COMPARING RUTTING PERFORMANCE UNDER A HEAVY VEHICLE SIMULATOR TO RUTTING PERFORMANCE AT THE NCAT PAVEMENT TEST TRACK

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Comparing Rutting Performance Under a Heavy Vehicle Simulator to Rutting Performance at the NCAT Pavement Test Track

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ABSTRACT

The Pavement Test Track is a full-scale, accelerated performance test facility for flexible pavements managed by the National Center for Asphalt Technology (NCAT) at Auburn University. Forty-six unique 200-foot test sections are installed around a 1.7-mile oval and subjected to accelerated damage via a fleet of tractors pulling heavy triple trailers. Methods and materials that produce better performance for research sponsors are identified so that future pavements can be selected based on objective life cycle comparisons. Using two sections built for the second cycle of testing, NCAT was asked by the research sponsor to validate rutting performance findings obtained with a Heavy Vehicle Simulator (HVS).

The HVS experiment did not include any type of accelerated aging, and testing was conducted at a single controlled temperature. In contrast, full-scale heavy truck traffic was applied to experimental pavements on the NCAT Pavement Test Track while test sections aged in an open environment for two full years and no attempt was made to control natural temperature cycling. In order to reconcile results from the two unique experiments, it was necessary to use the load versus temperature versus performance record at the NCAT track to construct an equivalent record of rutting versus traffic at the age and temperature of the HVS experiment.

A rutting performance model was previously developed using load-temperature spectra data from the first cycle of testing at the NCAT track. In this approach, separate model parameters account for the effect of age-hardening and temperature sensitivity of hot-mix asphalt. These two parameters were used to convert performance data over the range of ages and temperatures relevant to the second cycle of track testing to the single age and temperature relevant to the HVS experiment. The conversion process for track data and a comparison to the HVS data are presented herein.

Keywords: Flexible Pavement, Full-Scale Testing, Heavy Vehicle Simulator, Rutting Model

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INTRODUCTION AND BACKGROUND

An experimental facility has been constructed near the campus of Auburn University that is being used by governmental agencies throughout the United States to conduct research designed to extend the life of flexible pavements. Managed by the National Center for Asphalt Technology (NCAT), the Pavement Test Track provides an opportunity for sponsors to answer specific questions related to flexible pavement performance in a full scale, accelerated manner where results do not require laboratory scale extrapolations or lifelong field observations.

Experimental sections on the 2.8 kilometer Pavement Test Track are cooperatively funded by external sponsors, most commonly state DOT's, with subsequent operation and research managed by NCAT. Forty-six different flexible pavements are installed at the facility, each at a length of 60 meters. Materials and methods unique to section sponsors are imported during construction to maximize the applicability of results. A design lifetime of truck traffic (10 million equivalent single axle loadings, or ESALs) is applied over a two-year period of time, with subsequent pavement performance documented weekly. An aerial photograph of the facility is provided in Figure 1, and detailed information about the project can be found at www.pavetrack.com.

Sponsors typically fund research on two or more sections so they can compare life cycle costs of common paving alternatives. In addition to assessing alternatives for sponsors, NCAT is responsible for guiding the overall effort in a direction that will address policy issues for the highway industry as a whole. Using two sections built for the second cycle of testing, NCAT was asked by the research sponsor to validate rutting performance findings obtained with a Heavy Vehicle Simulator (HVS). The HVS experiment, shown in Figure 2, did not include any type of accelerated aging, and testing was conducted at a single controlled temperature. In contrast, full-scale heavy truck traffic was applied to experimental pavements on the NCAT Pavement Test Track while test sections aged in an open environment for two full years and no attempt was made to control natural temperature cycling.

The primary objective of the research effort described herein was to validate the HVS-measured relationship between mixes containing identical aggregate blends produced with SBS-modified PG76 versus unmodified PG67. This will facilitate more diverse HVS rutting experiments in the future.

EXPERIMENTAL DESIGN

Test Section Construction

The same surface mixes were placed on HVS test sections and later on test sections at the NCAT track, one blended with SBS-modified PG76 and the other blended with unmodified PG67. Stockpile materials were long-hauled from Florida to the track and liquid asphalt of the same origin and grade were obtained in order to facilitate a successful comparison. Mix design information is provided in Tables 1 and 2 (Sirin, et al., 2003). As-built properties of the HVS sections, which were built first, were used as target values for the NCAT sections. Sponsor representatives approved the quality of the NCAT sections after a detailed review process before traffic operations were initiated. Detailed information on the respective experiments can be found in cited references (Sirin et al., 2003) (Powell, 2004).

Accelerated Loading

Test sections on the NCAT Pavement Test Track are loaded with heavy triple trailer trains with an average gross vehicle weight of 690 kN driven by human drivers at a cruise speed of 70 km per hour. Individual single axles are loaded to optimize the efficiency of pavement damage, which averages approximately 11.8 ESALs per truck pass. Each vehicle in the five truck fleet laps the track approximately 400 times a day in order to induce damage in experimental pavements.

The HVS test sections were loaded with a Mark IV model device built by Dynatest. Loading was applied using a wide base tire inflated to 790 kPa supporting a 40 kN load. The unit was run in unidirectional mode at a speed of 10 km per hour. Wander was set at 100 mm (in 25 mm increments), and testing was terminated when approximately 12.5 mm of rutting had been induced (Sirin et al., 2003).

