely in the construction, maintenance, and rehabilitation of asphalt pavements. For example, bulk properties such as viscosity and storage stability are typical of those found in conventional asphalt emulsions. Particle size distributions too are also similar to those of everyday emulsions.

Yet, in other important ways, the surfactant formulation at the heart of the Warm Mix Asphalt emulsion imparts performance capabilities that are not feasible with classical emulsifier formulations. For example, the warm mix surfactant formulation allows complete coating of dense-graded aggregate at temperatures as low as 60°C (140°F), conditions which require in conventional emulsions either high chemical

loadings or high doses of water or other retarding adjuvant. Machine operators applying micro-surfacing during desert summers know the necessity of high emulsifier dosages and retarder loadings to achieve complete aggregate coating at temperatures approaching 60°C. High emulsifier and retarder contents are costly. Components in the Warm Mix Asphalt emulsifier package have overcome this difficulty.

Similarly, the Warm Mix Asphalt surfactant package allows mix workability and compactability to be maintained without sacrificing either cure rate or density. This is a vexing trade-off for formulators of load-bearing paving compositions when trying to use conventional, solvent-free asphalt emulsions. Grâve mixes, or other cold mixes used in Europe, are a poignant example of this confounding trade-off: voids in the compacted grâve (and other emulsion-based cold mix) pavements typically exceed 10%. Lower air voids may be achieved, but only if slow-setting emulsions are used, which in turn creates undesirable conditions such as lengthened cure rates, slow release to traffic, and raveling. Components in the Warm Mix Asphalt surfactant system are formulated to control rheology at the interface between the binder and aggregate surface and also between the binder and minute droplets of residual water (<0.1%) in the mix. Control of this interfacial rheology according to the materials used and mix temperatures employed allows good compaction at low temperatures.

Lastly, the Evotherm® Warm Mix Asphalt emulsifier package is formulated with adhesion promoters, which allow control of moisture resistance properties. The Warm Mix Asphalt emulsifier formulation used in this test track project was tailored to improve binder adhesion to the mixed mineralogy (silicate and calcareous) aggregate present in both the binder and surface mixes.

PURPOSE AND SCOPE

The purpose of this study was to evaluate the rutting potential of WMA mixes under accelerated loading. WMA was placed in three sections of the NCAT Test Track, after the testing cycle had already begun. The WMA was used as the surface course on two of the three sections. The WMA was produced using the Evotherm® process. The Evotherm® was incorporated into the same mix designs used previously on two of the sections. Laboratory tests were conducted to evaluate performance of the mixes and the field performance of the mixes was monitored.

MATERIALS

Test Sections

The emulsion based WMA was placed on three sections of the NCAT Test Track. Figure 1 shows the layout of the sections. N1 and N2 were milled to a depth of 127 mm (5 inches) to complete the structural rehabilitation of those sections. Two lifts of 19.0 mm NMA WMA were placed in section N1 and N2. The binder for the surface mix was varied for each section. An HMA control with a PG 67-22 binder was placed in section N1. PG 67-22 is a binder grade similar to AC-30 used in the Southeastern United

States. The high temperature binder properties are tested at 67 °C. Although the gradation and design asphalt content were the same as that used initially for the structural sections (discussed below) it was felt that a new control section was still needed. Typically when a testing cycle begins at the NCAT Test Track a single truck is used initially, with the remaining three trucks gradually added. In the case of the WMA test sections, the entire fleet of trucks was returned to the track as soon as the mix was compacted and allowed to cool. Therefore if increased rutting were to be observed, it could be due to the differing manner in which the traffic was applied or it could be due to the performance of the WMA. A new HMA control section would allow this difference to be ascertained. The binder for section N2 was the Evotherm® emulsion produced using the same PG 67-22 base asphalt as used in Section N1 plus 3 percent, by weight of binder residue, latex.

