Standard Method of Test for

Estimating Fatigue Resistance of Asphalt Binders Using the Linear Amplitude Sweep

AASHTO Designation: T XXX-10

1. SCOPE

1.1. This test method covers the indication of asphalt binders' resistance to fatigue damage by means of cyclic loading employing a linearly ramping amplitude sweep test. The amplitude sweep is conducted using the Dynamic Shear Rheometer at the continuous intermediate temperature performance grade (PG Grade) of the asphalt binder. The test method can be used with material aged using AASHTO T 240 (RTFOT) and/or 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, Effect of Heat and Air on Rolling Film of Asphalt (Rolling Thin-Film Oven Test)
R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
T 315, 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, and is then followed by a series of oscillatory load cycles at systematically increasing amplitudes at a constant frequency to cause accelerated fatigue damage. The continuum damage approach is used to calculate the 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. PROCEDURE

6.1. *Condition the asphalt binder in accordance with T 240 (RTFOT) for short-term performance, or follow with R 28 (PAV) for long-term performance.*

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

6.2.1. 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.

6.3. *Test protocol* – Two types of testing are performed in succession. The first is designed to obtain information on the rheological properties, and the second is intended to measure the damage characteristics of the material.

6.3.1 *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.

6.3.1.1 *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 load of 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 0.1 – 30 Hz. Data is sampled at a rate of ten unique frequencies per decade, or the following specific frequencies can be used (all in Hz):

0.1	0.4	0.7	1.0	4.0	7.0	10	16	22	28
0.2	0.5	0.8	2.0	5.0	8.0	12	18	24	30
0.3	0.6	0.9	3.0	6.0	9.0	14	20	26	

Dynamic shear modulus [|*G**|, Pa] and phase angle [δ, degrees] is recorded at each frequency.

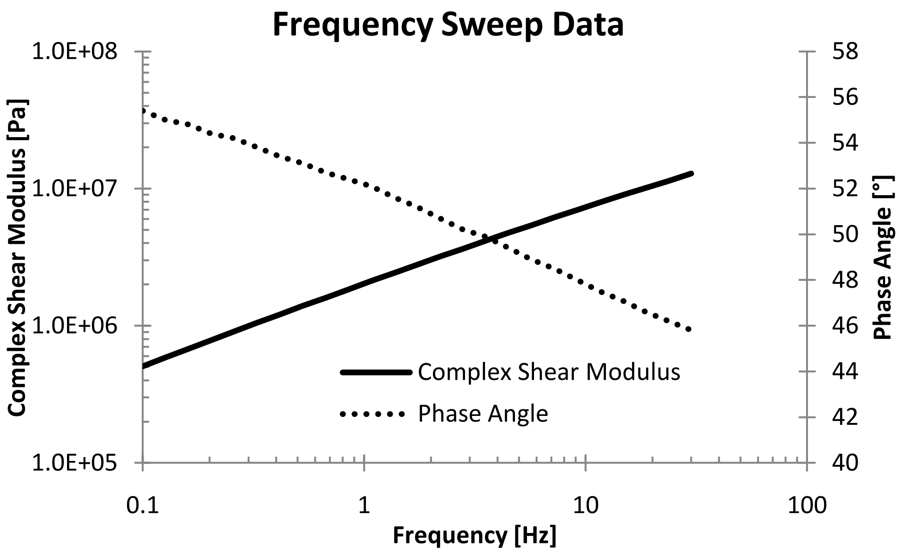

FIGURE 6.1 – Example output from frequency sweep test.

6.3.2. *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 10 second intervals of constant strain amplitude, where each interval is followed by another interval of increased strain amplitude as follows: 0.1%, 1.0%, 2.0%, 3.0%, 4.0%, 5.0%, 6.0%, 7.0%, 8.0%, 9.0%, 10%, 11%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, 20%, 21%, 22%, 23%, 24%, 25%, 26%, 27%, 28%, 29%, 30%. Peak shear strain and peak shear stress is recorded every 10 load cycles (1 sec), along with phase angle [δ, degrees] and dynamic shear modulus [|*G**|, Pa].