Rutting Performance Measurements

Every Monday, trucking operations were suspended on the NCAT track so that surface condition studies could be conducted to thoroughly document field performance of all experimental sections over time. Field performance evaluations focused on the middle 45 meters of each 60-meter test section, which eliminated the effect of transitional quality on either end. The middle 45-meter research portion of each test section was then broken into three 15-meter measurement replicates, each containing a randomly located transverse profile across which elevations were measured on a weekly basis. A precision level (known commercially as a "Dipstick") was walked across each of three stratified random locations within each section. Known elevations on either end of the profile could then be used to close each traverse, producing elevations that could be used to compute both left and right wheelpath rutting in an accurate manner on a weekly (continuous) basis.

Multi-depth temperature measurements were automatically made for each section on an hourly basis. Detailed records were maintained of the trucking operations that also facilitated an hourly record of traffic application. The seasonal temperature effect of the track's unconditioned environment can be seen in Figure 3 (due to the placement of a surface treatment in January of 2005, the analysis was only performed through December of 2004). A similar record of traffic, temperature and performance was maintained for the HVS experiment, which facilitated the preparation of Figure 4 (Sirin et al., 2003).

ANALYSIS OF RESULTS

Load-Temperature Spectra

Comparing HVS performance to track performance is difficult for several reasons. Most importantly, traffic on the NCAT track is applied as test pavements undergo natural temperature cycling between the work hours of 5:00 AM and 11:00 PM. Axle passes in the hot afternoon induce more rutting than axle passes in the cooler early morning or late evening. As seen previously in Figure 3, this effect is even more pronounced on the NCAT track since it takes two full calendar years to apply the 10 million ESAL design loading. For example, traffic applied in the afternoon hours in the middle of July have a vastly different effect on rut depth than traffic applied in the afternoon hours in the middle of January. To account for this effect, a methodology has been developed to allow ESALs to be weighted as a function of pavement temperature at the time of each unique load event.

Rather than simply using the total number of applied ESALs to evaluate performance, this approach utilizes the sum of weighted hot ESALs for predictive purposes. Pavement temperature at the time of each load event is used to sort ESALs into the same temperature bands that provide the framework of the performance grading (PG) system for asphalt binders. "Cold" ESALs (applied when the pavement surface temperature is less than 34°C) are not considered at all (for rutting performance), and progressively higher weight factors are assigned for ESALs applied within hotter PG grading bands. The result is an effective ESAL value that can be very different from the total ESALs applied. This methodology is known as the "load-temperature spectra" approach, where Figure 5 shows the value of weight factors for ESALs applied when pavement surface temperatures fall within each PG band (Powell, 2006). The origin of Figure 5 is provided as background material in the following paragraphs.

As a result of the structural experiment on the 2003 NCAT Pavement Test Track, it was possible to quantify the elastic component of pavement response at different temperatures under passing loads. A regression model to predict stiffness as a function of mix temperature was developed from data collected on the 2003 track. The equation that was used to predict stiffness as a function of mid-depth temperature takes the form (Timm and Priest, 2006):

$$Stiffness_{Est} = \frac{2{,}793{,}344}{e^{(0.05976 \times °C)}} \quad \text{Equation 1}$$

Stiffness estimates are useful parameters because they give some indication of how much HMA will resist deformation at different temperatures; however, what is needed is an estimate of permanent deformation at different temperatures. Since the objective was to generate what is in effect a rutting weight factor to apply to ESALs applied when pavement surface temperatures fell within successively hotter temperature bands, the following equation was used to estimate compliance:

$$Compliance_{Est} = \frac{1}{Stiffness_{Est}} = \frac{1}{\left(2{,}793{,}344 \cdot e^{(-0.05976 \times °C)}\right)} = \frac{e^{0.05976 \times °C}}{2{,}793{,}344} \quad \text{Equation 2}$$

Equation 2 was used to calculate a compliance value at the midpoint temperature of each PG band. Since rutting was not observed on the NCAT tack when ESALs were applied on pavements with surface temperatures cooler than 34°C (the low end of the 34°C to 40°C PG band), estimated compliance at 37°C (in the middle of the band) served as the reference point in the development of temperature factors for ESALs applied to hotter pavement surfaces. Compliance was estimated at the midpoint of all hotter PG bands, and each midpoint estimate was divided by compliance at 37°C (since it was the reference point).

Surface temperatures were used because they are the most straightforward values to obtain in practice (or to estimate for future predictions) on open roadways; however, the variation in temperature as a function of depth in pavement structures is an important factor that can be considered using other means (Powell, 2006). It should be noted that Equation 1 was developed using mid-depth temperatures; however, that is because it was derived empirically based on elastic layer analysis and it was important to use a value that represented the entire HMA layer as a homogeneous mass.

