BS EN 12697-24:2012

BSI Standards Publication

Bituminous mixtures — Test methods for hot mix asphalt

Part 24: Resistance to fatigue

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National foreword

This British Standard is the UK implementation of EN 12697-24:2012. It supersedes BS EN 12697-24:2004 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/510/1, Asphalt products.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Bituminous mixtures - Test methods for hot mix asphalt - Part 24: Resistance to fatigue

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

Asphalt - Prüfverfahren für Heißasphalt - Teil 24: Beständigkeit gegen Ermüdung

This European Standard was approved by CEN on 23 March 2012.

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Foreword

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of an identical text or by endorsement, at the latest by November 2012, and conflicting national standards shall be withdrawn at the latest by November 2012.

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

This document supersedes EN 12697-24:2004+A1:2007.

The main changes with respect to the previous edition are as follows:

— clarification in the scope that tests using different failure criteria are not comparable;

— definition of conventional criteria of fatigue for constant force deleted, leaving just constant displacement;

— definitions of the average and standard deviation of the fatigue life of a series of specimens for the two-point and four-point bending tests on prismatic specimens removed;

— symbols for the frequency of the sinusoidal load applications and angular speed revised;

— requirements on age and drying of specimens added in the main text and removed from the individual annexes;

— limits on interpolation defined;

— alternative criterion given in a note;

— requirement for checking (rather than calibration of) the test equipment added in the main text and removed from the individual annexes;

— requirement added for the test report to include information on the chosen test method, the used testing equipment, results of the last check on calibration of the testing equipment and the age of the specimen at the time of testing;

— the tolerance for the displacement of the trapezoidal specimen widened;

— measurements on the three-point bending test on prismatic specimens started after fewer cycles;

— note added on rotating the specimen in four-point bending test on prismatic specimens;

— the optional requirement for choosing frequency spectrum of initial complex (stiffness) moduli removed from the four-point bending test on prismatic specimens;

— the principle, equipment, procedure and calculations of the indirect tensile test on cylindrical specimens revised.

This document is one of a series of standards for bituminous mixtures which includes the following:

EN 12697-1, *Bituminous mixtures — Test methods for hot mix asphalt — Part 1: Soluble binder content*

EN 12697-2, *Bituminous mixtures — Test methods for hot mix asphalt — Part 2: Determination of particle size distribution*

EN 12697-3, *Bituminous mixtures — Test methods for hot mix asphalt — Part 3: Binder recovery: Rotary evaporator*

EN 12697-4, *Bituminous mixtures — Test methods for hot mix asphalt — Part 4: Binder recovery: Fractionating column*

EN 12697-5, *Bituminous mixtures — Test methods for hot mix asphalt — Part 5: Determination of the maximum density*

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 12697-10, *Bituminous mixtures — Test methods for hot mix asphalt — Part 10: Compactibility*

EN 12697-11, *Bituminous mixtures — Test methods for hot mix asphalt — Part 11: Determination of the affinity between aggregate and bitumen*

EN 12697-12, *Bituminous mixtures — Test methods for hot mix asphalt — Part 12: Determination of the water sensitivity of bituminous specimens*

EN 12697-13, *Bituminous mixtures — Test methods for hot mix asphalt — Part 13: Temperature measurement*

EN 12697-14, *Bituminous mixtures — Test methods for hot mix asphalt — Part 14: Water content*

EN 12697-15, *Bituminous mixtures — Test methods for hot mix asphalt — Part 15: Determination of the segregation sensitivity*

EN 12697-16, *Bituminous mixtures — Test methods for hot mix asphalt — Part 16: Abrasion by studded tyres*

EN 12697-17, *Bituminous mixtures — Test methods for hot mix asphalt — Part 17: Partial loss of porous asphalt specimen*

EN 12697-18, *Bituminous mixtures — Test methods for hot mix asphalt — Part 18: Binder drainage*

EN 12697-19, *Bituminous mixtures — Test methods for hot mix asphalt — Part 19: Permeability of specimen*

EN 12697-20, *Bituminous mixtures — Test methods for hot mix asphalt — Part 20: Indentation using cube or Marshall specimens*

EN 12697-21, *Bituminous mixtures — Test methods for hot mix asphalt — Part 21: Indentation using plate specimens*

EN 12697-22, *Bituminous mixtures — Test methods for hot mix asphalt — Part 22: Wheel tracking*

EN 12697-23, *Bituminous mixtures — Test methods for hot mix asphalt — Part 23: Determination of the indirect tensile strength of bituminous specimens*

EN 12697-24, *Bituminous mixtures — Test methods for hot mix asphalt — Part 24: Resistance to fatigue*

EN 12697-25, *Bituminous mixtures — Test methods for hot mix asphalt — Part 25: Cyclic compression test*

EN 12697-26, *Bituminous mixtures — Test methods for hot mix asphalt — Part 26: Stiffness*

EN 12697-27, *Bituminous mixtures — Test methods for hot mix asphalt — Part 27: Sampling*

EN 12697-28, *Bituminous mixtures — Test methods for hot mix asphalt — Part 28: Preparation of samples for determining binder content, water content and grading*

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

EN 12697-30, *Bituminous mixtures — Test methods for hot mix asphalt — Part 30: Specimen preparation by impact compactor*

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

EN 12697-32, *Bituminous mixtures — Test methods for hot mix asphalt — Part 32: Laboratory compaction of bituminous mixtures by vibratory compactor*

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

EN 12697-34, *Bituminous mixtures — Test methods for hot mix asphalt — Part 34: Marshall test*

EN 12697-35, *Bituminous mixtures — Test methods for hot mix asphalt — Part 35: Laboratory mixing*

EN 12697-36, *Bituminous mixtures — Test methods for hot mix asphalt — Part 36: Determination of the thickness of a bituminous pavement*

EN 12697-37, *Bituminous mixtures — Test methods for hot mix asphalt — Part 37: Hot sand test for the adhesivity of binder on precoated chippings for HRA*

EN 12697-38, *Bituminous mixtures — Test methods for hot mix asphalt — Part 38: Common equipment and calibration*

EN 12697-39, *Bituminous mixtures — Test methods for hot mix asphalt — Part 39: Binder content by ignition*

EN 12697-40, *Bituminous mixtures — Test methods for hot mix asphalt — Part 40: In situ drainability*

EN 12697-41, *Bituminous mixtures — Test methods for hot mix asphalt — Part 41: Resistance to de-icing fluids*

EN 12697-42, *Bituminous mixtures — Test methods for hot mix asphalt — Part 42: Amount of coarse foreign matters in reclaimed asphalt*

EN 12697-43, *Bituminous mixtures — Test methods for hot mix asphalt — Part 43: Resistance to fuel*

EN 12697-44, *Bituminous mixtures — Test methods for hot mix asphalt — Part 44: Crack propagation by semi-circular bending test*

EN 12697-45, *Bituminous mixtures — Test methods for hot mix asphalt — Part 45: Saturation ageing tensile stiffness (SATS) conditioning test*

EN 12697-46, *Bituminous mixtures — Test methods for hot mix asphalt — Part 46: Low temperature cracking and properties by uniaxial tension tests*

EN 12697-47, *Bituminous mixtures — Test methods for hot mix asphalt — Part 47: Determination of the ash content of natural asphalts*

prEN 12697-48, *Bituminous mixtures — Test methods for hot mix asphalt — Part 48: Inter-layer bond strength*[1)]

prEN 12697-49, *Bituminous mixtures — Test methods for hot mix asphalt — Part 49: Skid resistance of asphalt in the laboratory*[1)]

prEN 12697-50, *Bituminous mixtures — Test methods for hot mix asphalt — Part 50: Scuffing resistance of surface course*[1)]

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, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1) In preparation.

1 Scope

This European Standard specifies the methods for characterising 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.

Results obtained from different test methods or using different failure criteria are not assured to be comparable.

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 12697-8, *Bituminous mixtures — Test methods for hot mix asphalt — Part 8: Determination of void characteristics of bituminous specimens*

EN 12697-26:2011, *Bituminous mixtures — Test methods for hot mix asphalt — Part 26: Stiffness*

EN 12697-27, *Bituminous mixtures — Test methods for hot mix asphalt — Part 27: Sampling*

EN 12697-29, *Bituminous mixtures — Test methods 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 for hot mix asphalt — Part 33: Specimen prepared by roller compactor*

3 Terms, definitions, symbols and abbreviations

For the purposes of this document, the following terms and 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 applications, $N_{f/50}$, when the complex stiffness modulus $S_{mix,0}$ has decreased to half its initial value

3.1.3
initial complex stiffness modulus
complex stiffness modulus, $S_{mix,0}$, after 100 load applications

3.1.4
fatigue life of a specimen
number of cycles $N_{i,j,k}$ corresponding to the conventional failure criterion 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.

3.2 Two-point bending test on trapezoidal specimens

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:

$$K_\varepsilon \times z = \varepsilon \tag{1}$$

$$K_\varepsilon = \frac{B^2 \times (B-b)^2}{4b \times h^2 \times \left[(b-B)\times(3B-b) + 2B^2 \times \ln\left(\frac{B}{b}\right)\right]} \tag{2}$$

3.2.2 Symbols

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

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

h_i is the height, in metres (m);

B_i is the large base, in metres (m);

b_i is the small base, in metres (m);

e_i is the thickness, in metres (m);

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 metres (m^{-1});

z_i is the amplitude of displacement imposed at the head of specimen i, in metres (m);

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 $\log(N) = a + (1/b)\log(\varepsilon)$;

r_2 is the linear correlation coefficient ($\log(N_i)$, $\log(\varepsilon_i)$);

$1/b$ is the slope of the fatigue line;

$\log(\varepsilon)$ is the average value of $\log(\varepsilon_i)$;

$S_{\log(\varepsilon)}$ is the standard deviation of $\log(\varepsilon_i)$;

$S_{\log(N)}$ is the standard deviation of $\log(N_i)$;

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

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 be converted to a maximum tension

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

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

where

$K_{\sigma i}$ is the constant for consideration of the geometry of specimen at constant strength;

P_{ij} is the amplitude of the strength, with which the head is applied, in Newtons (N);

ε_{jmax} is the maximum relative strain of the specimen corresponding with the displacement imposed at the head;

σ_{jmax} is the greatest relative tension of the specimen, corresponding to the strength, with which the head is applied.

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

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);

$v_i\%$ is the vacuum, achieved by the geometric method as a proportion of atmospheric pressure, in percent (%);

$K\sigma_i$ 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 $\varepsilon_{j\,max}$

P_{ij} is the amplitude of the strength with which the head is applied, in Newtons (N);

$\sigma_{j\,max}$ is the greatest relative tension of the specimen, corresponding to the strength, with which the head is applied.

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

N_{ij} is the fatigue life.

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

N_{ij} is the conventional fatigue life.