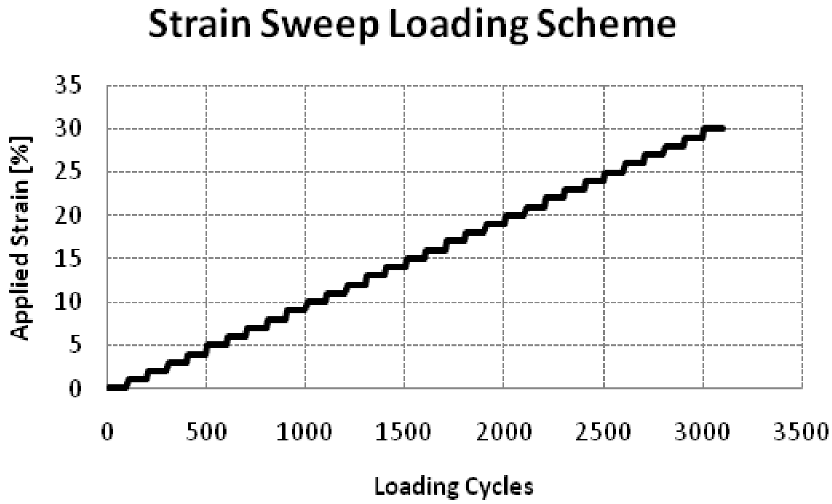

FIGURE 6.2 – Loading scheme for amplitude sweep test

7. CALCULATION AND INTERPRETATION OF RESULTS

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

7.1.1. First, data for the dynamic modulus [$|G^*|(\omega)$] and phase angle [$\delta(\omega)$] for each frequency is converted to storage modulus, $G'(\omega)$:

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

7.1.2. A best-fit straight line is applied to the plot of log ω as the abscissa and log $G'(\omega)$ as the ordinate to the form of:

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

7.1.3. The value obtained for m is recorded as the value α by performing the following transformation:

$$\alpha = 1 + 1 / m$$

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

- NOTE: The following damage calculation method is adapted from Y.R. Kim et al. (11.1).

7.2.1. The damage accumulation in the specimen is calculated using the following summation:

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

Where I_D = initial damaged value of $|G^*|$ from the 1.0% applied strain interval, MPa.
γ_0 = Applied strain for a given data point, dimensionless.
$|G^*|$ = dynamic shear modulus, MPa.
α = Value reported in Section 7.1.3.
t = Testing time, sec.

7.2.2. 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 entire test at 30% applied strain.

7.2.3. For each data point at a given time t, values of $|G^*|\cdot\sin \delta$ and $D(t)$ is recorded (it is assumed that $|G^*|\cdot\sin \delta$ at $D(0)$ is equal to the average undamaged value of $|G^*|\cdot\sin \delta$ from the 0.1% strain interval, and $D(0) = 0$). The relationship between $|G^*|\cdot\sin \delta$ and $D(t)$ can then be fit to the following power law relationship:

$$|G^*|\cdot\sin \delta = C_0 - C_1 (D)^{C2}$$

Where C_0 is the average value of $|G^*|\cdot\sin \delta$ from the 0.1% strain interval. Coefficients C_1 and C_2 are curve-fit coefficients, which are derived through linearization of the power law in the form shown below:

$$\log(C_0 - |G^*| \cdot sin\delta) = \log(C_1) + C_2 \cdot \log(D)$$

Using the above equation, C_1 is the intercept and C_2 is the slope a line formed as $\log(C_0 - |G^*|\cdot sin\delta)$ versus $\log(D)$, ignoring data corresponding to damages less than 100.

7.3. The value of $D(t)$ at failure, D_f, is defined as that which corresponds to a 35% reduction in undamaged $|G^*|\cdot\sin \delta$ (C_0). The calculation is as follows:

$$D_f = (0.35)(C_0 / C_1)\text{^}(1 / C_2)$$

7.4. 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

$$B = 2\alpha.$$

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

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

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

8. REPORT

8.1. *Report the following, if known*:

8.1.1. Sample identification,

8.1.2. PG Grade and Test Temperature, nearest 0.1°C

8.1.3. Fatigue model parameters *A* and *B*, 4 significant figures.

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

9. PRECISION AND BIAS

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

10. KEYWORDS

10.1. Asphalt binder, fatigue, DSR.

11. REFERENCES

11.1. 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.

[1] The numbers in parentheses refer to the list of references at the end of this standard.