WMA Test Sections

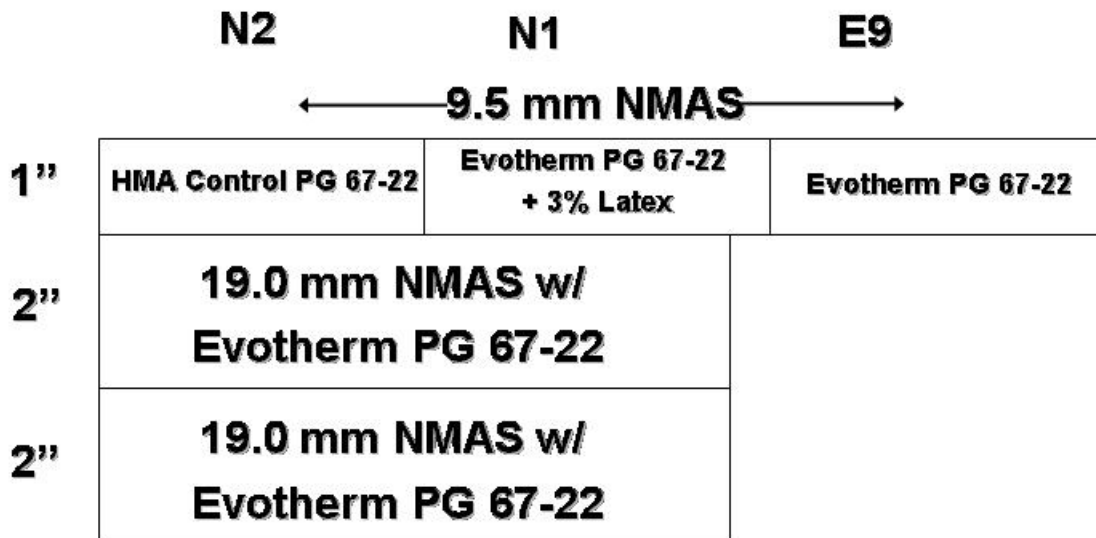


Figure 1. Test Section Layout.

Since latex is also an emulsion, the two systems are readily compatible. Section E9 was also milled to a depth of 25 mm (1.0 inch) and inlaid with a WMA surface mix. Section E9 showed no distress before milling, but section E9 was inlaid in order to ensure that a WMA section would remain in place when the track was rehabilitated for the 2006 testing cycle to receive an additional 10 million ESALs. The surface mix for section E9 was the Evotherm® emulsion produced using the same PG 67-22 base asphalt as used in Section N1.

Mix Designs

The aggregates used for this project were the same as the aggregates used for the original test sections in the structural experiment performed at the NCAT Test Track. Table 1 presents the percentages for each aggregate used in each of the asphalt mixtures constructed. As shown in Table 1, a blend of granite, limestone, and coarse sand was

used for both asphalt mixtures. This will possibly important later in the report with regards to the moisture susceptibility testing conducted on the different test sections.

Table 2 presents the target gradations used for the two asphalt mixes (the same mix design was used for the base and binder layers). Also included in Table 2 are the optimum asphalt contents for each of the two asphalt mixes. The surface course was a 9.5mm nominal maximum aggregate size (NMAS) Superpave asphalt mixture, while the base and binder mixture was a 19.0mm NMAS Superpave mix. Each mixture was designed with a compactive effort (N_{design}) of 80 gyrations in the Superpave Gyrotory Compactor (SGC) and used a PG 67-22 asphalt binder according to Alabama Department of Transportation (DOT) specifications.

TABLE1 Aggregate Percentages Used in Test Sections

Aggregate Type	Percentages	
	Surface	Base, Binder
Granite #89's	24	0
Granite M10's	29	29
Limestone #57's	0	20
Limestone #78's	0	31
Limestone #8910's	27	0
Coarse Sand	19	19
Fly Ash	1	1

TABLE 2 Target Gradations and Optimum Asphalt Contents for Test Sections

Sieve Size	Percent Passing	
	Surface	Base, Binder
25.0	100	100
19.0	100	94
12.5	100	84
9.5	99	72
#4	83	53
#8	62	45
#16	47	36
#30	34	28
#50	19	15
#100	11	8
#200	5.0	5.0
Asphalt Content	6.3	4.5

RESULTS AND DISCUSSION

Construction

All of the paving, except the surface mix for section N1, was completed on October 28, 2005. Due to a shortage of emulsion, the surface mix of N2 was not placed until November 4, 2005. A mixing temperature of 115 °C (240 °F) was targeted for the WMA mixes. The mix was dumped directly into a Blaw-Knox Model PF-3200 paver using end-dump trucks. The mix was compacted with a Dynapac Model CC522 roller. The contractor used the same roller pattern that they typically used with the HMA produced with the same gradations, with one exception, described below. An infrared camera was used to monitor the thermal consistency of the paving. One advantage of WMA, apparent in Figure 2, is that due to the lower production temperatures used with WMA there is less of a thermal driver, compared to ambient temperatures, which apparently results in less thermal segregation.