3.3.2.5 Fatigue line

p_σ is the slope of fatigue line $\ln(\sigma_{j\,max}) = f(\ln(N_{ij}))$;

$\hat{\sigma}_6$ is the tension corresponding to 10^6 cycles, in megapascals (MPa);

$s_{\sigma x/y}$ 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 %;

N is the number of element tests (number of specimens at the level of tension $\sigma_{j\,max}$ times the number of levels) where $N = n*l$;

s_N is the estimation of the standard deviation of ln(N_{ij}).

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

$N_{\varepsilon jmax}$ is the average number of cycles obtained at the level of tension $\sigma_{j\,max}$;

l is the number at the level of tension $\sigma_{j\,max}$;

n is the number of specimens at the level of tension $\sigma_{j\,max}$.

3.4 Three-point bending test on prismatic shaped specimens

3.4.1 Symbols

The symbols are as follows:

$2A_t$ is the amplitude of the approximate stress function, in megapascals (MPa);

$2A_t$ is the amplitude of the approximate strain function, in megapascals (MPa);

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 microns (µm);

$2D_0$ is the total amplitude of displacement function, in microns (µm);

DDE is the density of dissipated energy, in megapascals (MPa) or megajoules per cubic metre (MJ/m^3);

$DE_{(total)}$ is the total density of dissipated energy throughout the whole test, in megajoules per cubic metre (MJ/m^3);

$DDE\,(x)$ is the density of dissipated energy at cycle x, in megajoules per cubic metre (MJ/m^3);

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/m^3);

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;

ε_a is the approximate strain function value;

ε_c is the cyclic amplitude of strain function;

ε_6 is the strain at 10^6 cycles;

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

3.5.1
(complex) stiffness modulus
ratio $S = S_{mix,n} \times e^{i\phi}$ 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
values for the initial modulus $S_{mix,0}$ in megapascals (MPa) of the complex modulus and for the initial phase lag ϕ_o in degrees of the complex modulus taken at the 100^{th} load application

3.5.3
fatigue life $N_{i,j,k}$
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 ($0 \le x \le L/2$), in millimetres (mm)

3.5.12
co-ordinate x_s
co-ordinate x where the deflection is measured ($A \le x_s \le L/2$), in millimetres (mm)

3.5.13
density ρ
geometrical density of the specimen, in kilograms per cubic metre (kg/m^3):

$$\rho = \frac{M_{beam} \times 10^9}{(H \times L \times B)} \quad (5)$$

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:

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

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:

$$M_{eq} = \frac{R(x_s)}{\pi^4}\times M_{beam} + \frac{R(x_s)}{R(A)}\times M_{clamp} + M_{sensor} \tag{7}$$

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:

$$T_{eq} = \frac{R(x_s)}{R(A)}\times T \tag{8}$$

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)

3.5.20
force F_0
amplitude of the total force at the two inner clamps, in Newtons (N)

3.5.21
frequency f [Hz] **and circular frequency ω**[rad/s]
frequency of the applied sinusoidal load:

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

3.5.22
inertia function $I(x_s)$
dimensionless function depending on the distance x_s used to account for mass inertia effects:

$$I(x_s) = M_{eq}\times\frac{Z(x_s)}{F_0}\times\omega_0^2\times 10^{-3} \tag{10}$$

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):

$$J(x_s) = T_{eq}\times\frac{Z(x_s)}{F_0}\times\omega_0\times 10^{-3} \tag{11}$$

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 $\theta(x_s)$
calculated phase lag in degrees during one cycle representing the system losses:

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

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:

$$\tan\left(\phi \times \frac{\pi}{180}\right) = \frac{\sin\left(\phi^*(x_s) \times \frac{\pi}{180}\right) - J(x_s)}{\cos\left(\phi^*(x_s) \times \frac{\pi}{180}\right) + I(x_s)} \quad (13)$$

3.5.27
modulus S_{mix} of the complex (stiffness) modulus or dynamic stiffness modulus
calculated modulus of the complex modulus for the specimen during one cycle, in megapascals (MPa):

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

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}):

$$K(x_s) = \frac{H \times A}{4L^3} \times R(x_s) \quad (15)$$

3.5.29
strain amplitude $\varepsilon = \varepsilon(x_s)$
maximum strain amplitude during one cycle which occurs between the two inner clamps, in microns per metre (µm/m):

$$\varepsilon = K(x_s) \times Z(x_s) \times 10^6 \quad (16)$$

3.5.30
stress amplitude σ
maximum stress amplitude during one cycle which occurs between the two inner clamps, in megapascals (MPa):

$$\sigma = S_{mix} \times \varepsilon \quad (17)$$

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:

$$\Delta W_{dis} = \pi \times \varepsilon \times \sigma \times \sin\left(\phi(x_s) \times \frac{\pi}{180}\right) \quad (18)$$

3.5.32
cumulated dissipated energy
summation of the dissipated energies per cycle up to cycle n:

$$W_{\text{dis,n(m)}} = \sum_{i=1}^{n} \Delta W_{\text{dis,i}} \quad (19)$$

Note 1 to entry: If the measurements are taken at intervals $n(i)$, it is recommended to use the trapezium rule:

$$W_{\text{dis,n(m)}} = n(1) \times \Delta W_{\text{dis,n(1)}} + \sum_{i=1}^{m} \left[0,5 \times \left(n(i+1) - n(i) \right) \times \left(\Delta W_{\text{dis, n(i+1)}} + \Delta W_{\text{dis,n(i)}} \right) \right] \quad (20)$$

3.5.33
amplitude
half the difference between the maximum and the minimum of a (sinusoidal) signal measured during one cycle

3.5.34
measuring error
difference between the true value of a physical quantity and the value indicated by the measuring instrument, expressed as a proportion of the true value, in percent (%)

3.5.35
accuracy class
permissible measuring error in the output signal of a transducer or sensor

3.5.36 Symbols

The symbols are as follows:

A_1 is the estimate of the slope, p;

A_0 is the estimation of the level of loading, Q;

B is the width of the prismatic specimen, in millimetres (mm);

D is the maximum nominal grain size of the mixture being tested, in millimetres (mm);

H is the height of the prismatic specimen, in millimetres (mm);

L is the effective length of the prismatic specimen, in millimetres (mm);

L_{tot} is the total length of the prismatic specimen, in millimetres (mm);

M_{beam} is the mass of the whole beam without the masses of the mounted clamps, in grams (g);

M_{clamps} is the masses of the two inner clamps, including the mass of the adhesive, and the mass of the load frame between the load cell and the jack, in grams (g);

M_{sensor} is the mass of the moving parts of the sensor, in grams (g);

M_{eq} is the equivalent mass, in grams (g);

$N_{\text{i,j,k}}$ is the length of life for specimen number i, the chosen failure criteria j and the set of test conditions k is cycles;

$N_{f/50}$ is the number of load applications at conventional failure when the modulus of the (complex) stiffness modulus has decreased to half its initial value;

Q is the level of the loading mode test condition corresponding to 10^6 cycles for the fatigue life according to the chosen failure criteria, k;

ΔQ is the confidence interval relative to Q;

S_{mix} is the initial value of the calculated modulus;

$S_{x/y}$ is the estimation of the standard deviation of the residual dispersion of the natural logarithms of fatigue lives, $\sigma_{x/y}$;

T is the coefficient for the system losses in the interpretation formulae for Young's modulus;

p is the slope of the fatigue line;

r is the correlation coefficient of the regression;

x is the distance from end of sample, in millimetres (mm);

x_s is the distance from the end of the specimen to where the sensor is placed, in millimetres (mm);

ε_i is the initial strain amplitude measured at the 100th load cycle;

f is the test frequency in Hertz (Hz);

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

Θ is the test temperature, in degrees Celsius (°C).

3.6 Symbols for indirect tensile test on cylindrical shaped specimens

The symbols are as follows:

ΔH is the horizontal deformation, in millimetres (mm);

N_f is the number of load applications at fatigue life;

P is the maximum load, in Newtons (N);

k, n are the material constants;

t is the specimen thickness, in millimetres (mm);

σ_o is the tensile stress at specimen centre, in megapascals (MPa);

ε_o is the tensile strain in $\mu\varepsilon$ at the centre of the specimen;

Ω is the specimen diameter, in millimetres (mm);

$\mu\varepsilon$ is the microstrain = 10^{-6} strain.

4 Sample preparation

4.1 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 days and 42 days 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 days after compaction of the asphalt and the gluing shall be performed at least 2 weeks after cutting. The time of manufacture for these samples is the time when they are cut.

4.2 Drying of the specimen

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 % and at a temperature not more than 20 °C. A test specimen shall be considered to be dry when two weighings performed at a minimum of 4 h apart differ by less than 0,1 %.

NOTE If a specimen has been stored under cover in the dry for at least 14 days, it can be assumed to be dry.

4.3 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. The bulk density of each specimen shall not differ by more than 1 % from the average apparent density of the batch. If it does differ outside this tolerance, the specimen shall be rejected.

5 Failure

The conventional failure criterion for the type of test undertaken, as defined in 3.1.2, shall be used to determine the failure life of a material unless otherwise prescribed. In such cases, the criterion used shall be included the test report.

6 Calculations

The test loads and frequencies shall be selected so that the results are calculated by interpolation and not by extrapolation with at least 20 % of the measurements either side of the calculated result.

7 Summary of the procedures

7.1 Two-point bending test on trapezoidal specimens

This method characterises the behaviour of bituminous mixtures under fatigue loading with controlled displacement by two-point bending using trapezoidal shaped specimens. The method can be used for bituminous mixtures with a maximum aggregate size of up to 20 mm on specimens prepared in a laboratory or obtained from road layers with a thickness of at least 40 mm. For mixtures with an upper size D between 20 mm and 40 mm, the test can be performed using the same principle but with adapted specimen sizes. For a given frequency of sinusoidal displacement, the method shall be carried out on several elements tested in a ventilated atmosphere at a controlled temperature.

7.2 Two-point bending test on prismatic shaped specimens

This method characterises the behaviour of bituminous mixtures under fatigue loading by 2-point-bending using square-prismatic shaped specimens. The method can be used for bituminous mixtures with a maximum aggregate size of up to 20 mm and on specimens prepared in a laboratory or obtained from road layers with a thickness of at least 40 mm.

7.3 Three-point bending test on prismatic shaped specimens

This method characterises the behaviour of bituminous mixes under fatigue loading, with controlled displacement by three-point bending using prismatic beam shaped specimens. The behaviour is characterised through the determination of the fatigue law in terms of strain (relation between strain and number of load cycles at failure) and the associated energy law. The method can be used for bituminous mixture specimens with a maximum aggregate size of 22 mm or for samples from road layers with a thickness of at least 50 mm. For a given frequency of sinusoidal displacement, the method shall be carried out on several elements tested at a controlled temperature.

