STATE OF FLORIDA

Investigation of Shear Failure of HMA Using Rotary Asphalt Wheel Tester (RAWT)

Research Report
FL/DOT/SMO/06-489

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February 2006

STATE MATERIALS OFFICE

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ABSTRACT

Instability rutting, which is shear related and occurs when the compacted mix cannot resist near surface critical stress conditions, is a major distress mode in flexible pavements. According to a NCHRP Report 465, the point at which excessive deformations occur from laboratory rut testing is the most important factor that determines the rutting performance of asphalt mixtures. However, a clear and complete failure mechanism has not been identified.

This research focuses on identifying a rheology model and a failure criterion for asphalt mixtures that are loaded under repeated shearing forces at high temperature. From the results of laboratory rut testing, it was found that a linear viscoelastic approach appears valid and suitable for characterizing the rutting behavior of asphalt mixtures, and an energy-based failure mechanism appears to be a valid shear failure criterion. From this observation, the parameter “shear failure time” developed in this study, appears to have potential for evaluating a mixture’s rutting performance.

INTRODUCTION

Background

A major load-associated distress mode of flexible pavements is rutting. From the field performance of pavements, two types of rutting are generally observed. The first is structurally related and is due to permanent deformation within pavement layers under traffic loads. The second is shear related and is due to the instability of asphalt mixtures. Monismith (1976) reported that criteria for limiting subgrade strain that can be used to minimize permanent deformation did not lead to excessive rutting at the pavement surface. McLean and Monismith (1974) also reported that subgrade stiffness appears to have little influence on rutting in the asphalt layer; the asphalt layer exerts significant influence on that rutting. From the literature, the second distress appears more critical. However, literature review has shown that several researchers have presented observations that attempt to explain near surface rutting, but a clear and complete identification of the failure mechanism does not exist.

From laboratory testing, the permanent deformation of an asphalt mixture subjected to a repeated load test to failure shows three stages: primary, secondary, and tertiary stages. In the primary stage, the strain rate decreases and becomes constant; in the second stage, the strain rate is constant up to the tertiary stage; and in the tertiary stage, the strain rate rapidly increases and finally reaches rupture. According to National Cooperative Highway Research Program (NCHRP) Report 465 (Witczak et al., 2002), it was reported the point at which the tertiary stage initiates is the most important point that determines the rutting performance of asphalt mixtures, and regression parameters related to the constant strain rate in the secondary phase showed fair or good correlation with field performance data. However, it is unclear what failure relationship can be made between the failure point and the strain rate in the secondary phase, because those are related. Furthermore, a mixture's failure is also dependent on the given stress level applied. Therefore, it is important to identify a failure criterion and generalize the stress-strain relation for a mixture's failure.

Although many laboratory tests have been developed and are being used in evaluating the rutting performance of asphalt mixtures, a need still exists for a practical, inexpensive, and reliable test device for the evaluation of an asphalt mixture's resistance to rutting. Based on that need, the Florida Department of Transportation (FDOT) conducted a research study to evaluate the Rotary Asphalt Wheel Tester (RAWT), manufactured by Pine Instrument Co. Although the RAWT testing conditions may not closely reflect traffic conditions in the field, the simple stress condition applied by the RAWT appears to be suitable for investigating the shear failure of asphalt mixtures. From the results of the RAWT tests compared with those from Asphalt Pavement Analyzer (APA) tests, which is widely used as a rutting performance test of asphalt mixtures, the system appears to provide reasonable prediction of rutting performance of asphalt mixtures.

Objectives

The primary objectives of this research study are listed below:

- Identify a proper rheology model that can characterize the physical behavior of asphalt mixtures at high temperature.
- Identify a failure criterion that can generalize the failure of asphalt mixtures in shear at high temperature.

- Develop and identify a key parameter that can effectively evaluate a rutting potential of asphalt mixtures.

Scope

The research focuses on identifying a proper rheology model and a failure criterion for specimens that are loaded under shearing forces at high temperature. However, it will not be feasible to examine all possible parameters that affect rutting within the scope of this project. Thus this research will focus on the effects of the following:

- Mixture: Two types of dense-graded mixes: coarse and fine-graded mixes are selected and used.
- Testing: Rotary Asphalt Wheel Tester (RAWT), which has been recently developed to conduct rutting performance evaluation of asphalt mixtures, is used as a main test in this study. The Asphalt Pavement Analyzer (APA) is also used as a supplementary test to confirm the results from the RAWT.
- Load Configuration: Three loading levels, 10, 13, and 15 N, are applied until a specimen fails. All tests are performed under fixed conditions: a loading rate, 75 cycles per minute and temperature, 45°C.

MATERIALS

Two types of dense-graded mixes: coarse and fine-graded mixes, which were designed by FDOT, were selected. Twelve coarse and twelve fine-graded specimens were prepared using Superpave Gyrator compactor targeting at 4% air void.

Rutting tests using RAWT were conducted at three different loading levels. Two coarse and fine-graded specimens were assigned to each loading test. The rest of the specimens, six coarse and six fine-graded specimens, were assigned to rutting tests using APA.

ROTRAY ASPHALT WHEEL TESTER (RAWT)

General Description

The Rotary Asphalt Wheel Tester (RAWT), which has been recently developed to conduct rutting performance evaluations of asphalt mixtures, operates on a similar principle as the Hamburg Wheel Tester (AASHTO T 324-04). A main difference is that a specimen is loaded along its diameter instead of from the top (Figure 1). Although its loading condition may not closely simulate traffic conditions in the field, the stress condition at the edge of the wheel may provide a simple shear stress condition. Based on the premise that rutting is mainly caused by shear stress, this test appears suitable to investigate a shear failure criterion of asphalt mixtures. Pictures (Figure 2) that were taken from specimens before and after the test was performed up to tertiary failure showed that failure had occurred at the expected position (i.e., at the edge of the wheel). This indicates the RAWT has the ability to capture the shear failure initiation of asphalt mixtures.

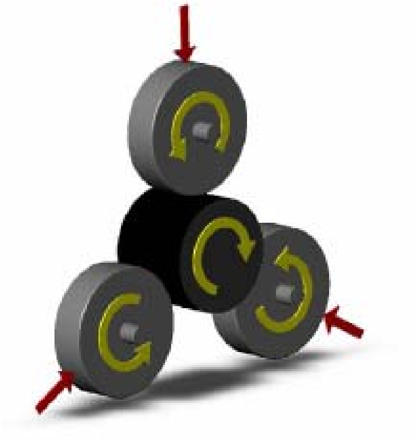

Figure 1. General Description of RAWT

Figure 2. Specimens before and after a RAWT test

Testing Procedure

As shown in Figure 3, the RAWT consists of an integral water bath with a heating element and temperature control, three stainless steel wheels, and a spring-loaded LVDT. The water temperature can be maintained within ± 0.5°C. A predetermined deadweight can be applied from the top loading wheel to a specimen carried by the mounting unit hanging underneath the water bath cover, while the other wheels provide reaction forces from the bottom. Built-in software in the RAWT records deformation versus number of cycles at a frequency of once per 30 cycles. The detail testing procedure is as follows:

- Prepare a Gyratory compacted specimen with 150-mm diameter by approximately 115-mm height.
- Mount the specimen and properly position it at the center of the loading wheel.
- Adjust a predetermined deadweight, which rests on top of the loading wheel.
- Place the specimen in the temperature controlled water bath and allow it equilibrate for one hour to the specified testing temperature.

- Adjust all other testing conditions, such as the loading rate and the test termination condition, either maximum rut depth or number of cycles.

For the purpose of this study, applied loading levels were varied and tested under a fixed loading rate (75 cycles per minute) and temperature (45°C).