The following derivation was used to construct Figure 5 and the resulting model for ESAL weight factor at temperatures hotter than 37°C:

$$ESAL_{Wt\ Factor\ Actual} = \frac{Compliance_{Est\ @\ Hotter^\circ C}}{Compliance_{Est\ @\ 37^\circ C}} \qquad \text{Equation 3}$$

$$ESAL_{Wt\ Factor\ Model} = \left(1.76\times10^{-5}\right)\cdot Temp_{Mid\ PG\ ^\circ C}{}^{3.01} \text{ (via Figure 5, > 34°C)} \qquad \text{Equation 4}$$

$$ESAL_{Model} = \sum\left(ESAL_{Hot\ Banded\ >34^\circ C} \times ESAL_{Wt\ Factor\ Model}\right) \qquad \text{Equation 5}$$

Rather than simply using the total number of applied ESALs to analyze performance, this approach utilizes the sum of weighted hot ESALs for analysis purposes. Cold ESALs (applied when the pavement surface temperature is less than 34°C) are not considered at all (for rutting performance), and progressively higher weight factors are assigned for ESALs applied within hotter PG grading bands. The result is an effective ESAL count that is very different from the total ESALs applied.

In order to facilitate this type of analysis, the track's hourly environmental record was combined with the hourly ESAL record. Using the relationship shown previously in Figure 5, effective ESALs were computed for each hour of traffic operations. In most winter months, the pavement surface was very cool and zero effective ESALs were computed. In midday periods during the summer months, the pavement surface was very hot and a large number of effective ESALs were computed. Data from Figure 3 were plotted again using effective ESALs as the abscissa, producing the rutting performance curves shown in Figure 6. Note that only 16 percent of the total traffic applied to the surface of the track actually impacted rutting performance (1.65 million effective ESALs versus 10 million total ESALs). The other 84 percent provide valuable input for durability, cracking, raveling, polishing, wear, etc., but serve no effective purpose in the rutting experiment.

As seen previously in Figure 4, testing in the HVS is relatively consistent and temperature corrections are not necessary. Applied traffic is 100 percent effective in inducing rutting in test pavements. References indicate that testing in the HVS can be completed within a single calendar month (Sirin et al., 2003).

Age Considerations

Another reason why it is difficult to compare performance between HVS and track test sections is because of the pronounced effect of aging on rutting performance. The response of flexible pavements changes dramatically between early life and late life. This can have a significant effect on track testing that takes two full calendar years to complete. A methodology has been developed within the framework of the load-temperature spectra approach to account for this type of age hardening.

When the ESAL weighting method shown previously in Figure 5 was applied to data from the 2000 track, it was found that the relationship between weighted traffic and field performance changed over time. The observed relationship between time and performance is presented as Figure 7. It was found by trail and error that a simple power series equation (also shown in Figure 7) provides a reasonable estimation of this effect that can be easily applied to pavements of all ages. Because an age of 301 days was found to provide the best correlation between laboratory and field performance, 301 days was chosen as the baseline age for this approach (Powell, 2006).

Using Figure 7, rutting performance measurements at all ages other than 301 days were adjusted to this point in time. Age corrections were applied to both track and HVS results (presented as Figures 8 and 9, respectively); consequently, large amounts of rutting in the HVS measured during the relatively short test are significantly reduced to approximate how much rutting would have been measured if the testing had been long-term (and more track-like). Even though the HVS rutting values are very small, the trend of better performance in the modified mixes is evident.

Performance Comparison

With the creation of Figures 8 and 9, it was then possible to directly compare rutting performance on the NCAT Pavement Test Track to rutting performance in the HVS. These figures were combined to create Figure 10, which generally shows good agreement between the different experiments. Although it was observed that the curves for the two complementary experiments are visually similar, the relatively small values that make up the adjusted curves for the HVS experiment make it difficult to identify relationships at higher numbers of wheel passes. For this reason, the best fit slopes of the linear portions of all curves were computed to facilitate further analysis.

It was found that the slope of the HVS unmodified curve was 2.7×10^{-6} mm per pass, while the slope of the modified curve in the HVS was 5.3×10^{-7} mm per pass. In comparison, it was found that the slope of the track's unmodified section was 1.7×10^{-6} mm per ESAL, while the slope of the modified section was 8.1×10^{-7} mm per ESAL. From this it was estimated that each pass of the HVS load wheel applied $((5.3 \times 10^{-7} / 8.1 \times 10^{-7}) + (2.7 \times 10^{-6} / 1.7 \times 10^{-6})) / 2) = 1.1$ ESALs per HVS wheel pass (with the specific load and wheel configuration deployed for this experiment). This is viewed as a reasonable and intuitively correct finding because the HVS was loaded at the 40 kN load corresponding to exactly one ESAL. The reduced speed of the HVS load wheel (at approximately 10 km per hour, compared to over 70 km per hour on the NCAT track) would be expected to increase the severity of induced rutting.

It was found in both experiments that the rate of rutting in modified pavements was considerably less than the rate in unmodified pavements. In the track study, the rate of rutting induced by effective ESALs and adjusted for age was approximately half the rate in the unmodified section. This finding is consistent with previous track experiments (Powell, 2006). In the HVS experiment, the rate of rutting induced by wheel passes and adjusted for age was approximately 1/5th the rate in the unmodified section. The rutting performance benefit of modified binders in surface mixes is evident in both cases.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made based on the results of this comparison study that will be useful to both the highway industry and accelerated performance testing practitioners:

1) The load-temperature spectra method of weighting traffic as a function of pavement temperature developed for the 2000 NCAT Pavement Test Track can be successfully applied to other pavements. While temperature correction itself may not be useful for constant (or nearly constant) temperature HVS testing, the age correction component can be used to extrapolate HVS results to long-term field expectations;
2) One pass of the relatively slow speed (10 km per hour) HVS loaded wheel assembly was found to be equal to 1.1 effective ESALs on the relatively high speed (70 km per hour) NCAT track; and
3) Replacing unmodified PG67 with modified PG76 binder in the research mix reduced the rutting rate by 50 percent on the NCAT track and 80 percent in the HVS.

