Standard Method of Test for

Estimating Damage Tolerance of Asphalt Binders Using the Linear Amplitude Sweep

AASHTO Designation: TP 101-12-UL

1. SCOPE

1.1. This test method covers how to determine asphalt binders' resistance to fatigue damage by means of cyclic loading employing systematically, linearly increasing load amplitudes. The amplitude sweep is conducted using the Dynamic Shear Rheometer at the intermediate pavement temperature determined from the performance grade (PG) of the asphalt binder. The test method can be used with binder aged using AASHTO T 240 (RTFOT) and AASHTO R 28 (PAV) to simulate the estimated aging for in-service asphalt pavements.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
M 320, Standard Specification for Performance-Graded Asphalt Binder
T 240, Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
R 28, Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
T 315, Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

2.2. *ASTM Standards*:
D 8, Standard Terminology Relating to Materials for Roads and Pavements
D 2872, Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)
D 6521, Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
D 7175, Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer

3. TERMINOLOGY

3.1 Definitions

3.1.1 Definitions of terms used in this practice may be found in Terminology D 8, determined from common English usage, or combinations of both.

4. SUMMARY OF TEST METHOD

4.1 Asphalt binder is first aged using Test Method AASHTO T 240 (ASTM D 2872) (RTFOT) to represent short-term aging of asphalt pavements, or the material may be further aged using AASHTO R 28 (ASTM D 6521-08) prior to testing in order to simulate long-term aging of asphalt pavements. A sample is prepared consistent with Test Method AASHTO T 315 (ASTM D 7175-05) (DSR) using the 8-mm parallel plate geometry with a 2-mm gap setting. The sample is tested in shear using a frequency sweep to determine rheological properties. The sample is then tested using a series of oscillatory load cycles at systematically increasing amplitudes at a constant frequency to cause accelerated fatigue damage. To quantify damage tolerance a rigorous viscoelastic continuum damage approach is used to calculate fatigue resistance from rheological properties and amplitude sweep results.

5. SIGNIFICANCE AND USE

5.1. This method is intended to evaluate the ability of an asphalt binder to resist fatigue damage by employing cyclic loading at increasing amplitudes in order to accelerate damage. The characteristics of the rate of damage accumulation in the material can be used to indicate the fatigue performance of the asphalt binder given pavement structural conditions and/or expected amount of traffic loading using predictive modeling techniques.

6. APPARATUS

6.1. Use the apparatus as specified in T 315.

7. PROCEDURE

7.1. Condition the asphalt binder in accordance with AASHTO T 240 (RTFOT) for short-term performance, or condition the asphalt binder in accordance with AASHTO T 240 (RTFOT) followed by AASHTO R 28 (PAV) for long-term performance.

7.2. *Sample preparation* – The sample for the Linear Amplitude Sweep is prepared following AASHTO T 315 for 8-mm plates. The temperature control also follows the AASHTO T 315 requirements.

> Note 1: In accordance to AASHTO T 315 provisions, it is suggested that spindle and plate temperature be raised to 64°C or higher before insertion of the asphalt sample to ensure sufficient adhesion is achieved, especially for highly modified and/or aged asphalt binders. Such provisions have been shown to prevent delamination in the majority of binders tested.

7.2.1. This test may be performed on the same sample that was previously used to determine the rheological properties in the DSR on PAV residue as specified in M 320.

7.3. *Test protocol* – Two types of testing are performed in succession. The first, (a frequency sweep), is designed to obtain information on the rheological properties, and the second (an amplitude sweep), is intended to measure the damage characteristics of the material.

7.3.1 *Determination of "alpha" parameter* – In order to perform the damage analysis, information regarding the undamaged material properties (represented by the parameter α) must be determined. The frequency sweep procedure outlined in Section 6.3.1.1 is used.

7.3.1.1 *Frequency sweep* –Frequency sweep test data is used to determine the damage analysis "alpha" parameter. The frequency sweep test is performed at the selected temperature, and applies oscillatory shear loading at constant amplitude over a range of loading frequencies. For this test method, the frequency sweep test is selected from the DSR manufacturer's controller software, employing an applied load of 0.1% strain over a range of frequencies from 0.2 – 30 Hz. Data is sampled at the following 12 unique frequencies (all in Hz):

0.2	0.4	0.6	0.8	1.0	2.0	4.0	6.0	8.0	10	20	30

Complex shear modulus [|*G**|, Pa] and phase angle [δ, degrees] are recorded at each frequency, as shown below.

