Evaluation of Performance Data from Repeated Load Test

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ABSTRACT

Recent research studies in the United States indicated that the future of asphalt mixture design should be based on in situ pavement performance. Therefore, a need exists to provide materials engineers with a viable tool for selecting the optimum mix by predicting its performance. One of the primary distress forms affecting pavement performance is rutting. The National Cooperative Highway Research Program 9-19 project indicated that the flow number is one test value that can be used as a criterion for evaluating mix propensity for rutting, as an augmentation to the complex dynamic modulus test. The Federal Highway Administration (FHWA) conducted the repeated load test on mixtures sampled from various construction projects throughout the United States. Outputs from the repeated load test for all project mixes were evaluated with basic statistics to identify which parameters could potentially serve as indicators for mixture rutting, thereby providing criteria for mix designers. A case study based on mixtures from the Florida Department of Transportation Heavy Vehicle Simulator (HVS) test track was included to further investigate whether laboratory results provide appropriate criteria for rutting prediction. The comparison suggested that results from laboratory repeated load test reflect rutting trends observed in the field test sections.

RÉSUMÉ

Des études récentes de recherche aux États-Unis montrent que l'avenir de la formulation des enrobés bitumineux devrait être fondé sur la performance en place. Par conséquent, on a besoin de fournir aux ingénieurs en matériaux des outils valables pour le choix de l'enrobé optimal par la prédiction de sa performance. Une des formes primaires de détérioration affectant la performance des chaussées est l'orniérage. Le projet 9-19 du programme national coopératif de recherche routière (NCHRP) a montré que le fluage est une valeur d'essai qui peut être utilisée comme critère pour évaluer la propension des enrobés à l'enrobage, comme une augmentation à l'essai de module dynamique complexe. L'administration fédérale des routes (FHWA) a réalisé l'essai de charges répétées sur des enrobés échantillonnés sur divers projets de construction à travers les États-Unis. Les données de l'essai de charges répétées pour tous les enrobés des projets ont été analysées avec des statistiques de base afin d'identifier quels paramètres pourraient potentiellement servir d'indicateur de l'orniérage des enrobés, procurant ainsi des critères aux concepteurs d'enrobés. Un cas d'étude basé sur des enrobés de la piste d'essai du simulateur de véhicules lourds (HVS) du Ministère des Transports de la Floride a été inclus pour examiner plus à fond si les résultats de l'essai de charges répétées en laboratoire reflètent les tendances observées sur les sections d'essais en chantier.

1.0 BACKGROUND

The National Cooperative Highway Research Program (NCHRP) projects were initiated in coordination with the Federal Highway Administration (FHWA) with a vision of basing the future of asphalt mixture design on in situ pavement performance. In order to put this advance in mix design in motion, the NCHRP 9-33 project was started to update the current Hot Mix Asphalt (HMA) manual for mix design and base it more on performance criteria [1]. Therefore, a need exists to provide materials engineers with a viable tool for selecting the optimum mix based on predicting its performance.

One of the primary distress forms that diminishes pavement performance is rutting. Several tests were developed over the past thirty years to attempt to address the laboratory prediction of in situ rutting. These tests include a punching shear test to determine if the mix placed in the field could keep the narrow tires of the early vehicles from punching through the pavement and causing failures [2]. Other tests that followed included the Marshall Stability test and Hveem Stabilometer test [3, 4] and wheel tracking tests [5, 6] that provided some ranking of mixes, but were not capable of directly measuring rutting performance. The Simple Shear Tester developed during the Strategic Highway Research Program (SHRP), which applies a horizontal shear load on a specimen glued between two platens, which control the vertical height as the load is applied, provides engineering properties of the materials [7]. All of these tests were developed to simulate and test in-place performance of asphalt mixtures but were limited in terms of cost, cumbersome application, equipment size, or test data variability.

Following the SHRP, the NCHRP 9-19 and NCHRP 9-29 projects were initiated to develop a Simple Performance Test (SPT) protocols and device that would provide fundamental engineering properties of HMA. The SPT is a compact, inexpensive, easy-to-use triaxial testing device, which is designed to measure repeatable engineering properties of HMA for use in determining the performance characteristics of flexible pavements [8]. NCHRP Report 465 recommended three candidate test methods for evaluating mixes with respect to rutting potential: the Complex Dynamic Modulus (|E*|) test, Repeated Load test, and the Static Creep test [9]. The repeated load test produces several out puts including flow number (load cycles at which shear deformation occurs under constant volume), microstrains ($\mu\varepsilon$) at flow, total microstrains at a certain number of load cycles, and the load cycles at a predetermined strain level. Results from NCHRP 9-19 indicated that the flow number is the value that can be used a criterion for evaluating mix propensity for rutting, as an augmentation to the complex dynamic modulus test [10].

The primary focus of the SPT up to this point in time has been to measure the |E*| for asphalt mixtures. In order to more quickly determine |E*|, a comprehensive model capable of predicting |E*| of HMA from the viscosity of asphalt binder and volumetric properties of the aggregate mix was developed [11]. The resulting Witczak model is capable of predicting |E*| of HMA over a range of temperatures, rates of loading (or frequency), and aging conditions. The inputs required in the Witczak model are usually obtained from the mix design process and asphalt binder specifications. Mix from Maryland was tested using both the SPT and the Witczak model and was compared to mixtures where field pavement performance was documented (e.g. WesTrack, MnRoad, FHWA ALF, etc.) [11, 12]. However, it was shown that the |E*| may not be as accurate for predicting mixture behaviour at higher temperatures. This finding indicated that more emphasis should be placed on evaluating the capabilities of the repeated load test for predicting in situ rutting performance.

1.1 Study Objectives

The purpose of this exercise was to investigate the repeated load test and identify which output parameters could potentially serve as indicators for mixture rutting. The possible outcome of the exercise would be the recommended rutting prediction criteria for mix designers. A case study was included to verify whether rutting indicators measured in the laboratory reflected rut depths observed in the field under an accelerated pavement testing facility. In addition, the hypothesis that flow number may not be the ideal criteria on which to base laboratory rutting prediction was tested and alternative parameters were investigated.

1.2 Research Approach Summary

The FHWA conducted the repeated load test on mixtures from various construction projects throughout the United States. Laboratory-blended performance specimens were tested at the job-mix formula optimum asphalt content and at ± 0.5 percent asphalt content. Outputs from the repeated load test for all project mixes were evaluated with basic statistics to identify overall data variability and that by material type. The idea is to base the criteria on test output that exhibits low statistical variation. Because of the conditions necessary for capturing the flow number parameter, complicated by the temperature limitations of the simple performance test equipment, many mixtures may never experience tertiary flow conditions. Therefore, alternative parameters that can serve as indicators of rutting potential were explored as viable alternatives if tertiary flow in a mixture does not occur.

