SLOVENSKI STANDARD
SIST EN 12697-24:2018

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SIST EN 12697-24:2012

Bitumenske zmesi - Preskusne metode - 24. del: Odpornost proti utrujanju

Bituminous mixtures - Test methods - Part 24: Resistance to fatigue

Asphalt - Prüfverfahren - Teil 24: Beständigkeit gegen Ermüdung

Mélanges bitumineux - Méthodes d'essai pour mélange hydrocarboné à chaud - Partie 24 : Résistance à la fatigue

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ICS:

93.080.20	Materiali za gradnjo cest	Road construction materials

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EUROPEAN STANDARD

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Bituminous mixtures - Test methods - Part 24: Resistance to fatigue

Mélanges bitumineux - Méthodes d'essai pour mélange hydrocarboné à chaud - Partie 24: Résistance à la fatigue

Asphalt - Prüfverfahren - Teil 24: Beständigkeit gegen Ermüdung

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
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European foreword

This document (EN 12697-24:2018) 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of an identical text or by endorsement, at the latest by December 2018, and conflicting national standards shall be withdrawn at the latest by December 2018.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 12697-24:2012.

Compared with EN 12697-24:2012, the following changes have been made:

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

— editing of several text sections in order to clarify the procedures [Ge];

— “load applications” amended to “load cycles" [Ge];

— Figure A.1 corrected: Key 3 pointing at the groove [A.1.2];

— completion of Figure E.3: Line 1 added to extensiometer in front view figure [E.2.5.3];

— introduction of new annex for cyclic indirect tensile test on cylindrical specimens (CIT-CY) [Annex F].

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 fatigue of bituminous mixtures using 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:

a) to rank bituminous mixtures on the basis of resistance to fatigue;

b) as a guide to relative performance in the pavement;

c) to obtain data for estimating the structural behaviour of the road; and

d) to judge test data according to specifications for bituminous mixtures.

Because this European Standard does not impose a particular type of testing device, the precise choice of the test conditions depends on the possibilities and the working range of the device used. For the choice of specific test conditions, the requirements of the product standards for bituminous mixtures need to 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 12697-8, *Bituminous mixtures — Test methods for hot mix asphalt — Part 8: Determination of void characteristics of bituminous specimens*

EN 12697-26, *Bituminous mixtures — Test methods — Part 26: Stiffness*

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, symbols and abbreviations

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

3.1 General

3.1.1
fatigue

reduction of strength of a material under repeated loading when compared to the strength under a single load

3.1.2
conventional criteria of failure

number of load cycles, $N_{f/50}$, when the absolute value of the complex stiffness modulus S_{mix} (stiffness modulus) has decreased to half its initial value $S_{mix,0}$

Note 1 to entry: In this standard not only the conventional criteria of failure, based on the reduction of stiffness, is presented. Also other failure criteria like the occurrence of macro cracks or the energy-based failure mechanism are used.

Note 2 to entry: Different test methods and different failure criteria might lead to results that are not comparable.

Note 3 to entry: In a displacement controlled fatigue test the reduction to half of the initial stiffness is a gradual process. In a force controlled test in most cases there will be a progressive collapse of the specimen.

3.1.3
initial complex stiffness modulus

complex stiffness modulus, $S_{mix,0}$, after 100 load cycles

3.2 Two-point bending test on trapezoidal shaped specimens (2PB-TR)

3.2.1
constant relative to maximum strain

constant that enables the head displacement z of the trapezoidal specimen of dimensions [B, b, e, h], to which a bending strain level ε is applied, to be converted into maximum strain

Note 1 to entry: The following formulae express K_ε and its relationship with the parameters mentioned above:

$$K_\varepsilon \cdot z = \varepsilon \quad (1)$$

$$K_{\varepsilon j} = \frac{(B_i - b_i)^2}{8 \cdot b_i \cdot h_i^2 \left[\frac{(b_i - B_i)\cdot(3B_i - b_i)}{2 \cdot B_i^2} + \ln \frac{B_i}{b_i} \right]} \quad (2)$$