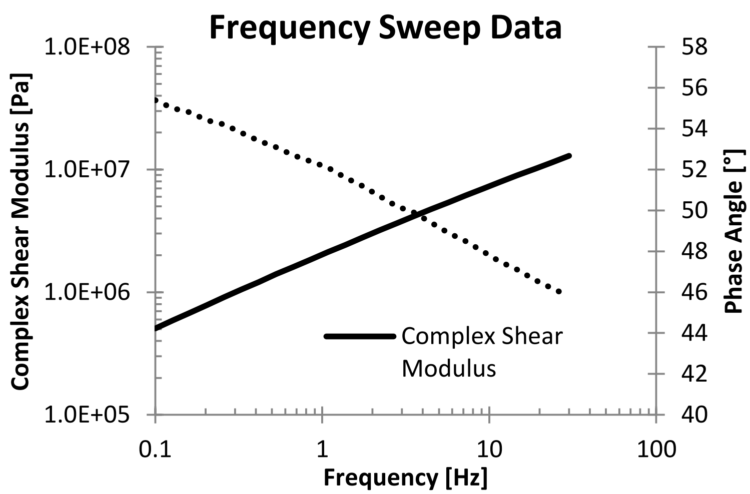

Figure 1– Example output from frequency sweep test.

7.3.2. *Amplitude sweep* – The second test is run at the selected temperature using oscillatory shear in strain-control mode at a frequency of 10 Hz. The loading scheme consists of a continuous oscillatory strain sweep. Strain is increased linearly from 0.1 to 30% over the course of 3,100 cycles of loading for a total test time of 310 sec. Peak shear strain and peak shear stress are recorded every 10 load cycles (1 sec), along with phase angle [|G*|, degrees] and Complex shear modulus [|G*|, Pa].

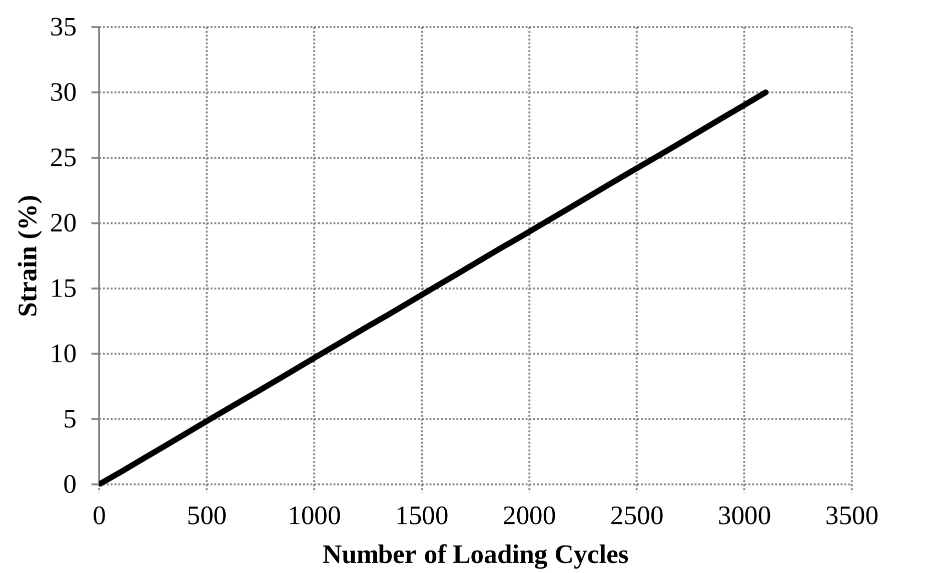

Figure 2– Loading scheme for amplitude sweep test

8. CALCULATION AND INTERPRETATION OF RESULTS

8.1 In order to determine the parameter α from frequency sweep test data, the following calculations are performed.

8.1.1. First, data for the dynamic modulus [|*G**|(ω)] and phase angle [δ(ω)] for each frequency is converted to storage modulus, *G'*(ω):

$$G'(\omega) = |G^*|(\omega) \times \cos \delta(\omega)$$

8.1.2. A best-fit straight line is applied to a plot with log ω on the horizontal axis and log *G'*(ω) on the vertical axis using the form:

$$\log G'(\omega) = m (\log \omega) + b$$

8.1.3. The value obtained for *m* is recorded and the value of α is obtained by performing the following transformation:

$$\alpha = 1 / m$$

8.1.4. For the results of the amplitude sweep test, the data is analyzed as follows:

8.1.5. The damage accumulation in the specimen is calculated using the following summation (Kim et al, 2006):

$$D(t) \cong \sum_{i=1}^{N} [\pi \gamma_0^2 (C_{i-1} - C_i)]^{\frac{\alpha}{1+\alpha}} (t_i - t_{i-1})^{\frac{1}{1+\alpha}}$$

where:

$C(t) = \frac{|G^*|(t)}{|G^*|_{initial}}$ which is |G*| at time *t* divided by the initial "undamaged" value of |G*|.