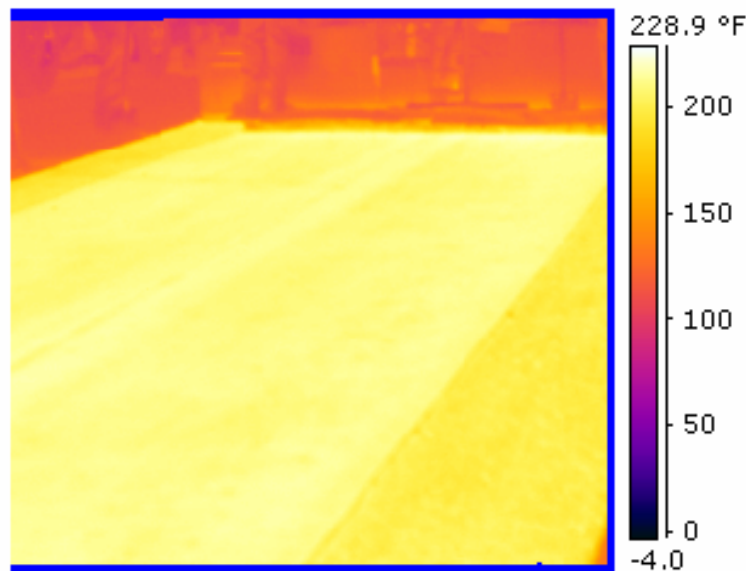


Figure 2. Infrared Image of Section N1 WMA Binder Layer taken behind Paver.

One potential concern with WMA, particularly for the systems that rely on water, is whether or not the mixes could be stored in a silo and maintain their WMA properties. The surface mix for section N1 was produced at 7 PM the day before it was placed. The mix was then loaded out at 1:30 PM the following day, but due to an equipment problem at the track, the mix was not placed until 3:15 PM. Due to the delay in placing the mix, the mix had cooled from the target compaction temperature of 107 °C (225 °F) to 96 °C (205 °F). As noted previously, section N1 had 3 percent latex added to the binder, which tended to make it more difficult to compact compared to the other mixes. For these reasons, a single vibratory pass was added to the roller pattern for the surface mix of Section N1 as compared to the roller pattern used for sections N2 and E9.

Nuclear density readings were used to monitor density during construction. Prior to opening the sections to traffic, three cores were taken from sections N2 and E9 and

four cores from section N1. The density results and compaction temperatures are shown in Table 3. The average densities for the WMA base and binder layers represent the average of seven cores. Since control sections were not placed for the base and binder lifts, density comparisons for those layers were made with the HMA base and binder layers that were originally placed in section N2 in 2003 (6). As noted previously, these mixtures were placed with the same mix design. The original binder and base layers in section N1 were placed with a polymer modified binder and therefore were not used for comparison. The in-place density of the WMA base layer was 3.1 percent higher (96.0 percent G_{mm} as compared to 92.9 percent G_{mm}). The in-place density of the WMA binder layer was 2.1 percent higher than the HMA (96.0 percent G_{mm} as compared to 93.9 percent G_{mm}). The densities of the PG 67-22 HMA control and Evotherm® using the PG 67-22 base binder surface mixes were nearly identical; the in-place density of the WMA surface mix in N1 with 3 percent latex was 1.3 percent higher, even though it was compacted at 96 °C (205 °F). The compaction temperature for the HMA surface mix was also less than desired for a portion of the section. Based on these observations, the WMA had improved density even at the lower production temperatures.

TABLE 3 Comparison of Evotherm® WMA and HMA In-Place Densities

Mix	Compaction Temperature, °C		Average Density, % G_{mm}		Standard Deviation, % G_{mm}	
	HMA	WMA	HMA	WMA	HMA	WMA
19.0 mm Base	155 ¹	108	92.9 ¹	96.0	NA	1.18
19.0 mm Binder	164 ¹	107	93.9 ¹	96.0	NA	0.91
9.5 mm PG 67-22 Surface	116-138	107	92.1	92.2	2.31	1.62
9.5 mm Surface with Latex	NA	96	NA	93.4	NA	0.68

¹Reference (6)