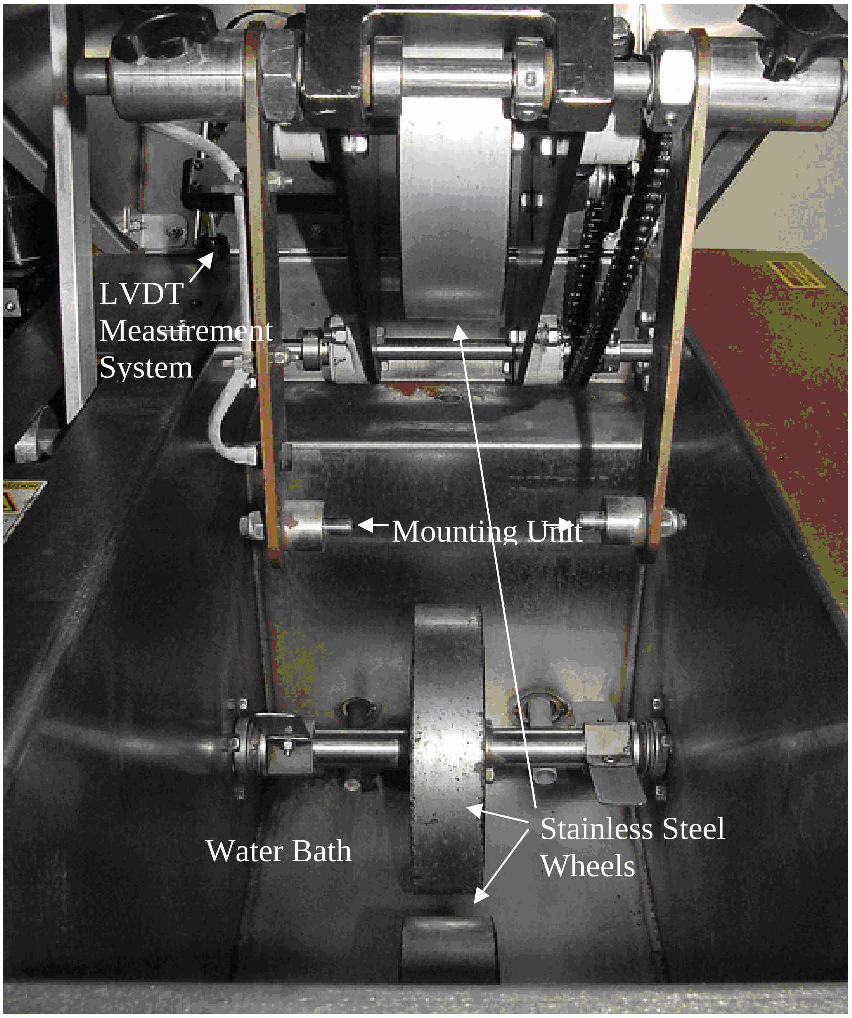

Figure 3. Product Overview

GENERAL DESCRIPTION OF PERMANENT DEFORMATION

Results from repeated load tests typically present permanent deformation versus number of loading cycles as shown in Figure 4. The permanent deformation curve can be divided into three stages: primary, secondary, and tertiary similar to a creep test. In the primary stage, a strain rate decreases and becomes constant; in the second stage, the strain rate is constant up to the tertiary stage; and in the last stage, the strain rate rapidly increases and finally reaches rupture.

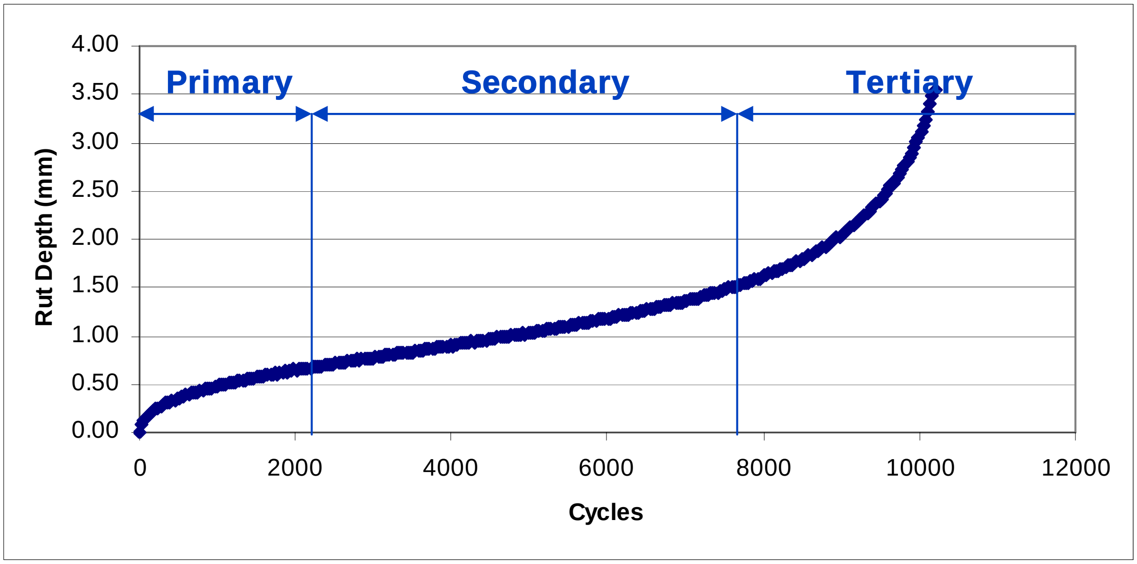

Figure 4. General Description of Rutting Test Results

Collop et al. (1995) reported that extra compaction dominates in the primary stage, and the effect of viscous flow becomes dominant in the secondary stage. Zhou and Scullion (2002) described the physical process of the primary stage is dominated by air voids, dislocations in the aggregate and asphalt binder. With the accumulation of permanent strain, asphalt mix work hardens, and micro cracks initiate and grow. In the tertiary stage, the micro cracks gradually propagate and coalesce to form macro cracks.

Meanwhile, from the creep test using a static load, Kenis and Sharma (1976) and Kaloush and Witczak (2002) presented a linear viscoelastic model adopting a time-independent plastic component that characterizes the rutting behavior of asphalt mixtures.

In summary, although identifying the meaning of each stage is beyond the scope of this study, it can be summarized that in the primary stage, all combined physical activities, such as post compaction due to air voids, dislocations in the aggregate and asphalt binder, elasticity, time-dependent delayed elasticities, and viscosity, appear. After instant or transient responses (elasticity, post compaction and delayed elasticities) have disappeared, the mixture viscosity (or micro cracks) remains in the second stage. Finally, failure (or macro cracks), which is represented as rapid increase of strain rate, develops in the tertiary stage.

IDENTIFYING A PROPER RHEOLOGY MODEL

The physical behavior of viscoelastic media is characterized as time and temperature dependent. At constant temperature, the time-dependent phenomena exhibit linear, or nonlinear behavior depending on applied stress levels. From literature review, three approaches: linear viscoelastic (e.g., Collop et al., 1995, Szydlo and Mackiewicz, 2005), linear viscoelastic-plastic (e.g., Abdulshafi and Majidzadeh, 1984 and Ramsamooj et al., 1998) and, non-linear viscoelatic or viscoplastic (e.g., Masad and Bahia, 2002 and Abbas et al., 2004) models appear and are primarily used to characterize the rutting behavior of asphalt mixtures. In this study, by performing the linear viscoelastic analysis on the tested data from RAWT tests, a proper rheology model will be identified.

According to the theory of viscoelasticity, from the creep test using a static load, the material is said to be linearly viscoelastic if stress is linearly proportional to strain at a given time, and the linear viscoelastic model is valid under the given stress and temperature (Figure 5). However, a repeated loading test, which applies repeated loading cycles with rest periods, may not be in accordance with the testing condition of the creep test. Furthermore, even if creep test data are available, it may not ensure whether a given mixture exhibits linearly viscoelastic behavior in that given dynamic testing condition.

