Project: WHRP (0092-14-20)

TPF-5 (302)

Modified Binder (PG+) Specifications and Quality Control Criteria

Task Report:

White Paper on:

Evaluation of Intermediate Temperature PG and PG+ Test Methods for Fatigue and Durability of Asphalt Binders

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May 2016

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Executive Summary

In the Task report #2 of this project, correlations between conventional PG + measures and new DSR based tests were evaluated. Based on these correlations, parameters determined from the LAS test (AASHTO TP101), and the BYET, which is now listed as the AASHTP TP123-Method A, were found to be good candidates to replace some of the PG+ conventional tests currently used to evaluate the fatigue cracking resistance of asphalt binders. The LAS and BYET are DSR-based test procedures and thus offer advantages regarding reduced time and effort to test binders as compared to the PG+ tests. In addition they show the potential for measuring engineering properties that are pavement performance related. Table 1 is copied from the Task report #2 in which the best alternatives to the conventional PG+ tests are shown, and the justification for the replacement recommendation.

Table 1- Recommendations for replacing PG + tests targeting intermediate temperature properties

Engineering Property or Distress	**Partner State Objective**	**Preliminary Recommendation**	**Justification**
Intermediate temperature elasticity and fatigue cracking	***Replace*** T51 ductility	Binder Yield Energy Test (BYET) - *Strain at Max. Stress* 5 °C	Logical ranking of modification types; good correlation between tests; no change in sample geometry; less material intensive; easier to run
	Replace toughness and tenacity	BYET *yield energy* at 25 °C.	No change in sample geometry; easier to run; widely available
	Address intermediate temperature (fatigue) cracking potential	Linear Amplitude Sweep (LAS) *Cycles to Failure*	Damage characterization test; DSR-based; evidence of correlation to field performance in Wisconsin
		BYET *yield energy at intermediate PG*	Easy to run; same geometry as current G*sinδ, widely available. Correlated well to full scale testing in ALF

Although recent studies showed a strong correlation between field cracking and LAS or BYET test results, the method of analysis for LAS data requires some advanced mathematical and model fitting skills for interpretation. The analysis of the BYET shows some challenges regarding effect of temperature and the difficulties of defining the yield point. Therefore, the objectives of this white paper are as follows:

- Compare LAS testing results with other simpler testing methods such as the Binder Yield Energy Test (BYET), ductility, or Elastic Recovery (ER) to determine if these simpler tests can be used as surrogates to indicate binders' fatigue cracking resistance.
- Discuss the need for changing the existing parameter (G*sinδ) and the practicality / feasibility of the LAS procedure, which has shown promise as an indicator of cracking resistance of pavements.

- Propose an implementation strategy for the LAS, and the simplest alternative, that can represent field cracking and recommend preliminary specification limitations based on the data collected from testing binders from the Pooled Fund Member states.

The analysis of the results indicates that there is no correlation between the LAS test results and any of the PG+ conventional tests such as ductility, toughness and tenacity, and elastic recovery. The analysis also shows that using the LAS cycles to failure (Nf) is not necessarily a user friendly task as it required advanced mathematical fitting and calculations. Results to date show that there is potential for using simpler alternatives to the LAS Nf which include the following parameters:

- LAS strain at peak stress measured at IT of PG grade using the TP101 procedure.
- Energy to 2500% strain measured using the BYET procedure at 25 C following TP123-Method B.

The challenge is to determine proper limits for standard specifications for either of these parameters. There are only two field studies with limited results (one in Wisconsin and the other is at the FHWA-ALF), both showing good correlations. Therefore tentative specification limits based on simple ranking of the binders in each state are proposed in this paper. In addition, mixture fatigue data to be collected in this pooled fund, and the field surveys discussed with member states, could be very critical to validate or calibrate the proposed specification criteria for binder fatigue.

Finally it is critical to note that the results of the study show that the changes to the limits for the $G^*.\sin\delta$ from 5000 kPa to 6000 kPa in the AASHTO M332 for the H, V, and E grades could result in more risk of fatigue cracking. The results of testing a large number of binders from the WCTG group show that fatigue life as measured in the LAS at PG-IT decreases significantly with higher $G^*.\sin\delta$ values. It is thus recommended that States re-consider this change, and instead use lower $G^*.\sin\delta$ limits as the traffic level increases. In other words, the limits for H, V, and E grades should decrease sequentially similar to the Jnr value limits.

Correlation of LAS results with Cracking of Mixtures and Pavements

In the current PG grading systems (including AASHTO M320 and M332) the parameter of G*sinδ is used as the control for fatigue cracking at intermediate temperatures. The validity and effectiveness of this parameter to determine contribution of modified binders to fatigue cracking has been questioned in many studies, and thus a few Highway Agencies have opted to amend the parameter with PG + testing such as Ductility and Toughness and Tenacity, or rely on tests to maintain a certain binder formulations that have worked well in the field, such as the Elastic Recovery.

Due to the uncertainties with these PG+ tests, one of the primary objectives of this Pooled Fund study is to:

> "…Validate and establish relevance of suggested new PG+ and quality control procedures in terms of mixture performance."

To date, the Linear Amplitude Sweep (LAS) test, which is a DSR-based binder test method, has shown promise in providing an indication of actual field performance. A study was conducted through the Wisconsin Highway Research Program that correlated LAS testing results with actual field cracking [1]. In this study, performance of seven field sections were compared with LAS and Superpave test results. From the LAS test, two parameters are generated from the testing method: A and B, which take the following form:

$$N_f = A\gamma^B$$

Where A and B are fatigue law fitting parameters and γ is the strain level of interest in the pavement. This equation is best understood graphically as shown in **Figure 1**.

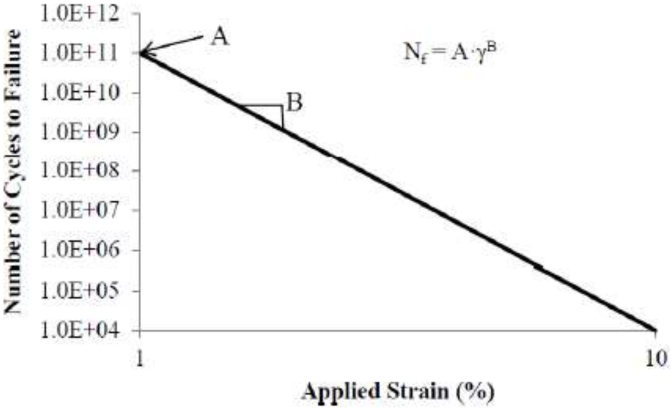


Figure 1: Fatigue law schematic for equation 1 [2].