A case study involving two mixtures of different binder grades were sampled from construction of the Florida Department of Transportation Heavy Vehicle Simulator (HVS) test track. The mixes were tested in the repeated load test setup and each of the outputs was compared with actual field rutting measured by the HVS. The investigation was limited to comparison of the two coarse-graded test sections. A comparison was conducted to investigate which laboratory output parameters best track the high-temperature mix performance observed in actual field rutting.

2.0 PERFORMANCE TEST FOR HOT MIX ASPHALT

The simple performance tester was manufactured as part of the NCHRP 9-29 "Simple Performance Tester for Superpave Mix Design" project [8]. The equipment was created based on findings from the NCHRP 9-19 "Superpave Support and Performance Models Management" project, which entailed the identification of a simple test to be used to verify performance characteristics of Superpave^{TM} (Superpave) mixture designs [9]. The NCHRP 9-29 project team was tasked with developing equipment specifications, procuring and evaluating first article equipment, and revising equipment specifications. The project team revealed that the SPT yielded satisfactory results with only minor revisions required [8].

The purposes of the SPT are to provide input to mechanistic-empirical pavement design procedures [13], currently by way of measuring the Complex Dynamic Modulus (|E*|), and to assist in asphalt mixture design. An auxiliary focus is on determining the potential of the tester as a quality verification or quality control tool for use in a field laboratory by a paving contractor. The sensitivity of the test to various mixture types, including a variety of designs and modified binders, is also being investigated by the FHWA and other researchers at University of Florida, University of Maryland, and Louisiana State University [14-17].

A view of the SPT device utilized in the FHWA Mobile Asphalt Testing Laboratory is captured in Figure 1 [18]. The Repeated Load Test was conducted in accordance with protocols currently established by NCHRP 9-19 and NCHRP 9-29 projects. An axial stress of 600 kPa was applied to test specimens in order to simulate the load level applied by a Superpave gyratory compactor in the laboratory. Because the mixtures tested by the FHWA thus far have been conventional, dense-graded mixes, all repeated load testing was done without the application of a confining pressure [10]. Repeated load tests were performed at the Effective Pavement Temperature for Rutting Damage ($T_{\text{eff rut}}$). The effective pavement temperature was calculated using the following equations [19-21]:

$$T_{\text{eff rut}} = 30.8 - 0.12(z_{cr}) + 0.92(MAAT_{\text{design}})$$

where: $T_{\text{eff rut}}$ = effective pavement temperature for rutting,
z_{cr} = critical depth down from pavement surface, mm
$MAAT_{\text{design}}$ = mean annual air temperature, degrees C,

and:

$$MAAT_{\text{design}} = MAAT_{\text{Average}} + K_{\alpha}\sigma_{MAAT}$$

where: K_{α}= K at appropriate reliability level of 95 percent (1.645)
σ_{MAAT} = standard deviation of distribution of MAAT for site location from LTPPBIND® [22].

Figure 1. Simple Performance Test (SPT) Device in FHWA Mobile Asphalt Laboratory

2.1 Repeated Load Test for Laboratory Prediction of Rutting

There are several output parameters that result from performing the Repeated Load Test; e.g. flow number, microstrain at flow number, total cycles to reach a certain amount of strain, and total strain accumulated at the end of specific number of load cycles. The flow number is defined in the SPT software as the number of load repetitions or cycles at which shear deformation, or flow, occurs under constant volume [18]. The stages of flow in a specimen being tested in repeated load are shown in Figure 2. The number of cycles when flow occurs, along with the microstrains (με) at flow number, are recorded and stored in the SPT software. The software provides a flow number for each specimen tested. Typical flow numbers range from 2,000 for conventional dense-graded mixtures to 25,000 cycles for polymer modified binder mixes. Meanwhile, the test continues to run even after the flow number is identified and the cumulative microstrains are recorded out to 10,000 load cycles or until 50,000 microstrains (5 percent strain) are accumulated. Typically, a mixture with a low value of microstrains can be expected to exhibit better rutting performance than a mixture with a higher number of microstrains. The software stops the test when the test specimen exhibits 5 percent strain (50,000 $\mu\varepsilon$) or when 10,000 load cycles have been applied. All results presented in this paper are for those mixtures upon which the test was terminated when the strain on the specimen reached the 5 percent strain level.

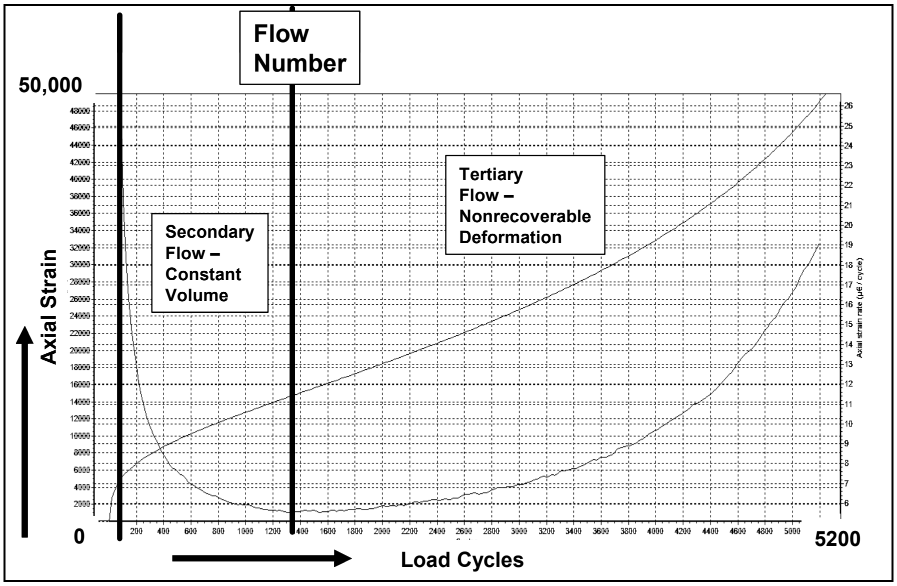

Figure 2. Stages of Flow As Measured in Repeated Load Test Portion of Simple Performance Test

2.2 Comparison of Output Parameters from Repeated Load Test

The FHWA Mobile Asphalt Testing Laboratory (MATL) travelled around the United States and at the request of a State Highway Agency, performed Repeated Load testing on mixes from various state construction projects using the SPT. During each site project, the MATL prepared performance test specimens based on the contractor's mix design. Four performance test specimens were prepared at the optimum asphalt content. Four additional specimens were each prepared at 0.5 percent above and below the optimum asphalt content, while keeping the gradation constant. The specimens were prepared targeting an air void content in the specimens close to the in-situ pavement density for that particular project, a value which ranged between six to eight percent. Each of these specimens was then tested in the SPT. Four to five samples were also collected from the plant-produced hot mix. Repeated load testing was then performed on samples prepared from the production samples.