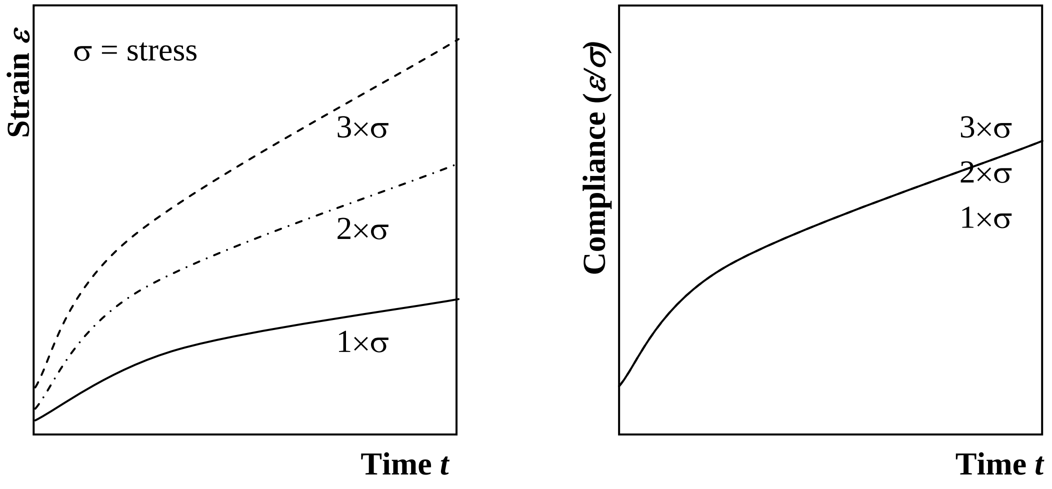

Figure 5. Illustration of Behavior of Linear Viscoelastic Materials

It was realized that the linearity of a mixture subjected to repeated loading could be indirectly recognized from computer simulation performed by a mathematical form used to represent the stress-strain-time relations of viscoelastic materials. According to Boltzmann's superposition principle (Findley et al., 1976), if the stress input $\sigma(t)$ is arbitrary (variable with time), this arbitrary stress input can be approximated by the sum of a series of constant stress inputs as shown in Figure 6 and described in Equation 1. This equation can be used to describe the creep strains at any time under any given stress history as long as the creep compliance *D(t)* is known.

$$\varepsilon(t) = \sum_{i=1}^{r} \sigma_i \cdot D(t-\xi_i) \cdot H(t-\xi_i) \tag{1}$$

where,

ξ is a dummy variable.

H(t-a) is a heaviside unit step function which is defined as follows:

$$H(t-a) = \begin{cases} 1 & \text{if } t \geq a \\ 0 & \text{if } t < a \end{cases}$$

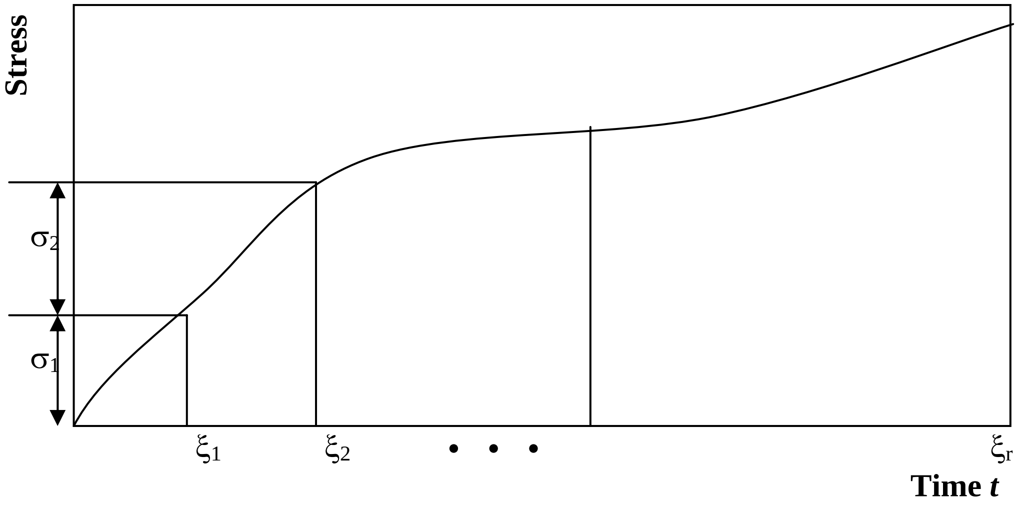

Figure 6. Variable Stress Input Approximated by the Sum of a Series of Constant Stress Inputs

The equation above can be expanded as a more generalized form for the computer simulation as follows:

$$\varepsilon(\xi_r) = \sigma_1 \cdot D(\xi_r - \xi_1) + \sigma_2 \cdot D(\xi_r - \xi_2) + \ldots + \sigma_r \cdot D(\xi_r - \xi_r) \tag{2}$$

In the process of this simulation, the number of data points appears critical since more finely divided time intervals provide a more accurate strain prediction. From the hundreds of preliminary tests, 50 data points per each unit of timescale appears acceptable when considering accuracy of the predicted strains and computation time.

For the computer simulation, a simple rheology model (Figure 7), a Burgers model, which is a four-element model consisting of a linear spring E_1, a spring element E_2 and dashpot element η_2 connected in parallel, and a linear viscous dashpot η_1 (Equation 3), was considered due to its simplicity, and the value of each component was properly assumed. Three different haversine stress levels, 10, 20, and 30 kPa, with a 0.1-s loading duration and a 0.9-s unloading duration was assumed and applied (Figure 8).

$$D(t) = \frac{1}{E_1} + \frac{1}{\eta_1} t + \frac{1}{E_2}(1 - \exp(-E_2 t / \eta_2)) \tag{3}$$

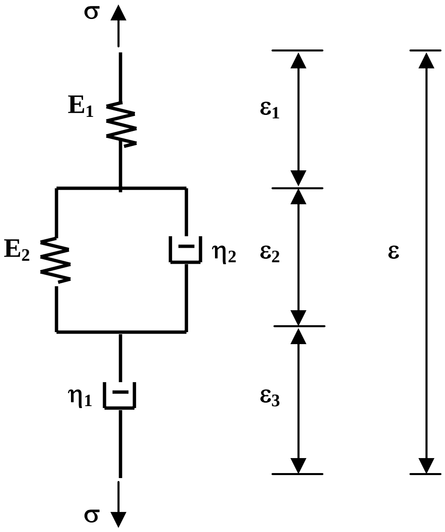

Figure 7. Burgers Model

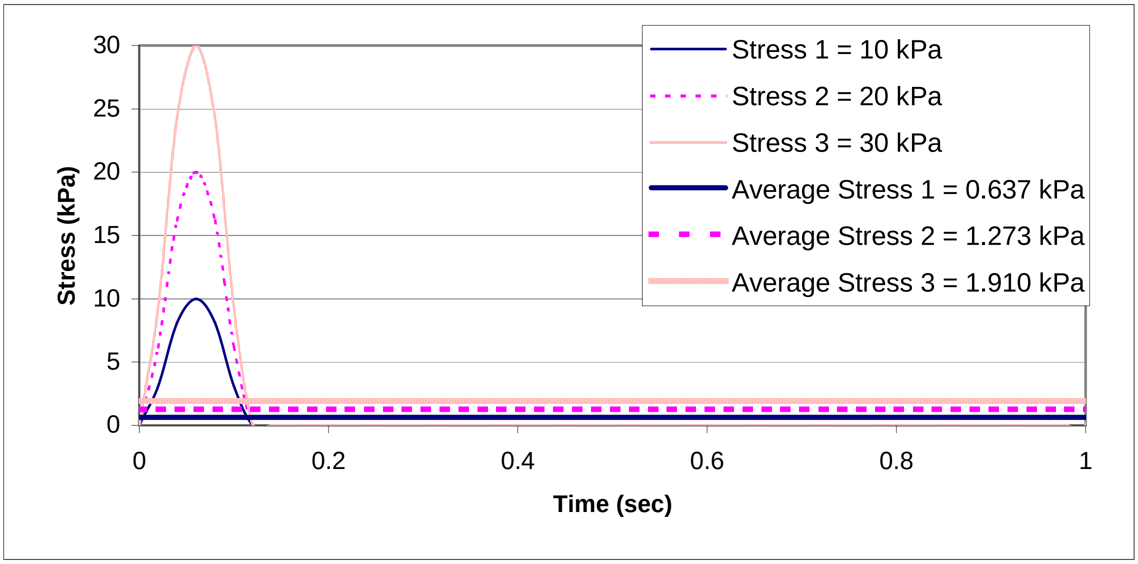

Figure 8. Stress Inputs for Computer Simulation

Similar to the Figure 5, the results of this simulation indicate the material is also said to be linearly vicoelastic if the repeated stress is linearly proportional to strain response at a given time, and the linear vicoelastic model is valid under the given repeated stress (Figures 9 and 10). It is also interesting to note that creep compliance can be obtained from the repeated load test (Figure 9).

