

DEFORMATION PARAMETERS OF THE ASPHALT MIXTURES

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Abstract

The deformational properties of asphalt mixtures measured by dynamic methods and fatigue allow a design the road to suit the expected traffic load. Quality of mixtures is also expressed by the resistance to permanent deformation. Complex modulus of stiffness and fatigue can reliably characterize the proposed mixture of asphalt pavement.

Key words: *fatigue, complex modulus, asphalt mixture, rheology, deformation properties.*

1. INTRODUCTION

The pavement has specified conditions to ensure safety, continuity and traffic efficiency. The pavement has to full-fill criteria, which are defined by design methodics; it has to have a necessary bearing capacity and has to withstand environmental load.

Materials used in structural layers of pavement are assessed following the qualitative conditions. The European standard STN EN 13 108-1: Asphalt mixtures, Material specifications. Part 1: Asphalt concrete defines a term „functional conditions“. The functional conditions are properties of asphalt mixtures which are defined by tests (fatigue test, rutting test, triaxial test). It is possible to use several types of tests to measure complex modulus and fatigue in accordance with the European standard STN EN 12697. The tests differ applied load and intensity. This article describes the measurement of deformational properties by two-point bending test.

2. MEASUREMENTS PRINCIPLE OF DEFORMATIONAL PROPERTIES AND FATIGUE BY TWO-POINT BENDING TEST

The rheology characters materials are tested with the complex modulus method.

The basic deformation characteristics include modulus of elasticity, deformation modulus, modulus of stiffness, creep modulus, Poisson's ratio.

Complex modulus is the ratio of tension and deformation at steady, harmonically variable oscillation in consideration of their mutual time shift.

$$E^* = \frac{\sigma_0}{\varepsilon_0} = \left(E_1^2 + E_2^2\right)^{\frac{1}{2}} \quad (1)$$

Fatigue is decrease of material resistance by repetitive loading in comparison with resistance by single loading [1].

According to the Slovak dimensioning method the fatigue is given by

$$S = a - b \cdot \log N_i \quad (2)$$

Where a, b - fatigue coefficients
 N_i - number of load cycles.

Measurement of the complex stiffness modulus is performed at the short-term alternating harmonic load. It expresses the proportion of maximum amplitudes of excitation tension (σ_0) and deformation induced by it (ε_0) and their phase shift (φ). The stress (force), which varies sinusoidally in time, is applied on to the element of linear viscoelastic material, the strain (deformation) varies in time with the same frequency as the stress, but it lags behind by the phase. Graphical representation of measurement and complex modulus evaluation is represented in Figure 1 and 2.

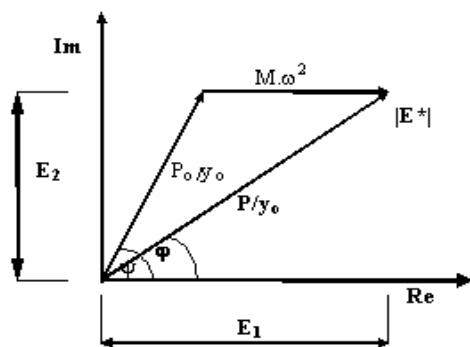


Fig. 1 Complex modulus

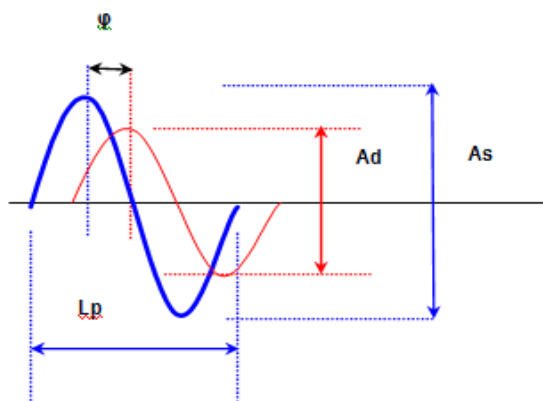


Fig. 2 Measurement of complex modulus L_p - length of period, φ -phase-shift, A_s -amplitude forces; A_d -amplitude deformations

3. TEST EQUIPMENT

The tests of the complex modulus and fatigue were carried out in the laboratory of Department of Construction Management. The equipment works with constant deviation. It is possible to change the frequency from 0.1 to 30Hz and temperature for the tests from -20 to 30°C.