7.4 Four-point bending test on prismatic shaped specimens

This method characterises the behaviour of bituminous mixtures under fatigue loading in four-point bending test equipment in which the inner and outer clamps are symmetrically placed and slender rectangular shaped specimens (prismatic beams) are used. The prismatic beams shall be subjected to four-point periodic bending with free rotation and translation at all load and reaction points. The bending shall be realised by loading the two inner load points (inner clamps) in the vertical direction, perpendicular to the longitudinal axis of the beam. The vertical position of the end-bearings (outer clamps) shall be fixed. This load configuration shall create a constant moment, and hence a constant strain, between the two inner clamps. The applied load shall be sinusoidal. During the test, the load needed for the bending of the specimen, the deflection and the phase lag between these two signals shall be measured as a function of time. The fatigue characteristics of the material tested shall be determined from these measurements.

7.5 Indirect tensile test on cylindrical shaped specimens

This method characterises the behaviour of bituminous mixtures under repeated load fatigue testing with a constant load mode using an indirect tensile load. A cylindrical specimen manufactured in a laboratory or cored from a road layer can be used in this test. A cylinder-shaped test specimen shall be exposed to repeated compressive loads with a haversine load signal through the vertical diametrical plane. This loading develops a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametrical plane, which causes the specimen to fail by splitting along the central part of the vertical diameter. The resulting horizontal deformation of the specimen shall be measured and an assumed Poisson's ratio used to calculate the tensile strain at the centre of the specimen.

NOTE An alternative failure criterion is that the fracture life can be determined as the total number of load applications before fracture of the specimen occurs. Further alternative failure criterions can be based on energy dissipation. The use of this criterion should be stated in the test report.

8 Checking of the testing equipment

The complete testing equipment shall be checked against at least one reference specimen with a known stiffness modulus (modulus and phase lag). To check the test equipment for Annex A, B, C or D, 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 Annex E an appropriate checking specimen with a known stiffness between 3 GPa and 14 GPa shall be used. The reference specimen shall be tested at not less than 2 frequencies, 1 temperature and 2 deflection levels. 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 mechanical equipment shall be checked for proper working and no procedure for the back-calculation software is permitted; or

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

NOTE The geometry of the reference specimen should be selected so that it will lead to a weight comparable with the weight of an asphalt specimen. The clamping of the reference specimen should 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) is also acceptable.

9 Test report

The test report shall include:

a) information on the chosen test method, the used testing equipment and results of the last check on the testing equipment;

b) identification of the mixture;

c) date that the test was undertaken and the age of the specimen at the time of testing (in days);

d) average air void content in the specimen, according to EN 12697-8;

e) method of manufacture or sampling, if applicable;

f) conditions of the fatigue testing (temperature, frequency, etc.);

g) chosen failure criterion (if not the conventional failure criterion);

h) average number of cycles and the standard deviation obtained for each strain or stress level;

i) representation of the fatigue line;

j) title of the relevant annex of this European Standard;

k) other results required by the relevant annex;

l) details not provided for in this European Standard;

m) any incidents which may have an effect on the results.

Annex A
(normative)

Two-point bending test on trapezoidal shaped specimens

A.1 Principle

A.1.1 General

A.1.1.1 This annex specifies a method to characterise the behaviour of bituminous mixtures under fatigue loading with controlled displacement by two-point bending using trapezoidal shaped specimens.

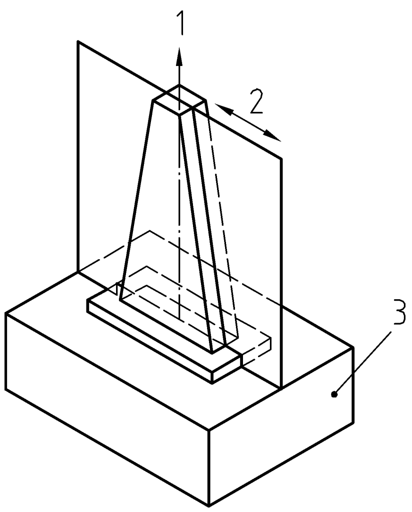
A.1.1.2 The method can be used for bituminous mixtures with aggregate having an upper sieve size of 20 mm, or on specimens prepared in a laboratory or obtained from road layers with a thickness of at least 40 mm. For mixtures with an upper sieve size D between 20 mm and 40 mm, the test can be performed using the same principle, but with adapted specimen sizes.

A.1.1.3 For a given frequency of sinusoidal displacement, the method shall be carried out on several elements tested in a ventilated atmosphere with a controlled temperature.

A.1.2 Element test

An element test shall consist of:

- imposing a constant amplitude sinusoidal displacement at the head of an isosceles trapezoidal console test piece, as shown in Figure A.1;
- recording the change in the force at head amplitude relative to the reaction of the test piece;
- measuring the fatigue life of the test piece when the failure criterion is achieved.



Key

1 force at head amplitude relative to the reaction of the test piece
2 constant amplitude sinusoidal displacement
3 groove in the metal base

Figure A.1 — Sinusoidal displacement at the head of specimen

A.1.3 Fatigue line

The fatigue line of the mixture element tests at the different displacement amplitude levels that the tests are performed shall be drawn. The fatigue line shall be 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 10^6 cycles ε_6 and the slope of the fatigue line 1/b shall be determined. The standard deviation of the residual dispersion of fatigue life sN and the quality index relative to ε_6, $\Delta\varepsilon_6$ may also be calculated.

A.2 Equipment

A.2.1 Test machine

The test machine shall consist of a system enabling the application of a sinusoidal displacement to the head of the specimen with a fixed frequency. The displacement shall vary less than 0,12 μm/N during the test. The test machine shall be capable of applying the load to specimens at a frequency of (25 ± 1) Hz and, if required for special purposes, at other frequencies ± 4 %.

NOTE If a frequency other than 25 Hz is used, it should be included in the test report. Results derived from tests at different frequencies may not be directly comparable.

A.2.2 Thermostatic chamber

The thermostatic chamber shall be ventilated and capable of allowing the temperature of the metal base of the specimens and the average temperature of the air draught at tens of millimetres from the specimens to be fixed with an accuracy of ± 1 °C throughout the duration of the test.

A.2.3 Measuring equipment

A.2.3.1 Force

Equipment for measuring the force at the head of the specimens shall measure to an accuracy of ± 2 % for values ≥ 200 N and to an accuracy of ± 2 N for values < 200 N.

A.2.3.2 Displacement

Equipment for measuring the displacements at the head of the specimens using sensors shall be capable of measuring by a static method to an accuracy of at least $\pm 1{,}5 \times 10^{-6}$ m. If calibration is undertaken by a static method, the indication of displacement in dynamic procedure shall be equal to the static one to less than 2 %.

A.3 Specimen preparation

A.3.1 Sawing and storing

A.3.1.1 The specimens shall be of an isosceles trapezoidal shape, and of constant thickness as shown in Figure A.2, for which the dimensions are given in Table A.1.

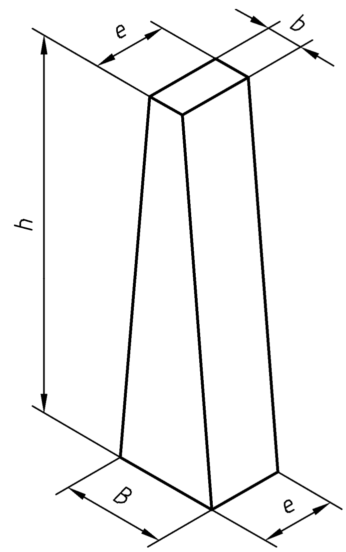


Figure A.2 — Geometry of the specimens

Table A.1 — Dimensions of the specimens

Dimensions of the specimens	Type of mixture		
	$D \leq 14$ mm	$14 < D \leq 20$ mm	$20 < D \leq 40$ mm
B	56 ± 1 mm	70 ± 1 mm	70 ± 1 mm
b	25 ± 1 mm	25 ± 1 mm	25 ± 1 mm
e	25 ± 1 mm	25 ± 1 mm	50 ± 1 mm
h	250 ± 1 mm	250 ± 1 mm	250 ± 1 mm

A.3.1.2 The specimens subject to the test shall be obtained, by sawing from slabs made in laboratory according to EN 12697-33, from slabs taken from road layers or from cores with a minimum diameter of 200 mm taken from road layers. The slabs shall be of adequate dimensions (see Table A.1) and shall have a thickness of not less than 40 mm.

A.3.2 Characteristics of the specimens

The specimens shall be measured to an accuracy of 0,1 mm. The standard deviation on v_i % shall be ≤ 0,7 %.

A.3.3 Embedding check

The specimens shall be embedded following a procedure that complies with the embedding check procedure. The embedding check shall be carried out using a specimen made of aluminium alloy type EN AW 2017T4 with a rectangular section (13,5 ± 1) mm × (30 ± 1) mm and a minimal length of 220 mm (see Figure A.3). The metal specimen shall be fixed onto the test machine. A force of about 200 N shall be applied on the top. The displacement and the strain shall be recorded. The metal specimen shall be fixed onto an L-shape frame made of steel of more than 80 mm × 80 mm section. A force shall be applied on the top of the specimen so that the measured strain is equal to the strain recorded on the test machine to ± 1 %. The displacement shall not differ by more than 5 %. An example of the equipment is shown Figure A.4.

NOTE Other procedures may be used if there are capable of giving the same results.