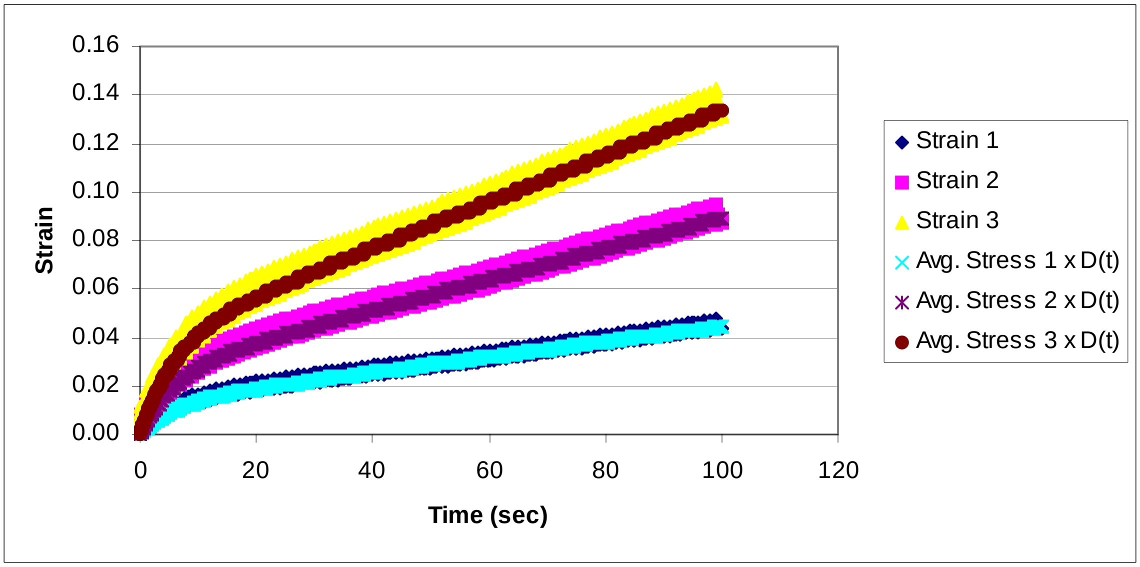

Figure 9. Behavior of Linear Viscoelastic Materials under Repeated Loading

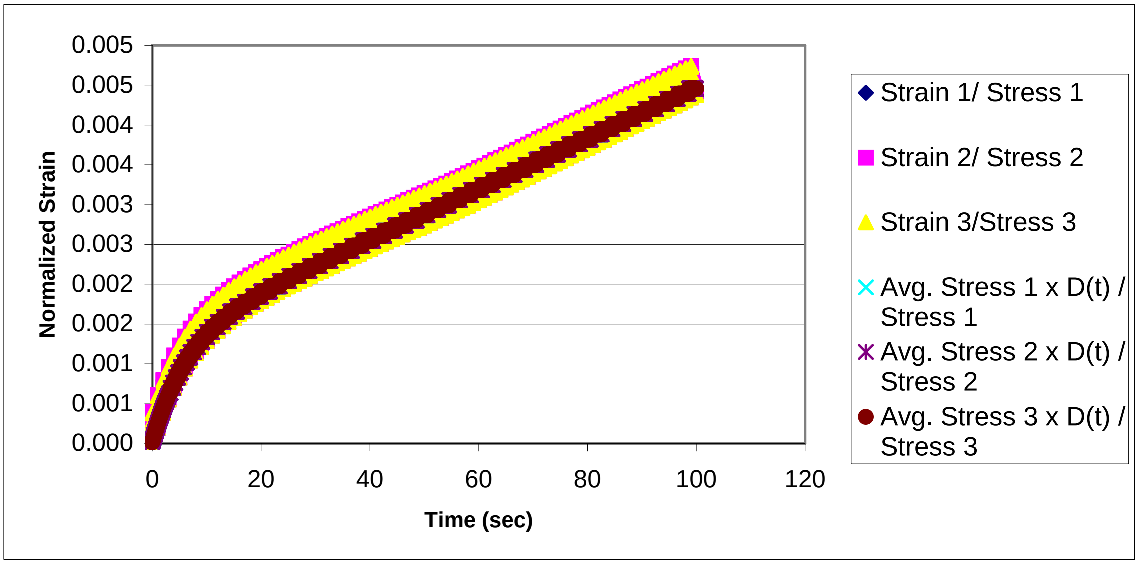

Figure 10. Normalized Behavior of Linear Viscoelastic Materials under Repeated Loading

In order to identify a proper rheology model, rutting using RAWT under three different loading levels, 10, 13, and 15 N, resulting in maximum shear stresses of 140, 177, and 205 kPa, were performed at a constant loading rate, 75 cycles per minute, and temperature, 45°C. Since this test was not designed as a shear modulus test, deformations were used instead of strains. However, the deformations may not vary from sample to sample in the same mix, because the geometry of the samples made was approximately equal. All deformation curves from the tests performed on two different mixes, coarse-graded and fine-graded mixes, were plotted in Figures 11 and 12, and their normalized deformation curves, which were divided by applied stresses, were also plotted in Figures 13 and 14. Three normalized curves of each mix were clearly superposed on one deformation curve. Consequently, it is concluded the linear vicoelastic model is valid on the mixtures, and the stress levels remain in a linear viscoelastic range.

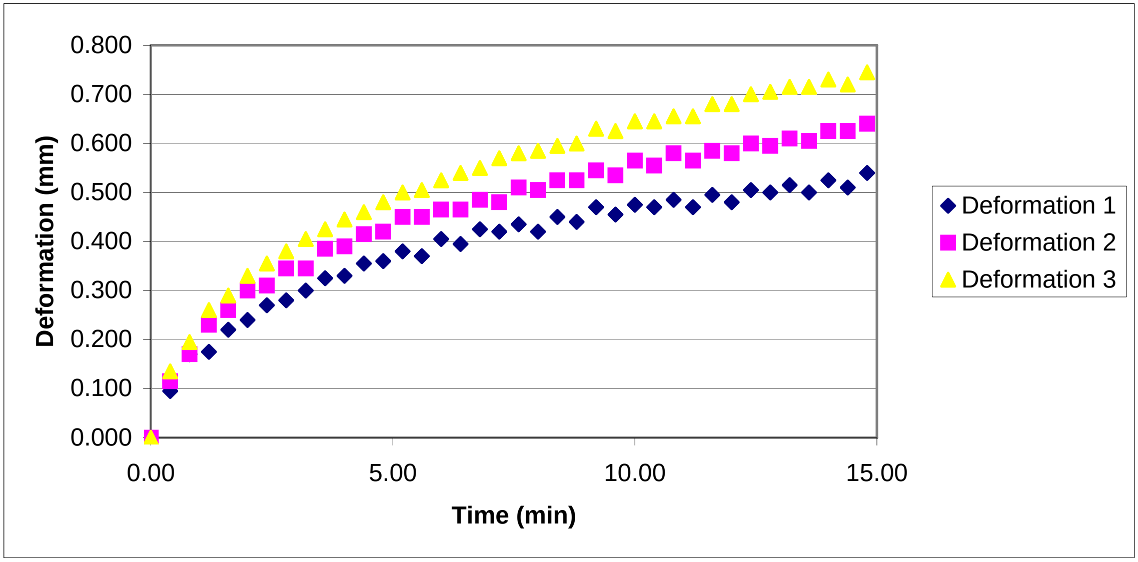

Figure 11. Deformations under Different Stress Levels (Coarse Mix)

