SLOVENSKI STANDARD
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Bitumenske zmesi - Preskusne metode - 26. del: Togost

Bituminous mixtures - Test methods - Part 26: Stiffness

Asphalt - Prüfverfahren - Teil 26: Steifigkeit

Mélanges bitumineux - Méthodes d'essai pour enrobés à chaud - Partie 26 : Rigidité

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Bituminous mixtures - Test methods - Part 26: Stiffness

Mélanges bitumineux - Méthodes d'essai - Partie 26: Module de rigidité

Asphalt - Prüfverfahren - Teil 26: Steifigkeit

This European Standard was approved by CEN on 26 February 2018.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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European foreword

This document (EN 12697-26:2018) has been prepared by Technical Committee CEN/TC 227 “Road materials”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2018, and conflicting national standards shall be withdrawn at the latest by December 2018.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN not be held responsible for identifying any or all such patent rights.

This document supersedes EN 12697-26:2012.

Compared with EN 12697-26:2012, the following changes have been made:

— the series title no longer makes the method exclusively for hot mix asphalt [Title];

— implementation of a real haversinusoidal load in Annex C;

— implementation of several technical corrections in all annexes;

— adjustment of procedures in all the tests;

— application of the correct wording within all the test procedures.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This European Standard specifies the methods for characterizing the stiffness of bituminous mixtures by alternative tests, including bending tests and direct and indirect tensile tests. The tests are performed on compacted bituminous material under a sinusoidal loading or other controlled loading, using different types of specimens and supports.

The procedure is used to rank bituminous mixtures on the basis of stiffness, as a guide to relative performance in the pavement, to obtain data for estimating the structural behaviour in the road and to judge test data according to specifications for bituminous mixtures.

As this standard does not impose a particular type of testing device the precise choice of the test conditions depends on the operating scope and working range of the device used.

For the choice of specific test conditions, the requirements of the product standards for bituminous mixtures should be respected.

The applicability of this document is described in the product standards for bituminous mixtures.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12697-6, *Bituminous mixtures — Test methods for hot mix asphalt — Part 6: Determination of bulk density of bituminous specimens*

EN 12697-7, *Bituminous mixtures — Test methods for hot mix asphalt — Part 7: Determination of bulk density of bituminous specimens by gamma rays*

EN 12697-27, *Bituminous mixtures — Test methods — Part 27: Sampling*

EN 12697-29, *Bituminous mixtures — Test method for hot mix asphalt — Part 29: Determination of the dimensions of a bituminous specimen*

EN 12697-31, *Bituminous mixtures — Test methods for hot mix asphalt — Part 31: Specimen preparation by gyratory compactor*

EN 12697-33, *Bituminous mixtures — Test methods — Part 33: Specimen prepared by roller compactor*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
stiffness modulus
relationship between maximum applied stress and maximum measured strain response and expressed as:

$$E = \frac{\sigma}{\varepsilon} \qquad (1)$$

3.1.2
complex modulus
relationship between stress and strain for a linear visco-elastic material submitted to a sinusoidal load wave form at time, t, where applying a stress $\sigma \times \sin(\omega \times t)$ results in a strain $\varepsilon \times \sin(\omega \times t - \Phi)$ that has a phase angle, Φ, with respect to the stress

The amplitude of strain and the phase angle are functions of the frequency, f, and the test temperature, Θ.

The stress strain ratio defines the complex modulus E^* as:

$$E^* = |E^*| \cdot (\cos(\Phi) + i \cdot \sin(\Phi)) \quad (2)$$

The complex modulus depends on the frequency f and the temperature θ. The complex modulus is characterised in two ways:

1. By the real component E_1 and the imaginary components E_2:

$$E_1 = |E^*| \cdot \cos(\Phi) \quad (3)$$

$$E_2 = |E^*| \cdot \sin(\Phi) \quad (4)$$

2. By the absolute value of the complex modulus $|E^*|$ and the phase angle, Φ:

$$|E^*| = \sqrt{E_1^{\,2} + E_2^{\,2}} \quad (5)$$

$$\Phi = \arctan\left(\frac{E_2}{E_1}\right) \quad (6)$$

This second characterization is more often used in practice. In linear elastic multi-layer calculations for instance the E^* modulus is generally used as input value for Young's modulus.

Note 1 to entry: For purely elastic materials, the phase angle is zero and then the complex modulus reduces to the Young's modulus. This happens when bituminous materials are at very low temperatures. Then the complex modulus reaches its highest possible value, noted E_∞.