γ_0 = applied strain for a given data point, percent

|G*| = Complex shear modulus, MPa

α = value reported in Section 8.1.4

t = testing time, seconds

> Note 2: The initial "undamaged" value of |G*| is the second data point, as the first point after change of material condition from rest differs from the undamaged modulus of material at the target loading frequency.

8.1.6. Summation of damage accumulation begins with the first data point for the 1.0% applied strain interval. The incremental value of $D(t)$ at each subsequent point is added to the value of $D(t)$ from the previous point. This is performed up until the final data point from the test at 30 percent applied strain.

8.1.7. For each data point at a given time t, values of C(t) and D(t) are recorded (it is assumed that C at D(0) is equal to one, and D(0) = 0). The relationship between C(t) and D(t) can then be fitted to the following power law:

$$C(t) = C_0 - C_1 (D(t))^{C2}$$

where:

C_0 = 1, the initial value of C,

C_1 and C_2 = curve-fit coefficients derived through linearization of the power law in the form shown below as suggested by Hintz et al. (2011):

$$\log(C_0 - C(t)) = \log(C_1) + C_2 \cdot \log(D(t))$$

Using the above equation,C_1 is calculated as the anti-log of the intercept and C_2 is calculated as the slope of the line formed as $\log(C_0 – C(t))$ versus $\log(D(t))$. For calculation of both C_1 and C_2, data corresponding to damages less than 10 are ignored.

8.1.8. The value of $D(t)$ at failure, D_f, is defined as the $D(t)$ which corresponds to the reduction in initial |G*| at the peak shear stress. The calculation is as follows:

$$D_f = \left(\frac{C\ at\ Peak}{C_1}\right)^{1/C_2}$$

8.1.9. The following parameters (A and B) for the binder fatigue performance model can now be calculated and recorded as follows:

$$A = \frac{f(D_f)^k}{k(\pi I_D C_1 C_2)^\alpha}$$

Where f = loading frequency (10 Hz).

$k = 1 + (1 - C_2)\alpha$

and

$B = 2\alpha$.

8.1.10 The binder fatigue performance parameter N_f can now be calculated as follows:

$$N_f = A_{35}(\gamma_{max})^{-B}$$

Where γ_{max} = the maximum expected binder strain for a given pavement structure, %.

9. REPORT

9.1. *Report the following, if known*:

9.1.1. Sample identification,

9.1.2. PG grade and test temperature, nearest 0.1°C

9.1.3. Fatigue model parameters A_{35} and B, four significant figures.

9.1.4. Binder fatigue performance parameter N_f, nearest whole number.

10. PRECISION AND BIAS

10.1. To be determined upon results of inter-laboratory testing.

11. KEYWORDS

11.1. Asphalt binder, viscoelastic continuum damage (VECD), fatigue, Performance Grading.

12. REFERENCES

12.1. Kim, Y., Lee, H. J., Little, D. N., and Kim, Y. R. (2006). "A simple testing method to evaluate fatigue fracture and damage performance of asphalt mixtures." *J. Assn. Asphalt Paving Technologists*, Vol. 75, pp. 755-788.

12.2. Hintz, C., Velasquez, R., Johnson, C., and H. Bahia. Modification and Validation of the Linear Amplitude Sweep Test for Binder Fatigue Specification, In *Transportation Research Record: Journal of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 99-106.

APPENDIX

(Non-mandatory Information)

X1. SAMPLE CALCULATIONS

X1.1. Example data from the amplitude sweep test is given in Table X1.1.

Table X1.1 – Example data output from amplitude sweep test

Testing Time	Shear Stress	Shear Strain	|G^*|	Phase Angle	|G^*|·sin δ
[sec]	[MPa]	[%]	[MPa]	[°]	[MPa]
34	0.212	1.996	10.646	49.18	8.057
35	0.212	2.001	10.619	49.22	8.041
36	0.212	2.003	10.595	49.26	8.028
37	0.211	2.003	10.574	49.29	8.016
38	0.211	2.004	10.555	49.32	8.005
39	0.211	2.003	10.539	49.34	7.995
40	0.210	2.003	10.524	49.37	7.987

X1.2. The following values have already been assumed:

$D(33) = 10.77$

$\alpha = 2.58$

$I_D = 8.345$ MPa

$|G^*| \cdot \sin \delta_{t=33} = 8.075$ MPa

X1.3. *Sample calculations:*

X1.3.1. To calculate the accumulation of damage from t = 33 sec to t = 34 sec,

$$D(34) = D(33) + [\pi I_D \gamma_0^2 (|G^*| \sin \delta_{i-1} - |G^*| \sin \delta_i)]^{\frac{\alpha}{1+\alpha}} (t_i - t_{i-1})^{\frac{1}{1+\alpha}}$$

$$D(34) = D(33) + [\pi (8.345)(1.996)^2 (8.075 - 8.057)]^{\frac{2.58}{1+2.58}} (34 - 33)^{\frac{1}{1+2.58}}$$

$$D(34) = 12.36$$

X1.3.2. This procedure is repeated, giving the following results shown in Table X1.2.