Dimensions in millimetres

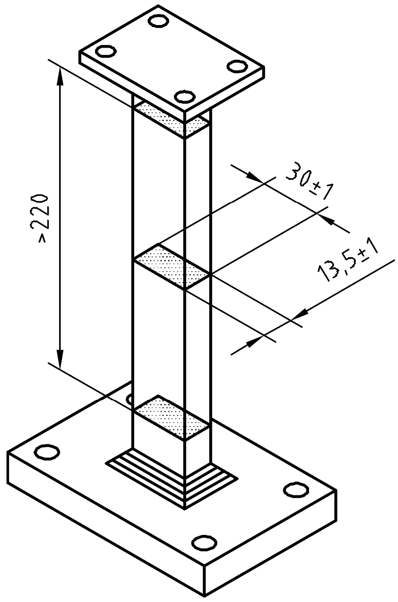
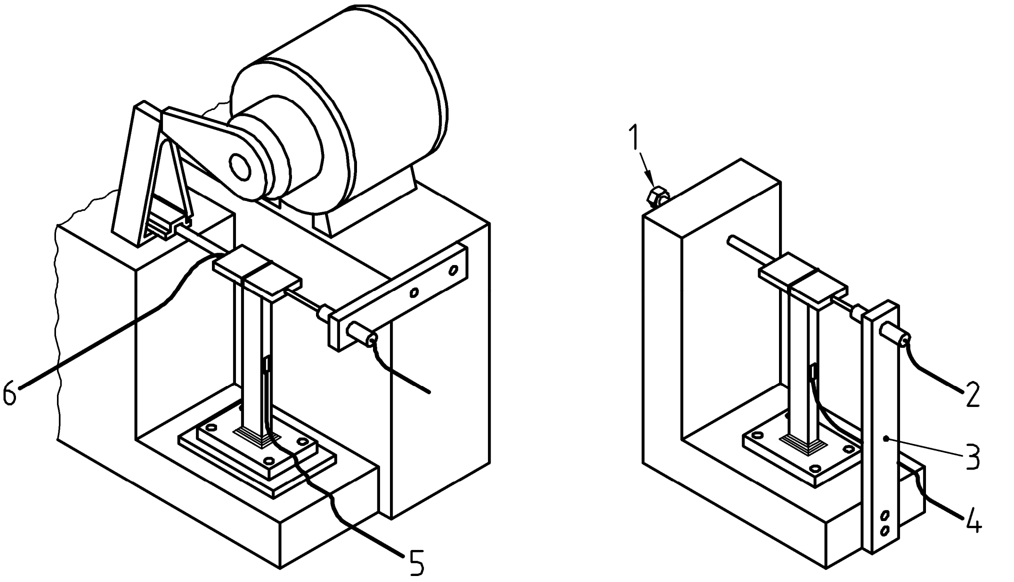


Figure A.3 — Example of aluminium alloy specimen



Key

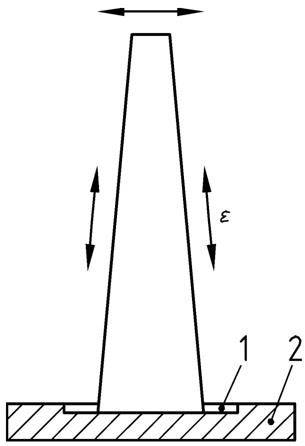
1 screw to apply the deformation
2 displacement measurement
3 support
4 measured strain
5 recorded strain
6 recorded stress

Figure A.4 — Example of equipment for embedment procedure verification

A.3.4 Gluing the ends

Before fitting to the test machines, each specimen shall be glued by its large base into the groove (about 2 mm deep) of a metal base with a minimum thickness of 20 mm, as shown in Figure A.5. This operation shall be carried out on a gluing rig, which ensures the positioning of the specimen on the base. The glue film shall be as thin as possible. An alternative fitting procedure may be used, provided it can be shown that no movements have taken place at the base of the sample.

NOTE A cap glued to the head of the specimen allows the displacement to be applied.



Key

1 groove of approximately 2 mm
2 metal base

Figure A.5 — Fixation of the specimen

A.4 Procedure

A.4.1 Preparing the test equipment

A.4.1.1 The thermostatic chamber and the loading equipment shall be brought to the test temperature. For each specimen i, the desired head displacement shall be calculated using the following formula:

$$z_i = \frac{\varepsilon_i}{K_i} \tag{A.1}$$

A.4.1.2 The specimen to be tested shall then be installed on the test machine. The adjustment of the displacement shall be ± 5 µm. If a metallic specimen is used to adjust the displacement, it shall be the same type as the metallic specimen described in A.2.1. The fatigue test shall not be started until it has been verified that the test temperature has been achieved in the specimen (if necessary by using a dummy specimen).

NOTE The specimens should not have been pre-stressed in any way because such an action(s) could modify the results.

A.4.2 Carrying out the fatigue test

The specimen i shall be moved sinusoidally at its head at the imposed displacement amplitude ± 5 µm until the failure criterion has been reached. Between 100 cycles and 500 cycles, the reaction forces shall be recorded to ± 2 % and the average reaction force calculated. The displacement z_i shall be measured and ε_i calculated for this element test. The number of cycles N_i at the failure criterion shall be measured with an accuracy of 300 cycles.

NOTE The average reaction force between 100 cycles and 500 cycles is defined as the initial value of the reaction force.

A.4.3 Choice of the strain

A.4.3.1 The deformations ε_i shall be selected so that either

- the values are approximately regularly spaced on a logarithmic scale, or
- there are at least 3 levels of deformation, with a homogeneous number of specimens (to 1 or 2 specimens) at each level. The average values shall be approximately regularly spaced on a logarithmic scale.

A.4.3.2 Further to the requirements of clause 6. The deformations shall be such that at least one third of the element tests provide results with $N \leq 10^6$ and at least one third of the element tests provide results with $N \geq 10^6$. When this is not the case, additional element tests shall be carried out.

A.4.4 Number of element tests

At least 18 element tests shall be used to determine the result.

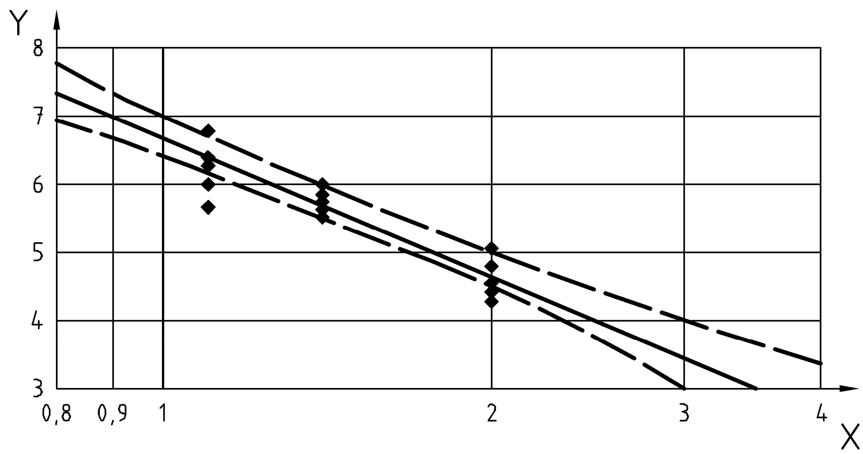
A.5 Calculation and expression of results

A.5.1 On the basis of the results representing the length of life N_i for ε_i chosen, the fatigue line shall be drawn by making a linear regression between the decimal logarithms of N_i and the decimal logarithms of ε_i having the following shape:

$$\lg(N) = a + \left(\frac{1}{b}\right) \times \lg(\varepsilon) \quad \text{(A.2)}$$

with correlation coefficient r_2.

NOTE An example of a fatigue line is shown in Figure A.6 in which the axes are the reverse of the way that they are often shown so that the slope is consistent with that defined for the test.



Key

Y log (N)
X log (ε/10 000)
N number of load cycles
ε strain

Figure A.6 — Example of fatigue line

A.5.2 For n results, the following shall be calculated:

— the estimation of the strain at 10^6 cycles:

$$\varepsilon_6 = 10^{b\times(6-a)} \tag{A.3}$$

— the estimation of the residual standard deviation S_N:

$$S_N = S_{\lg(N)} \times \sqrt{\frac{(1-r_2^2)\times(n-1)}{(n-2)}} \tag{A.4}$$

— the quality index $\Delta\varepsilon_6$:

$$\Delta\varepsilon_6 = 0{,}5\,\varepsilon_6 \times (10^{-2b\times S_0} - 10^{2b\times S_0}) \tag{A.5}$$

where

$$S_0 = S_N \sqrt{\left[\frac{1}{n} + \frac{(\lg(\varepsilon_6) - \lg(\varepsilon))^2}{(n-1)\times S^2_{\lg(\varepsilon)}}\right]} \tag{A.6}$$

A.6 Test report

The test report shall refer to the items listed in Clause 9, together with:

a) ε_6;

b) $\Delta\varepsilon_6$;

c) the slope l/b;

d) the estimation of the residual standard deviation sN;

e) correlation coefficient r_2.

NOTE 1 test result comprises measurements on not less than 18 individual specimens.

A.7 Precision

A.7.1 General

Reproducibility and repeatability of the two-point test method on isosceles specimens have been determined according ISO 5725-2 [2] with 11 laboratories (in 3 European countries), using different equipment. The experiment was on asphalt concrete AC14 at 10 °C and 25 Hz in 2001.

A.7.2 Results relating to ε_6:

— repeatability, standard deviation, σ_r = 1,43 µstrain;

— repeatability, limit 95 %, r = 4,2 µstrain;

— reproducibility, standard deviation, σ_R = 1,43 µstrain;

— reproducibility, limit 95 %, R = 8,3 µstrain.

A.7.3 Results relating to l/b:

— repeatability, standard deviation, σ_r = 0,021 3;

— repeatability, limit 95 %, r = 0,060 2;

— reproducibility, standard deviation, σ_R = 0,022 7;

— reproducibility, limit 95 %, R = 0,064 2.

Annex B
(normative)

Two-point bending test on prismatic shaped specimens

B.1 Principle

This annex specifies a method to characterise the behaviour of bituminous mixtures under fatigue loading by two-point bending, using square-prismatic shaped specimens. The method can be used for bituminous mixtures with maximum aggregate size of 20 mm, on specimens prepared in a laboratory or obtained from road layers with a thickness of at least 40 mm.

B.2 Equipment

B.2.1 Test machine

The test machine shall consist of a system enabling the application of a sinusoidal displacement to the head of the specimen with a fixed frequency. The displacement shall vary less than 0,1 µm/N during the test. The test machine shall be capable of applying the displacement to specimens at a frequency of (25 ± 1) Hz and, if required for special purposes, at other frequencies ± 4 %.

NOTE If a frequency other than 25 Hz is used, it should be included in the test report. Results derived from tests at different frequencies are not directly comparable.

B.2.2 Thermostatic chamber

The thermostatic chamber shall be ventilated and capable of allowing the temperature of the metal base of the specimens and the average temperature of the air draught at tens of millimetres from the specimens to be fixed with an accuracy of ± 1 °C throughout the duration of the test. If the test machine is entirely contained within the thermostatic chamber, the temperature of the metal base of the specimens shall satisfy the conditions relating to the air draught. This temperature shall then be recorded instead of the air temperature. The chamber shall be calibrated to an accuracy of 0,5 °C.

B.2.3 Measuring equipment

B.2.3.1 Force

Equipment for measuring force shall determine the force at the head of the specimens from the electrical current consumption of the electro-dynamic swinger used to an accuracy of ± 1 N. There shall be a system for logging the forces measured.

B.2.3.2 Displacement

Equipment for measuring the displacements at the head of the specimens using sensors shall be capable of measuring to an accuracy of at least $\pm 10^{-3}$ m. There shall be a system for logging the displacements measured.

B.2.3.3 Temperature

Measuring probes for measuring the temperature of the metal base plate of the specimen shall have an accuracy of 0,1 °C. There shall be a system for logging the temperatures measured.

B.3 Specimen preparation

B.3.1 Sawing

The specimens shall be of square column shape and of the dimensions given in Table B.1. The specimens shall be obtained by sawing, from slabs made in laboratory according to EN 12697-33, from slabs of a minimal thickness of 40 mm or from cores with a minimum diameter of 200 mm taken from road layers. The longitudinal axis of the slab shall be parallel with the axis of compaction.