3.1.3
secant modulus
relationship between stress and strain at the loading time, *t*, for a material subjected to controlled loading (force or displacement):

$$E(t) = \frac{\sigma(t)}{\varepsilon(t)} \tag{7}$$

with stress, $\sigma(t)$, and strain, $\varepsilon(t)$, at time *t*

Note 1 to entry: The strain law is

$$\varepsilon(t) = \alpha_i \cdot t^n \tag{8}$$

where α_i and *n* are constants.

Note 2 to entry: Several successive tests can be carried out on the same specimen for different values of α_i. For linear visco-elastic materials, the secant modulus obtained for different values of α_i at the same temperature depends on the loading time, *t*, only.

3.2 Symbols

For the purposes of this document, the following symbols apply:

D maximum aggregate size in an asphalt mix in millimetre (mm);

E the elastic stiffness (modulus), in megapascals (MPa);

*E** the visco-elastic complex modulus, in megapascals (MPa);

|E|* absolute modulus of the complex modulus, in megapascals (MPa);

E_1 the real component of the complex modulus, in megapascals (MPa);

E_2 the imaginary component of the complex modulus, in megapascals (MPa);

E_∞ the highest possible value of the complex modulus, in megapascals (MPa);

F the loading force, in newtons (N);

h the mean thickness of the specimen, in millimetres (mm);

H the height of a cylindrical specimen, in millimetres (mm);

l_0 the original length of the measurement area in millimetres (mm);

Δl the elongation of the measurement area in micrometers (μm);

L the span length between outer supports in bending tests, in millimetres (mm);

m mass of the movable parts in grams (g);

M weight of the sample in grams (g);

t the loading time, in seconds (s);

Θ the test temperature, in degrees celsius (°C);

z the displacement, in millimetres (mm);

f the test frequency in Hertz (Hz);

σ the applied stress, in megapascals (MPa);

ε the applied strain, in micrometer per meter or in microstrain (µm/m);

ε_{max} the maximum strain applied to the test specimen, in micrometer per meter or in microstrain (µm/m);

ω the angular speed, in radians per second (rad/s);

φ the phase shift between the force and the displacement in degrees (°);

Φ the modulus phase angle of the material (argument), in degrees (°);

γ the form factor which is a function of specimen size and form (1/mm or mm^{-1});

μ the mass factor which is a function of the mass of the specimen and the mass of the movable parts that influence the resultant force by their inertial effects in grams (g);

ν the Poisson's ratio;

Ø the diameter of a cylindrical specimen, in millimetres (mm).

4 Principle

Suitable shaped samples are deformed in their linear range, under repeated loads or controlled strain rate loads. From the measured force and deformation signal, amplitudes of the stress and strain, and the phase angle between both are calculated. Based on measured stress and strain desired moduli can be calculated.

5 Sample preparation

5.1 Age of the specimens

Prior to the start of testing, the specimens shall be stored on a flat surface at a temperature of not more than 20 °C for between 14 d and 42 d from the time of their manufacture. In the case of samples requiring cutting and/or gluing, the cutting shall be performed no more than 8 d after compaction of the asphalt and the gluing shall be performed at least 2 weeks from cutting. The time of manufacture for these samples is the time when they are cut.

NOTE 1 The storage time influences the mechanical properties of the specimen.

NOTE 2 For test purposes other than for CE marking, different storage times can be applied.

5.2 Drying of the specimens

After sawing and before gluing and/or testing, the specimens shall be dried to constant mass in air at a relative air humidity of less than 80 % at a temperature not more than 20 °C. A test specimen shall be considered to be dry after at least 8 h drying time and when two weighings performed minimum 4 h apart differ by less than 0,1 %.

5.3 Dimensions and bulk density of the specimens

The dimensions of the specimens shall be measured according to EN 12697-29.

The bulk density shall be determined in accordance with EN 12697-6 or EN 12697-7. The bulk density of each specimen shall not differ by more than 1 % from the average density of the batch. Otherwise, the specimen shall be rejected.

5.4 Number of test specimens

For all test methods described in this standard, the stiffness modulus of a minimum of 4 specimens shall be tested. The average of these results determine the stiffness modulus for the tested mix.

6 Checking of the testing equipment

The completely assembled testing equipment shall be checked periodically with at least one reference specimen with a known stiffness modulus (modulus and phase lag). To check the test equipment for Annexes A and B, the bending moment (*E.I*) of the specimen(s) shall be chosen to be equal to the bending moment of a normal asphalt test specimen (adopting a stiffness modulus for the asphalt in the range of 3 GPa to 14 GPa); for Annexes C, D, E and F an appropriate checking specimen with a known stiffness between 3 GPa and 14 GPa shall be used.