Bending tests are widely used for measuring the stiffness modulus and assessing the fatigue resistance of asphaltic paving materials. The two-point bending test on trapezoidal specimens is, arguably, the most repeatable and reproducible bending test method detailed in the relevant EN 12697 standards. In this test, the specimen is mounted as a vertical cantilever. The base is fixed and the top is moved sinusoidally with a constant displacement amplitude. The trapezoidal specimens are tested simultaneously and stiffness are subjected to a constant strain amplitude at a selected frequency and temperature until the stiffness modulus decreases to a user-selected target level (normally 50 percent of its initial value).



Fig. 3 Two Point Trapezoidal Bending Beam Machine (from Cooper Technology)

4. TESTED MIXTURES AND MEASUREMENTS RESULTS

4.1. Mixtures

The mixtures were composite from aggregate and binders. A binder in 1st mixture (A1) is classic asphalt binder B 50/70 and in 2nd mixture (A2) polymer modified bitumen PmB 70/100-83. A mixture is the same, only asphalt binder is other (B 50/70 or PmB 50/70-83). The mixture is for both pavements AC11.

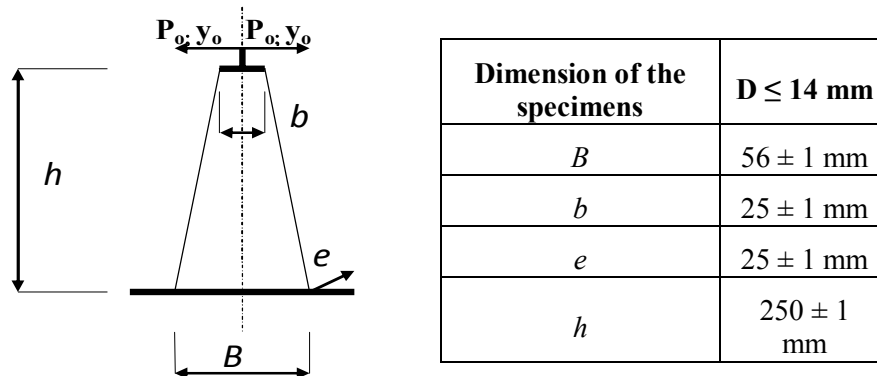
MIXTURE	MIXTURE 1 (A1) [%]	MIXTURE 2 (A2) [%]
Binder type	Bitumen 70/100	PmB 70/100-83
Binder	5,60	5,60
Filer	7,08	7,08
0/2 mm	29,26	29,26
2/4 mm	15,58	15,58
4/8 mm	22,66	22,66
8/11 mm	19,82	19,82
Together	100,00	100,00

Tab. 1 Percentage of aggregate in the mixture of AC 11 [%]

4.2 Measurements results

4.2.1 Complex modulus

The measurements were performed on trapezoidal specimens according to Figure 4.



Key: P_0 – acting force; y_0 – deformation

Fig. 4 Scheme of measuring

A temperature for measuring is $+15$ °C and frequency 10 Hz. The measuring was prepared though by temperature from -10 °C to $+27$ °C. The results are on Table 2 and Figure 5. The complex modulus (E^*) is different by temperatures $+10$ °C and $+15$ °C by the same frequency (10 Hz):

- $E^*_{T=10^\circ\text{C}; F=10\text{ Hz}} = 8364,7$ MPa
- $E^*_{T=15^\circ\text{C}; F=10\text{ Hz}} = 5938,0$ MPa

The course of complex modulus by temperature and frequency shows Table 2. Complex modulus may be measured by $\epsilon < 50 \cdot 10^{-6}$ (microstrains).