3.2.2 Symbols

Where a strain of 1 microstrain (µstrain) is equal to 10^{-6} by convention, the symbols are as follows:

i the index of the specimen for an element test (varies from 1 to n);

h_i is the height, in millimetres (mm);

B_i is the large base, in millimetres (mm);

b_i is the small base, in millimetres (mm);

e_i is the thickness, in millimetres (mm);

v_i	is the void content of the specimen *i* by geometric method, in percent (%);
$K_{\varepsilon i}$	is the constant, relative to the maximum strain, in inverse millimetres (mm^{-1});
z_i	is the amplitude of displacement imposed at the head of specimen *i*, in millimetres (mm);
ε_i	is the maximum relative strain of specimen *i* corresponding with the displacement imposed at the head;
N_i	is the conventional fatigue life of specimen *i*;
a	is the ordinate of the fatigue line according to the formula $\lg(N) = a + (1/b)\lg(\varepsilon)$;
r_2	is the linear correlation coefficient ($\lg(N_i)$, $\lg(\varepsilon_i)$);
$1/b$	is the slope of the fatigue line;
$\lg(\varepsilon)$	is the average value of $\lg(\varepsilon_i)$;
$S_{\lg(\varepsilon)}$	is the standard deviation of $\lg(\varepsilon_i)$;
$S_{\lg(N)}$	is the standard deviation of $\lg(N_i)$;
ε_6	is the strain corresponding to 10^6 cycles;
s_N	is the estimation of the residual standard deviation of the decimal logarithms of fatigue lives;
$\Delta\varepsilon_6$	is the quality index of the test;
n	is the number of specimens.

3.3 Two-point bending test on prismatic shaped specimens (2PB-PR)

3.3.1

constants for consideration of the geometry of specimen

constants that enable the strength of the head P_{ij} of the specimen *i* of dimensions b_i, e_i and $h_{i,}$ to which a bending strength is applied, to calculate the maximum tension

Note 1 to entry: The following formulae express $K_{\sigma\,i}$ and its relationship with the parameters mentioned above:

$$K_{\sigma i} \cdot P_{ij} = \sigma_{jmax} \tag{3}$$

where

$K_{\sigma i}$	is the constant for consideration of the geometry of specimen at constant strength (mm^{-2});
P_{ij}	is the amplitude of the strength, with which the head is applied, in Newtons (N);
σ_{jmax}	is the greatest relative tension of the specimen, corresponding to the strength, with which the head is applied.

$$K_{\sigma i} = \frac{6\,h_i}{b_i^2 \cdot e_i} \tag{4}$$

where

$K_{\sigma i}$	is the constant for consideration of the geometry of specimen at constant strength (factor in accordance with EN 12697–26);

b_i	is the base, in millimetres (mm);
h_i	is the height, in millimetres (mm);
e_i	is the width, in millimetres (mm).

3.3.2 Symbols

Where a strain of 1 microstrain (μstrain) is equal to 10^{-6} by convention, the symbols are as follows:

3.3.2.1 Sample *i*

h_i	is the height, in millimetres (mm);
b_i	is (A) small base or (B) base, in millimetres (mm);
e_i	is the thickness, in millimetres (mm);
m_i	is the mass, in grams (g);
$v_\mathrm{i}\%$	is the vacuum, achieved by the geometric method as a proportion of atmospheric pressure, in percent (%);
$K\sigma_\mathrm{i}$	is the constant for consideration of the geometry of specimen at constant strength, in inverse millimetres (mm^{-1}).

3.3.2.2 Strength at head and greatest tension at specimen *i* at level of tension $\sigma_{\mathrm{j\ max}}$

P_ij	is the amplitude of the strength with which the head is applied, in Newtons (N);
$\sigma_{\mathrm{j\ max}}$	is the greatest relative tension of the specimen, corresponding to the strength, with which the head is applied, in megapascal (MPa).

3.3.2.3 Fatigue life of a specimen *i* at the level of tension $\sigma_{\mathrm{j\ max}}$

$N\sigma_\mathrm{ji}$	is the fatigue life in a force controlled test.