The fatigue law parameter "A" represents the intercept while the parameter "B" is the asphalt binder's N_f (cycles to failure) sensitivity to strain applied (slope of the fatigue law line). A binder with a higher "B" parameter will have a greater reduction in N_f with increasing strain level.

In the WisDOT-WHRP study, several LAS parameters were correlated with the percentage of cracked field sections to determine which of the LAS parameters most accurately correlates with field performance. Results of the study concluded that the N_f value at 2.5% strain measured at the PG Intermediate Temperature shows the highest correlation with cracked field segments as shown in Figure 2.

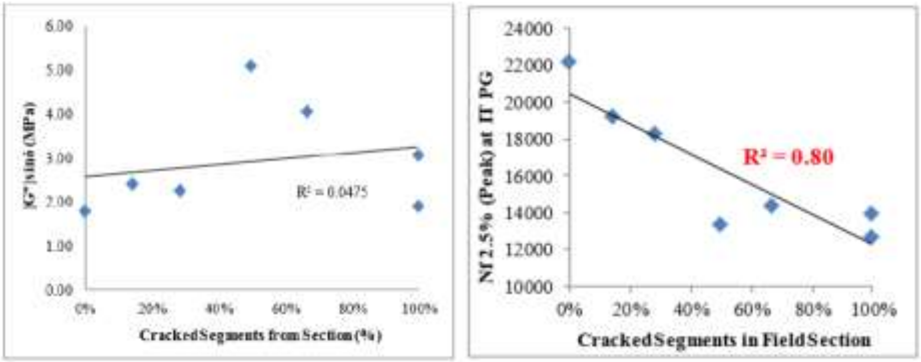


Figure 2: Results comparing field cracking sections to LAS at 2.5% strain and the G*sin δ parameter.

As can be seen in the Figure, LAS results show a high correlation with actual field cracking performance while there is no correlation with the Superpave G*sinδ parameter.

In a separate study conducted at the University of Wisconsin, two laboratory mixtures were prepared for Indirect Tension Fatigue testing [3]. The number of cycles to failure or N_f values of the mixtures was correlated with the LAS N_f at 2.5% strain and the Superpave G*sinδ of each corresponding binder. Results of the study are shown below in **Figure 3**.

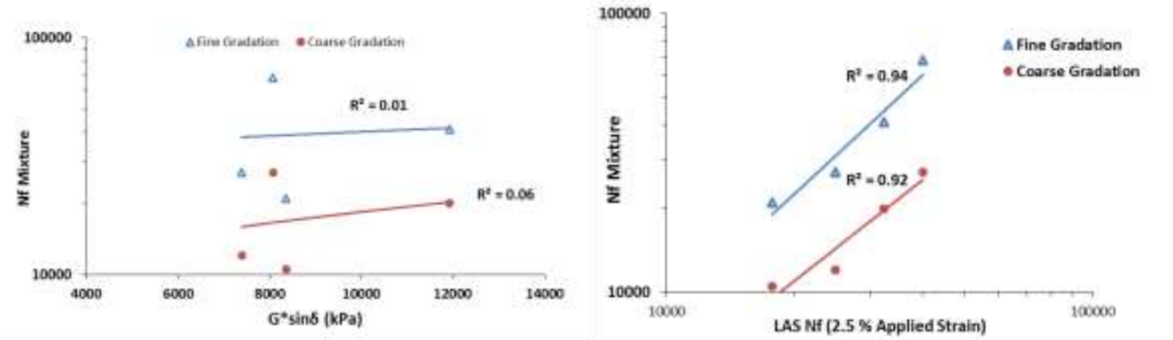


Figure 3: Correlation between laboratory mixture fatigue (Nf mixture) and binder testing results (G*sinδ and LAS N_f at 2.5% strain).

Results from the laboratory mixture performance testing validate the results measured from the WHRP field cracking study. LAS N_f at 2.5% strain has the higher correlation with mixture performance measures in comparison with Superpave parameter.

Despite the high correlations between LAS and mixture/field performance, the LAS procedure (AASHTO TP101) has yet to be considered for implementation into state specifications. One factor that may contribute to this delay in implementation is the advanced mathematical fitting analysis required to estimate the fatigue life N_f of the binder. There exists an excel spreadsheet template that is capable of analyzing data from the LAS testing results, but the template requires an understanding of the Visco-Elastic Continuum Damage (VECCD) concepts and may make the use of the software and confidence checks difficult for operators.

Given the promising correlation between LAS testing results and mixture or pavement performance, the following sections aim to identify other binder testing measures that can most closely correlate to the LAS testing N_f values. The Western Cooperative Testing Group (WCTG) binder database, and the current Pooled Fund database, were used to determine which candidate test methods allow determining parameters that correlate with the LAS. For those parameters that show promise correlating with the LAS testing results, usage and implementation considerations are discussed at the end of the white paper.

Correlations of simpler parameters with LAS Nf parameter

The LAS parameter N_f at 2.5% strain is correlated with the following PG+ binder testing parameters:

- **The Binder Yield Energy Test (BYET)-** AASHTP TP123 Method A, which determines three parameters:
    - *Yield Energy,* is calculated as the summation of the area under a given binder's stress-strain curve up to the yield (maximum) stress. Yield energy of an asphalt binder sample is intended to indicate and asphalt binder's resistance to fatigue damage [4].
    - *Energy to 2500% strain,* this property is calculated as the area under the stress versus strain curve to the strain level of 2500%. The benefit as compared to the Yield Energy is that post yield binder behavior can be captured..
    - *Strain at peak stress*: This parameter is also determined from the BYET test but with no calculation of energy. The strain at peak stress is known as a measure of binder's ductility or strain tolerance before yielding starts.
- **Ductility** (ASTM D 113): Ductility is a measurement of an asphalt binders' elongation to failure using a dog-bone shaped specimens in a large temperature controlled bath.
- **Elastic recovery** (AASHTO T301 and AASHTO TP123- Method B): elastic recovery is a measurement of an asphalt binder's ability to recovery strain after loading. Two procedures were used in this study: AASHTO T 301/ASTM D6084 and AASHTO TP123. T301 is conducted in a large water bath with dog-bone shaped specimens and the AASHTO TP123-Method B procedure is conducted in a DSR with 8 mm plates.