It is recommended the load-temperature spectra approach be refined in the future to better reflect the variety of temperature-stiffness relationships that exist for mixes blended with different asphalt binders. The methodology described herein was developed based on the average temperature-stiffness relationship observed on the 2003 NCAT Pavement Test Track's structural experiment (Priest and Timm, 2006). Different weight factors could be developed for different binder grades using measured temperature versus response relationships in either the laboratory or the field. This could improve the overall meaning of the new methodology.

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- Florida Department of Transportation
- Georgia Department of Transportation
- Indiana Department of Transportation
- Mississippi Department of Transportation
- Missouri Department of Transportation
- North Carolina Department of Transportation
- Oklahoma Department of Transportation
- South Carolina Department of Transportation
- Tennessee Department of Transportation
- Texas Department of Transportation
- Federal Highway Administration
- Old Castle Materials

The author is solely responsible for the contents of this paper, and the views expressed do not necessarily reflect the views of the researchers or the research sponsors.

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FIGURES

FIGURE 1 Aerial Photograph of NCAT Pavement Test Track

FIGURE 2 Photograph of Heavy Vehicle Simulator Used in Study (FDOT, 2008)

FIGURE 3 Rutting Performance at NCAT Pavement Test Track

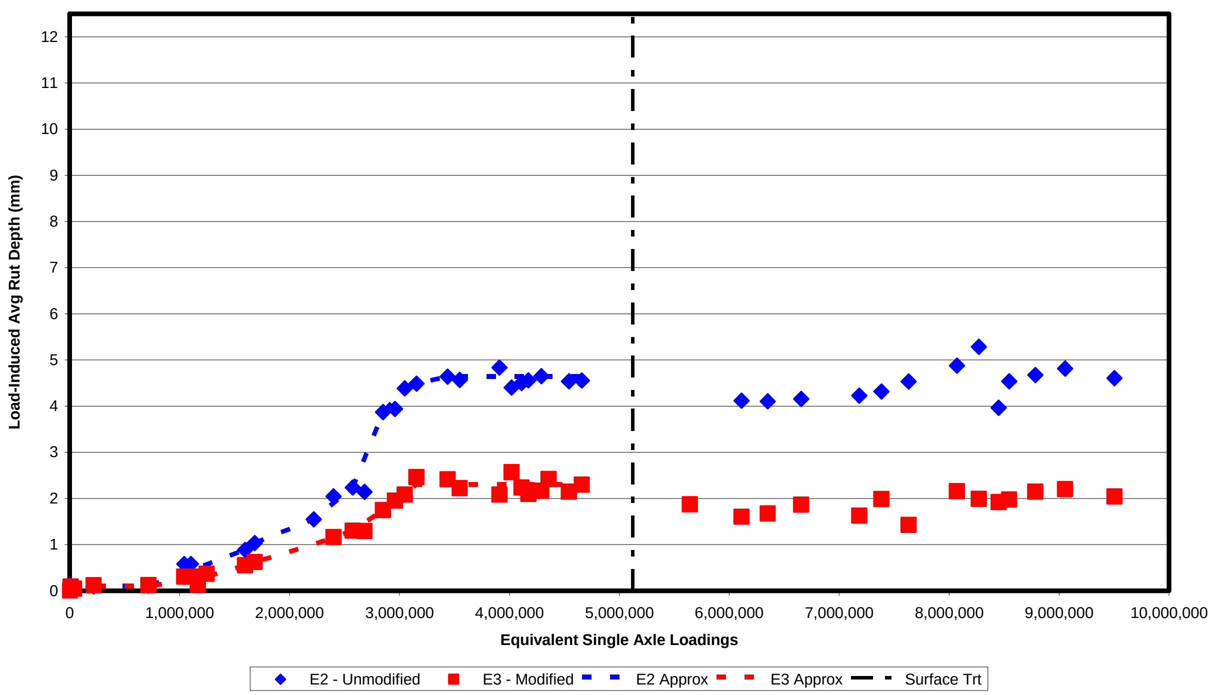


FIGURE 4 Rutting Performance in Heavy Vehicle Simulator

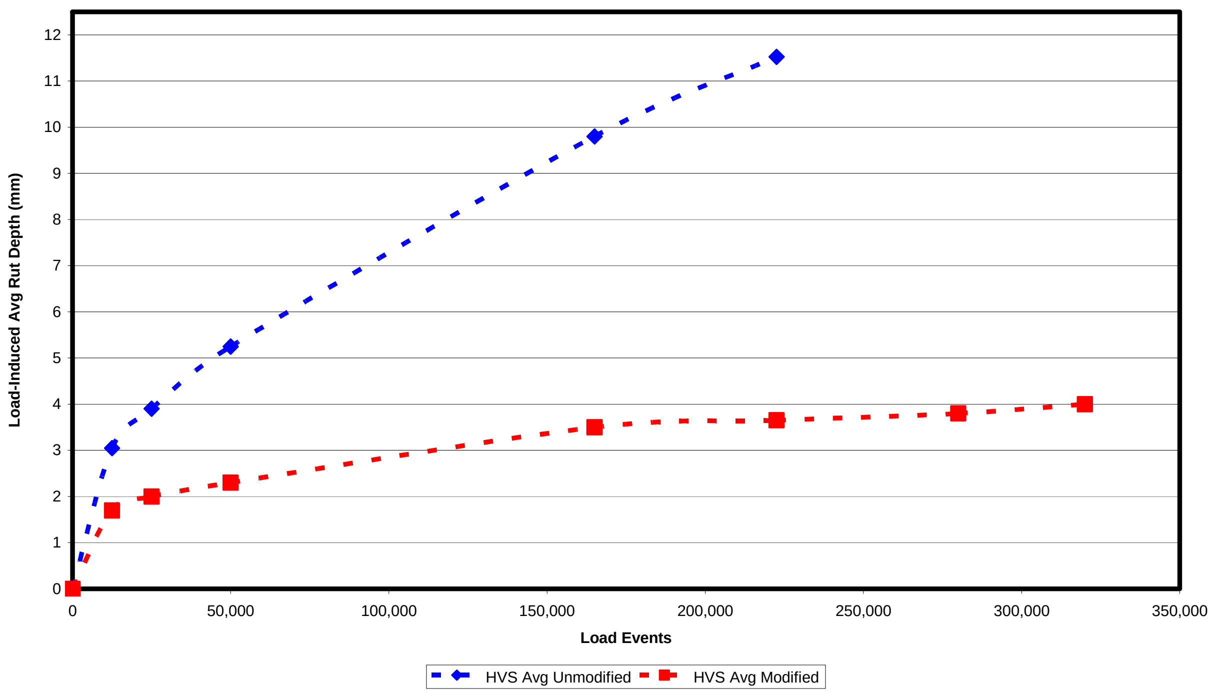


FIGURE 5 Model for ESAL Weight Factor at Temperatures Hotter than 37°C

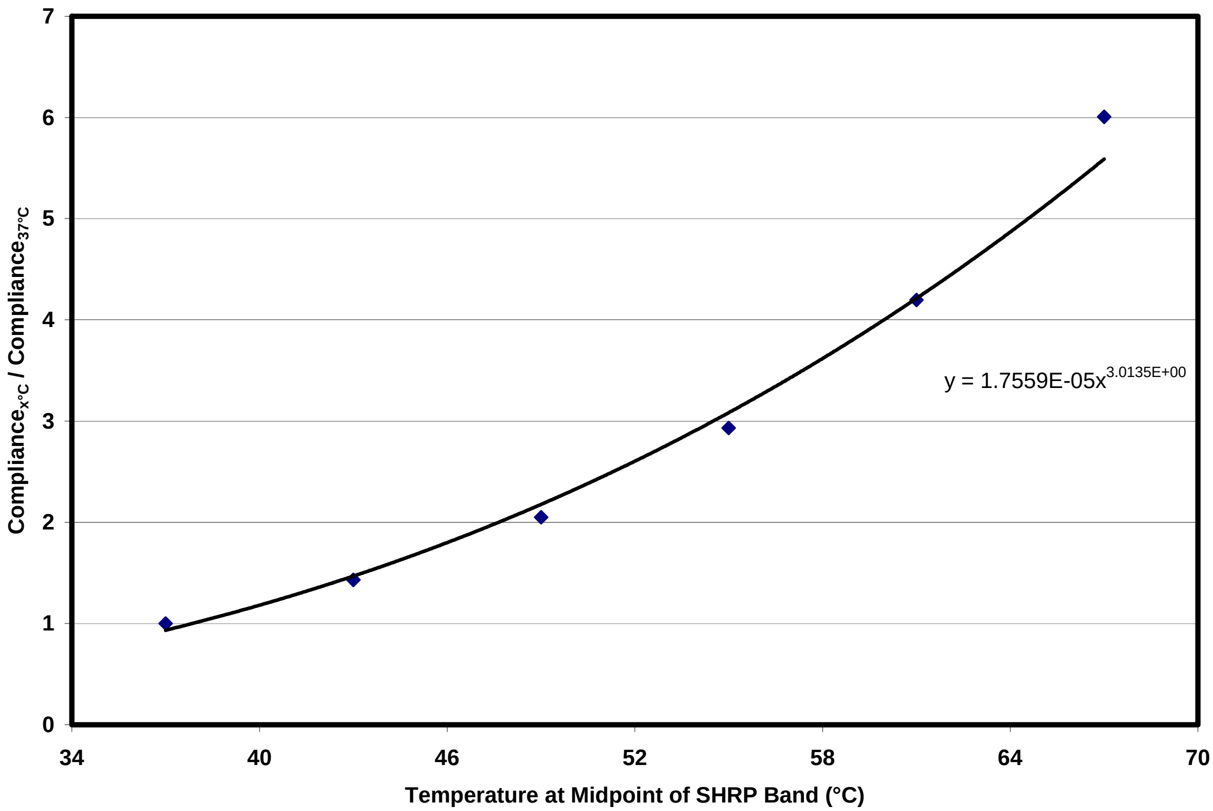


FIGURE 6 Temperature Weighted Rutting Performance on NCAT Pavement Test Track

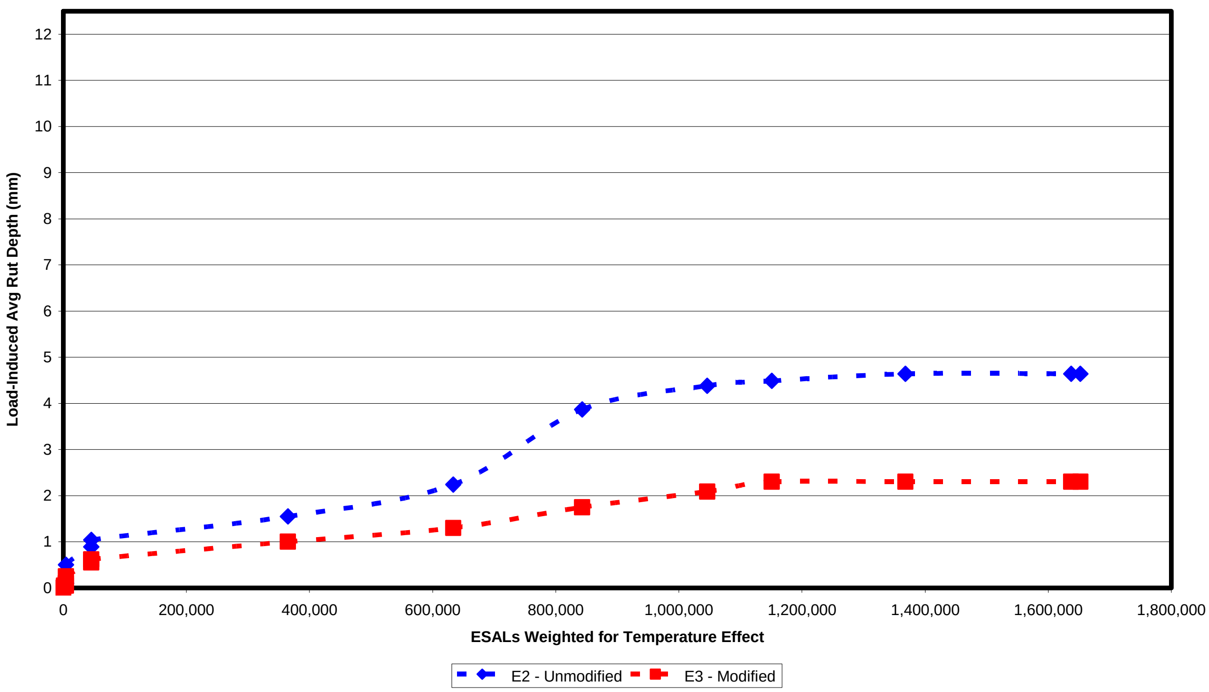


FIGURE 7 Model to Account for the Effect of Aging on Rutting Performance (Powell, 2008)