Repeated load test data from seven State asphalt mixtures was collected for both laboratory-blended mix design and plant-sampled replicates, as seen in Table 1. The test temperature for the repeated load testing for mixes from all the states except Louisiana was 45ºC. The Louisiana mix was tested at 54ºC, due to its climatic conditions. The test temperatures of 45ºC and 54ºC were close to the effective pavement temperature for rutting at each particular location.

Table 2 shows the details on how the Coefficient of Variation (CV) is calculated for the three output parameters. The reason for calculating CV is it allows a measure of variation in each output parameter under similar conditions. One of the objectives of the investigation was to identify the repeated load test output parameter(s) that are less variable, in order that they can be used as a viable alternative indicator for identifying rutting. The outcome of the exercise was to explore whether the performance of various mixtures can be predicted more quickly and with less effort by utilizing other repeated load test output such as the number of load cycles at an intermediate strain level (e.g. 1 percent, 2 percent, etc.). This approach would certainly be less destructive to the specimen, as it entails retaining more of the structural integrity of the specimen, and therefore may provide more accurate predictions.

Table 1. Coefficient of Variation (CV) for Repeated Load Test Output Parameters

State	Sample Type	Mix Description	Temperature °C	CV for Flow Number, %	CV for µStrain @ Flow, %	CV for Total Cycles to reach 5 percent Strain, %
Louisiana	Mix Design	25 mm, Fine Gradation, PG 64-22	54	9.0	12.9	14.4
	Production Mix			10.8	14.4	18.6
North Carolina	Mix Design	9.5 mm, Fine Gradation, PG 70-22	45	9.2	11.1	12.5
	Production Mix			24.1	17.8	29.0
Washington	Mix Design	12.5 mm, Coarse Gradation, PG 64-28	45	20.2	13.3	21.6
	Production Mix			11.8	5.2	9.8
Kansas	Mix Design	19 mm, Fine Gradation, PG 64-22	45	11.3	14.1	17.6
	Production Mix			16.6	9.7	19.6
Minnesota	Mix Design	12.5 mm, Fine Gradation, PG 70-28	45	19.3	7.6	20.8
	Production Mix			13.5	11.8	13.7
Massachusetts	Mix Design	12.5 mm, Coarse Gradation, PG 64-28	45	12.3	9.0	14.9
	Production Mix			13.6	5.0	15.3
New York	Mix Design	12.5 mm, Coarse Gradation, PG 64-28	45	12.8	7.9	11.7
	Production Mix			20.9	6.8	26.8

After repeated load testing on both the mix design and plant produced specimens was complete, the CV was calculated for each set of four samples for the three output parameters: flow number, microstrain at flow number, and total cycles at 5 percent strain, as seen in Table 2. The CV was obtained by dividing the standard deviation of the output parameter of the four specimens by the average of that parameter. The CV for each set of four specimens was then averaged for all the laboratory-blended mix design and plant-produced mix specimens. The averaged CV of the repeated load test output parameters for the designed and plant-produced material is presented in Table 1.

Table 2. Determination of Coefficient of Variation (CV) for Repeated Load Test Output

Mix Design – Change in Asphalt Content keeping Gradation Constant	Optimum Asphalt Content – 0.5%	4 Specimens	CV for Flow Number	CV for Microstrain at Flow Number	CV for Total Cycles at 5 percent Stain
	Optimum Asphalt Content	4 Specimens	Same as above	Same as above	Same as above
	Optimum Asphalt Content + 0.5%	4 Specimens	Same as above	Same as above	Same as above
Average Mix Design Results			**Average CV for Flow Number**	**Average CV for Microstrain at Flow Number**	**Average CV for Total Cycles at 5 percent Stain**
Plant Produced Samples	Production Sample 1	4 Specimens	CV for Flow Number	CV for Microstrain at Flow Number	CV for Total Cycles at 5 percent Stain
	Production Sample 2	4 Specimens	Same as above	Same as above	Same as above
	Production Sample 3	4 Specimens	Same as above	Same as above	Same as above
	Production Sample 4	4 Specimens	Same as above	Same as above	Same as above
Average Plant Produced Sample Results			**Average CV for Flow Number**	**Average CV for Microstrain at Flow Number**	**Average CV for Total Cycles at 5 percent Stain**

As seen in Table 1, the variation fluctuated with mixture type and source however, overall the average CV was 14.7 percent for flow number. Literature has suggested that this is a level of variation deemed reasonable for laboratory testing at high temperatures, under which conditions data integrity is difficult to maintain [8]. Computation of the overall average CV for the microstrain at flow and total cycles to 5 percent strain parameters showed similar variation as that of flow number (10.5 percent and 17.6 percent, respectively). Therefore, it appears that other parameters from the test may be used with or in lieu of the flow number.

3.0 CASE STUDY ON RUTTING: LABORATORY PREDICTION VERSUS FIELD PERFORMANCE

Thus far, only limited research has been conducted to investigate the validity of the flow number criteria for predicting mixture performance in the field [10]. The Florida Department of Transportation (FDOT) has built an accelerated loading test facility which is used to track the actual rutting performance of various asphalt mixtures. Two coarse-graded mixtures and one fine-graded mixture were sampled by FDOT at the time of construction and were compacted in order to be tested in the laboratory with the repeated load test. Although the comparison of laboratory and field rutting performance is not done directly, a relative analysis of the trend may demonstrate the ability of the repeated load test in predicting rut potential. This was also done to test the findings presented previously that indicated that alternative output such as microstrain at flow and total cycles at 5 percent strain appear suitable for identifying mixture rut potential.

3.1 Florida Department of Transportation Heavy Vehicle Simulator Test Track

FDOT's Accelerated Pavement Testing and Research program is housed within the new State Materials Research Park in Gainesville. The accelerated loading is performed using a Heavy Vehicle Simulator (HVS), Mark IV model. The HVS is an electrically powered (using external electric power source or electricity from an on-board diesel generator), fully automated, and mobile unit. The load was applied on all test sections by a Goodyear G165 (305 mm wide) super-single tire loaded to 40 kN at a speed of 12 km/h. The load was applied in unidirectional mode with a 100 mm wheel wander, in 25 mm increments, with the tire pressure maintained at approximately 790 kPa. The tests were conducted at a controlled pavement temperature of 50°C to a depth of 50 mm using radiant heaters.