Although in the WHRP study it was recommended that LAS be conducted at the PG intermediate temperature, the T301/D6084 and Ductility tests are run mostly at 25 C. Therefore to avoid confounding the effects of aging and temperature, Many binders were tested using the LAS procedure at 25 °C and at IT-PG temperature. The correlations at PG – IT and at 25 C are shown in **Table 1 and Table 2,** respectively.

Table 1: Correlation between LAS N_f at 2.5% strain measured **at PG-IT temperature** and PG+ and candidate testing methods.

Testing Method	PG+ Testing Temperature, °C	Aging Condition	LAS Aging Condition	Correlation with LAS at PG-IT R^2 - value
BYET Energy to 2500% Strain	25	PAV	PAV	0.58
Elastic Recovery (T301)-Exponential fit	25	RTFO	RTFO	0.17
Tenacity	25	Unaged	RTFO	0.11
BYET Strain at peak Stress	IT-PG	PAV	PAV	0.13
BYET Strain at peak Stress (correlation is illogical)	25	PAV	PAV	0.09
Toughness	25	Unaged	RTFO	0.06
BYET Energy to 2500% Strain	IT-PG	PAV	PAV	0.00
Ductility	4	RTFO	RTFO	0.04
Ductility	25	Unaged	Unaged	0.00
BYET Yield Energy	25	PAV	PAV	0.00
BYET Yield Energy	IT-PG	PAV	PAV	0.00
Elastic Recovery (ER DSR)	25	PAV	PAV	0.00

As shown in **Table 1**, there is a very poor correlation between each PG+ binder method result with the LAS N_f at 2.5% measured at PG-IT temperature with the exception of Energy to 2500% strain measured at 25 C. This correlation is difficult to explain since the LAS and BYET are both very sensitive to change in temperature, and therefore having high correlation at different temperatures is difficult to explain.

In order to better understand the effects of temperature and aging condition on the correlation with LAS N_f in this case, all binders were tested using the LAS procedure at 25 °C and correlated with other procedures as shown in **Table 2** below. The results confirm that the Energy at 2500% strain has the highest correlation, but it remains very poor when the LAS is done at 25 C.

Table 2: Linear correlation between candidate testing methods and LAS Nf at 2.5% strain measured at 25 °C.

Testing Method	Testing Temperature, °C	PG+ Aging Condition	LAS Aging Condition	Correlation with LAS results at 25 C R^2 - value
BYET- Energy to 2500% Strain	25	PAV	PAV	0.14
Elastic Recovery DSR	25	PAV	PAV	0.10
BYET-Yield Energy	25	PAV	PAV	0.05
BYET-Strain at Peak Stress (Correlation is illogical)	25	PAV	PAV	0.03
Elastic Recovery (T301)	25	RTFO	RTFO	0.00

Results of this analysis highlight the finding that none of the current PG+ (ductility, toughness and tenacity, and Elastic recovery) are good candidates to be used as surrogates for the LAS test to determine Nf at 2.5% strain. However the analysis shows the potential of using the BYET as a surrogate to LAS. This is encouraging since at least one full scale study at FHWA has shown the BYET to relate to pavement performance, it is a DSR-based test, and it is easier to analyze than the LAS.

The selection of BYET Parameters

Although reasonable trends in correlation between LAS and BYET were observed, an acceptable correlation was only observed when the Energy at 2500% strain was used, and results at 25 C for the BYET are correlated with results for the LAS at PG-IT (see Table 1).

To explain the selection of the energy at 2500%, a review of the details of results is needed. In order to calculate the yield energy, the area under the stress strain curve is calculated to the maximum stress, as shown in **Figure 4**.

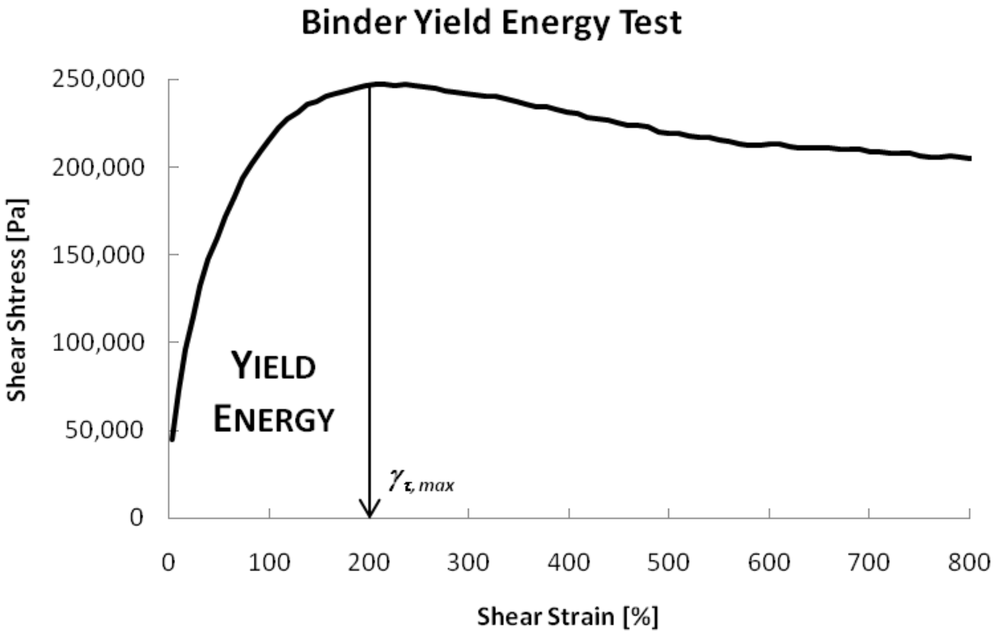


Figure 4: Stress-strain schematic demonstrating how stress strain curves are determined from the BYET test [4].