Laboratory Testing

During construction of the test sections, samples of each asphalt mixture were obtained and used to produce test specimens used for performance testing. These specimens were prepared in the laboratory located at the NCAT Test Track. Laboratory testing included: mixture volumetrics, Asphalt Pavement Analyzer testing, and Tensile Strength Ratio testing. These particular tests were conducted to determine if the results from laboratory evaluations of Warm Mix Asphalt technologies were valid for field performance

Mixture Volumetrics

For each asphalt mixture, six specimens were produced to determine mixture volumetrics. Test results are illustrated in Table 4. From the results, it can be observed that the inclusion of Evotherm® reduced air voids of the SGC specimens almost 40 percent at a compaction temperature of almost 38 °C (100 °F) lower than that of the control mixtures. The improvement in laboratory density was influenced by the measured asphalt content and gradation of the WMA test sections. The asphalt content of the WMA samples was determined according to ASTM D 2172 and the gradation determined

according to ASTM C117/C136. As seen in Table 5, for the base and binder layers, the measured asphalt content was 1.1 percent higher than the design asphalt content, which would provide additional densification of the WMA sections. As for aggregate gradation, a finer gradation would also aide in densification, and the results indicated that the base and binder WMA, overall, was finer than the control base and binder layers. Both of these factors would also have affected the field compaction shown in Table 3. When introducing the emulsion into the HMA plant, two factors need to be considered to obtain the appropriate asphalt content: 1) the specific gravity of the emulsion is slightly less than the specific gravity of asphalt binder; 2) the target asphalt content is based on the emulsion residue. Therefore, the plant setting for the binder must be increased over the setting for a conventional asphalt binder to account for the water in the emulsion which will be flashed off as steam during the mixing process. Apparently there was an error in this calculation for the base and binder layers, resulting in the high measured asphalt content for the WMA base and binder layers.

TABLE 4 Lab Air Voids for Test Sections

Mix	Compaction Temperature, °C		Average Air Voids, %		Standard Deviation, %	
	HMA	WMA	HMA	WMA	HMA	WMA
19.0 mm Base	151 ¹	108	4.0	2.3	NA	0.34
19.0 mm Binder	151 ¹	108	4.6	2.6	NA	0.41
9.5 mm PG 67-22 Surface	151	108	4.9	3.2	0.33	0.59
9.5 mm Surface with Latex	NA	108	NA	2.4	NA	0.22

¹Reference (6)

TABLE 5 Measured Gradations and Asphalt Contents for Test Sections

Sieve Size, mm	Percent Passing			
	WMA Surface	HMA Surface ¹	WMA Base, Binder	HMA Base, Binder ¹
25.0	100	100	100	100
19.0	100	100	96	93
12.5	100	100	87	83
9.5	100	100	81	72
4.75	85	81	65	51
2.36	60	63	50	43
1.18	45	51	40	35
0.600	31	38	28	27
0.300	18	21	16	15
0.150	10	12	10	9
0.075	6.1	6.8	6.3	5.6
Asphalt Content	6.6	6.2	5.5	4.4

¹Reference (6)

Asphalt Pavement Analyzer

Once the air void contents of the design specimens were determined, each mixture set was placed in the APA to determine the laboratory rut resistance of each asphalt mixture. All testing was conducted at 64 °C (147 °F). Testing was conducted using a hose pressure of 120 psi and a vertical load of 120 pounds, paralleling the testing parameters of the laboratory evaluations (2-5).

Test results for the different mixtures are presented in Table 6. The rutting potential of the WMA and HMA surface mixes compare well. Although the reduced aging of the binder in the WMA section might tend to increase rutting potential, the improved density of the samples may tend to negate this to some extent. This correlates to the findings from the laboratory evaluation of Evotherm®; the relationship between air voids and rut depth was weak (4). As expected, the addition of latex reduces the rutting potential of the WMA surface mix. The increase in measured rut depth for the WMA base layer probably results from high measured asphalt content and extremely low voids for this set of samples.