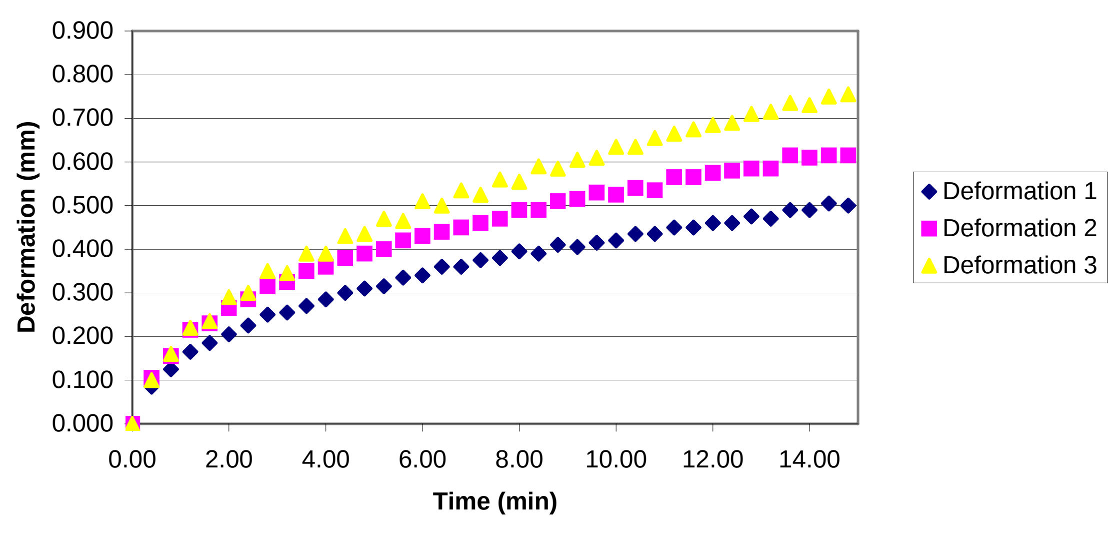

Figure 12. Deformations under Different Stress Levels (Fine Mix)

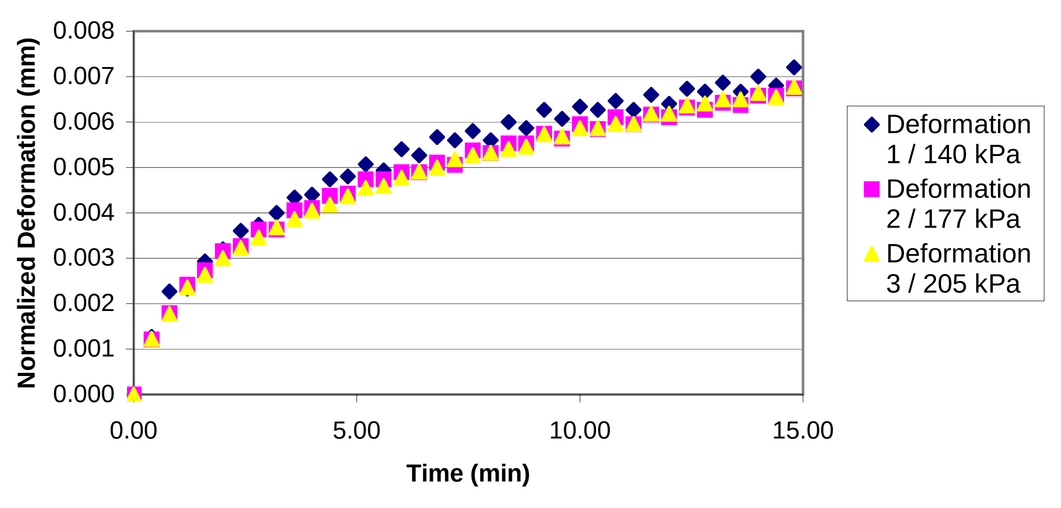

Figure 13. Normalized Deformations (Coarse Mix)

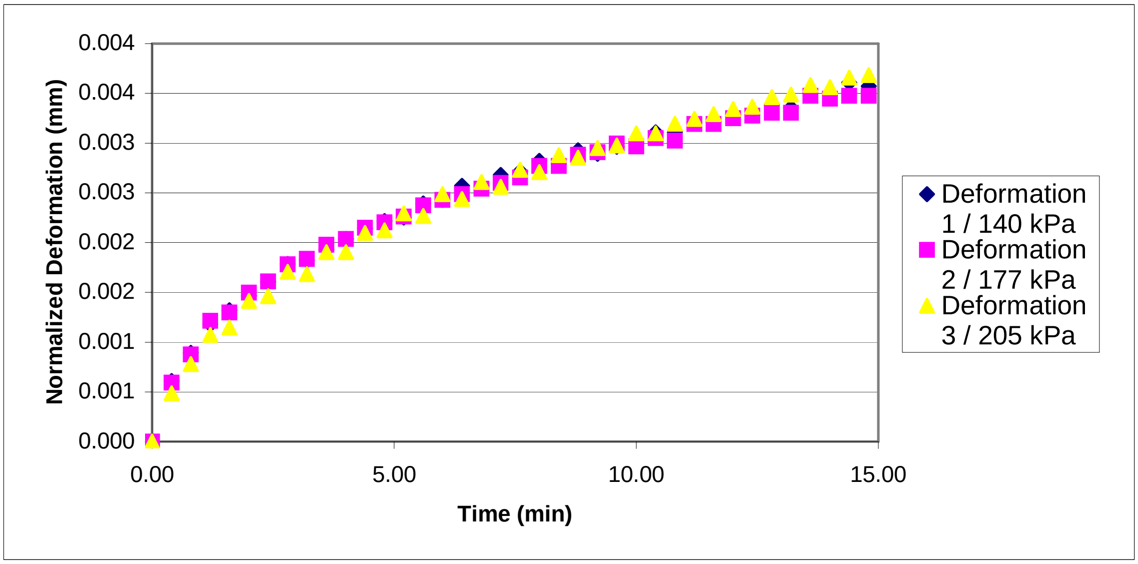

Figure 14. Normalized Deformations (Fine Mix)

INVESTIGATION OF SHEAR FAILURE OF HMA

One popular shear failure criterion is the well-known Mohr-Coulomb failure theory. This theory is the most widely accepted failure criterion for characterizing the strength of unbound granular materials or fine-grained soils subjected to various confined stress conditions. This approach however may not be effective for a material that exhibits time and temperature dependence. Therefore, a more effective failure criterion, characterizing the shear failure of asphalt mixtures, needs to be identified

Zhang et al. (2001), Roque et al. (2002), and Birgisson et al. (2002) proposed a fundamental failure mechanism for evaluating the cracking performance of asphalt mixtures. In their work, the failure of asphalt mixtures is governed by two properties: energy dissipation and energy threshold. Specifically, a crack will initiate and/or grow when energy dissipated from a mixture exceeds the energy threshold of the mixture at any point in the material. Kim et al. (2003) reported that the energy threshold could be determined from a point where a macro crack begins from a long-term creep test performed up to failure. They also showed the energy threshold obtained from the creep test has a good agreement with those obtained from fatigue and tensile strength tests. This implies the energy threshold is a fundamental material property that is independent of loading mode or loading history. In this study, it is of particular interest to determine whether the failure mechanism proposed can be used as a failure criterion that determines energy threshold of mixtures subjected to shear stresses at high temperature.