In the schematic shown in **Figure 4** there is a clear well defined yield or maximum stress after which the stress gradually decreases to a constant value. Different types of binder modification can result in stress-strain curves that take different shapes, and in some cases, it is difficult to estimate the true yield (maximum) stress value. A good example is shown for 2 binders, one with a well-defined peak, while another with undefined peak is shown in **Figure 5.**

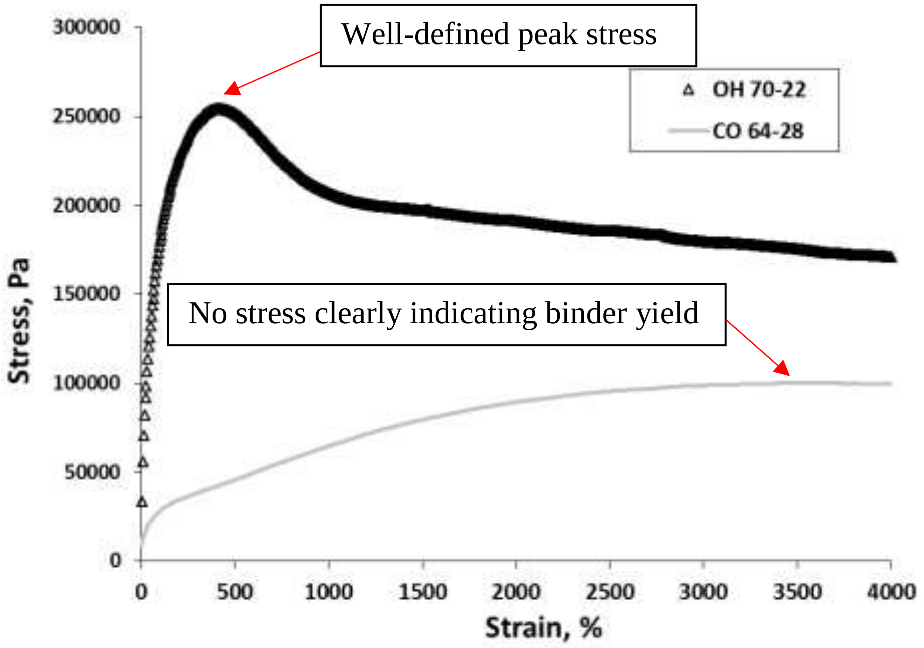


Figure 5: Comparison between two distinctly different stress-strain curve types as measured by the BYET procedure at 25 °C.

For the binders shown in **Figure 5**, one has a clear peak stress at around 373% strain and the other does not reach a maximum stress until 3574% strain. In this example, the CO 64-28 binder has a yield energy greater than any binder included in this study, but the OH 70-22 binder is able to maintain a stress higher than that off the CO 64-28 binder through the end of the BYET test. By specifying the strain up to which the energy is calculated (2500%), the CO 64-28 is properly ranked with respect to the other binders.

Changing the temperature makes the process of defining a peak stress (Yield) more troublesome. As shown in **Figure 6**, when the same binders are compared at 4 °C, they behave much differently, and while the Ohio binder shows double peak behavior, the CO binder now shows a much clearer peak stress and more of a ‘normal’ yielding behavior. The post peak stress-strain curve for the OH 70-22 binder could be the result of limited de-bonding from the Dynamic Shear Rheometer parallel plates and/or partial cohesive failure.

To understand if the strain at the peak stress at 4 C and 25 C are related, the plot shown in Figure 7 is prepared. As can be observed, the strains at the two temperatures are related and show a correlation higher than 50 %. The two binders that are out of the correlation line (shown with circles around data points) are from Colorado; the State of Colorado requires the ductility test at 4 C, which could explain the unique behavior as compared to other binders. The results of the correlations of strain at peak stress shows that there is a fair trend confirming the behavior of binders within the range of 4 C to 25 C, which is the critical range for fatigue cracking. In other words, relative resistance to cracking could be similar and not critically dependent on the testing temperature within this range.

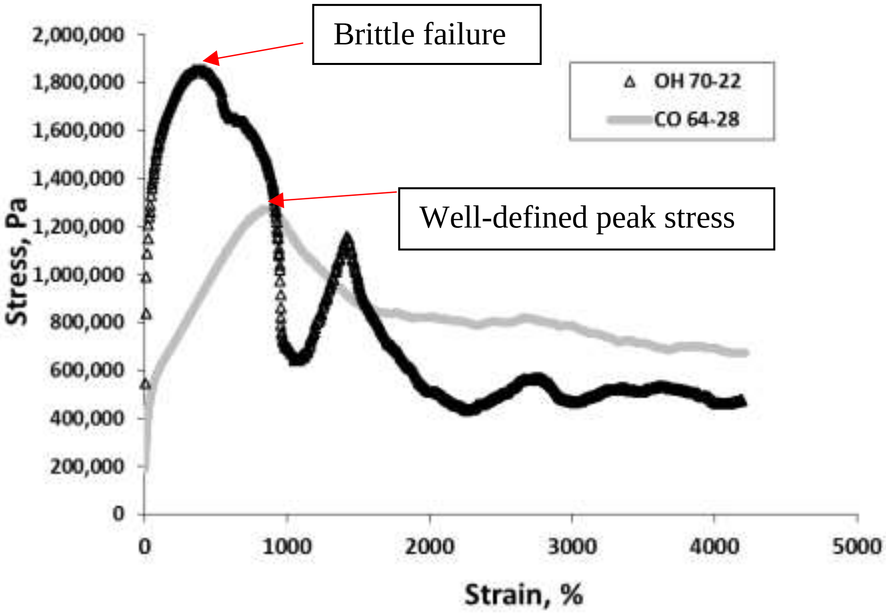


Figure 6: Stress strain curves clearly showing differences in binder yield at different temperatures.