The checking should be applied for each applied test temperature. For cyclic tests (Annex A, B, D, and F) the reference specimen shall be tested at not less than 6 frequencies and 2 deformation levels. For impulsive tests (Annex C), the reference specimen shall be submitted to a minimum of 4 trials in regular test conditions. For monotonic tests (Annex E), the reference specimen shall be tested in at least 4 loading times and 2 displacement amplitudes.

The back-calculated stiffness moduli shall be within 2 % with respect to the known modulus and within 1,0° for the known phase lag. If, due to the electronic components or mechanical equipment, systematic deviations (or larger deviations) of:

— the stiffness modulus are observed, all electronic components and/or mechanical equipment shall be checked for proper working. No procedure for use of back-calculation software is permitted;

— the phase angle is observed, a correction procedure for the back-calculation software is permitted.

The geometry of the reference specimen shall be selected so that it will lead to a mass comparable with the mass of an asphalt specimen. The clamping of the reference specimen shall be equal to the procedure for an asphalt specimen. A reference material with a phase lag unequal to zero is preferred but a material like aluminium (*E* around 70 GPa, phase lag is zero) or comparable materials is also acceptable.

7 Test methods

7.1 General

The following test methods can be adopted by use of the relative form and mass factor (see Clause 9). The testing procedures that shall be followed are described in Annexes A, B, C, D, E and F. If other test procedures are used to characterize stiffness properties of bituminous mixtures, the equivalence shall first be verified by comparison with one of these procedures and a statement on that equivalence shall be attached to the test reports.

7.2 Codification of tests

7.2.1 Sinusoidal bending tests

The bending test options are:

— 2PB-TR: test applying two point bending to trapezoidal specimens, see Annex A;

— 2PB-PR: test applying two point bending to prismatic specimens, see Annex A;

— 3PB-PR: test applying three point bending to prismatic specimens, see Annex B;

— 4PB-PR: test applying four point bending to prismatic specimens, see Annex B.

7.2.2 Indirect tensile test (pulse or cyclic)

The indirect tensile test options are:

— IT-CY: test applying pulse indirect tension to cylindrical specimens, see Annex C;

— CIT-CY: test applying cyclic indirect tension to cylindrical specimens, see Annex F.

7.2.3 Cyclic or monotonous uniaxial tests

The direct uniaxial test options are:

— DTC-CY: test applying cyclic tension-compression to cylindrical specimens, see Annex D;

— DT-CY: test applying monotonous direct tension to cylindrical specimens, see Annex E;

— DT-PR: test applying monotonous direct tension to prismatic specimens, see Annex E.

7.2.4 Loading conditions

The specific parameters of the loading signal (amplitude, frequency, loading and/or rest time) shall be controlled by a feedback control, which may be based either on the force or on the displacement.

The waveform should be harmonic. Any distortion is the sign of an abnormal set up or of a resonance phenomenon that can disturb the measurement.

7.2.5 Load amplitudes

The amplitude of the load shall be such that no damage can be generated during the time needed to perform the measurements.

Experience with a number of test methods has shown that for most bituminous mixtures strains should be kept at a level lower than 50 microstrain (= 50×10^{-6} m/m) to prevent fatigue damage.

NOTE 1 It is known that, beyond certain levels of strain, nonlinear behaviour (e.g. stress dependency) can be displayed by the material. In such a case, the proportionality between stress and strain is no longer valid and the concept of complex modulus defined above is no longer correct. This limit depends on the material but it also varies with temperature for a given material.

Special attention should be given in the highest range of temperature. Therefore, it is recommended to perform linearity tests at the highest temperature to be undertaken within the testing programme. This test consists of measuring the complex modulus at a fixed frequency for an increasing range of strains (or stresses) and to determine the value of strain at which the modulus is no longer constant (starts to decrease).

Attention should be paid to the danger of fatigue damage during testing by minimising the number of cycles or loading time at each applied stress level and/or minimising the number of stress levels. It is recommended to carry out also a reverse scheme of stress levels in order to see if any fatigue damage has occurred (see also NOTE 1).

NOTE 2 The admissible level of deformation is determined for the direct tensile test by a preliminary test at 10 °C, 50 microstrain and loading times 3 s and 300 s.

7.2.6 Loading frequencies

The range of frequencies is device dependent.

NOTE Most equipment is able to cover a range between 0,1 Hz and 50 Hz. However, it is preferable to make the range of loading frequencies as wide as possible in order to allow a logarithmic presentation of the isotherms. A typical set of frequencies could be 0,1 Hz, 0,2 Hz, 0,5 Hz, 1 Hz, 2 Hz, 5 Hz, 10 Hz, 20 Hz, 50 Hz and again the starting frequency of 0,1 Hz. This last measurement is to check that the specimen has not been damaged during the loading with various frequencies. If the difference between stiffness of the specimen at the first and last measurements at identical frequency and at the same temperature is greater than 3 %, it can be concluded that the specimen is damaged and, therefore, cannot be used for further testing (e.g. at different temperatures).