TABLE 6 APA Rut Depths for Test Sections

Mix Type	SGC Avg. Air Voids at N _{design} , %		Avg. APA Rut Depth, mm	
	WMA	HMA	WMA	HMA
9.5 mm Surface w/ PG 67-22	3.18	4.95	7.85	7.56
9.5 mm Surface w/ PG 67-22 +Latex	2.45	NA	5.14	NA
9.5 mm Surface w/PG 76-22 (SBS)	NA	5.2	NA	3.83 ¹
19.0 mm Binder	2.57	3.7	5.71	5.84 ¹
19.0 mm Base	2.35	3.7	7.40	5.84 ¹

¹Reference (7)

. Moisture Resistance

Specimens were also prepared so Tensile Strength Ratio (TSR) testing could be conducted on the asphalt mixtures. There was concern during the laboratory evaluations that incomplete drying of the aggregates during the production of WMA could lead to tenderness of the mix or increased susceptibility to moisture damage. The TSR samples were prepared at the Test Track during construction without reheating the mix. Preparing TSR samples during production presents a challenge to accurately obtain the sample air voids. TSR test results are shown in Table 7. Testing was conducted according to ASTM 4867 and included one freeze/thaw cycle. From the results, only the HMA control mixture satisfied the Superpave requirement of 0.80 for moisture resistance. However, it should be noted that the average air void contents for the control samples were outside the allowable air void content range, and this may have influenced the TSR value for the control mixture. Low air voids would tend to increase the TSR value. Additional samples will be produced within the allowable range, and a new TSR value will be determined. This is also true for the mixture containing latex; additional samples will be made so a TSR value can be determined.

TABLE 7 TSR Test Results for Test Sections

Mix Type	Avg. Air Voids		Indirect Tensile Strength		TSR
	Unconditioned	Conditioned	Unconditioned, psi	Conditioned, psi	
HMA Control	4.6	4.4	104.1	98.0	0.94
Evotherm® Surface	6.2	6.2	118.0	52.9	0.45
Evotherm® Surface w/ Latex					
Evotherm® Base	7.6	7.7	98.1	32.4	0.33
Evotherm® Binder	8.0	8.1	106.9	40.6	0.38

As was mentioned earlier in the report, the asphalt mixtures were a blend of granite and limestone aggregates. In the blends, the granite aggregate made up a good percentage of the fine aggregate used, and this may have partly contributed to the low TSR values. Previous research has suggested that moisture damage in the fine aggregate is more detrimental to the asphalt mixture than damage in the coarse aggregate portion. Also, Alabama DOT specifications do not require a freeze-thaw cycle when conducting TSR tests. The addition of a freeze-thaw cycle produces a more severe test. Preliminary TSR tests conducted on laboratory produced material, prior to construction, indicated TSR values that were 10 to 40 percentage points higher than the comparable HMA mixes. These tests utilized two hours of oven aging at compaction temperature and did not employ a freeze-thaw cycle.

Field Performance

As noted previously, it would have been preferable to construct the WMA sections sooner so that they could have received more traffic in warmer weather, but unfortunately due to the contractor's schedule this could not be done. As such, the sections received 515,333 ESALs in a 43 day period. Paving of the surface mix of section N1 commenced at 3:15 PM on November 4, 2005 and the full fleet of trucks was returned to the track at 5:00 PM that evening. Figure 3 shows the daily maximum air and pavement temperatures during the loading period. As shown in Figure 3, the sections were exposed to warm weather immediately after construction.