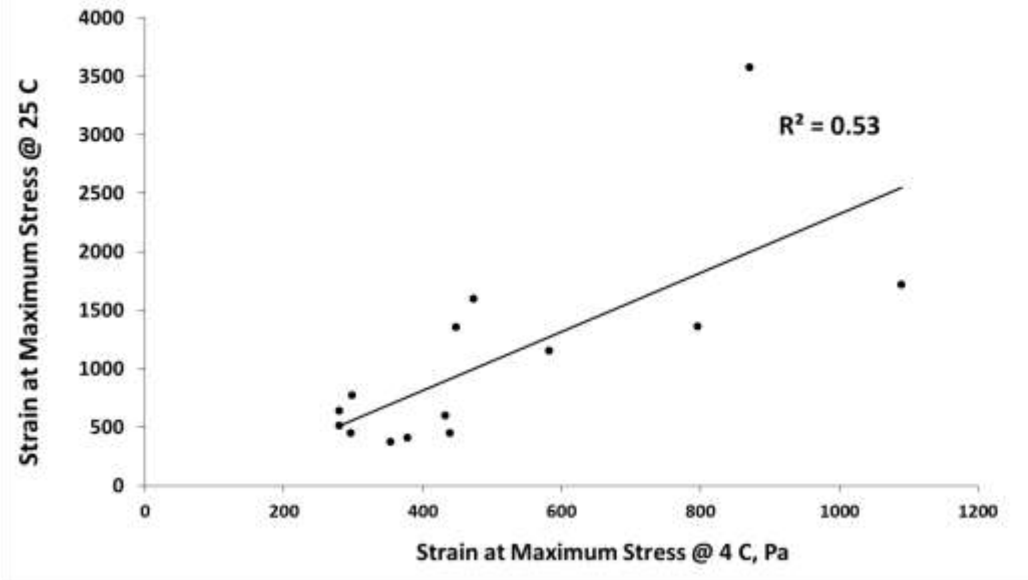
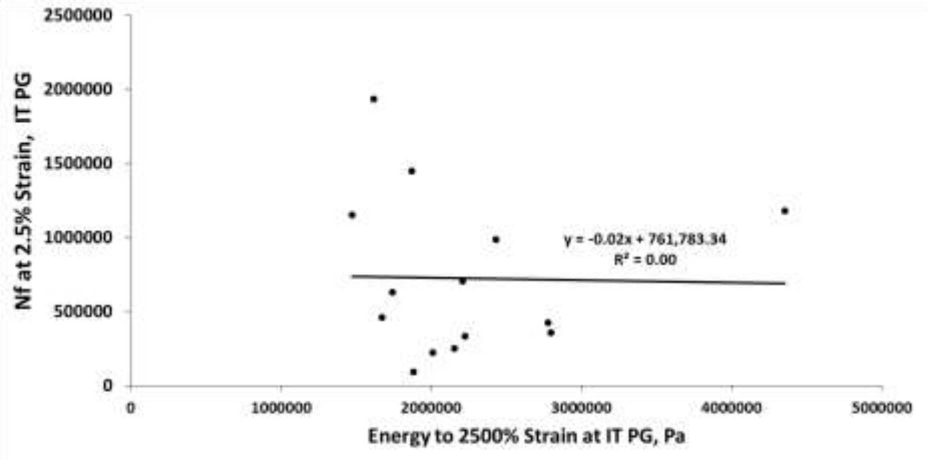


Figure 7: Strain at Peak Stress measured by the BYET at 25 C and 4 C for all Pooled fund study binders.

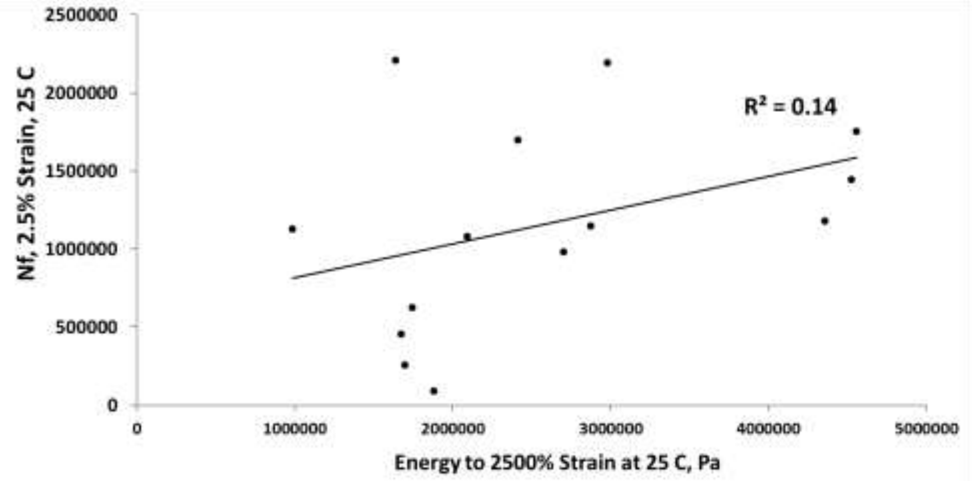
Investigating of Detailed Relationships between BYET and LAS

BYET Energy to 2500% strain is a failure indicator that considers the stress and strain tolerance of an asphalt binder; therefore it is logical to correlate with the LAS N_f at 2.5% strain. **Figure 8**

(a), (b), and **(c)** are plotted to show simple correlations between the two parameters for combinations of temperature conditions. All testing is done after the PAV aging. The plot in (a) is for correlations at PG-IT temperature and plot in (b) is for testing at 25 C. Both plots show poor correlations. One of the possible explanations is that these two tests are conducted at very different loading rates; the LAS is done at 10 Hz for up to 30% strain per 0.1 sec , while the BYET is done at 2.3% strain per second up to 3000 % strain or more.



(a) Correlation at IT of PG Grades



(b) Correlation at 25 C

Figure 8: Correlations between binder BYET energy to 2500% strain and LAS N_f at 2.5% strain at various combinations of temperatures.

Another potential explanation for the large scatter in the correlation plots at 25 C (Figure 8-b) is related to the intended climatic temperature of the asphalt binder. Binders included in the Pooled Fund study were sampled from a wide range of producers and PG grades range from 76-22 in Ohio to 58-34 in Wisconsin. The intermediate temperature for measuring the G*sinδ range from 16 °C to 31 °C for the PG58-34 and PG76-22 binders, respectively. To better understand the implications of having different G*sinδ values at 25 C, the data in the plots shown in **Figure 8 (b)** are sorted into two groups: binders intended to meet grades above and below an intermediate temperature of 22 °C, shown in **Figure 9**.