Table B.1 — Dimensions of the specimen (B)

Dimensions of the specimens mm	Type of mixture	
	$D \leq 22$ mm	$D > 22$ mm
B	40 ± 1	80 ± 1
E	40 ± 1	80 ± 1
H	160 ± 1	320 ± 1

B.3.2 Characteristics of the specimens

The specimens shall be measured to an accuracy of 0,1 mm. The standard deviation on v_i % shall be ≤ 0,5 %. If the coefficient of variation of the geometry of the specimen is $K_{\sigma i} \leq 1$ %, the applied displacement at the head per level of tension shall be the same at all levels of tension.

B.3.3 Gluing the ends

During fitting to the test machines, each specimen shall be attached with its upper face on the metal plate of the test machine that has a minimum thickness of 20 mm.

NOTE A cap glued to the head of the specimen allows the displacement to be applied.

B.4 Procedure

B.4.1 Preparing the test equipment

The thermostatic chamber and the loading equipment shall be brought to the test temperature. The power supply for the electro-dynamic swinger shall be adjusted using the calibration line for the intended displacement at the head. The fatigue shall not be started until after a minimum of 1 h for temperature stabilisation or after verification that the test temperature is achieved in the specimen (if necessary by using a dummy specimen).

B.4.2 Carrying out the fatigue test

B.4.2.1 The head of the specimen shall be moved sinusoidally with the intended displacement amplitude.

NOTE 1 This amplitude corresponds with the intended tension and is given by the following formula:

$$P_{ij} = \frac{\sigma_{j\,max}}{K_{\sigma i}} \tag{B.1}$$

where

P_{ij} is the amplitude of the strength applied to the head, in Newtons (N);

$\sigma_{j\,max}$ the greatest relative tension of the specimen, corresponding to the strength applied to the head;

$K_{\sigma i}$ is the constant for consideration of the geometry at constant strength.

NOTE 2 The initial value of the displacement is defined as abscissa of the linear regression of the linear part of the line that is obtained when the displacement is adjusted to the cycles.

B.4.2.2 The test shall be stopped when the amplitude of the displacement is greater than 280 µm.

B.4.3 Choice of the tension

The test shall be carried out at not less than 3 levels of tension with a minimum of 6 repetitions per level. The levels of tension shall be chosen for the material so that the average fatigue life of the series lies between 10^4 and 10^6 cycles for a minimum of 2 levels, and between 10^6 and 10^7 for at least one level.

B.5 Calculation and expression of results

B.5.1 On the basis of the results representing the length of life, N_{ij} and level of tension $\sigma_{j\,max}$, the fatigue line shall be drawn by making a linear regression between the natural logarithms of $\sigma_{j\,max}$ having the following shape:

$$\ln(N_{ij}) = A_0 + A_1 \times \ln(\sigma_{j\,max}) \tag{B.2}$$

where

N_{ij} is the length of life of the specimen i at level of tension $\sigma_{j\,max}$;

$A_{\varepsilon 0}$, $A_{\sigma 0}$ are the parts of axes of fatigue line at constant strength;

$A_{\varepsilon 1}$, $A_{\sigma 1}$ are the slope of fatigue line at constant strength.

B.5.2 The following properties shall be calculated:

— estimation of $A_{\sigma 0}$, designated as $\hat{A}_{\sigma 0}$;

— estimation of $A_{\sigma 1}$, designated as $\hat{A}_{\sigma 1}$;

— correlation coefficient of the regression r_σ;

— slope $p_\sigma = 1/\hat{A}_{\sigma 1}$;

— estimation of the standard deviation $\sigma_{\sigma\,x/y}$, designated as $s_{\sigma\,x/y}$

$$s_{\sigma\,x/y} = s_N \times \sqrt{\frac{(1 - r_\sigma^{\,2}) \times (N - 1)}{N - 2}} \tag{B.3}$$

where

s_N is the estimation of the standard deviation of N_{ij};

r_ε, r_σ are the correlation coefficient of the regression;

N is the number of element tests.

— estimation of the tension at 10^6 cycles:

$$\hat{\sigma}_6 = e^{\frac{-A_{\sigma 0} + \ln(10^6)}{A_{\sigma 1}}} \tag{B.4}$$

— confidence interval of 95 % of $\hat{\sigma}_6$ designated as $\Delta\hat{\sigma}_6$:

$$\Delta\hat{\sigma}_6 = \hat{\sigma}_6 \times \left(-1 + e^{-2 p_\sigma \times s_{\sigma 0}}\right) \tag{B.5}$$

with

$$s_{\sigma 0} = s_{\sigma\, x/y} \times \sqrt{\frac{1}{N} + \frac{\left(\ln(\hat{\sigma}_6) - \ln(\sigma)\right)^2}{(N-1) \times s_\sigma^{\;2}}} \tag{B.6}$$

where

$\hat{\sigma}_6$ is the tension, corresponding to 10^6 cycles;

σ is the tension at a middle point;

s_σ is the estimation of the standard deviation of $\sigma_{j\,max}$;

N is the number of element tests.

— the estimation of the standard deviation of $\sigma_{j\,max}$ is

$$s_\sigma = \sqrt{\sum_{j=1}^{l} \sum_{i=1}^{n} \left(\frac{\ln(\sigma_{j\,max}) - \ln(\sigma)}{N-1}\right)^2} \tag{B.7}$$

where

$\sigma_{j\,max}$ is the greatest relative tension of the specimen, corresponding to the strength applied to the head;

σ is the tension at a middle point;

l is the number of tension levels $\sigma_{j\,max}$;

n is the number of specimens at tension levels $\sigma_{j\,max}$;

N is the number of element tests.

— the tension at a middle point is

$$\sigma = e^{\sum_{j=1}^{l} \sum_{i=1}^{n} \frac{\ln(\sigma_{j\,max})}{N}} \tag{B.8}$$

where

$\sigma_{j\,max}$ is the greatest relative tension of the specimen, corresponding to the strength applied to the head;

l is the number the level of tensions $\sigma_{j\,max}$;

n is the number of specimens at the level of tension $\sigma_{j\,max}$;

N is the number of element tests.

— s_N is the estimation of the standard deviation of ln(N_i):

$$s_N = \sqrt{\frac{\sum_{j=1}^{l}\sum_{i=1}^{n}\left[\ln(N_{ij}) - \left(\sum_{j=1}^{l}\sum_{i=1}^{n}\frac{\ln(N_{ij})}{N}\right)\right]^2}{N-1}} \tag{B.9}$$

where

N_{ij} is the length of life of the specimen i at level of tension $\sigma_{j\,max}$;

l is the number of tension levels $\sigma_{j\,max}$;

n is the number of specimens at the level of tension $\sigma_{j\,max}$;

N is the number of element tests.

B.6 Test report

The test report shall refer to the items listed in Clause 9, together with:

a) choice of test strength controlled;

b) average number of cycles and the standard deviation obtained for each level of tension;

c) tension corresponding with 10^6 cycles $\hat{\sigma}_6$;

d) confidence interval of $\hat{\sigma}_6$ for a probability of 95 %;

e) slope p;

f) estimation of the residual standard deviation $s_{x/y}$.

NOTE 1 test result comprises measurements on not less than 18 individual specimens.

B.7 Precision

The precision of this test has not yet been established.

Annex C
(normative)

Three-point bending test on prismatic shaped specimens

C.1 Principle

C.1.1 General

This method characterises the behaviour of bituminous mixes under fatigue loading, with controlled displacement by three-point bending using prismatic beam shaped specimens. The behaviour is characterised through the determination of the fatigue law in terms of strain (relation between strain and number of load cycles at failure) and the associated energy law. The method can be used for bituminous mixture specimens with maximum aggregate size of 22 mm or for samples from road layers with a thickness of at least 50 mm. For a given frequency of sinusoidal displacement, the method shall be carried out on several elements tested at a controlled temperature.

C.1.2 Element test

An element test shall consist of applying a constant amplitude sinusoidal displacement to the mid-span point of a beam shaped specimen supported at both of its ends. The result shall be obtained from the correlation of the maximum initial strain at the mid-span section of the specimen, and the number of cycles needed to reduce to half the initial stiffness of the specimen. Throughout the element test, the strain at the mid-span section of the specimen shall be recorded regularly against the number of cycles.

C.1.3 Fatigue line

Element tests shall be carried out on specimens drawn from a homogenous group at different displacement amplitudes. A fatigue line of the mixture under test shall be drawn by an approximation of the results of the element tests.

C.2 Equipment

C.2.1 Test machine

Any kind of servo-hydraulic control press capable of generating sinusoidal cyclic loading of the required frequency and amplitude.

C.2.2 Load cell

Load cell, used to measure the dynamic load, with a reading accuracy of ± 0,002 kN over a measuring range of ± 2,5 kN.

C.2.3 Extensometer and displacement sensor

Extensometer, used to measure the strain at the mid-span section of the specimen, shall have a measuring base of (50 ± 0,5) mm, a measuring range of between ± 0,2 mm and ± 0,5 mm and a reading accuracy of better than ± 0,025 µm. The sensor that measures the displacement of the piston rod that applies the load shall have a displacement range greater than or equal to ± 2,0 mm and a reading accuracy of better than ± 5,0 µm.

C.2.4 Clamping device

A device capable of clamping a specimen (beam) in the bending frame in order to provide horizontal translation and rotation freedom at all supports. The back-calculated stiffness modulus for a reference beam with a known stiffness modulus shall be within 2 % for the modulus, and within 0,5° for the phase lag.

C.2.5 Data acquisition equipment

An automatic data acquisition system that shall consist of a computer and an analogue or digital conversion board. The board shall be capable of generating a record of both the load and extensometer signal functions, and shall have a resolution such that the error due to the signal conversion process shall be equal to or smaller than the reading accuracy of the load cell and the extensometer.

C.2.6 Thermostatic chamber

A chamber containing the specimen and clamping devices that shall be capable of maintaining a constant temperature of (20 ± 1) °C.

C.2.7 Other general equipment

Trays, scales and thermometers.

The test equipment shall be calibrated according to Clause 8.

C.3 Specimen preparation

C.3.1 Manufacturing and sawing

The test beam specimens shall be obtained from samples manufactured in accordance with EN 12697-33. The dimensions of the test beams shall be (300 ± 10) mm × (50 ± 3) mm × (50 ± 3) mm. At least 10 test beams of the same mixture shall be manufactured in order to obtain the fatigue law of the material.

C.3.2 Clamping devices preparation

The test beams shall have two opposite sawn sides of (300 ± 10) mm × (50 ± 3) mm. In order to clamp the test beam to the support mechanism (see C.2.4), three pieces of square tubing shall be used. The first piece of tube shall be glued to one of the sawn faces of the specimen so as to be equidistant from both ends. Two other tube sections shall be glued to the opposite sawn face. Their position shall match the position of the simple supports described in A.4.1. The centre of each tube section shall be at the same distance from the centre of the tube section glued to the opposite face of the beam.