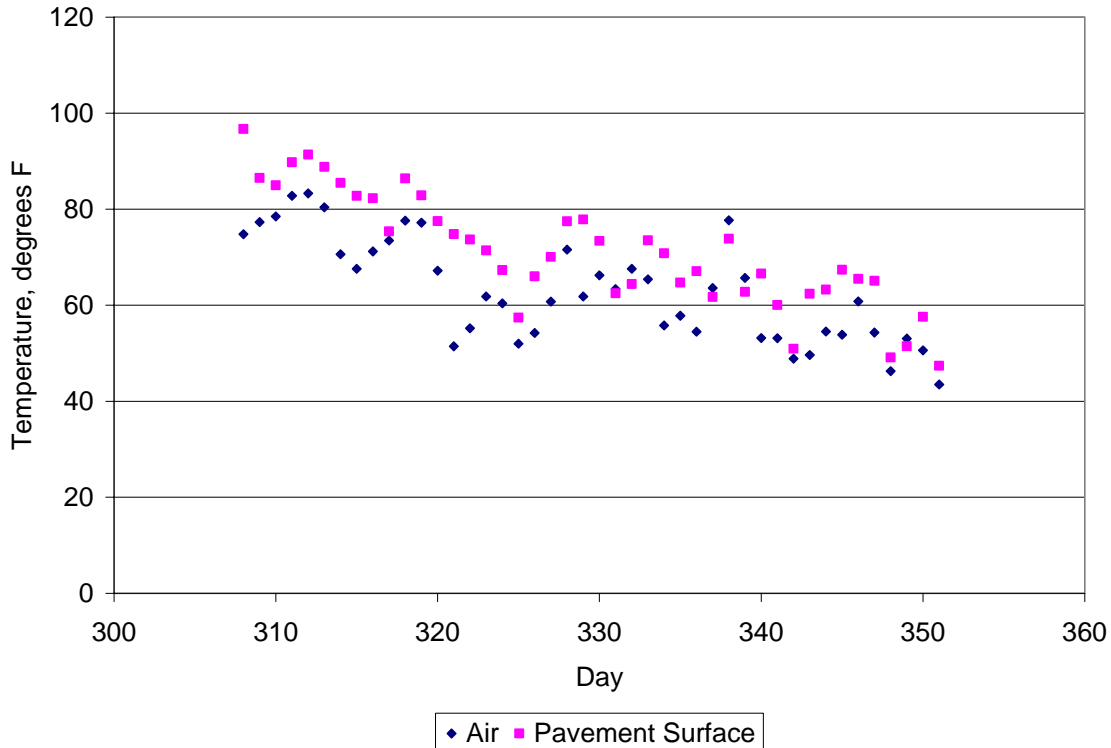


Figure 3. Maximum Air and Pavement Temperature during Loading Period.

At the completion of trafficking, wire-line rut depth measurements were taken in each of the three sections. Three readings were taken in each wheel path. Table 8 shows the rut depth measurements for each section. Basically all of the sections performed the same with 1.1 mm of rutting or less, although numerically the two Evotherm® sections performed slightly better with an average rut depth of 0.9 mm. The APA tests indicated that section E9 and N2, both of which used the PG 67-22 base should perform similarly with improved performance in section N1 due to the addition of the latex. This suggests that WMA, produced with the Evotherm® process, should provide good rutting performance even under conditions where traffic is quickly returned to the pavement.

Core samples were taken to assess any in-place moisture damage which may have occurred. Nine full depth cores were taken from the right wheel path of sections N1 and N2. The cores were wrapped in plastic wrap to maintain their in situ moisture immediately after coring. The cores were transported to NCAT's main laboratory. The cores were then wet sawed into paving layers and re-wrapped in plastic. Three of the samples from each section/layer were selected for as-received tensile strength testing. First the weight in water and saturated surface dry weight was determined for each of these cores. The samples were conditioned to 25 °C and the indirect tensile strength determined. The remaining cores were dried to a constant mass at 50 °C. These samples were then subdivided into conditioned and unconditioned sets and tested according to ASTM D 4867. This technique allows an assessment of the current state of moisture damage in the pavement as well as the expected deterioration, if any, of the future pavement (8). The results of this analysis were not available at the time this report was written. This analysis will allow the authors to better assess the effect of the low TSR

values observed during construction. The improved density, in situ, would be expected to improve the mixtures resistance to moisture damage.

TABLE 8 Field Rut Depth Measurements after 513,333 ESALs

Section	Surface Mix	Average Rut Depth, mm			Std.
		LWP	RWP	Avg.	
E9	Evotherm PG 67-22	0.8	1.1	0.9	1.19
N1	Evotherm PG 67-22 + 3% Latex	1.1	0.7	0.9	0.52
N2	HMA PG 67-22	1.0	1.1	1.1	0.29

CONCLUSIONS

WMA test sections, consisting of base, binder and surface layers, were successfully constructed at the NCAT Test Track to assess rutting performance using Evotherm®. The sections performed well through the end of the loading cycle. Specific conclusions include:

- WMA produced using the Evotherm® process was successfully stored in a silo for 17 hours.
- In-place densities of the WMA surface layers were equal to or better than the HMA surface layers even when compaction temperatures were reduced by 8 to 42 °C (15 to 75 °F). Significantly improved in-place densities were observed for the WMA base and binder layer, however the asphalt contents were also higher than expected for these sections.
- Laboratory rutting susceptibility tests conducted in the APA indicated similar performance for the WMA and HMA surface mixes using the PG 67-22 base asphalt.
- The two WMA sections and HMA section showed excellent field performance in terms of rutting after the application of 515,333 ESALs in a 43 day period.
- The WMA in section N1 showed good rutting performance even though traffic was returned to the sections 1.75 hours after paving commenced.
- Laboratory tests indicated increased potential for moisture damage with the WMA mixes. Field cores have been taken to corroborate this result after trafficking.

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