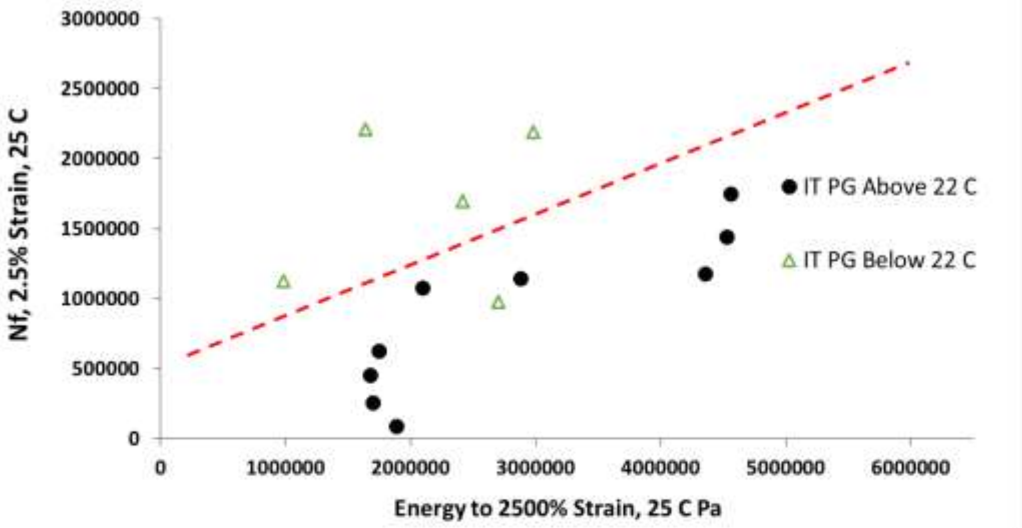


Figure 9: Correlation plot between energy to 2500% strain and N_f at 2.5% strain at 25 C.

When grouped by intermediate temperature of the grade (PG-IT), there are clear trends between BYET energy to 2500% strain and LAS N_f at 2.5% strain. In general, the binders intended to meet lower grades have higher LAS N_f values, but do not necessarily increase the energy under the BYET stress strain curve. **Figure 10** shows the revised correlation between BYET and LAS at 2.5% strain for only the binders with intermediate grades above 22 °C.

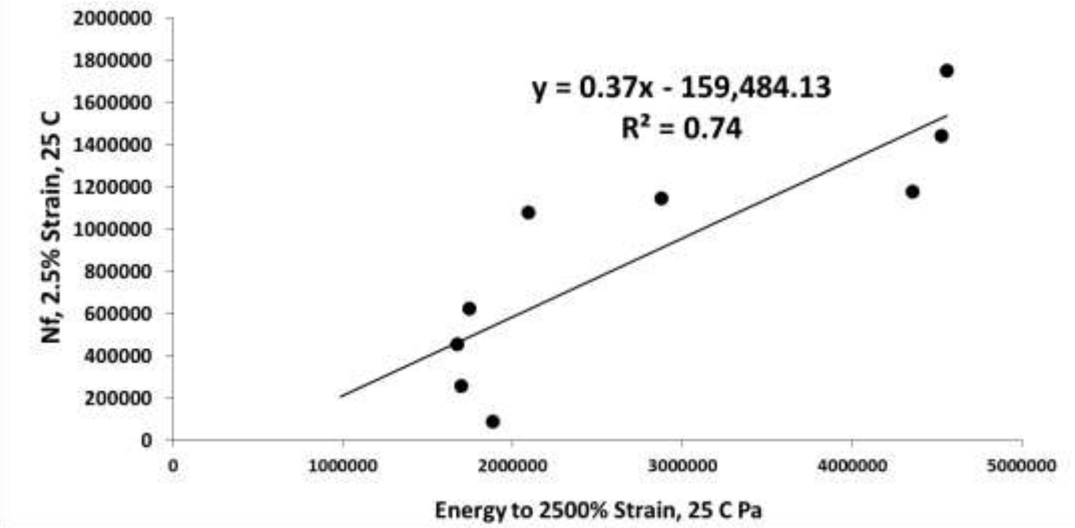


Figure 10: Correlation between BYET energy to 2500% strain and LAS N_f at 2.5% strain only considering binder intended to meet intermediate temperature grades above 22 °C.

In **Figure 10**, the correlation between BYET energy to 2500% and LAS N_f at 2.5% is increased to 0.78 after removing binders intended to meet softer grades of asphalt. This correlation is particularly compelling because any data point in this trend can be removed without changing the linear trend or correlation value. Results of this analysis show that binder yield and damage properties of an asphalt binder depend significantly on the grade they were intended to meet. Therefore it will be critical to consider the validity of testing for fatigue at one temperature that is considerably different than the specific climatic conditions or the temperature that truly represents the conditions at which fatigue is expected in the field.

Using Simpler Parameters from the LAS

As mentioned earlier, one of the drawbacks related to LAS testing is the advanced mathematical analysis required to derive the fatigue law parameters and N_f values. A data analysis template has been created by University of Wisconsin researchers for implementing the LAS procedure in its full form. However, one simpler alternative parameter, which is the LAS strain at peak stress, has been proposed in the past. As shown in **Figure 11**, in the amplitude sweep portion of the LAS test, a stress strain curve can be generated to determine the strain at maximum stress. This parameter has some similarities to the BYET strain at peak (yield) stress value. As shown in Figure 11, the peak damage (maximum stress) varies between binders and it could be easier to search the data for a given test to determine the strain corresponding to the maximum stress.

The correlations between LAS strain at peak stress and N_f at a strain levels of 2.5, 5 and 10% are shown in **Figure 12**, which shows logical trend for strain at peak stress with LAS N_f at all strain levels. However, as the LAS applied strain is increased, the correlations increase significantly; at 10% strain the correlation is more than 90%.