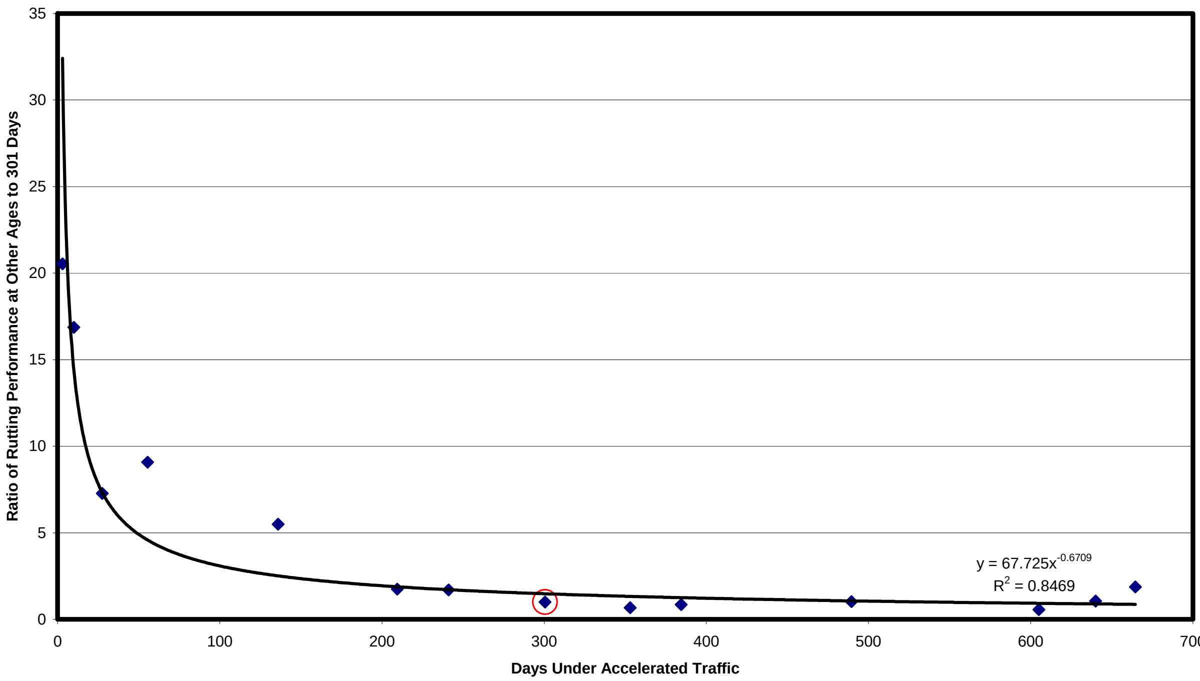


FIGURE 8 Rutting Performance on NCAT Pavement Test Track Corrected to 301 Days

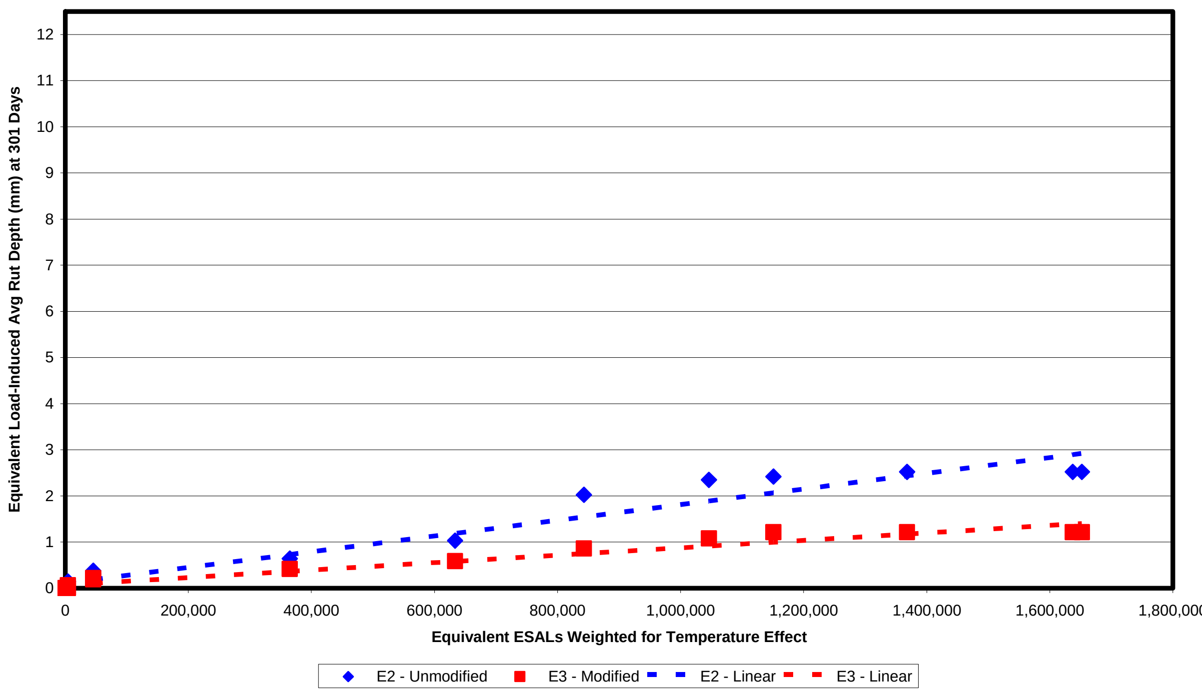


FIGURE 9 Rutting Performance in Heavy Vehicle Simulator Corrected to 301 Days

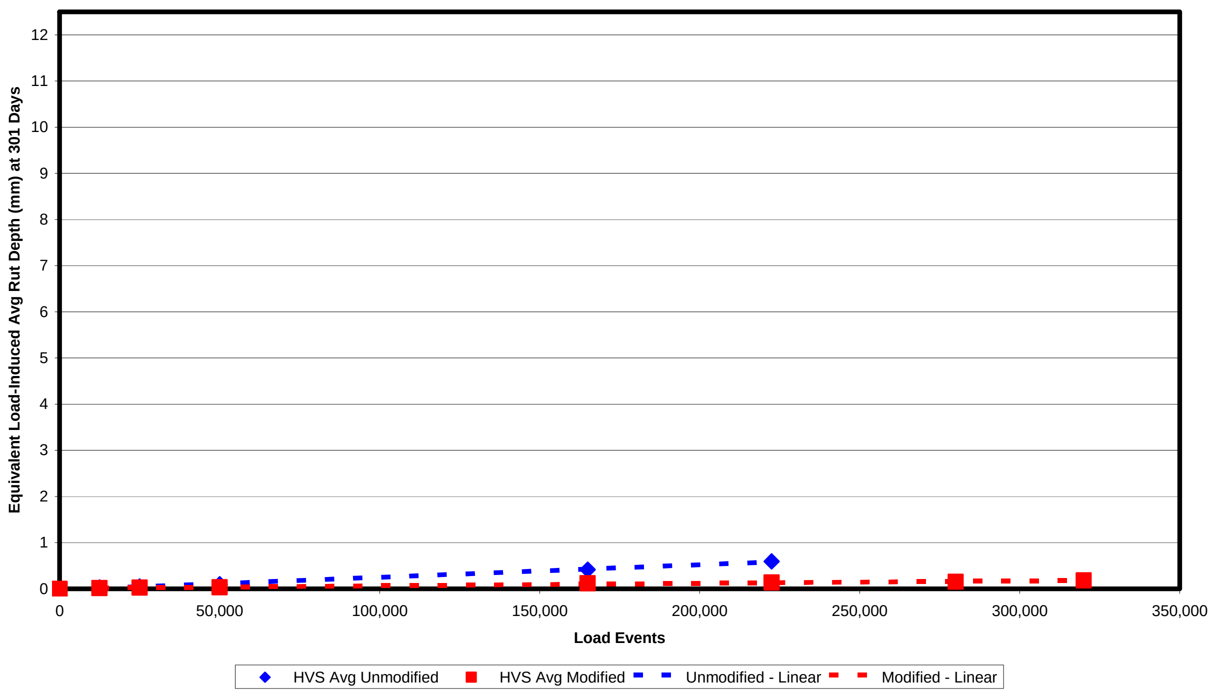
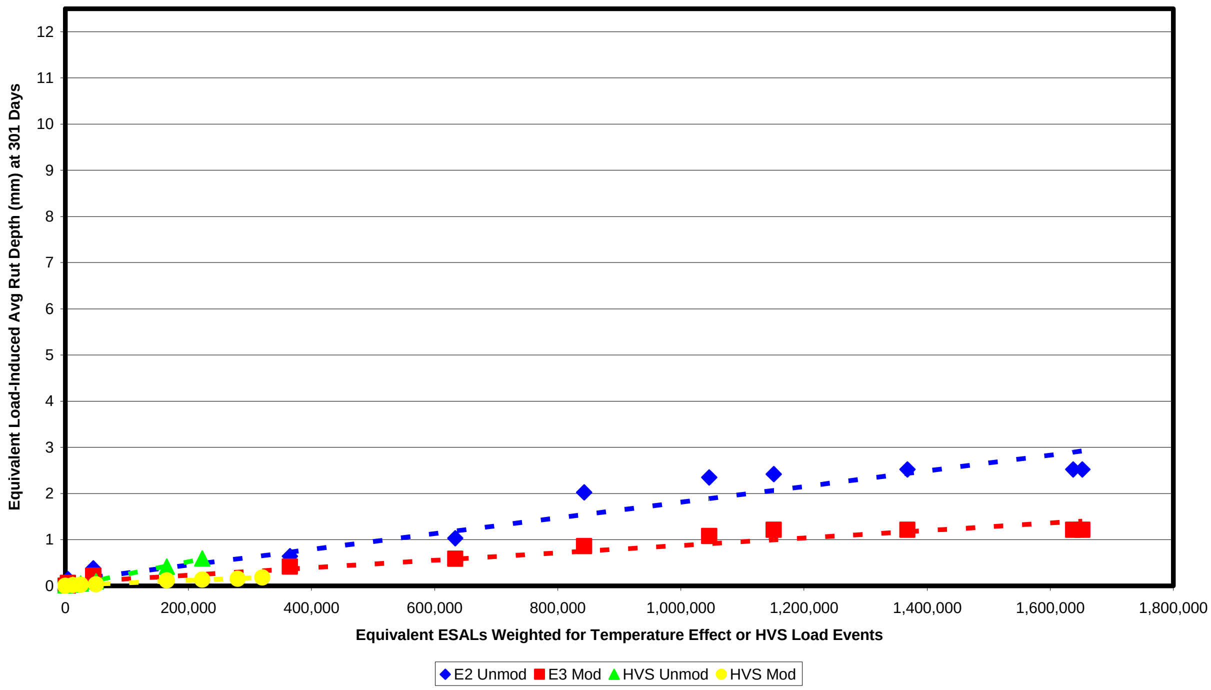


FIGURE 10 Age and Temperature Corrected Rutting Performance Comparison



TABLES

TABLE 1 Study Mix Aggregate Blend (Sirin et al., 2003)

Type Material		FDOT Code	Producer		PIT NO		Date Sampled	