C.4 Procedure

C.4.1 Preparing the test equipment

C.4.1.1 The specimen shall be clamped to the support mechanism through the two metallic tubes glued to one of its faces and to the piston rod through the tube glued to the opposite face. The tubes shall be clamped to both the supports and the piston rod by means of jacks or other suitable devices. The support mechanism shall be capable of moving and tilting its axes.

NOTE The ability to move and tilt is necessary in order to prevent the specimen from being stressed due to bending or torque efforts originating during the process. Such stresses can modify the behaviour during the test.

C.4.1.2 The extensometer shall be fixed to the face of the beam where the two metallic tubes are glued and positioned at the geometric centre of such face. The thermostatic chamber and the loading equipment shall be brought to the test temperature.

C.4.2 Carrying out the fatigue test

Once the specimen and extensometer have been assembled and brought to the test temperature, a cyclic displacement of the piston rod shall be applied according to the following sinusoidal function:

$$D_C = D_0 \times \sin(2 \times f \times t) \tag{C.1}$$

where

D_C is the displacement at instant t, in microns (µm);

$2D_0$ is the total amplitude of displacement function, in microns (µm);

f is the wave frequency, in Hertz (Hz);

t is the time, in seconds (s).

The wave frequency shall be 10 Hz, and the total amplitude $2D_0$ shall vary from test to test. The loading shall continue until the conventional failure criterion (3.1.1) is reached.

NOTE The values of the total amplitude usually range from 80 µm to 350 µm, depending on the mixture.

C.4.3 Load function, extensometer signal function, and displacement function recording

C.4.3.1 The functions shall be recorded every 500 cycles, starting at cycle 100.

NOTE Hence the readings are triggered at cycles 100, 600, 1 100, 1 600…, and recorded during one whole cycle.

C.4.3.2 The load, extensometer signal and displacement functions shall be defined at each cycle by at least 50 equally time-gapped points. The reading frequency for each function shall be greater than $50F$ where F is the frequency of the applied displacement wave.

C.4.4 End of test

The amplitude of the dynamic load shall be calculated after the previous cycle and prior to the following cycle as the difference between the maximum and minimum values of the load recorded during the cycle being considered. The test shall be finished when the amplitude of the cyclic load calculated at cycle N is half of the amplitude of the cyclic load calculated at cycle 200, the failure criterion.

C.5 Calculation and expression of results

C.5.1 Calculation of the stress function and the strain function at a cycle

C.5.1.1 The stress of the mixture shall be assessed by means of the stress at the mid-span point of the face of the test specimen where the two supports are placed. The stress shall be determined for each cycle using the following formula:

$$\sigma = P \times \frac{3\,(L - 20)}{2\,(b \times e^2)} \tag{C.2}$$

where

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

P is the instant load, in megapascals (MPa);

L is the distance between supports, in millimetres (mm);

b is the width of specimen, in millimetres (mm);

e is the thickness of specimen, in millimetres (mm).

NOTE The stress is normal to a plane perpendicular to the support face plane.

C.5.1.2 The strain of the specimen shall be assessed by means of the tensile strain at the same point where the stress is calculated. The strain shall be determined at each cycle using the following formula:

$$\varepsilon = \frac{2\,EXT \times (L - 20)}{2B \times L - B^2 - 400} \tag{C.3}$$

where

ε is the instant strain;

EXT is the instant extensometer signal, in millimetres (mm);

B is the measuring base of the extensometer, in millimetres (mm);

L is the distance between supports, in millimetres (mm).

NOTE 1 The strain is normal to a plane perpendicular to the support face plane.

NOTE 2 Because the load and stain gauge signal functions are defined by more than 50 points per cycle, the stress and strain functions are defined by more than 50 points per cycle.

C.5.2 Calculation of the dynamic modulus, phase difference angle, and density of dissipated energy at one cycle

C.5.2.1 The dynamic modulus shall be determined at each cycle using the following formula:

$$MD = \frac{\sigma_c}{\varepsilon_c} \tag{C.4}$$

where

MD is the dynamic modulus, in megapascals (MPa);

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

ε_c is the cyclic amplitude of strain.

NOTE The dynamic modulus at a cycle is defined as the quotient of the cyclic amplitude of the stress over the cyclic amplitude of the strain. The cyclic amplitude of a function at a cycle is the absolute value of the difference between its maximum and minimum value during that cycle.

C.5.2.2 The phase difference between the stress function and the strain function shall be determined through a least square approximation for both the stress and the strain (defined by more than 50 equally time spaced points) according to the following formulae:

$$\sigma_a = A_t \times \sin\,(2\pi \times F \times t + B_t) + K_t \tag{C.5}$$

$$\varepsilon_a = A_\varepsilon \times \sin\,(2\pi \times F \times t + B_\varepsilon) + K_\varepsilon \tag{C.6}$$

where

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

ε_a is the approximate strain function value, in megapascals (MPa);

$2A_t$ is the amplitude of the approximate stress function, in megapascals (MPa);

$2A_t$ is the amplitude of the approximate strain function, in megapascals (MPa);

F is the frequency of the load wave, in ten Hertz (10 Hz);

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);

K_t, K_ε are constants.

C.5.2.3 The phase difference angle shall be determined using the following formula:

$$\Phi = (B_\varepsilon - B_t) \times \frac{180}{\pi} \quad \text{(C.7)}$$

where

Φ is the phase difference angle in degrees.

NOTE The phase angle is defined as the existing phase difference between the stress and the strain.

C.5.2.4 The density of dissipated energy shall be determined using the calculated cyclic amplitude of the stress and the strain and the phase difference angle using the formula:

$$DDE = T_c \times \varepsilon_c \times \sin(\phi) \times 0{,}25\,\pi \quad \text{(C.8)}$$

where

DDE is the density of dissipated energy, in megapascals (MPa) or megajoules per cubic metre (MJ/m^3).

NOTE The density of dissipated energy results from the asphalt mixture at the point where the stress and the strain are calculated.

C.5.2.5 The cyclic amplitude of displacement shall be determined in the same way as the stress and strain cycle amplitudes, and shall remain constant throughout the test.

C.5.2.6 The total density of dissipated energy throughout the whole test shall be calculated from the density of dissipated energy at each one of the recorded cycles using the following approximate formula:

$$DDE(total) = 200\ DDE(200) + 500 \sum_{i=1}^{m} [DDE(200 + 500i)] \quad \text{(C.9)}$$

where

$DE(total)$ is the total density of dissipated energy throughout the whole test, in megajoules per cubic metre (MJ/m^3);

$DDE\ (x)$ is the density of dissipated energy at cycle x, in megajoules per cubic metre (MJ/m^3);

N is the number of cycle at end of test;

m is $(N – 200)/500$.

C.5.3 Determination of the fatigue law and energy law

The controlled displacement fatigue law and the energy law shall be determined from the results of not less than 10 element tests. The fatigue law and energy law shall be obtained through least square approximation of the set of coupled values, according to the following formulae:

$$\varepsilon = k_1 \times N^{k_2} \quad \text{(C.10)}$$

$$W = k_3 \times N^{k_4} \quad \text{(C.11)}$$

$$\varepsilon_6 = k_1 \times 10^{6k_2} \quad \text{(C.12)}$$

where

ε_6 is the strain at 10^6 cycles;

ε is the half-cyclic amplitude of strain function at cycle 200;

W is the total density of dissipated energy throughout the whole test, in megajoules per cubic metre (MJ/m^3);

N is the total number of cycles;

k_1, k_2 are coefficients of the strain fatigue law;

k_3, k_4 are coefficients of the energy fatigue law (k_3 in megajoules per cubic metre (MJ/m^3); k_4 is adimensional).

NOTE The fatigue law is defined using coupled values of the half-cyclic amplitude of the strain at cycle 200 [1/2 ε_c (200)] and the total number of cycles. The energy law is defined using coupled values of the total density of dissipated energy throughout the test [$DDE(total)$] and the total number of cycles.

C.6 Test report

The test report shall refer to the items listed in Clause 9, together with:

a) fatigue law constants, *a, b*;

b) energy law constants, *c, d*;

c) strain for 10^6 cycles;

d) details of each element test:

   1) dimensions of the beam shaped specimen (width and thickness at midsection, length);

   2) relative densities;

   3) measuring base of the extensometer;

4) for each cycle:

   i) cyclic amplitude of central displacement, in microns (µm);

   ii) cyclic amplitude of central displacement, in Newtons (N);

   iii) cyclic amplitude of stress function, in megapascals (MPa);

   iv) cyclic amplitude of strain function;

   v) dynamic modulus;

   vi) phase difference angle;

   vii) density of dissipated energy, J/m^3;

5) total energy of dissipated energy throughout the test;

6) total number of cycles to failure during the operating conditions.

NOTE 1 test result comprises measurements on not less than 18 individual specimens.

C.7 Precision

The precision of this test has not yet been established.

Annex D
(normative)

Four-point bending test on prismatic shaped specimens

D.1 Principle

D.1.1 General

This annex specifies a method to characterise the behaviour of bituminous mixtures under fatigue loading using four-point-bending test equipment in which the inner and outer clamps are symmetrically placed and slender rectangular shaped specimens (prismatic beams) are used. The prismatic beams shall be subjected to four-point periodic bending with free rotation and translation at all load and reaction points. The bending shall be realised by loading the two inner load points (inner clamps) in the vertical direction, perpendicular to the longitudinal axis of the beam. The vertical position of the end-bearings (outer clamps) shall be fixed. This load configuration shall create a constant moment, and hence a constant strain, between the two inner clamps. The applied load shall vary sinusoidally. During the test, the load required to bend the specimen, the deflection and the phase lag between these two signals shall be measured as a function of time. Using these measurements, the fatigue characteristics of the material tested shall be determined.

NOTE 1 The width B and height H of the specimen should be at least three times larger than the maximum aggregate size D (although this ratio may be eased to two and a half times D for large values of D because of the practicality of testing very large specimens). In order to ensure the slenderness of the beam, the effective length between the outer clamps L should be at least six times the maximum value for B and/or H.

NOTE 2 Technical limitations of the apparatus in combination with the maximum grain size in the asphalt mixture can make it difficult to comply with the requirements of the ratios B/D and/or H/D. If either of these requirements are not met, the test will not be strictly in accordance with this annex, and this non-compliance should be explicitly mentioned in the report.

Several element tests shall be carried out in a ventilated atmosphere at a controlled temperature for a given frequency f of sinusoidal load applications.