The main objective of this round of research with the HVS test track was to study the performance of coarse-graded Superpave mixtures. Results from the first experiment had shown that polymer modified asphalt mixtures clearly performed better than unmodified mixtures in terms of rutting performance [23]. Therefore, the main intent was to replicate these results using coarse-graded mixtures as opposed to the fine-graded mixtures tested in the first experiment. A secondary objective was to compare the rutting performance of coarse-graded and fine-graded Superpave mixtures.

Construction of the test track was started in March, 2003 and the test track consists of seven distinct test lanes (1 through 7), each divided into three replicate test sections. All test sections had the same pavement structure in terms of layer thickness and base course material. The only difference was in the top two asphalt concrete layers, where different mixtures were placed. In this experiment, a total of 50 mm of asphalt concrete was placed in two layers, over 265 mm of a limerock base course. Details of the pavement cross sections are show in Figure 3.

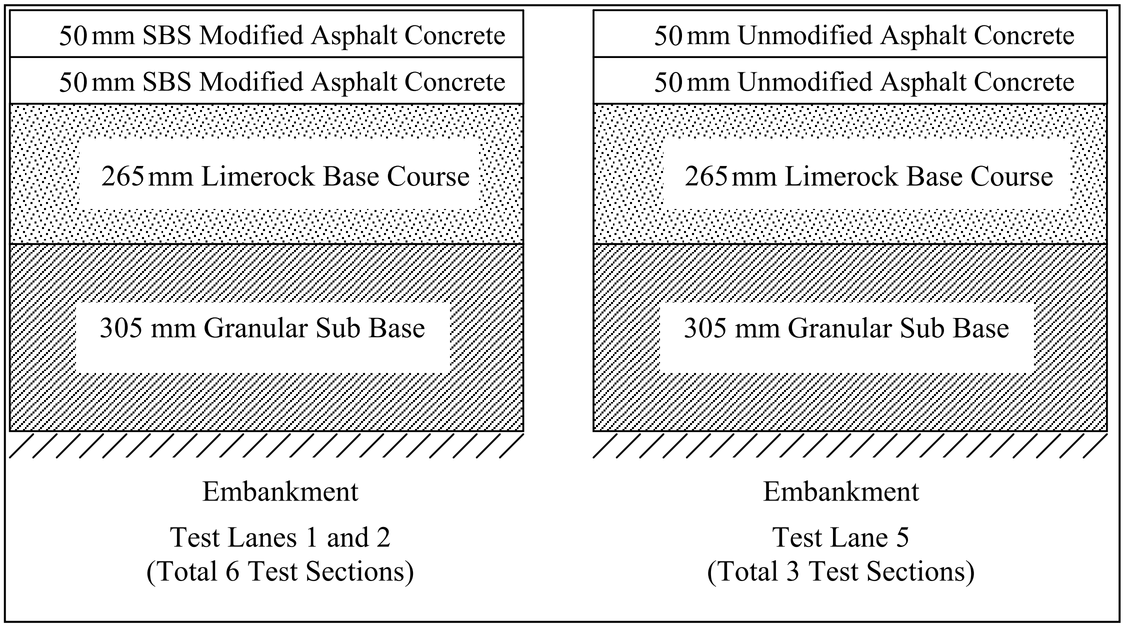

Figure 3. Florida Heavy Vehicle Simulator Pavement Cross Sections

All the mixtures placed had the same aggregate gradation and volumetric properties with the primary difference being the asphalt binder used. Two main binder types were used: a Styrene-Butadiene-Styrene (SBS) modified asphalt binder conforming to Performance Graded (PG) 76-22, and a virgin binder conforming to PG 67-22. The mix designs are shown in Table 3. During placement of all these layers (both asphalt and supporting layers), all standard FDOT density requirements, and acceptance criteria were applicable. All the asphalt layers, for instance, were compacted to 93±1 percent of the maximum specific gravity.

Table 3. Florida Heavy Vehicle Simulator Mix Designs for Coarse-Graded Superpave Mixtures

Coarse Graded Mix (Compacted at 124°C)	PG 67-22	8.2	4.0	14.1	72	4.80	2.253
Coarse Graded Modified Mix (Compacted at 135°C)	PG 76-22	7.9	4.0	14.0	71	4.75	2.249

Note: V_a = air voids, N = number of design gyrations, VMA = Voids in Mineral Aggregate, VFA = Voids Filled with asphalt, P_{be} = effective asphalt binder content, G_{mm} = maximum specific gravity of mix

3.2 Laboratory Prediction of Rutting in HVS Test Track Mixtures

Mixture samples were collected during the paving of HVS test track from sections with the PG 67-22 coarse mixtures (surface and binder lifts) and PG 76-22 fine and coarse mixtures (both surface lifts). Performance test specimens were prepared from these samples and tested in the FHWA SPT. The repeated load test was run using the SPT at an axial stress of 600 kPa (representative of load applied to mixture in a gyratory compactor) and contact stress of 30 kPa. The pulsating load was applied for 0.1 second, followed by a 0.9 second rest period. This test was run on specimens in the unconfined mode at the effective pavement temperature for rutting, computed as 53.4°C for the HVS test track structure in Gainesville. During the repeated load test, it was observed that the specimens prepared from the PG 76-22 mixes were indeed very stiff and thus, in the interest of time, the test was terminated when the accumulated microstrain on the specimens was between 1 to 2 percent strain.

In Section 2, various mixtures were presented and the output parameters from the repeated load test indicated that an inventory of the load cycles at an intermediate strain level may be an adequate indicator of mix rut potential, which would reduce the effort and time associated with this destructive test. Therefore, the total cycles at strain levels of 1 percent, 2 percent, and at flow number were extracted from the repeated load test software and plotted in Figure 4. Observation of the figure shows that prediction at 1 percent strain clearly shows the polymer modified mixtures withstanding a much greater level of load cycles than the unmodified mix. The same is true at 2 percent strain, for the mixtures that reached that level of strain (unmodified coarse-graded and modified fine-graded).