From the literature, energy dissipation can be accurately determined by the rate of creep compliance, represents an energy dissipation rate of viscoelastic materials. Hence, it is recommended to perform a creep test using a static load to determine the linear slope of the creep compliance curve in the second stage, but it also possible to determine the creep compliance rate of a mixture from a repeated loading test as shown before. However, the compliance rate of a mixture can be determined only when the applied average stress, which can be obtained from exact stress distribution over time, and accurate strain are known. Since only applied maximum shear stress and deformation are available from the RAWT test, it is feasible to use “pseudo compliance rate.” Here, pseudo compliance rate represents a slope of a creep deformation curve at steady state divided by maximum shear stress applied. Although the value of the pseudo compliance rate is not the same as the true creep compliance rate of a mixture, it is necessary to note that the pseudo compliance rate is, in principle, the same material property as a true creep compliance rate that is constant in the same mixture, whereas only its relative value is different. To obtain the pseudo compliance rate, a power function (Equation 4), which is widely used to interpret creep data, was used to fit the deformation curves, and the pseudo compliance rate $\dot{D}_{pseudo}$ was determined from maximum shear stress $\tau_{\max}$ and the slope at the point at which the secondary stage begins bmt_{steady}^{m-1} (Equation 5). Besides, the compliance rate of a mixture should be decided from a relatively undamaged steady state. A 15-min loading period (t_{steady} = 15 min) appears appropriate for determining the compliance rate at the steady state. The pseudo compliance rates obtained from three different loading levels applied to two different mixes are presented in Figure 15.

$$d(t) = a + bt^{m} \tag{4}$$

where,

a, b, m: regression coefficients

$$\dot{D}_{pseudo} = \frac{\dot{d}(t_{steady})}{\tau_{\max}} = \frac{b \cdot m \cdot t_{steady}^{\ m-1}}{\tau_{\max}} \tag{5}$$

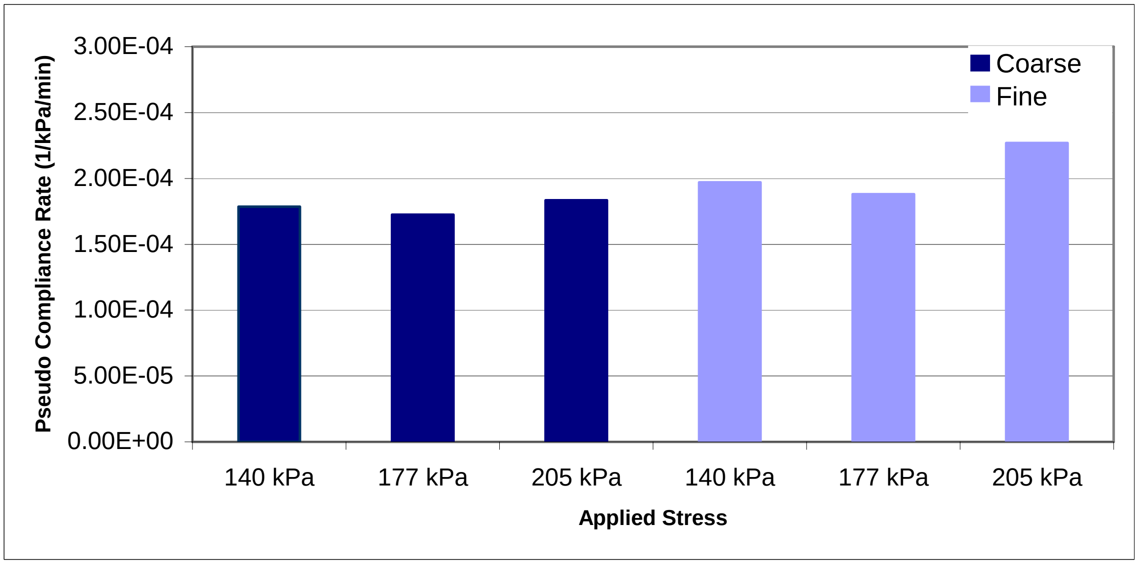

Figure 15. Pseudo Compliance Rate

To apply the concept of energy threshold, it is important to identify the point at which a macro crack initiates. By examining the deformation curves performed up to failure (Figure 16), a S-shape function, which is used for fitting S-shape data (Equation 6), could be applicable to an inverse time-deformation data plot. To do this, time data were assigned to y axis, while the deformations were assigned to x axis. From the six deformation curves fitted by the function used, a strong correlation with measured deformation data (average R2 = 0.999, R2 > 0.998 in all cases) was obtained.

$$y(x)=\frac{\beta_0-\beta_3}{1+\left(\frac{x}{-\beta_2}\right)^{-\beta_1}}+\beta_3 \tag{6}$$

The parameters have the following interpretations:

β_0: value of y at the lower end of the curve

β_1: a measure of the slope

β_2: concentration (x) corresponding to the value of y midway

β_3: value of y at the upper end of the curve

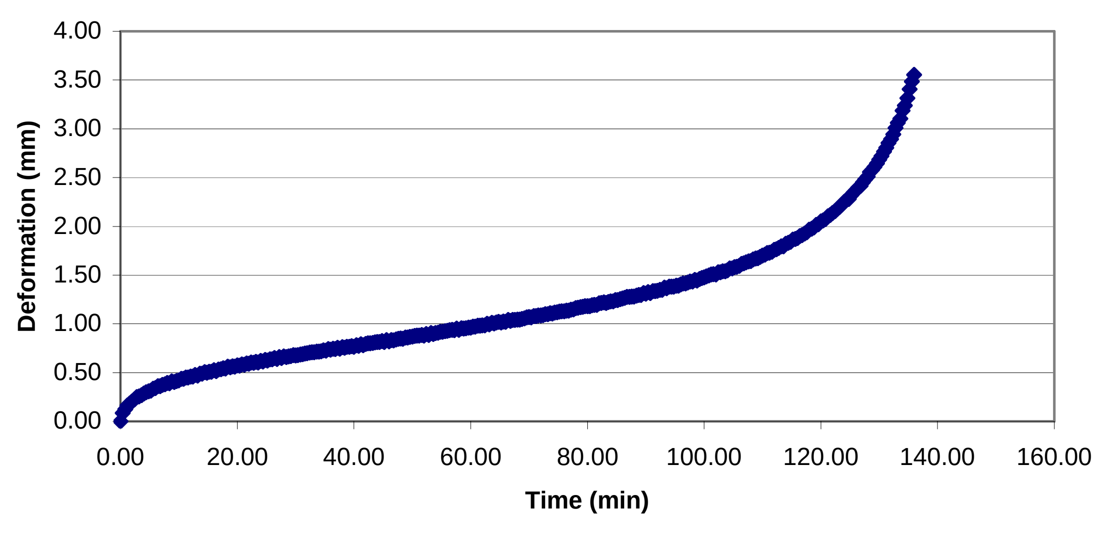

Figure 16. General Plot of Rut Dept versus Time Data

The S-shape function is an efficient nonlinear model to identify the point at which a macro crack initiates and provides computational simplicity. From the inverse plot of deformation versus time data (Figure 17), if a macro crack occurs at a certain point, the slope of the S-shape function begins to rapidly decrease. The point can be identified as a minimum value in the plot of a second derivative of the S-shape function d^2y/d^2x (Figure 17). Consequently, the minimum value will be the point where a macro crack initiates t_c. Figures 18 and 19 show deformation curves where the failure times were determined. It shows that the failure times are well matched with failure times that can be visually identified from the plot.