1. S-1-A Stone		41	Rinker Mat. Corp		TM-489 87-089		9/11/00	
2. S-1-B Stone		51	Rinker Mat. Corp		TM-489 87-089		9/11/00	
3. Screenings		20	Anderson Mining Corp		29-361		9/11/00	
4. Local Sand			V.E.Whitehurst & Sons, Inc		Starvation Hill		9/11/00	
Percentage by Weight Total Aggregate Passing Sieves								
BLEND		12%	25%	48%	15%	JMF	Control	Restricted
Number		1	2	3	4		Points	Zone
S	3/4" 19.0mm	99	100	100	100	100	100	
I	1/2" 12.5mm	45	100	100	100	93	90-100	
E	3/8" 9.5mm	13	99	100	100	89	-90	
V	No. 4 4.75mm	5	49	90	100	71		
E	No. 8 2.36mm	4	10	72	100	53	28-58	39.1-39.1
	No. 16 1.18mm	4	4	54	100	42		25.6-31.6
S	No. 30 600µm	4	3	41	96	35		19.1-23.1
I	No. 50 300µm	4	3	28	52	22		
Z	No. 100 150µm	3	2	14	10	9		
E	No. 200 75µm	2.7	1.9	5.9	2.2	4.5	2-10	
	G_{sb}	2.327	2.337	2.299	2.546	2.346		

TABLE 2 Study Mix Properties (Sirin et al., 2003)

Mix Type	Asphalt Binder	% Binder	V_a @N_{des}	VMA	VFA	P_{be}	G_{mm}
Superpave Mix (compacted at 300°F)	PG67-22	8.2	4.0	14.5	72	4.97	2.276
Modified Superpave Mix (compacted at 325°F)	PG76-22	7.9	3.8	14.2	73	4.90	2.273