3.3.2.4 Fatigue life relative to sample *i* at the strain level ε_j

$N\varepsilon_\mathrm{ji}$	is the conventional fatigue life in a displacement controlled test.

3.3.2.5 Fatigue line

p_σ	is the slope of fatigue line $\ln(\sigma_{\mathrm{j\ max}}) = f(\ln(N_\mathrm{ij}))$;
$\hat{\sigma}_6$	is the tension corresponding to 10^6 cycles, in megapascals (MPa);
$s_{\sigma\ \mathrm{x/y}}$	is the estimation of the residual standard deviation of the natural logarithms of fatigue lives;
$\Delta\hat{\sigma}_6$	is the confidence of $\hat{\sigma}_6$ for a probability of 95 %, in megapascal (MPa);
N	is the number of element tests (number of specimens at the level of tension $\sigma_{\mathrm{j\ max}}$ times the number of levels) where $N = n*l$;
s_N	is the estimation of the standard deviation of $\ln(N_\mathrm{ij})$.

3.3.2.6 Fatigue life of a series of *n* specimens (A) at a strain level $\varepsilon_{\mathrm{jmax}}$ or (B) at the level of tension $\sigma_{\mathrm{j\ max}}$

$N_{\sigma\mathrm{jmax}}$	is the average number of cycles obtained at the level of tension stress $\sigma_{\mathrm{j\ max}}$;
$N_{\varepsilon\mathrm{jmax}}$	is the average number of cycles obtained at the level of tension strain $\varepsilon_{\mathrm{i\ max}}$

3.4 Three-point bending test on prismatic shaped specimens (3PB-PR)

3.4.1 Symbols

The symbols are as follows:

$2A_{\mathrm{t}}$	is the amplitude of the approximate stress function, in megapascals (MPa);
$2A_{\varepsilon}$	is the amplitude of the approximate strain function, in meter per meter (m/m);
B	is the measuring base of the extensometer, in millimetres (mm);
B_{t}	is the phase angle of the approximate stress function, in radians (rad);
B_{ε}	is the phase angle of the approximate strain function, in radians (rad);
D_{c}	is the displacement at instant *t*, in micrometres (µm);
$2D_0$	is the total amplitude of displacement function, in micrometres (µm);
DDE	is the density of dissipated energy, in megapascals (MPa) or megajoules per cubic metre (MJ/m³);
DDE (*x*)	is the density of dissipated energy at cycle *x*, in megajoules per cubic metre (MJ/m³);
EXT	is the instant extensometer signal, in millimetres (mm);
L	is the distance between supports, in millimetres (mm);
MD	is the dynamic modulus, in megapascals (MPa);
N	is the number of cycles at the end of the test;
P	is the instant load, in megapascals (MPa);
W	is the total density of dissipated energy throughout the whole test, in megajoules per cubic metre (MJ/m³);
b	is the width of the specimen, in millimetres (mm);
e	is the thickness of specimen, in millimetres (mm);
f	is the wave frequency, in Hertz (Hz);
m	is $(N - 200)/500$;
t	is the time, in seconds (s);
ε	is the instant strain or half-cyclic amplitude of strain function at cycle 200, in 10^{-6} (µm/m);
ε_{a}	is the approximate strain function value, in 10^{-6} (µm/m);
ε_{c}	is the cyclic amplitude of strain function, in 10^{-6} (µm/m);

ε_6 is the strain at 10^6 cycles, in 10^{-6} (µm/m);

σ is the instant stress, in megapascals (MPa);

σ_a is the approximate stress function value, in megapascals (MPa);

σ_c is the cyclic amplitude of stress function, in megapascals (MPa);

Φ is the phase difference angle, in degrees (°).

3.5 Four-point bending test on prismatic shaped specimens (4PB-PR)

3.5.1
(complex) stiffness modulus

ratio $S = S_{\text{mix,n}} \times e^{\text{i}\Phi}$ of the calculated stress and strain during cycle n in the specimen

Note 1 to entry: The stiffness modulus defines the relationship between stress and strain for a linear viscoelastic material subjected to sinusoidal loading.