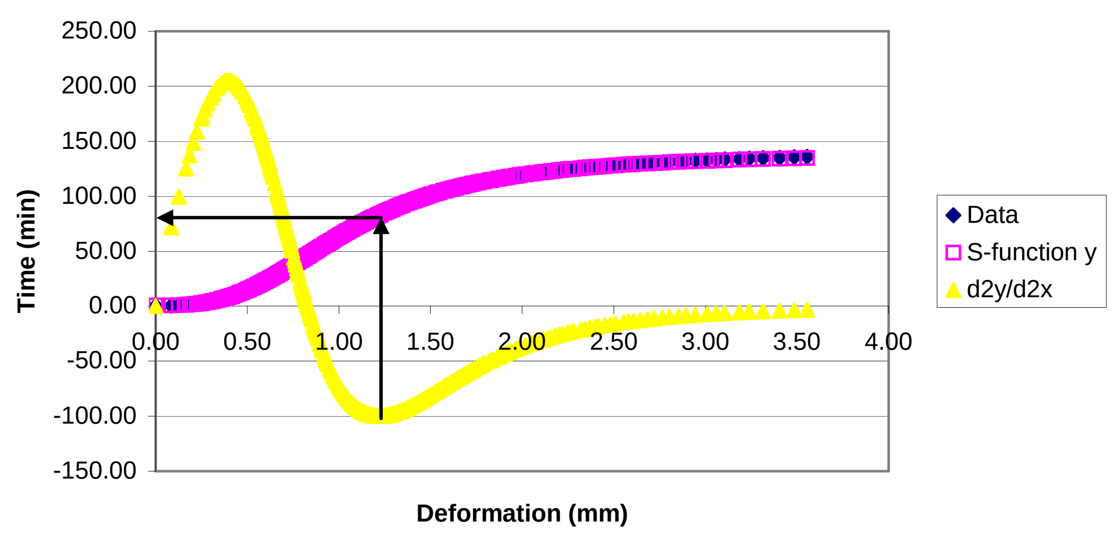

Figure 17. Description of Capturing Macro Crack Initiation

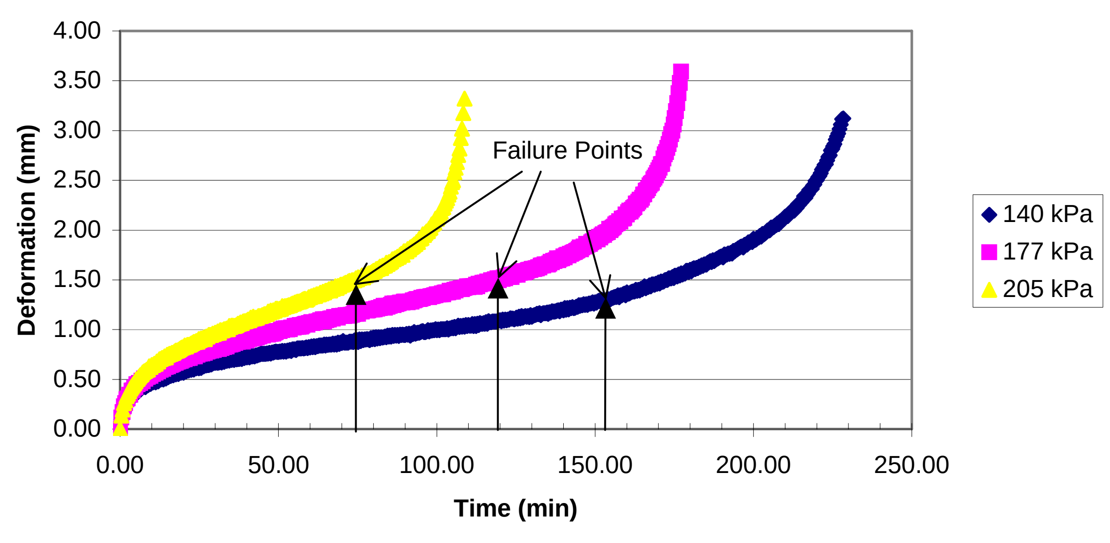

Figure 18. Deformation Curves with Failure Times (Coarse Mix)

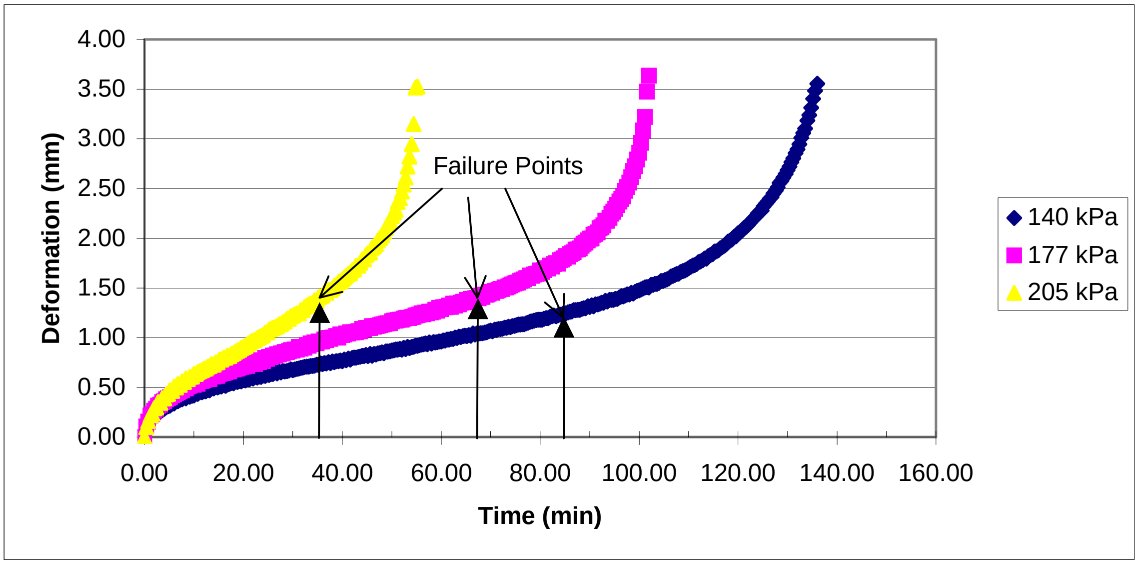

Figure 19. Deformation Curves with Failure Times (Fine Mix)

Energy threshold, which is defined as dissipated creep strain energy *DCSE* by the authors (Zhang et al., 2001, Roque et al., 2002, and Birgisson et al., 2002), can be obtained from a creep test (Equation 7). However, energy threshold obtained by use of the pseudo compliance rate may not be the same as its original definition. Due to this limitation, “pseudo energy threshold” was evaluated instead of creep strain energy. This was accomplished by replacing the creep compliance rate of a mixture $\dot{D}(t_{steady})$ and the applied static load σ_0 with the pseudo compliance rate $\dot{D}_{pseudo}$ and the maximum shear stress τ_{max}, respectively, but it should be noted that the pseudo energy threshold is also a constant material property, whereas only its relative value is different compared to the dissipated creep strain energy threshold.

$$DCSE = \int_0^{t_c} \sigma_0 \cdot \dot{\varepsilon}(t_{steady})dt = \int_0^{t_c} \sigma_0{}^2 \cdot \dot{D}(t_{steady})dt = \sigma_0{}^2 \cdot \dot{D}(t_{steady}) \cdot t_c \qquad (7)$$

Figure 20 shows that the pseudo energy threshold obtained from the coarse and fine-graded mixes subjected to three different stress levels, 140, 177, and 205 kPa. Although some variations between mixtures are present, pseudo energies are approximately equal in the same mix. Furthermore, the trend of pseudo energy generally has an inverse correlation to that of the pseudo compliance rate shown in Figure 15. The inverse correlation is in accordance with the premise that a lower value of a compliance rate represents less susceptibility to damage growth and results in increase of energy tolerance. Consequently, dissipated creep strain energy threshold appears constant in an asphalt mixture and suitable to be used as a failure criterion that determines mixture's energy tolerance in shear.

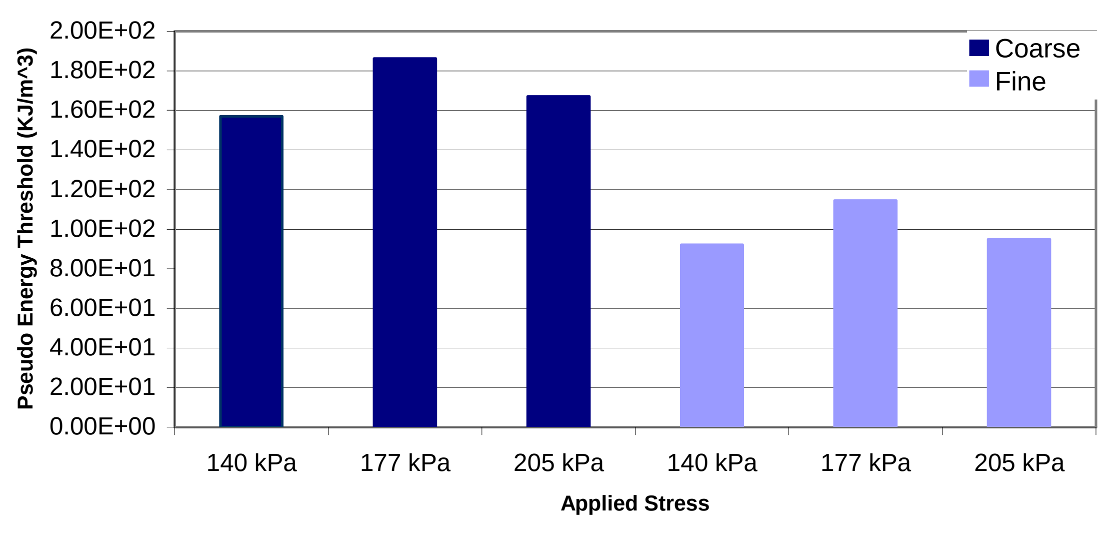

Figure 20. Pseudo Energy

DEVELOPMENT AND EVALUATION OF A SHEAR FAILURE CRITERION

According to NCHRP Report 465 (Witczak et al., 2002), it was reported the time or the number of cycles at which the macro crack initiates is the most important factor that determines the rutting performance of asphalt mixtures. However, the study has not provided clear mechanistic explanation, and also it was limited in applying its test result to various stress states obtained from in-place pavements.