NOTE 3 The dissipated energy per cycle can be split up into three parts:

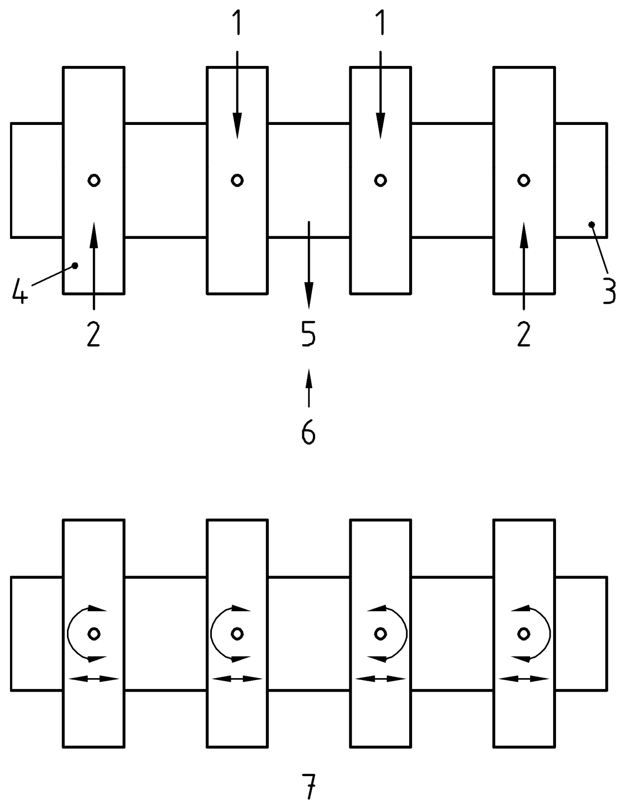
1) Viscous Energy Dissipation in the beam due to bending.
2) Fatigue damage (creation of micro defects, etc.).
3) System losses (damping).

2) is much smaller than 1) and can be ignored in the interpretation. However, 3) can play a role in the interpretation of the data, particularly if the test frequency ω is close to the first resonance frequency of the test machine. The influence of 3) can only be determined by calibration measurements using an elastic material with a known Young's modulus. In the interpretation formulae, the coefficient for the system losses is denoted by T. The exact value for T has to be derived from the calibration stiffness measurements. In general, the influence can be ignored because the test frequency is far below the first resonance frequency of the system and a zero value for T can therefore be adopted.

D.1.2 Element test

For each element test, two inner and two outer clamps shall be symmetrically located with respect to the centre of the prismatic specimen $L_{tot}/2$. Constant and equal loads shall be applied at the two inner clamps. The applied force, the measured deflection and the (system) phase lag between force and deflection shall be recorded. The fatigue life of the test specimen shall be determined according to the chosen failure condition.

NOTE The principal concepts of an element test are shown in Figure D.1.



Key

1 applied load
2 reaction
3 specimen
4 specimen clamp
5 deflection
6 return to original position
7 free translation and rotation

Figure D.1 — Basic principles of 4-point bending

D.1.3 Fatigue line

Specimens shall be drawn from a homogeneous group for repeated element tests under the same test conditions. The tests shall be repeated at different levels with respect to the chosen loading test condition (i.e. different deflection levels in the case of the constant deflection mode or different force levels in the case of the constant force mode). The fatigue line of the mixture shall be drawn under the chosen test condition (set of frequency, temperature and loading mode) and the resulting values shall be calculated as follows:

— level, Q, of the loading mode test condition corresponding to 10^6 cycles for the fatigue life according to the chosen failure criteria k;

— slope of the fatigue line plotted in log-log space p;

— estimation of the standard deviation of the residual dispersion of the natural logarithms of fatigue lives $S_{x/y}$.

The confidence interval relative to Q: ΔQ.

D.2 Equipment

D.2.1 Test machine

Equipment that shall be capable of applying a sinusoidal load to a specimen by a suitable mechanism via two inner clamps mounted on the specimen (see Figure D.1). The frequency of the load, f, shall be in the range 0 to 60 Hz with an accuracy of 0,1 Hz. The equipment shall be constructed of corrosion-resistant metal. The testing system shall be provided with a system to control the loading mode of the specimen in such a way as to meet the requirements for the execution of the test. The load cell shall have a measuring range of at least ±2 000 N and shall comply with the specifications for transducers of accuracy class 0,2. The measurement of the force shall take place midway between the two inner clamps. The measurement of the displacement shall take place at the top surface or the bottom surface of the specimen between or at one of the two inner clamps.

NOTE 1 The resonance frequency of the load cell and the coupled moving mass should be at least 10 times as high as the test frequency.

NOTE 2 The displacement transducer should have a measuring range of ±1,0 mm and should comply with the specification for transducers of accuracy class 0,2.

NOTE 3 The resonant frequency of the transducer and the coupled moving mass should be at least 10 times as high as the test frequency.

NOTE 4 The deflection should be measured at the diagonal centre of the top or bottom surface, $x = L/2$. In order to check the required pure bending of the specimen, the deflections of the two inner clamps should also be measured.

D.2.2 Clamping device

A device capable of clamping a specimen (beam) in the bending frame in order to provide horizontal translation and rotation freedom at all supports. The back-calculated stiffness modulus for a reference beam with a known stiffness modulus shall be within 2 % for the modulus and within 0,5° for the phase lag (see D.2.5).

The outer and inner clamps shall be designed to permit rotation freedom and horizontal movements of the specimen within the clamps. The assumed pure bending between the two inner clamps shall be checked by measuring the deflections at the inner clamp, $x = A$, and in the middle of the specimen, $x = L/2$.

NOTE The ratio of the amplitudes of the centre deflection and the deflection at the inner clamps should be a constant defined using the following formula:

$$\frac{Z(L/2)}{Z(A)} = \frac{R(A)}{R(L/2)} = \frac{3L^2 - 4A^2}{4A \times (3L - 4A)} \quad \text{(D.1)}$$

A should be chosen within the interval 0,25 < A/L < 0,4 and preferably close to one third of the effective length L (ASTM configuration). In this case, the ratio will be 1,15. If A/L is chosen outside this interval, the formulae given in this annex are no longer applicable and their use would introduce substantial errors.

D.2.3 Thermostatic chamber

Thermostatic chamber which shall be ventilated and enable the average temperature of the air draught at least 10 mm from the specimens to be fixed with an accuracy of ± 1 °C (throughout the duration of the test). Regulation shall be to an accuracy of 0,5 °C.

D.2.4 Electronic data registration equipment

D.2.4.1 Electronic data registration equipment in which the transducer signals shall be amplified by low-noise amplifiers, preferably in such a way that a value of 10 V or ± 10 V corresponds to the full-scale deflection of the measuring range of the transducer concerned.

NOTE Output sockets should be provided for connecting data recording and/or processing instruments.

D.2.4.2 Using analogue or digital measuring instruments, the output of the amplifiers shall be displayed and recorded with an accuracy of 1 N for the force and 1 μm for the displacement.

NOTE A digital data sampling process in combination with a (fast) Fourier transform is recommended. The output of this Fourier transform is a discrete frequency spectrum.

D.2.4.3 For the calculation of the strain, stress, dynamic stiffness modulus and (material) phase lag, the values of the frequency components at the test frequency f shall be capable of being recorded.

NOTE This procedure enables a check on the required single sinusoidal signals with the chosen frequency, and a direct measurement of the system phase lag between force and deflection.

D.2.5 Checking of the test equipment

The test equipment shall be checked according to Clause 8.

D.3 Specimen preparation

D.3.1 Dimensions

D.3.1.1 The specimen shall have the shape of a prismatic beam with the following nominal proportions and tolerances:

— total length L_{tot} shall not exceed the effective length L by more than 10 %;

— difference between maximum and minimum measured value of the width and of the height shall not be greater than 1,0 mm; the difference between minimum and maximum measured value of the length shall not be greater than 2,0 mm;

— angle between adjacent longitudinal surfaces shall not deviate from a right angle by more than 1°.

NOTE It is also recommended that:

— effective length L should not be less than six times whatever the highest value is for the width B or the height H;

— width B and the height H should be at least three times the maximum grain size D in the tested material (although this ratio may be eased to two and a half times D for large values of D because of the practicality of testing very large specimens).

D.3.1.2 The total length shall be measured four times with a ruler with an accuracy of 1,0 mm in the centre of the top and the bottom surfaces. The height and the width shall be measured with vernier callipers with an accuracy of 0,1 mm at the places where the clamps are to be installed ($x = 0$, $x = A$, $x = L - A$, $x = L$). The length of the test specimen shall be calculated as the arithmetic mean of the length measurements. The width and the height of the specimen shall be calculated similarly from the width measurements and the height measurements, respectively. Specimens not complying with the specimen requirements shall not be tested.

NOTE Technical limitations of the apparatus in combination with the maximum grain size in the asphalt mixture can make it difficult to comply with the requirements as to width B, $B/D > 3$ and $H/D > 3$. If any of these requirements are not met, the test will not be strictly in accordance with this annex and this non-compliance should be explicitly mentioned in the report.

D.3.2 Sawing

The specimens subject to the test shall be obtained by sawing from slabs made in laboratory or taken from road layers. The slabs made in the laboratory shall have at least a thickness of the required height H plus 20 mm. The beams shall be sawn from the middle. The distance of the beam to the border of the slab shall be at least 20 mm. In principle, the same procedure holds for beams sawn from slabs taken from road layers. If the thickness of the road layer is too small to meet the requirement with respect to the ratio between height H and the maximum grain size D, the beams shall be rotated over an angle of 90°. In such cases, the width B of the beam shall not be able to meet the requirement and shall be reported.

The longitudinal axis of the beam shall be parallel with the axis of compaction.

D.3.3 Condition

The specimen shall be inspected visually and striking externals concerning homogeneity, compaction, void content or the existence of large aggregate particles shall be noted.

D.3.4 Mounting

For the mounting system of the inner and outer clamps on the beam, a system which realises the best possible rotation and translation freedom shall be used. The required bending of the beam shall be checked by measuring the deflection at two different places between the two inner clamps (see D.2.2). The beam shall be weighed as well as all the moving parts between the load cell and the beam (e.g. moving frame, clamps and deflection sensor). The points on the beam where these masses have there influence shall be determined in order to correctly calculate the mass factor.

NOTE 1 Normally, the locations where the masses act are at the inner clamp(s).

NOTE 2 In the test set-up, the specimen should be rotated through 90° along its longitudinal axis with respect to its position, either in the slab made in the laboratory or obtained from the road unless, using aggregates with a high flakiness index. The rotation means that the specimen will not be tested in the direction that it would be loaded in the pavement. If the specimen is not rotated, it should be included in the test report.

D.4 Procedure

D.4.1 Preparing the test equipment

D.4.1.1 The thermostatic chamber and the loading equipment shall be brought to the test temperature for not less than the time given in Table D.1. In order to prevent ageing and deformation of the specimen, the acclimatisation shall not last longer than six hours.