Care should be taken to avoid resonance phenomena especially at high frequencies.

7.3 Controlled strain rate loading

7.3.1 Test method

Uniaxial direct tensile test on cylindrical or prismatic specimens (DT-CY and DT-PR see Annex E) can be adopted.

NOTE The procedure gives comparable test results to sinusoidal loading for loading time less than 1 s, if the moduli at the loading time, *t*, expressed in seconds, are compared to the complex modulus at a frequency in Hertz (Hz):

$$f = \frac{1}{2\pi \cdot t} \tag{9}$$

7.3.2 Loading conditions

A controlled rate displacement shall be applied to a specimen in direct tension to provide a constant strain rate so that the strain law is:

$$\varepsilon(t) = \alpha_i \cdot t \tag{10}$$

7.3.3 Strain amplitudes for direct tensile tests

7.3.3.1 Preliminary test

For direct tensile tests, at least one element test shall be performed in accordance with Annex E in order to determine the level of the stiffness of the mixture. The conditions shall be a temperature of 10 °C, strain amplitude of 50 microstrain, loading force $F > 200$ N and loading times 3 s and 300 s.

7.3.3.2 Strain amplitudes during the test

The maximum strain during the direct tensile tests shall be less than the values given in Table 1.

Table 1 — Strain expressed in microstrain to be applied during a controlled strain rate test in accordance with the stiffness determined by a preliminary test to 50 microstrain

Test temperature Θ °C	**Stiffness**, 10 °C, 3 s		**Stiffness**, 10 °C, 300 s	
	< 7,5 GPa	≥ 7,5 GPa	< 1 GPa	≥ 1 GPa
	Strain amplitude microstrain			
≤ 10	100	50	–	–
$10 \le \Theta < 20$	–	–	200	100
$20 \le \Theta \le 40$	–	–	300	200

7.3.3.3 Test loading times

A series of tests shall be performed on the same specimen with various loading times and with the same maximum strain given in Table 1. Four loading times shall be used for at least one test temperature, and at least two loading times for the other test temperatures.

8 Temperatures

The temperature of the climatic chamber, in the vicinity of the specimen, shall be equal to the specified temperature to ± 0,5 °C. Also a dummy specimen which is close to the tested specimen with an inside thermocouple can be used for the temperature check. For each test temperature, unless check testing indicates that a consistent temperature is reached in a shorter period of time, the specimen shall be placed in the climatic chamber for at least 4 h before testing.

NOTE 1 Requirements for test temperatures can be determined in the product standards for the bituminous mixtures.

NOTE 2 The closer tolerance for the direct tensile tests is necessary because master curves need to be derived from the results.

To model reality, the temperatures should cover the extremes of climatic conditions in actual full-scale conditions. To allow a precise determination of a master curve of the stiffness modulus by shifting the isotherms, the test temperatures should be chosen close enough to each other. However, Product Specifications generally define one temperature and one frequency.

To determine a master curve of the stiffness modulus, the difference between two isotherms should not exceed 10 °C. A typical set of temperatures could be −30 °C, −20 °C, −10 °C, 0 °C, +10 °C, +15 °C, +20 °C, +30 °C, +40 °C. The temperature of 40 °C should be used with care especially as it may result in possible problems of nonlinearity and also for possible creep of the specimens (especially in the case of bending tests).

9 Expression of results

The measurements that shall be obtained during the test are the applied force, F, in newton (N), the displacement, z, in millimetres (mm) and their phase angle φ, in degrees (°). The places where they are measured depend on the test device (see Table 2).

The two components of the complex modulus, when required, shall be calculated in megapascal (MPa) in using Formula (10) for the real component E_1 and Formula (11) for the imaginary component E_2.

$$E_1 = \gamma \cdot \left(\frac{F}{z} \cdot \cos(\varphi) + 10^{-6} \cdot \mu \cdot \omega^2 \right) \tag{11}$$

$$E_2 = \gamma \cdot \frac{F}{z} \cdot \sin(\varphi) \tag{12}$$

The mechanical material characteristics shall be derived from the measurements using the specific factors given in Table 2.

NOTE 1 The accuracy of the experimentally determined complex modulus is dependent on the correct choice of the form factor and the mass term. This requires a correct evaluation of the loading conditions as well as a precise calibration of the test set up.

The stiffness modulus (the absolute value of the complex modulus |E*|) and the phase angle φ, an equivalent representation of the complex modulus, shall be derived using Formulae (5) and (6).