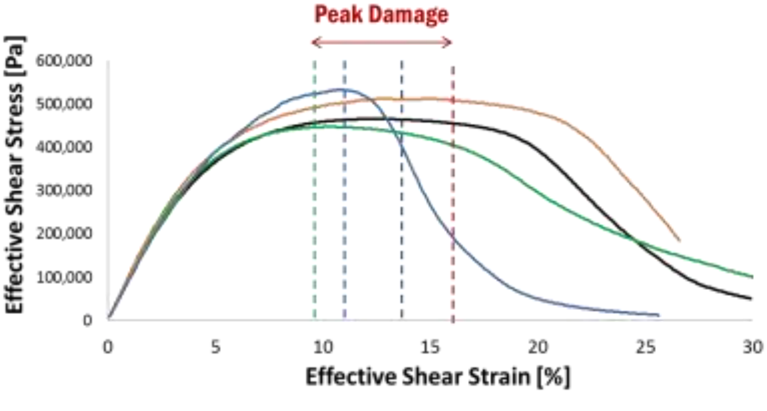
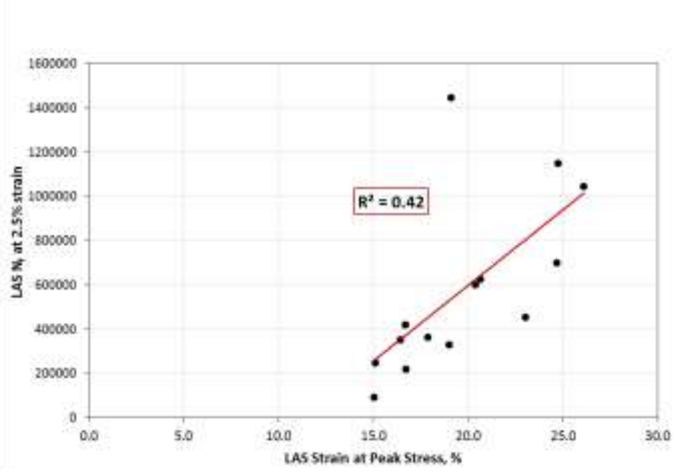
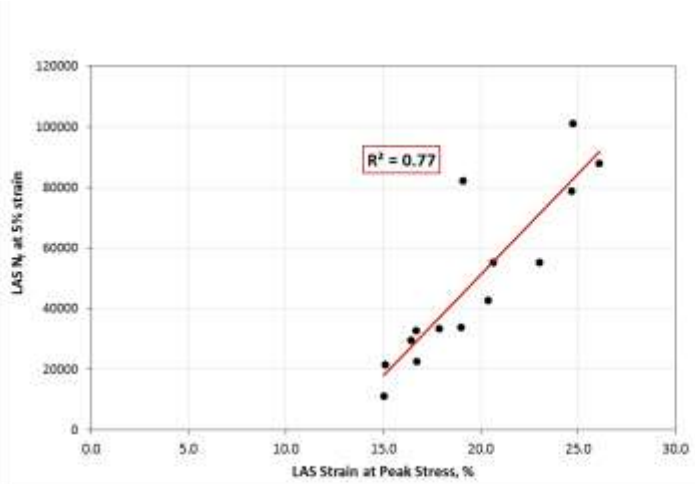


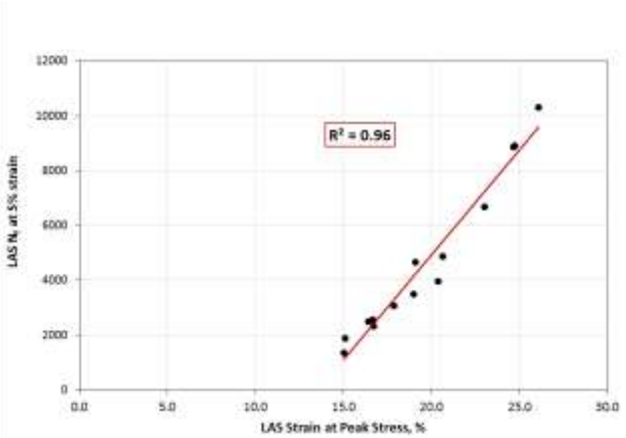
Figure 11 Typical LAS stress versus strain plots for different binders



(a) Nf at 2.5% Strain



(b) Nf at 5 % strain



(c) Nf at 10 % strain

Figure 12: Correlation between LAS strain at peak stress and LAS N_f at strains of 2.5%, 5% and 10% for plots **(a), (b)** and **(c)**, respectively.

The trends and correlations are very promising as they show that strain at peak stress in LAS is a good alternative for the LAS Nf parameter. It should also be mentioned that although the WHRP study recommended a LAS applied strain level of 2.5%, the other strain level considered in the WHRP study, 5% strain, also showed a promising correlation with field cracking resistance, as shown in **Figure 13**.

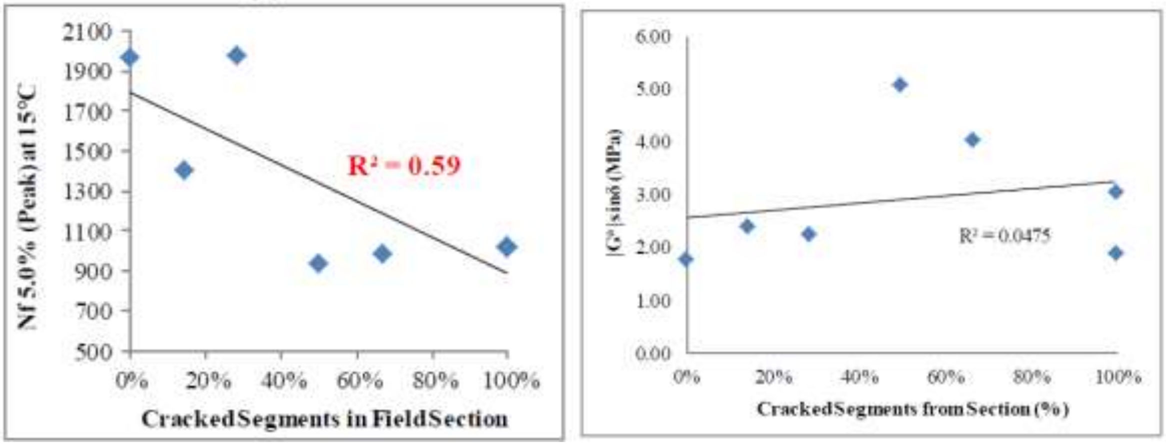


Figure 13: Correlation between LAS N_f at 5% strain and cracked field segments (left) compared with correlation between Superpave G*sinδ and cracked field segments (right).

Implementation and Usage Considerations for LAS and BYET

Testing results and analyses presented in this paper indicate that the LAS testing methods show promise in more accurately representing cracking resistance of modified binders used in pavements. In addition the BYET has been shown in a study by FHWA to correlate every well with the fatigue cracking on the Accelerated Loading Facility. However, little information is available to validate this finding and set limits for these testing methods to be implemented for practical use. The purpose of the following sections is to propose a methodology for understanding usage of and implementing the LAS and BYET test into state specifications. In order to help the member states identify how a future state specification using the LAS would rank the binder provided for this study, LAS results on the PAV binder at intermediate testing temperatures were tabulated and categorized by state as shown in **Table 3.**

Table 3: Ranking of binders within each state based on the LAS Nf at 2.5% strain, Strain at Peak stress of the LAS and BYET energy to 2500% strain.