Temperature [°C]	COMPLEX MODULUS E^* [MPa]				
	Frequency [Hz]				
	1	5	10	15	20
-10	14158	16769	17744	17700	18503
-10	14351	17063	18073	18219	18970
0	10727	13551	14698	15062	15538
0	10874	13723	14927	15407	15943
10	4991	7827	8923	9586	10009
10	4494	7098	8122	8778	9233
10	4832	7844	9138	9818	10260
10	3786	6256	7276	7873	8272

15	3021	5749	7055	7773	8366
15	2151	4284	5315	5958	6451
15	2339	4759	5867	6506	7014
15	2216	4436	5515	6173	6660
27	695	1798	2487	2915	3275
27	713	1755	2460	2922	3327

Tab. 2 Values of complex modulus by different temperatures of mixture 1 (AC 11)

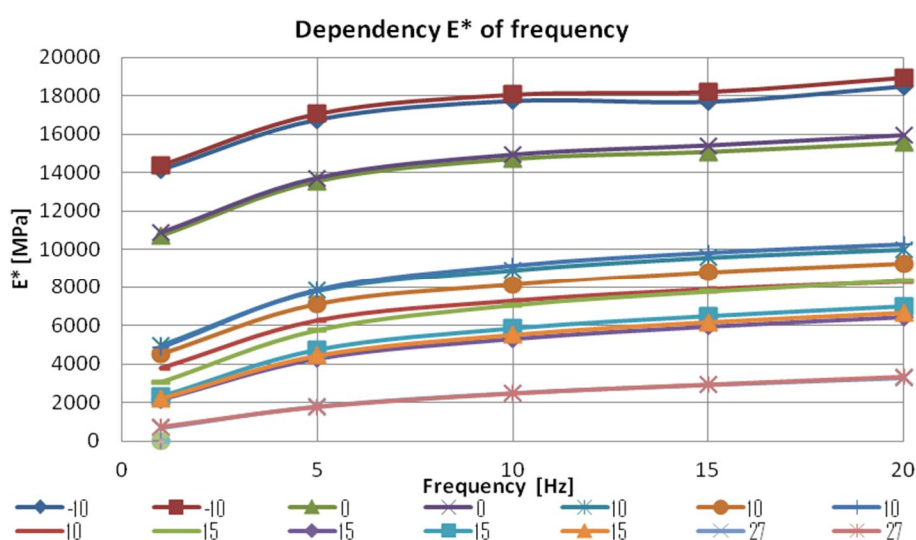


Fig. 5 Scheme of dependency E^* of frequency ($T = -10\text{ }^{\circ}\text{C}$ to $+27\text{ }^{\circ}\text{C}$) for mixture 1

The similar results were measured on mixture 2 (with PmB 70/100-83):

- $E^*_{T=10^{\circ}\text{C}; F=10\text{ Hz}} = 5844,0\text{ MPa}$
- $E^*_{T=15^{\circ}\text{C}; F=10\text{ Hz}} = 4032,0\text{ MPa}$.

4.2.2 Fatigue

The results of the measurements are from specimens, which were loaded by temperature $T = +10\text{ }^{\circ}\text{C}$ with loading in unit of measure COOPER by frequency $F = 25\text{ Hz}$. The fatigue line is estimated in a bi-logarithmic system as a linear regression of fatigue life versus amplitude levels. Using these results, the strain corresponding to an average of 1.10^6 cycles (ϵ_6) and the slope of the fatigue line $1/b$ was determined for number of the specimens in Table 3. The parameters are:

- ϵ_6
- $\Delta\epsilon_6$
- slope $1/b$
- estimation of the residual standard deviation s_N

e) correlation coefficient r^2 .