APPENDIX

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	Dynamic Modulus	Phase Angle	$\|G^*\|\cdot\sin\delta$
[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	Dynamic Modulus	Phase Angle	$\|G^*\|\cdot\sin\delta$	$D(t)$
[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:

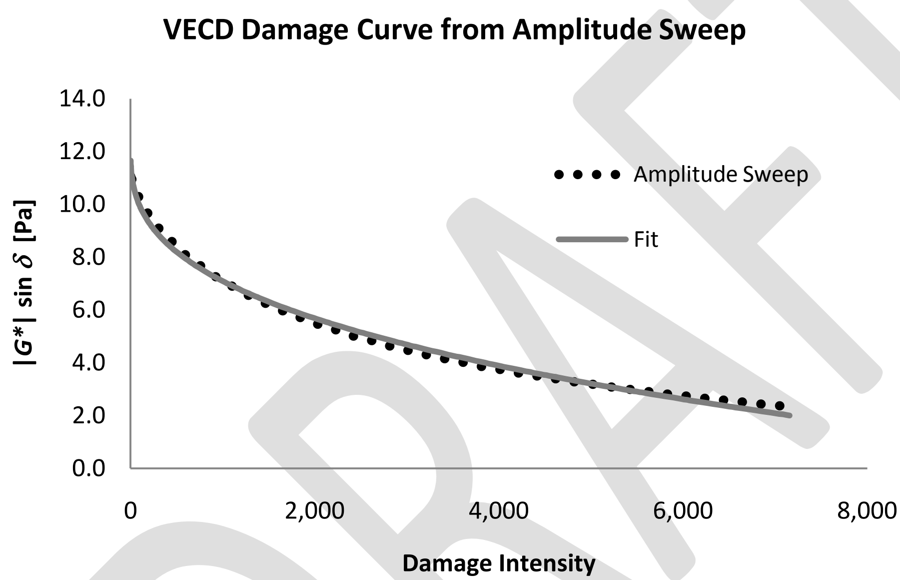

FIGURE X2.1 – Example $|G^*|\cdot\sin\delta$ versus damage plot with curve-fit from Section 7.2.

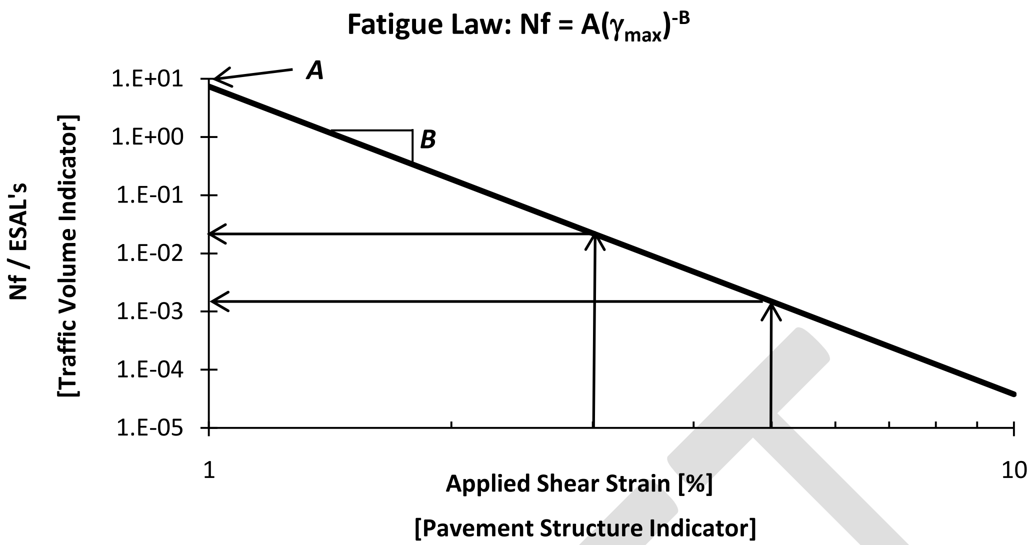

FIGURE X2.2 – Plot of fatigue parameter N_f (normalized to 1 million ESAL's) versus applied binder shear strain on a log-log scale. Allowable fatigue life can be determined for given strain amplitudes, as shown by the arrows.