State	Binder ID	LAS N_f in 1000s at 2.5% Strain @ PG-IT	LAS-NF Rank	LAS strain at Peak stress	LAS – Strain at peak Rank	BYET Energy to 2500% Strain, kPa	BYET Rank
Wisconsin	70-28	625.4	1	20.6	1	1,746	1
	58-34	420.5	2	16.7	3	985	3
	64-34	328.6	3	19.0	2	1,639	2
Ohio	76-22	1932.4	1	26.1	1	4,527	2
	70-22	1447.4	2	19.1	2	4,558	1
	64-22-Unmodified	253.6	-	11.7	-	609	-
	64-28	248.9	3	15.1	3	2,876	3
Kansas	70-28	1177.2	1	17.9	3	4,356	1
	64-34	982.0	2	20.4	2	2,415	3
	64-28	700.5	3	24.7	1	2,982	2
Colorado	76-28	1150.9	1	24.7	1	2,093	2
	64-28	219.3	2	16.7	2	1,699	1
	64-22- Unmodified	80.7	-	11.7	-	2,586	-
Idaho	70-28-13435	455.3	1	23.0	1	1,674	3
	64-34	352.4	2	16.4	2	2,702	1
	70-28 - 13474	90.8	3	15	3	1,883	2

Results from **Table 3** show that in each state the PG 70s and PG 76s outperform the other binders with only one exception in Idaho, which could be an outlier. The results also show that the PG 64s have a very wide range of Nf values ranging between 81,000 for unmodified to 700,000 for the 64-28 in Kansas.

In order to propose tentative specifications to use the LAS or BYET to control fatigue cracking of binders, the data in **Table 3** was used to propose preliminary limits for each binder testing method included in the table. Four different specification limits are selected following the Traffic level categories to correspond with the current AASHTO M 332 terminology: Standard (S), Heavy (H), Very Heavy (V) and Extreme (E).

Limits for each traffic level category were determined by calculating the average value for all binders with identical ranking in **Table 3**. For example, the "E" traffic category limit was determined by calculating the average value for binders ranked number one from each state in **Table 3**. Values for binders ranked number 2 were used to calculate the "V" specification limit, and values for binders ranked number 3 binders were used to calculate the "H" specification limit. **Table 4** summarizes the proposed limits after rounding the numbers to logical values based on the results collected to date in the Pooled Fund study.

Table 4: Proposed failure specification criteria for LAS and BYET energy to 2500% strain.

Traffic Level	AASHTO TP 101		AASHTO TP 123 Energy to 2500%, kPa
	LAS N_f at 2.5% strain in 1000s	LAS Strain at peak stress, %	
Standard	≥ 80	≥ 12	≥ 750
Heavy	≥ 300	≥ 16	≥1500
Very Heavy	≥ 700	≥ 18	≥ 2500
Extreme	≥ 1100	≥ 22	≥ 3200

The above specification limits are proposed solely based on the ranking of measurements from the 16 different Pooled Fund binders. Survey data and mixture performance testing from paving projects and lab produced mixtures will be used as part of this study to validate or revise the proposed failure criteria.

AASHTO M332 and the Use of better limits for G*.sinδ

It should be noted that the M332 includes the G*.sinδ parameter similar to the M320, but the limit has been increased arbitrarily from 5000 kPa to 6000 kPa for the H,V and E grades. This means that the M332 is allowing the H,V and E binders to be stiffer at intermediate temperatures, although the expected traffic is higher than the S grade. This study clearly indicates that the fatigue resistance of binders measured in the LAS decreases for stiffer binders in general. Figure 14 is plotted using the WCTG database and it shows that there is a significant trend between increase in G*.sinδ value and "decrease" of fatigue life. All tests are done at the PG-IT temperature. It is thus critical that the current AASHT M332 limits for the G*.sinδ be re-considered and in fact reduced (not increased) for higher traffic volumes, because increasing the limits with traffic could increase risk of fatigue failures. In other words allowing binders that are stiffer at PG-IT for higher traffic grades (V and E grades) could put pavements at more risk of failure by this increase in the limit.

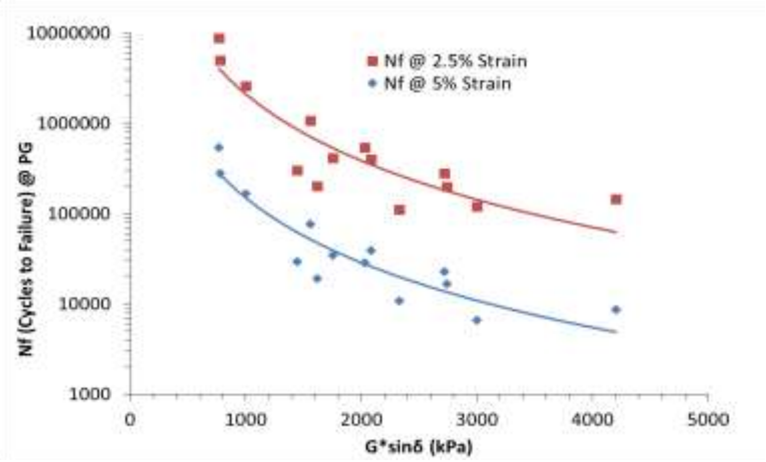


Figure 14. Relationship between LAS Nf at IT-PG and G*.sind for numerous modified and un-modified binders

Concluding Remarks and Recommendations

Based on the analysis of the data collected to date the following findings and recommendations are stated:

- Fatigue resistance of binders collected from this Pooled Fund study partners vary significantly as measured by the AASHTO TP 101 LAS procedure. The resistance as measured by the Nf at 2.5 % strain ranges from 80,000 to approximately 2,000,000 cycles when measured the IT-PG temperatures.
- The strain at peak stress, and the BYET energy to 2500% strain, are proposed as simpler parameters that can be used as surrogates for the more complicated parameter Nf at 2.5% strain, which requires an advanced level of curve fitting and computations.
- Tentative limits to be used as a starting point for controlling fatigue of binders are proposed based on data collected to date. The limits are specified for the 4 traffic levels of S,H,V, and E used in the AASHTO M332. These limits require validation using the mixture testing and field survey data planned for in the remaining part of the study.
- For the next actions regarding this topic of the project, testing will be focused on determining the relationship between binder and mixture testing performance. Two mixture performance testing methods were selected in the current scope of the work for the Pooled Fund: Semi-Circular Beam (SCB) and Indirect Tension Fatigue (IDT Fatigue) testing. Objectives of mixture performance testing include: 1) determining which asphalt binder testing method(s) correlate with mixture cracking resistance and 2) understand the extent to which binder properties influence the performance of an asphalt mixture. Results from the mixture performance testing phase can help member states better understand whether or not the binder candidate test methods merit further consideration for specification implementation.

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