Category	$\text{Fat}_{\epsilon \min}$ [strain $\times 10^6$]
$\text{Fat}_{\epsilon \min 310}$	310
$\text{Fat}_{\epsilon \min 260}$	260
$\text{Fat}_{\epsilon \min 220}$	220
$\text{Fat}_{\epsilon \min 190}$	190
$\text{Fat}_{\epsilon \min 160}$	160
$\text{Fat}_{\epsilon \min 135}$	135
$\text{Fat}_{\epsilon \min 115}$	115
$\text{Fat}_{\epsilon \min 100}$	100
$\text{Fat}_{\epsilon \min 85}$	85
$\text{Fat}_{\epsilon \min 70}$	70
$\text{Fat}_{\epsilon \min 60}$	60
$\text{Fat}_{\epsilon \min 50}$	50
$\text{Fat}_{\epsilon \min \text{NR}}$	-

Tab. 3 Values of fatigue (EN12697-24:2003; part 24)

The results of the measurements are on Table 4 and the examples of the mixtures fatigue in form of Wöhler's diagrams are on Fig. 6 and 7.

Mixture	T [°C]	F [Hz]	$\epsilon_6 \cdot 10^{-6}$ [mikrostrain]	b [-]	r^2 [-]	sN	$\Delta \epsilon_6$	Category
1	+10	25	87,44	-0,206	0,955	0,143	4,61E-10	$\text{Fat}_{\epsilon \min 85}$
2	+10	25	139,00	-0,294	0,116	0,827	3,47E-08	$\text{Fat}_{\epsilon \min 135}$

Tab. 4 Values of fatigue (ϵ_6)