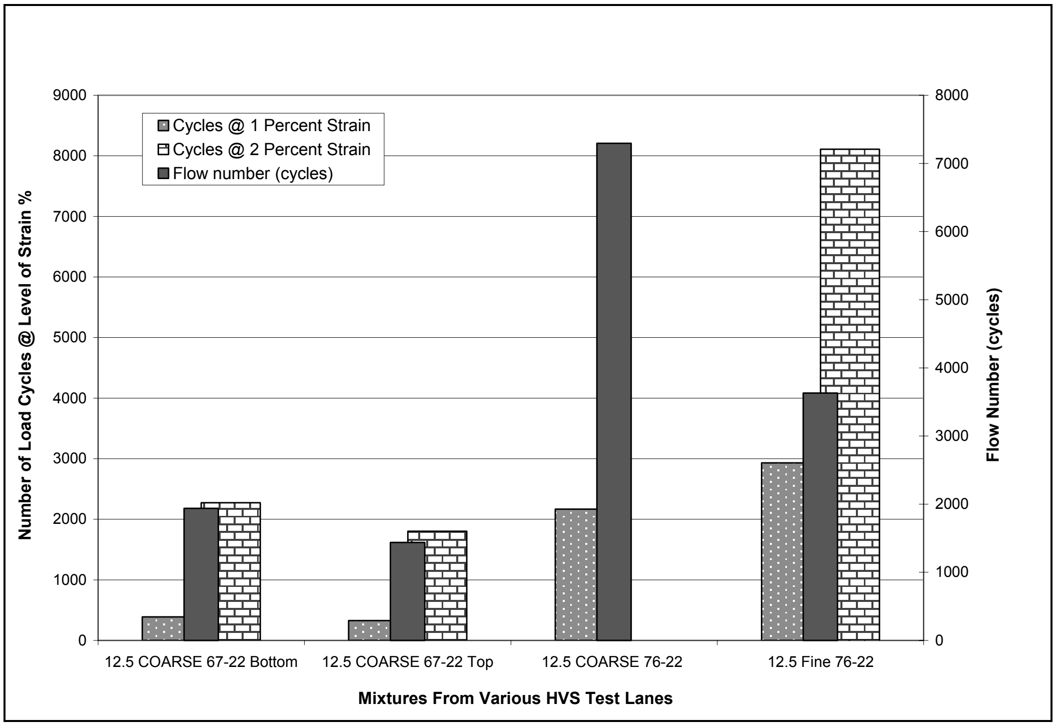

Figure 4. Comparison of Output from Repeated Load Test for Four Heavy Vehicle Simulator (HVS) Mixtures

Because FDOT limited field testing to only the coarse-graded mixtures, the remaining portion of the case study will focus on the coarse-graded PG 76-22 and 67-22 mixtures that constitute the surface lifts in the HVS test track. Average values of the repeated load test results for both coarse-graded mixes are presented in Table 4.

Table 4. Laboratory versus Field Data for Coarse Mixes from Florida Heavy Vehicle Simulator (HVS) Test Track

	12.5 mm Coarse Gradation PG 67-22	**12.5 mm Coarse Gradation PG 76-22**	**Percent Difference**
Flow Number, Cycles	1,438	7,296	80%
Microstrain @ Flow Number, Microstrain	18,061	14,620	24%
Cycles @ 1 Percent Strain, Cycles	328	2,166	85%
Total Rut Depth @ 70,000 HVS Passes, mm	22	8	150%
Slope of Rut Depth	0.024%	0.0040%	500%

Again, a lower amount of microstrains at the flow number is indicative of more cycles required to induce flow, and consequently better rut resistance. The results presented are the flow number, microstrain at flow, and total cycles to reach 1 percent strain for both the HVS mixes. Observation of data from the repeated load test suggested that the microstrain at flow reflects the flow number trend, but both flow number and microstrain at flow are valid parameters only if tertiary flow occurs in the mixture. Figure 5 shows the strain curves obtained during the repeated load test on specimens prepared from both HVS mixes. The mixture with the PG 67-22 binder required 1,000 load cycles to reach 15,000 microstrain (1.5 percent strain), while the mixture with the PG 76-22 binder underwent approximately 9,000 load cycles to reach the same amount of strain. Further inspection of Figure 5 shows the different phases of flow for each mixture. Both mixes undergo primary flow, a measure of the initial consolidation of the mix as it begins to be loaded, and secondary flow. Secondary flow can be described as linear strain that occurs in the specimen with additional load cycles, but prior to shear deformation occurring under constant volume. At the point where shear deformation occurs under constant volume, a flow number is identified by the test device software and the tertiary flow condition begins. As seen in the figure, the PG 67-22 mixture goes into tertiary flow relatively quickly (within 2,000 load cycles). The strain curve for the PG 76-22 mixture does not exhibit tertiary flow conditions therefore, the provision of flow number from the repeated load test software, which is given for each specimen tested, is of questionable validity since it is clear from the output that flow does not occur. This condition was seen often in the case of polymer modified mixtures. Because a majority of the States where rutting is a problem use modified binder mixes, it is demonstrated in this figure that identification of other parameters besides flow number is essential for providing accurate predictions of rutting.

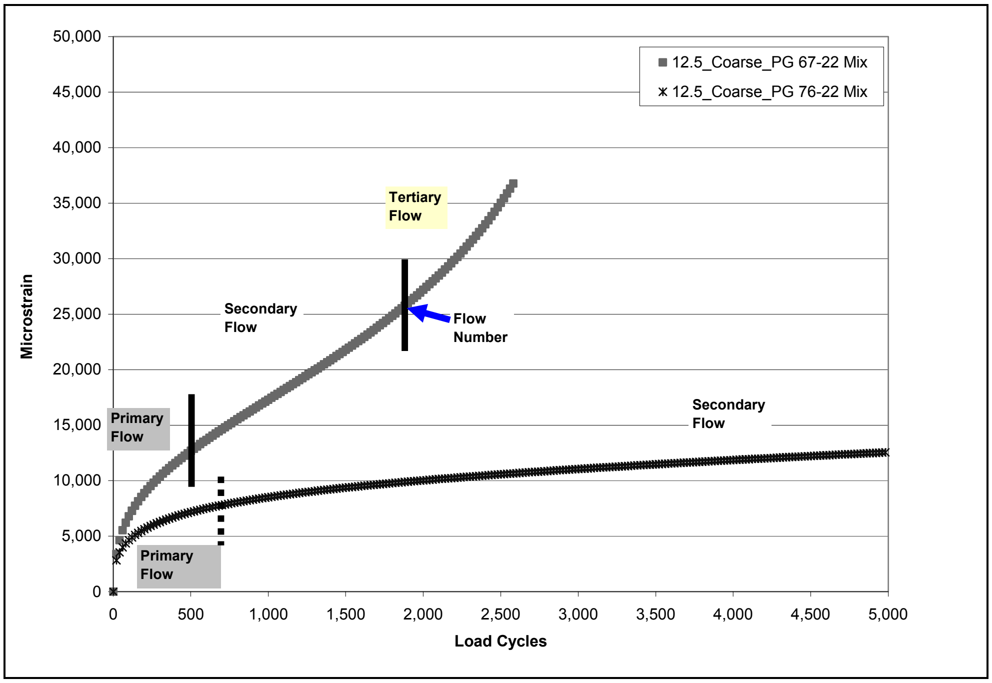

Figure 5. Repeated Load Test Strain Curves for Heavy Vehicle Simulator (HVS) Coarse-Graded Mixtures

3.3 Field Measurement of Rutting in HVS Test Track

Rutting data from the HVS test track largely confirmed the results from the first experiment, with the fully-modified pavement sections exhibiting superior performance than test sections made with unmodified asphalt pavement, as seen in Figure 6. The unmodified pavement sections reached a rut depth of 22 mm within only 70,000 load passes. In fact, based on the slopes calculated for the rutting curves in Table 4, the lane with the unmodified mixture would continue to rut linearly with increasing load passes of the HVS. Whereas in the polymer modified sections, the rutting curve flattened out at a depth of approximately 8 mm and the testing was halted at 200,000 load passes. There was also a large amount of variability in the observed rutting between replicate test sections.