Based on the research work performed in this study, the shear failure of an asphalt mixture subject to repeated loading was governed by two properties: pseudo energy dissipation and pseudo energy threshold. When accumulated energy dissipated from a mixture reaches its energy threshold, a macro crack, which is expressed as rapid increase of the creep rate at the tertiary stage, initiates and propagates. Conversely, the failure time or cycle number at which the macro crack initiates could be determined from the relation between pseudo energy dissipation and pseudo energy threshold. From this observation, “shear failure time”, which can be defined as the pseudo energy threshold of a mixture divided by the applied maximum shear stress and its pseudo creep rate measured, was developed as shown in Equation 8. The benefit of shear failure time are the rutting performance of mixtures can be characterized as a single parameter, and the input shear stress can be varied and replaced as more realistic stress.

$$Shear\ Failure\ Time = \frac{Pseudo\ Energy\ Threshold}{\tau_{\max}{}^{2} \cdot \dot{D}_{pseudo}} \tag{8}$$

In order to estimate realistic stress, a typical pavement structure with a low elastic modulus on a hot summer day was assumed as shown in Figure 21. Since the primary focus of this study was to evaluate instability rutting, highest maximum shear stress, 135 kPa, was obtained from the maximum shear stress distribution near the surface of the asphalt layer using the elastic layer computer program BISAR (De Jong et al., 1973). The highest maximum shear stress was then used as the input stress for the determination of the shear failure time of the coarse-graded and fine-graded mixes used in this study. From this analysis, the coarse-graded mix appears to have higher rutting resistance than the fine-graded mix as shown in Figure 22.

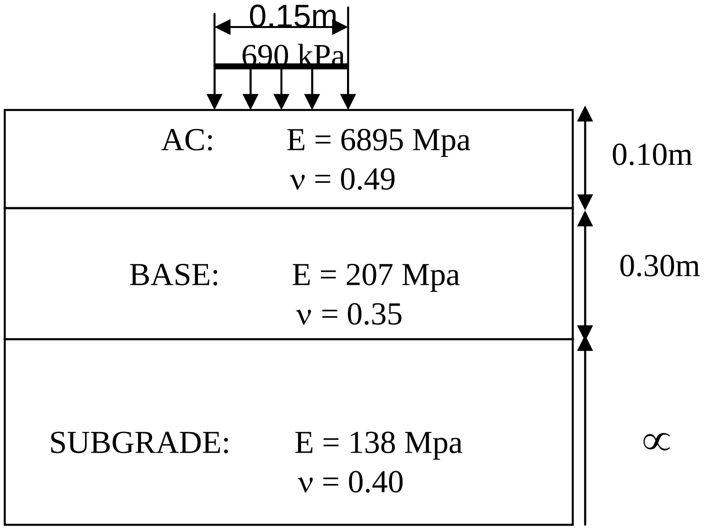

Figure 21. Schematic of Pavement Systems Used.

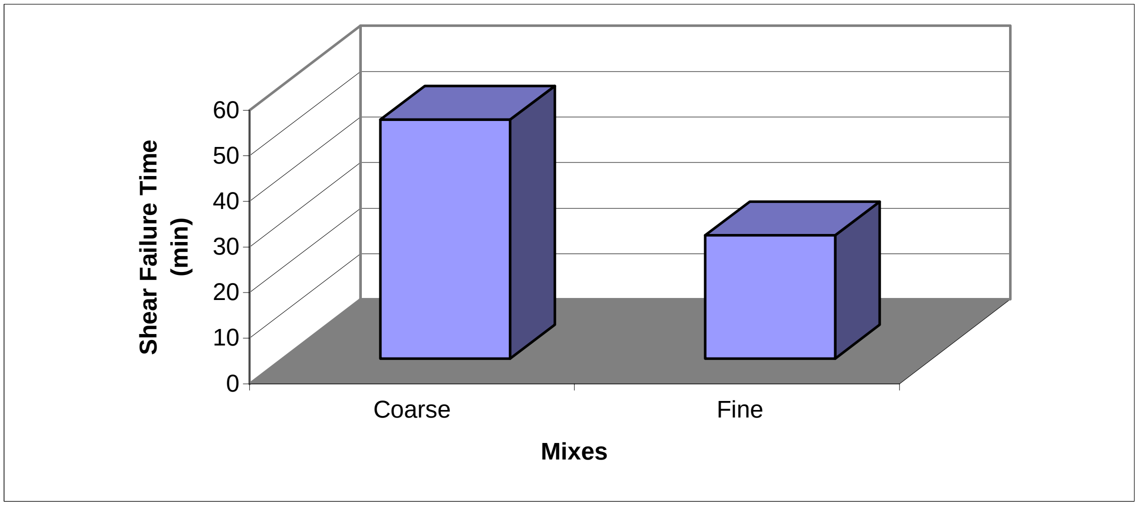

Figure 22. Shear Failure Times of Coarse and Fine Mixes

To ensure the performance evaluation, the coarse-graded and fine-graded mixes were tested using Asphalt Pavement Analyzer (APA) recommended by AASHTO TP 63-03. The results of six coarse and six fine-graded specimens from APA tests are summarized in Table 1. Although some variability is present from sample to sample, the average rut depth of each mix indicates that the coarse-graded mix performs better than the fine-graded mix.

Table 1. APA Test Results

No. of Spec.	Coarse Mix Rut Depth (mm)	Fine Mix Rut Depth (mm)
1	2.35	2.90
2	3.05	2.05
3	3.10	3.45
4	3.35	3.05
5	2.80	3.65
6	2.75	3.90
Average	2.90	3.17

SUMMARY AND CONCLUSIONS

The primary focus on this research was to identify a rheology model and a failure criterion, characterizing the rutting behavior of dense-graded asphalt mixtures. To this purpose, coarse and fine-graded mixes were prepared and tested using the Rotary Asphalt Wheel Tester (RAWT) at three different stress levels. Based on a rigorous analytical study, a linear viscoelastic model appears suitable to characterize the material response of asphalt mixtures, and an energy-based failure criterion, employed to generalize the failure of mixtures in shear, appears to be used as a shear failure criterion. In addition, a single parameter, shear failure time, developed in this study was compared to APA test results indicating that shear failure time could be used as a good indicator for assessing the rutting potential of asphalt mixtures.

Based on the findings of this investigation, the following conclusions can be made:

- Under the limited testing conditions (e.g., loading levels, loading rates, and temperature) the linear viscoelastic approach appears valid and suitable to characterize the physical behavior of asphalt mixtures at high temperature.
- Energy threshold, which is used for characterizing the cracking resistance of asphalt mixtures in tension, appears to be a valid failure criterion of asphalt mixtures in shear as well.
- Shear failure time, which is developed from the rigorous analytical study performed in this research, appears to have great potential for evaluating a mixture's potential for ultimate rutting performance.
- Although it is still under investigation, the Rotary Asphalt Wheel Tester (RAWT), which is newly developed as a tool to evaluate the rutting potential of asphalt mixtures, appears to provide consistent, reliable test data.

RECOMMENDATIONS

The following recommendations are based on the findings and conclusion from this research:

- The information from the Rotary Asphalt Wheel Tester (RAWT) is currently insufficient and limited. It is expected that by adopting optional configurations, such as more frequent data acquisition, that can be controlled by users, the device will be more improved and enhanced.

- At this point, this research is limited to identifying a failure mechanism of rutting and developing a framework to evaluate the rutting potential of asphalt mixtures. The developed failure criterion still requires validation utilizing field performance data.
- The physical behavior of asphalt mixtures was only investigated under the limited testing conditions (e.g., loading levels, loading rates, and temperature). The testing parameters are not conclusive at this stage. By expanding the testing conditions to a broader range, it is expected that a reliable conclusion will be made.

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