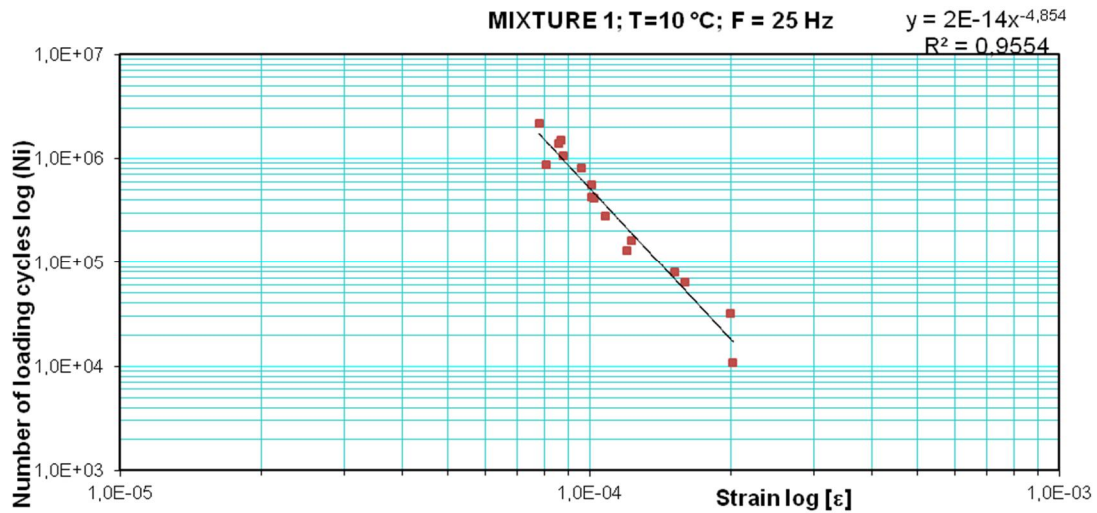


Fig. 6 Fatigue of mixture A1

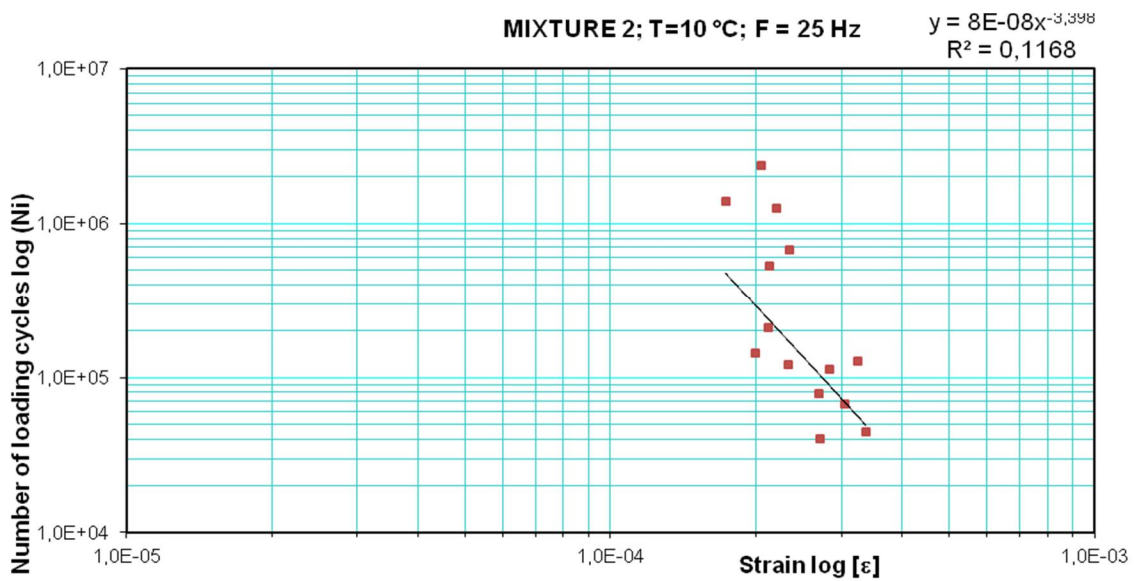


Fig. 7 Fatigue of mixture A2

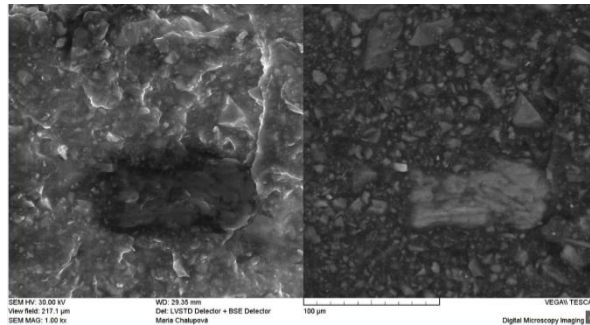
4.2.3 Master curve

For evaluation by means of principal curves - after introducing the gas constant - at the frequency of 3 to 97 Hz is valid the relation (Verstraeten, J. (1972): Moduli and critical strains in repeated bending of bituminous mixes: application to pavement design):

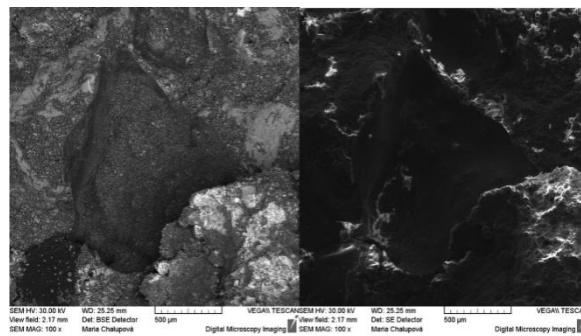
$$\alpha_T = \exp \frac{\Delta H}{R} \left(\frac{1}{T} - \frac{1}{T_s} \right) \quad (3)$$

where ΔH - the apparent energy activation ($2 \cdot 10^5 \text{ Jmol}^{-1}$)
 R - universal gas constant ($8.31434 \text{ Jmol}^{-1}\text{K}^{-1}$)

Cavity less fracture



Cavity



Cavity-Fracture-Aggregate in fracture

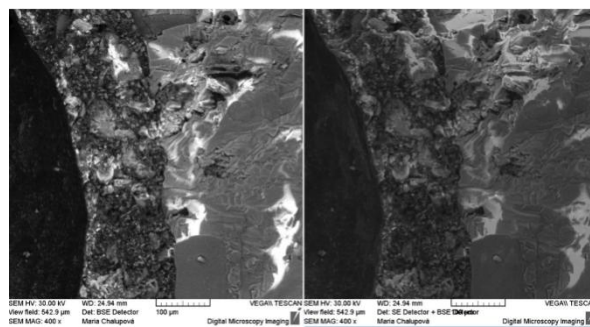


Fig. 8 The figuration of mixtures by Scanning electron microscope after fatigue test
 T , T_s - temperatures expressed in °K (T_s is the reference temperature).