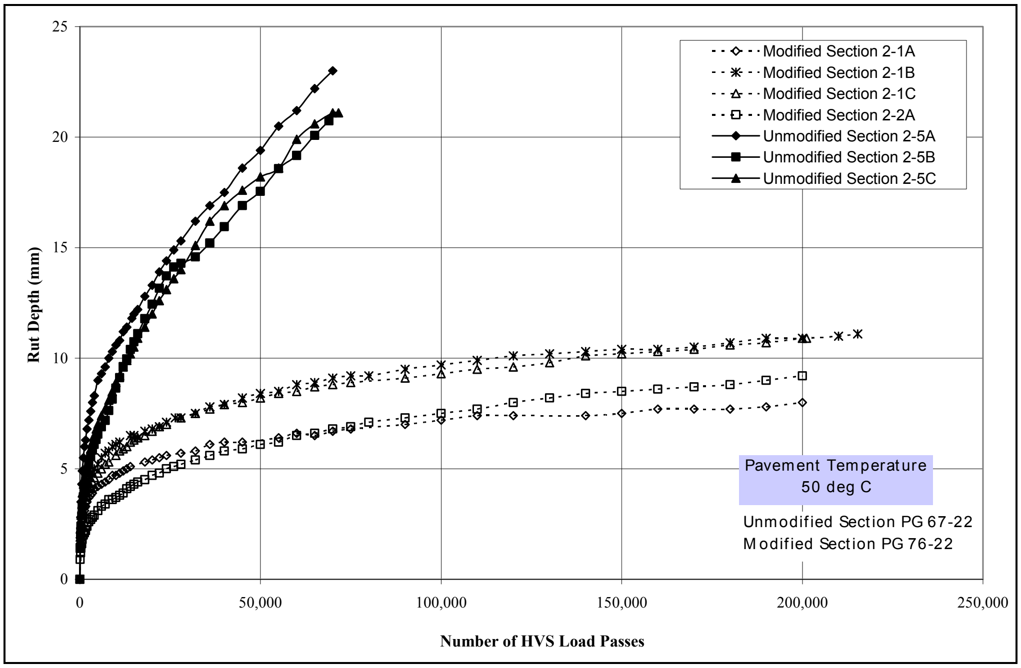

Figure 6. Rutting Performance of Modified and Unmodified Sections of Heavy Vehicle Simulator (HVS) Test Track

3.4 Results: Field Observations versus Laboratory Predictions

A relative comparison was made between the repeated load test laboratory results and rutting measured in the field under the HVS. The rut data reported in Table 4 is after 70,000 load passes by the HVS on both sections. At the end of 70,000 load passes, the mix with the PG 67-22 neat binder rutted 22 mm and the mix with PG 76-22 modified binder had 8 mm of rutting. Based on the rutting curve for the unmodified HVS mix plotted in Figure 6, one would expect that this mixture would experience tertiary flow as the rut depths continue to increase with more load passes with the HVS. Conversely, the slope of the rutting curves (see Table 4) for the modified mixture is relatively flat and indicates that the maximum rut depth had peaked even before 200,000 passes and an increase in rutting would not be expected. In general, rut depths measured in the HVS field sections appeared to correlate well with the different output parameters predicted from the repeated load test.

In order to compare the trend from laboratory repeated load testing with field rut depths, Figure 7 plots the repeated load test strain percentage with increasing load cycles, as well as the rut depth measured in the field lanes with increasing number of HVS passes, for the unmodified HVS mixture. Inspection of the figure shows that the laboratory prediction of shear deformation in tertiary flow, which occurs within 2,000 load cycles, reflects the field rutting that increases steadily towards 25 mm and may have continued similarly if the HVS wasn't terminated when the mix reached a rut depth of 25 mm. The agreement between laboratory and field observations was encouraging since most State agencies will rely on laboratory testing, as most do not have the special capability of measuring pavement field performance.

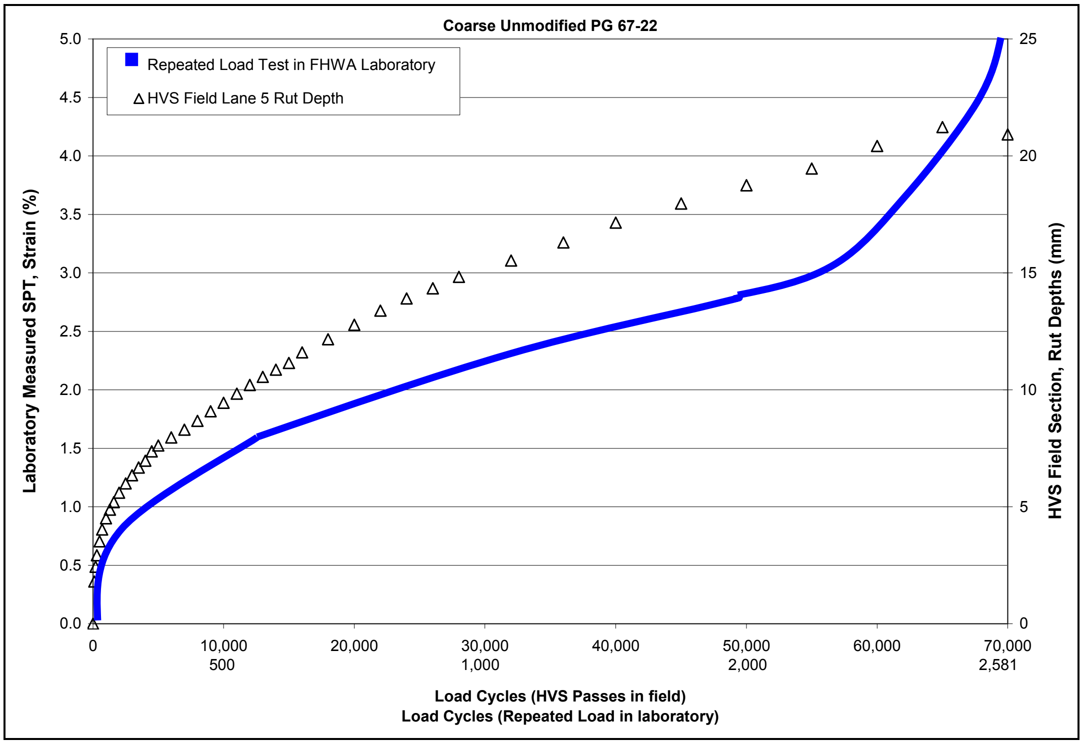

Figure 7. Laboratory Prediction and Field Rut Depths of Unmodified Sections of Heavy Vehicle Simulator (HVS) Test Track