3.5.2
initial (complex) stiffness modulus

Initial value $\text{S}_{\text{mix,0}}$ in megapascals (MPa) of the (complex) stiffness modulus and for the the initial phase angle ϕ_0 in degrees (°) of the complex modulus taken at the 100th load cycle

3.5.3
fatigue life $N_{\text{i,j,k}}$ of a specimen

number of cycles for specimen *i*, corresponding with the chosen failure criteria *j* (e.g. conventional failure *j* = *f*/50) at the set of test conditions k (temperature, frequency and loading mode)

Note 1 to entry: A loading mode could be constant deflection level, or constant force level, and or any other constant loading condition.

3.5.4
test condition *k*

set of conditions under which a specimen is tested

Note 1 to entry: This set contains the applied frequency *f*, the test temperature Θ and the loading mode (constant deflection, or constant force, and or constant dissipated energy per cycle.

3.5.5
total length L_{tot}

total length of the prismatic specimen, in millimetres (mm)

3.5.6
effective length *L*

distance between the two outer clamps, in millimetres (mm)

3.5.7
width *B*

width of the prismatic specimen, in millimetres (mm)

3.5.8
height *H*

height of the prismatic specimen, in millimetres (mm)

3.5.9

mid-span length *a*

distance between the two inner clamps, in millimetres (mm)

3.5.10

co-ordinate *A*

distance between the left outer ($x = 0$) and left inner clamp ($x = A$), in millimetres (mm)

3.5.11

co-ordinate *x*

distance between x and the left outer clamp ($0 \leq x \leq L/2$), in millimetres (mm)

3.5.12

co-ordinate x_S

co-ordinate x where the deflection is measured ($A \leq x_S \leq L/2$), in millimetres (mm)

3.5.13

density ρ

geometrical density of the specimen, in kilograms per cubic metre (kg/m^3):

$$\rho = \frac{M_{\text{beam}} \cdot 10^9}{(H \cdot L \cdot B)} \qquad (5)$$

3.5.14

mass M_{beam}

total mass of the prismatic beam, in kilograms (kg)

3.5.15

damping coefficient *T*

coefficient needed for calculation of the system losses, in kilograms per second (kg/s)

Note 1 to entry: This coefficient can only be established by tuning the equipment with a reference beam of which the stiffness modulus and (material) phase angle are known. In good working equipment, the coefficient T can be neglected (adopting a zero value).

3.5.16

weighing function $R(x)$

dimensionless function depending on the distance x to the left outer clamp, the co-ordinate A of the left inner clamp and the effective length L between the two outer clamps:

$$R(x) = \frac{12\,L^3}{A \cdot (3L \cdot x - 3x^2 - A^2)} \qquad (6)$$

3.5.17

equivalent mass M_{eq}

weighed mass in kilograms (kg) of the moving parts of beam (M_{beam}), sensor (M_{sensor}) and clamps (M_{clamp}) whose values depend on the place where the deflection $Z(x_S)$ is measured:

$$M_{\text{eq}} = \frac{R(x_S)}{\pi^4} \cdot M_{\text{beam}} + \frac{R(x_S)}{R(A)} \cdot M_{\text{clamp}} + M_{\text{sensor}} \qquad (7)$$

3.5.18

equivalent coefficient for damping

weighed coefficient for the damping in the system in kilograms per second (kg/s), the value of which depends on the place where the deflection $Z(x_S)$ is measured:

$$T_{\mathrm{eq}} = \frac{R(x_{\mathrm{s}})}{R(A)} \cdot T \tag{8}$$

3.5.19

deflection $Z(x_S)$

amplitude of the deflection of the beam during one cycle, measured on or between the two inner clamps at a distance x_S from the left outer clamp, in millimetres (mm)

Note 1 to entry: With a perfect sinusoidal signal is the peak-peak value twice the amplitude of the signal.