The example of master curve for mixture 1 (A1) shows Figure 10.

Master curve for E^* [MPa] of mixture 1 (A1)

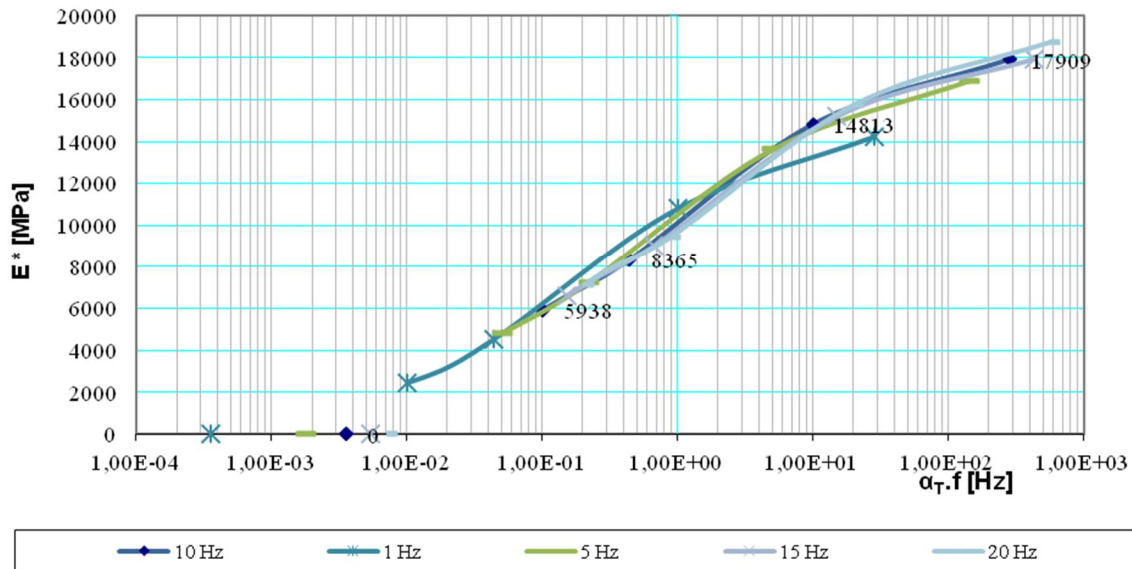


Fig. 10 Master curve in dependent on temperature and frequency (for mixture A1)

The results obtained from measuring construction layers by the effects of moving cart weighing 100 kN (design method now use 115 kN too in Slovak Republic) imply that:

- by reducing the temperature, the value of E^* , E_1 , E_2 , σ_0 rises and vice-versa, the phase angle φ (FI) decreases
- value of phase angle (φ) is temperature dependent, lower values were obtained at $\pm 0^\circ\text{C}$, when a flexible component of viscoelastic material is demonstrated
- value of maximum tension (σ_0) expresses the size of the harmonic excitation force (P_0) which effects the free end of the testing sample.

5. CONCLUSIONS

It is recommended that the functional test of fatigue for asphalt mixtures design is used during the design of asphalt mixtures; such test will determine the mixture life expectancy of pavement regarding its operational performance. It is important to know not only the proportional strain at 1 million cycles ϵ_6 , but also the trend of fatigue line from Wöhler diagram for the assessment of mixtures following fatigue resist. If the trend of fatigue line is different, it will be necessary to consider which mixture is more suitable for particular construction layer. As an addition, master curves should be used to assess the asphalt mixtures in shortened mode during which the influence of temperature, frequencies and amount of applied strenght is excluded.

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