Figure 6 illustrated that the maximum rut depth for the modified mixture was reached within 200,000 HVS passes and there is no projected increase in rutting. This finding appears to indicate that progression of the mix into tertiary flow would not be expected. In fact, Figure 8 shows that the laboratory-predicted strain curve enters into primary and secondary flow conditions, but the mix does not go into tertiary flow even at 10,000 load cycles. Likewise, the field rutting curve has a flat slope (Table 4) and the modified mixture slowly accumulated rut depth to a maximum of 10 mm. This rut depth is less than half of that measured in the unmodified mixture.

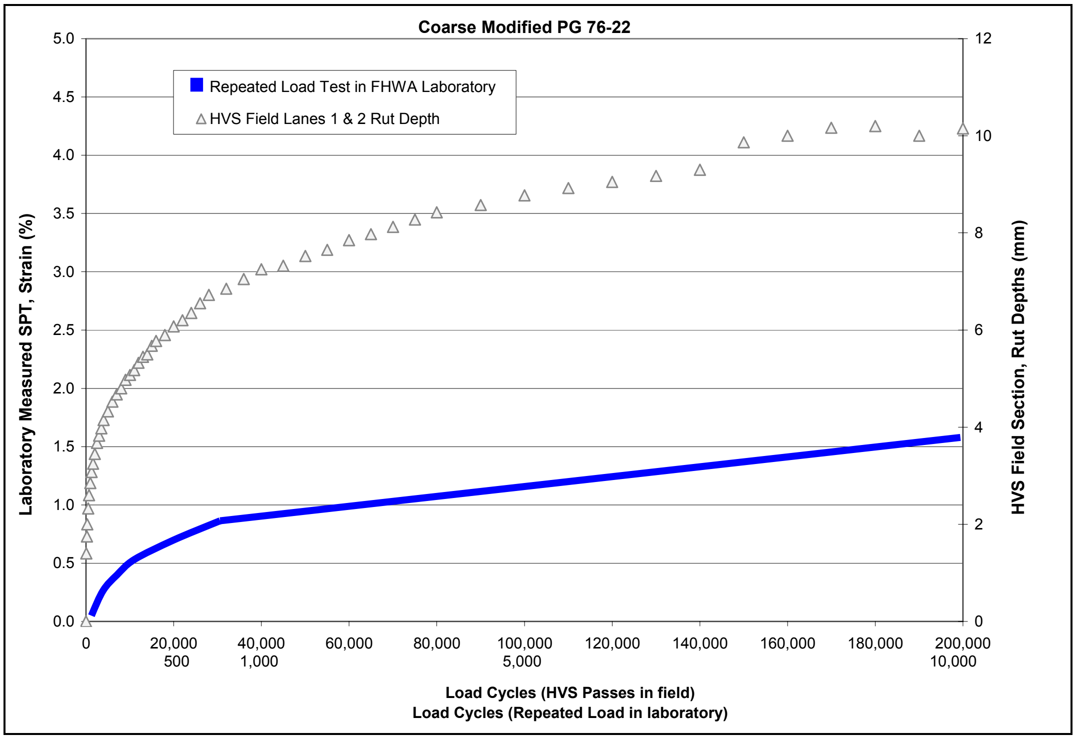

Figure 8. Laboratory Prediction and Field Rut Depths of Modified Sections of Heavy Vehicle Simulator (HVS) Test Track

Another observation to be considered comes from repeated load test results for asphalt mixtures that take a considerable amount of time before entering into tertiary flow, if ever. The repeated load test data in Figure 8 clearly shows that the modified mix never enters the tertiary flow phase. Likewise, this finding is reflected in the field rut measurements for the modified sections where the rut depth ceases to consolidate more after 150,000 passes of the HVS (Figure 8). For those mixes, the total cycles at 1 percent strain can be used as a measure of the mix stiffness, in lieu of flow number. The reason is, as observed in the data presented previously in Section 2.2, both the flow number and total cycles at 1 percent strain were equally capable of distinguishing mix propensity for rutting. The flow number and total cycles at 1 percent strain were better parameters for distinguishing this difference than the microstrain at flow number value. The difference in microstrain at flow number between the two mixes was only 24 percent (Table 4), despite the fact that there was considerable difference in actual field rut depths. Therefore, it appears that microstrain at flow may not be a good indicator to identify mixes for their rutting potential. Flow number and total cycles at 1 percent strain showed greater differences between the mix values, suggesting that these parameters may be better suited to identify mixes' rutting potential.

4.0 SUMMARY AND CONCLUSIONS

The repeated load test was one of the candidate tests selected as part of NCHRP 9-19 project to evaluate the asphalt mixture propensity for rutting. Essentially, four output parameters result from the repeated load test and were evaluated; flow number, microstrain at flow, total cycles at a certain strain level, and total strain at the end of certain number of load cycles. This study dealt with analysing results from the repeated load test and recommending output parameter(s) that could be used as a viable alternative or supplementary indicator of the rutting potential of asphalt mixtures. Identification of output parameters that could potentially serve as indicators for mixture behaviour at high temperatures helps to provide rutting criteria for the mix design process. Laboratory-blended and plant-produced mix specimens from various construction projects and of different material sources were tested in the repeated load test using the Simple Performance Tester.

Analysis of the results indicated that of all the outputs from the repeated load test, the microstrain at flow exhibits lower variability than flow number and total cycles at a certain strain level. These findings suggest that the use of the total strain accumulated at the end of certain number of cycles or total cycles to reach a predetermined strain level may be better indicators for rutting than flow number, especially in the case of polymer modified mixtures. Statistical analysis of the results suggested that the overall Coefficient of Variation was lower for microstrain at flow, followed by flow number, and total cycles to reach 5 percent strain. For instances when the mixture is stiff (e.g. polymer modified mixes), test specimens require numerous load cycles to reach tertiary flow, if ever. In such scenarios, the total cycles to reach 1 percent strain parameter may be used to characterize the mixture's tendency to rut rather than the flow number. Evaluation of the variation of test output such as cycles at intermediate strain levels (1 percent, 2 percent, etc.) is recommended for future research.