3.5.20

force F_0

amplitude of the total force at the two inner clamps, in Newtons (N)

3.5.21

frequency f_0 [Hz] and circular frequency ω_0 [rad/s]

frequency of the applied sinusoidal load:

$$\omega_0 = 2\pi \cdot f_0 \tag{9}$$

3.5.22

inertia function $I(x_S)$

dimensionless function depending on the distance x_S used to account for mass inertia effects:

$$I(x_{\mathrm{s}}) = M_{\mathrm{eq}} \cdot \frac{Z(x_{\mathrm{s}})}{F_0} \cdot \omega_0^2 \cdot 10^{-3} \tag{10}$$

3.5.23

damping function $J(x_S)$

dimensionless function depending on the distance x_S used to account for damping (non-viscous) effects in the system (system losses):

$$J(x_{\mathrm{s}}) = T_{\mathrm{eq}} \cdot \frac{Z(x_{\mathrm{s}})}{F_0} \cdot \omega_0 \cdot 10^{-3} \tag{11}$$

3.5.24

measured phase lag $\varphi^*(x_S)$

measured phase lag in degrees (°) during one cycle between the applied sinusoidal load and the measured deflection $Z(x_S)$

3.5.25

system phase lag θ (x_S)

calculated phase lag in degrees (°) during one cycle representing the system losses:

$$\tan\left(\theta \cdot \frac{\pi}{180}\right) = \frac{T_{\mathrm{eq}} \cdot \omega_0}{M_{\mathrm{eq}} \cdot \omega_0^2} \tag{12}$$

3.5.26

phase lag ϕ

calculated phase lag in degrees (°) during one cycle between the occurring stress and strain in the specimen at the applied frequency:

$$\tan\left(\phi \cdot \frac{\pi}{180}\right) = \frac{\sin\left(\phi^*(x_{\mathrm{s}}) \cdot \frac{\pi}{180}\right) - J(x_{\mathrm{s}})}{\cos\left(\phi^*(x_{\mathrm{s}}) \cdot \frac{\pi}{180}\right) + I(x_{\mathrm{s}})} \tag{13}$$

3.5.27

the complex (stiffness) modulus or dynamic stiffness modulus S_{mix}

calculated modulus of the complex modulus for the specimen during one cycle, in megapascals (MPa):

$$S_{\mathrm{mix}} = \frac{12F_0 \cdot L^3}{Z(x_{\mathrm{s}}) \cdot R(x_{\mathrm{s}}) \cdot B \cdot H^3} \cdot \sqrt{1 + 2[\cos(\phi^*(x_{\mathrm{s}})) \cdot I(x_{\mathrm{s}}) - \sin(\phi^*(x_{\mathrm{s}})) \cdot J(x_{\mathrm{s}})] + [I^2(x_{\mathrm{s}}) + J^2(x_{\mathrm{s}})]} \tag{14}$$

3.5.28

constant K relative to (maximum) strain

constant that enables the calculation of the maximum bending strain amplitude at the place where the deflection is measured, in inverse millimetres (mm^{-1}):

$$K(x_{\mathrm{s}}) = \frac{H \cdot A}{4L^3} \cdot R(x_{\mathrm{s}}) \tag{15}$$

3.5.29

strain amplitude $\varepsilon = \varepsilon\ (x_{\mathrm{s}})$

maximum strain amplitude during one cycle which occurs between the two inner clamps, in micrometres per metre (µm/m):

$$\varepsilon = K(x_{\mathrm{s}}) \cdot Z(x_{\mathrm{s}}) \cdot 10^6 \tag{16}$$

3.5.30

stress amplitude σ

maximum stress amplitude during one cycle which occurs between the two inner clamps, in megapascals (MPa):

$$\sigma = S_{\mathrm{mix}} \cdot \varepsilon \cdot 10^{-6} \tag{17}$$

3.5.31

dissipated energy per cycle

dissipated viscous energy in the beam per unit volume ΔW_{dis} and per cycle, in kilojoules per cubic metre (kJ/m^3) that, for sinusoidal strain and stress signals, is:

$$\Delta W_{\mathrm{dis}} = 10^{-3} \cdot \pi \cdot \varepsilon \cdot \sigma \cdot \sin\left(\phi(x_{\mathrm{s}}) \cdot \frac{\pi}{180}\right) \tag{18}$$