Table X1.2 – Example data output and damage calculation from amplitude sweep test

Testing Time	Shear Stress	Shear Strain	Complex Modulus	Phase Angle	|G^*|·sin δ	$D(t)$
[sec]	[MPa]	[%]	[MPa]	[°]	[MPa]	
34	0.212	1.996	10.646	49.18	8.057	12.36
35	0.212	2.001	10.619	49.22	8.041	13.79
36	0.212	2.003	10.595	49.26	8.028	15.06
37	0.211	2.003	10.574	49.29	8.016	16.26
38	0.211	2.004	10.555	49.32	8.005	17.35
39	0.211	2.003	10.539	49.34	7.995	18.40
40	0.210	2.003	10.524	49.37	7.987	19.26

X2.1 The following example plots may be useful in visualizing the results:

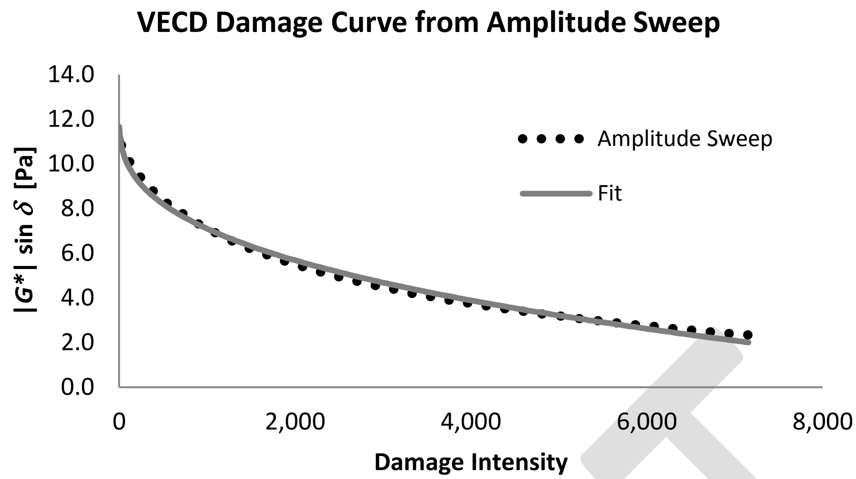

FIGURE X2.1 – Example |G*|·sin δ versus damage plot with curve-fit from Section 7.2.

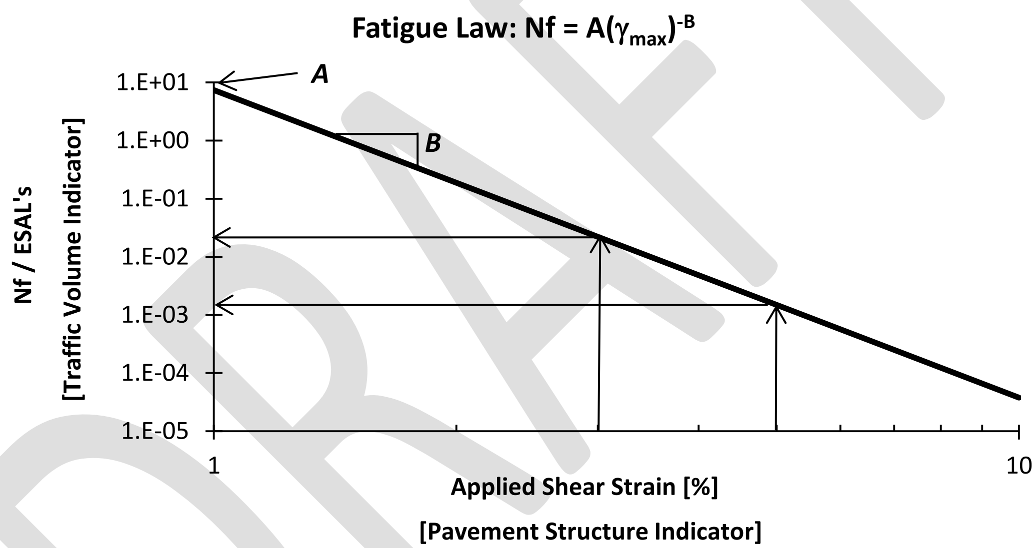

FIGURE X2.2 – Plot of fatigue parameter N_f (normalized to 1 million ESAL's) versus applied binder shear strain on a log-log scale. Allowable fatigue life can be determined for given strain amplitudes, as shown by the arrows.