Additionally, a case study was conducted to observe the effectiveness of each of the output parameters to predict field rutting. Two mixes with different gradations and asphalt grades (Fine and Coarse PG 67-22 and Coarse PG 76-22) were sampled from construction of the Florida Department of Transportation Heavy Vehicle Simulator (HVS) test track. Repeated load test was conducted on specimens prepared from these samples. The output parameters were then compared with the actual field rutting that occurred on the HVS test track. The results indicate that flow number and total cycles at a certain strain level have better correlation to actual field rutting than the microstrain at flow, suggesting that flow number and total cycles at certain strain level are better predictors of field rutting.

A relative comparison between laboratory repeated load test results and field rutting measured in the Florida Department of Transportation HVS test track, for the same unmodified and modified mixtures, showed a strong correlation between lab predictions and field performance. Based on this comparison, it was clear that the flow number parameter may not be capable of characterizing the tertiary zone of some mixtures as precisely as other output such as total accumulated strain or resultant number of cycles at failure. Compounding influences of changes in gradation and asphalt binder contents for samples taken from production may be better evaluated by observing both the flow number and total cycles at 1 percent strain or accumulated strain.

REFERENCES

1. National Cooperative Highway Research Program (NCHRP). "A Mix Design Manual for Hot Mix Asphalt", NCHRP 9-33 Unpublished Interim Report, National Research Council, National Academies, Washington, D.C. (2005).

2. The Asphalt Institute. The Asphalt Handbook, Manual Series No. 4, The Asphalt Institute, Lexington, Kentucky (1998 edition, reprinted in 2000).

3. Roberts FL, Kandhal PS, Brown ER, Lee DY, Kennedy TW. Hot Mix Asphalt Materials, Mixture Design, and Construction, National Asphalt Pavement Association (NAPA) Research and Education Foundation, Lanham, Maryland (1996).

4. Kennedy TW, Huber GA, Harrigan ET, Cominsky RJ, Hughes CS, Von Quintus H, Moulthrop JS. "Superior Performing Asphalt Pavements (Superpave): The Product of the SHRP Asphalt Research Program", SHRP-A-410 Report, National Research Council, National Academies, Washington, D.C. (1994).

5. Transportation Research Board (TRB). "Loaded Wheel Testers in the United States", Transportation Research Circular E-C016, National Research Council, National Academies, Washington, D.C. (2000).

6. Zang J, Cooley A, Kandhal PS. "Comparison of Fundamental and Simulative Test Methods for Evaluating Permanent Deformation of Hot-Mix Asphalt", Transportation Research Record No. 1789, National Research Council, National Academies, Washington, D.C. (2002).

7. Tayebali A, Khosla NP, Malpass GA, Waller HF. "Evaluation of Superpave Repeated Shear at Constant Height Test to Predict Rutting Potential of Mixes: Performance of Three Pavement Sections in North Carolina", Transportation Research Record No. 1681, National Research Council, National Academies, Washington, D.C. (1999).

8. Bonaquist R, Christensen D, Stump W. "Simple Performance Tester for Superpave Mix Design: First-Article Development and Evaluation", NCHRP Report 513, National Research Council, National Academies, Washington, D.C. (2003).

9. Witczak M, Kaloush K, Pellinen T, El-Basyouny M, Von Quintus H. "Simple Performance Test for Superpave Mix Design", NCHRP Report 465, National Research Council, National Academies, Washington, D.C. (2002).

10. National Cooperative Highway Research Program (NCHRP). "Superpave Support and Performance Models Management", NCHRP Project 9-19 Unpublished Final Report, National Research Council, National Academies, Washington, D.C. (2005).

11. Pellinen T. "Investigation of the Use of Dynamic Modulus as an Indicator of Hot-Mix Asphalt Performance", Ph.D. Dissertation, Arizona State University (2001).

12. Stuart K, Mogawer W, Romero P. "Validation of Asphalt Binder and Mixture Test That Measured Rutting Susceptibility Using the Accelerated Loading Facility", Interim Report, Turner Fairbank Highway Research Center, Federal Highway Administration, McLean, Virginia (1999).

13. National Cooperative Highway Research Program (NCHRP). "Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures", NCHRP Project 1-37A Final Report, National Research Council, National Academies, Washington, D.C. (2004).

14. Dongré R, Myers L, D'Angelo J, Paugh C, Gudimettla J. "Field Evaluation of Witczak and Hirsch Models for Predicting Dynamic Modulus of Hot-Mix Asphalt", Journal, Association of the Asphalt Paving Technologists, 74 (2005).

15. Birgisson B, Roque R. "Evaluation of Gradation Effect on Dynamic Modulus", Transportation Research Board, National Research Council, National Academies, Washington, D.C. (2005).

16. Schwartz C. "Evaluation of Witczak Dynamic Modulus Prediction Model", Transportation Research Board, National Research Council, National Academies, Washington, D.C. (2005).

17. Mohammad L, Wu Z, Myers L, Abadie C, Cooper S. "Laboratory Characterization and Empirical Prediction of Dynamic Modulus of Superpave Mixtures", Transportation Research Board, National Research Council, National Academies, Washington, D.C. (2005).

18. Industrial Process Controls Global, Ltd. Dynamic Modulus Test Software Reference, Boronia, Australia (2003).

19. National Cooperative Highway Research Program (NCHRP). "Simple Performance Test for Superpave Mix Design", NCHRP Project 9-19 Unpublished Interim Report, National Research Council, National Academies, Washington, D.C. (2003).

20. Strategic Highway Research Program (SHRP). "The Superpave Mix Design Manual for New Construction and Overlays", SHRP-A-407 Report, National Research Council, National Academies, Washington, D.C. (1994).

21. Strategic Highway Research Program (SHRP). "Weather Database for the SUPERPAVE Mix Design System", SHRP-A-648A Report, National Research Council, National Academies, Washington, D.C. (1994).

22. PaveSys. LTPPBIND® Program, Version 2.1, Pavement Systems, LLC (1999).

23. Tia M, Roque R, Sirin O, Kim H. "Evaluation of Superpave Mixtures With and Without Polymer Modification By Means of Accelerated Pavement Testing", Final Report prepared for the Florida Department of Transportation, Department of Civil and Coastal Engineering, University of Florida, Gainesville, Florida (2002).