Table D.1 — Minimum time required to bring specimens to test temperature

Test temperature °C	**Time** h
0	2
20	1

D.4.1.2 The different masses of the moving parts shall be calculated as follows:

— M_{beam}, the mass of the whole beam without the masses of the mounted clamps;

— M_{clamps}, the masses of the two inner clamps, including the mass of any adhesive (if used), and the mass of the load frame between the load cell and the loading mechanism;

— M_{sensor}, the mass of the moving parts of the sensor.

If, in order to check the pure bending mode, a second sensor is placed at one of the two inner clamps, this mass shall be added to the mass of the clamps.

D.4.1.3 The equivalent mass M_{eq} shall be calculated for use in the calculation of the stiffness modulus.

NOTE The value of the equivalent mass depends on the distance x_s where the sensor is placed.

D.4.2 Carrying out the fatigue test

D.4.2.1 The beam with the two outer and two inner clamps shall be mounted into the load frame. The beam shall then be moved sinusoidally at the chosen frequency f at the initial imposed displacement. The necessarily force shall be applied through the load frame connected to the two inner clamps. The chosen loading mode (i.e. constant deflection or constant force) shall be ensured by a feedback of the measured force or displacement. The force, displacement and phase lag between force and displacement shall be recorded after the first100 cycles and regularly thereafter.

NOTE The intention is make at least 100 measurements that are taken at regular intervals over the test duration ($n = 100$ to $n = N_{f,50}$).

D.4.2.2 The initial value of the calculated modulus S_{mix} shall be calculated from the measured values for force, displacement and phase lag after the hundredth cycle ($n = 100$). The fatigue test shall be continued until the calculated modulus S_{mix} has dropped to half its initial value or until the specimen breaks.

D.4.3 Choice of test conditions

For a given temperature and frequency, the test shall be undertaken at not less than three levels in the chosen loading mode (e.g. three strain levels with the constant deflection mode) with a minimum of six repetitions per level. The levels for the chosen loading mode shall be chosen in such a way that the fatigue lives are within the range 10^4 to 2×10^6 cycles.

D.4.4 Data processing

D.4.4.1 Using the obtained data of the force, deflection and phase lag between these two signals measured at load cycles $n(i)$, the relevant results shall be calculated using the formula given in 3.5. The relevant test results shall be tabulated and graphically presented and related to the load cycle number $n(i)$ at which they are measured. These test results are:

— strain amplitude;

— stress amplitude;

— modulus of the complex modulus (dynamic stiffness modulus).

NOTE The following optional test results can also be calculated:

— (material) phase lag;

— dissipated energy per cycle;

— cumulated dissipated energy up to cycle $n(i)$.

D.4.4.2 In order to determine the initial values, the first load cycle number $n(i)$ shall be the 100th load cycle.

D.4.4.3 If a Fourier transform is used, the dissipated energy shall be calculated using all the frequency components of the obtained discrete frequency spectrum (Parsival's law). The chosen test frequency f shall be equal to one of the frequency components in the discrete frequency spectrum. If the digital data is sampled over an integer amount of cycles, the mean calculated values over this amount of cycles shall be defined to correspond with the first cycle in this sample.

D.5 Calculation and expression of results

D.5.1 On the basis of the results representing the length of life $N_{i,j,k}$ for the chosen failure criteria j and the set of test conditions k, the fatigue line shall be drawn by making a linear regression between the natural logarithms of $N_{i,j,k}$ and the natural logarithms of the initial strain amplitude (strain amplitude at the 100th cycle). The shape of the fatigue line is expressed in the following formula:

$$\ln (N_{i,j,k}) = A_0 + A_1 \times \ln (\varepsilon_i) \quad (D.2)$$

where

i is the specimen number;

j represents the chosen failure criteria;

k represents the set of test conditions;

ε_i is the initial strain amplitude measured at the 100th load cycle.

D.5.2 The fatigue lives shall be measured at least at three levels for the type of loading mode with at least six repetitions per level. The following values shall be calculated:

— estimation of A_1 noted as the slope p;

— estimation of A_0 noted as q;

— correlation coefficient of the regression r;

— estimation of the residual standard deviation, $\sigma_{x/y}$, noted $s_{x/y}$;

— estimation of the initial strain for the chosen failure criteria at which a fatigue life of 10^6 can be expected for the given set of test conditions.

D.6 Test report

The test report shall refer to the items listed in Clause 9, together with:

a) description of the check that the test equipment and mounting of the specimen are working appropriately, including the results of that test;

b) average number of cycles and the standard deviation obtained for each level of the chosen loading mode, if required;

c) initial strain corresponding with a fatigue life of 10^6 cycles for the chosen failure criteria and set of test conditions;

d) slope p of the fatigue line;

e) individual measured data points.

NOTE 1 test result comprises measurements on not less than 18 individual specimens.

D.7 Precision

The precision of this test has not yet been established.

Annex E
(normative)

Indirect tensile test on cylindrical shaped specimens

E.1 Principle

This annex characterises the behaviour of bituminous mixtures under repeated load fatigue testing with a constant load mode using an Indirect Tensile Test (ITT). A cylindrical specimen manufactured in a laboratory or cored from a road layer can be used in this test. A cylinder shaped test specimen shall be subjected to repeated compressive loads with a haversine load signal through the vertical diametral plane. This loading results in repeated tensile stress pulses perpendicular to the direction of the applied load which cause the specimen to fail by splitting along the central part of the vertical diameter. At intervals during a test, the variation in horizontal deformation of the specimen during a load cycle shall be measured and the resilient deformation before the next pulse is applied shall be determined. The resilient deformation or, if cyclic loading (without rest periods between load cycles) is applied, the amplitude of horizontal deformation and an assumed Poisson's ratio shall be used to calculate the tensile strain at the centre of the specimen. Fracture (fatigue) life shall be defined as the total number of load applications before a fracture of the specimen occurs. The conventional failure criterion can be applied to tests conducted with cyclic loading without a rest period between load impulses. Further failure criteria can be defined according the dissipated energy during loading.

E.2 Equipment

E.2.1 Test machine

The testing machine shall be capable of applying repeated haversine load pulses with rest periods at a load range of at least 0,5 kN to 10 kN with an accuracy of 0,25 %.

NOTE 1 To reach required loads, a test device capable of loads up to 50 kN may be used.

NOTE 2 The maximum load capacity required depends on the size of the specimen, the temperature and the stiffness modulus of the material.

E.2.2 Displacement

Sensor for measuring the displacements along the horizontal diametral plan, capable of measuring to an accuracy of 0,1 % over a measuring range of 2,0 mm to 3,75 mm.

NOTE Two extensometers connected in series, type 632.11C from MTS Corporation have been found to be suitable, as have LVDT displacement transducers with the appropriate characteristics.

E.2.3 Thermostatic chamber

The thermostatic chamber shall be capable of controlling a temperature range from 2 °C to 20 °C and with an accuracy of at least ± 1 °C.

E.2.4 Recording and measuring system

Recording and measuring devices for determining the compressive load and the horizontal deformations which shall be capable of measurement at a minimum frequency of 400 Hz.

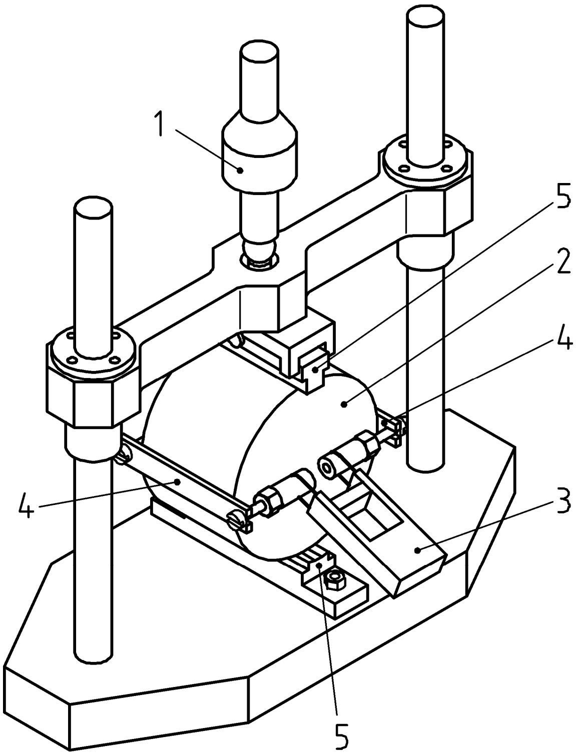
NOTE If cyclic loading is applied, the frequency of the measurement system shall be capable of measuring at least 20 values per load impulse (e.g. if a frequency of $f = 10$ Hz is applied, the system should enable the measurement with a rate of 200 Hz).

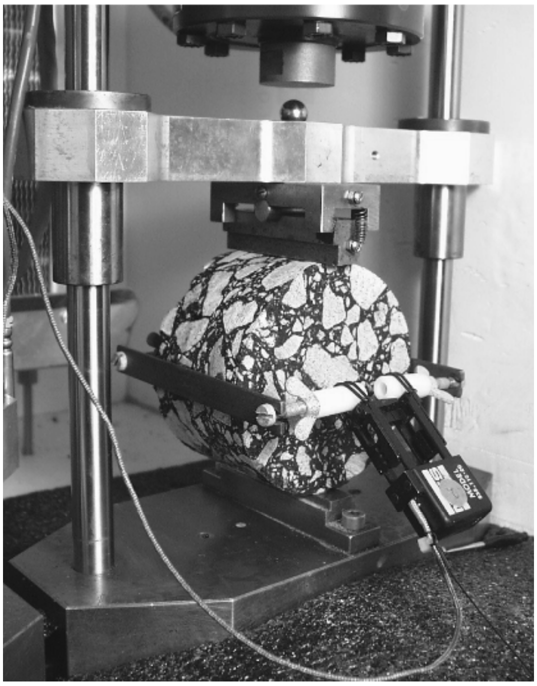
E.2.5 Loading frame

E.2.5.1 Frame

The loading frame (such as that shown in Figure E.1) shall consist of two loading strips. The upper strip shall be fixed to a beam mounted on ball bushing guided posts.

NOTE The ball bushing guided posts centre the specimen, keep the loading strips in the vertical plan and eliminate undesirable movement of the specimen during testing. In the loading frame shown in Figure E.1, an additional static load of (1,0 ± 0,1) kg is applied by the upper cross-head.





Key

1 load cell
2 asphalt specimen
3 extensometer
4 deformation strips
5 loading strips

Figure E.1 — The loading device with loading and deformation strips and specimen in place

E.2.5.2 Loading strips

Loading strips (see Figure E.2) with concave surfaces and rounded edges shall have radii of curvature of (50 ± 2,5) mm and a width of (12,7 ± 0,2) mm for specimens of 100 mm nominal diameter, and radii of curvature of (75 ± 3,75) mm and a width of (19,1 ± 0,2) mm for specimens of 150 mm nominal diameter.

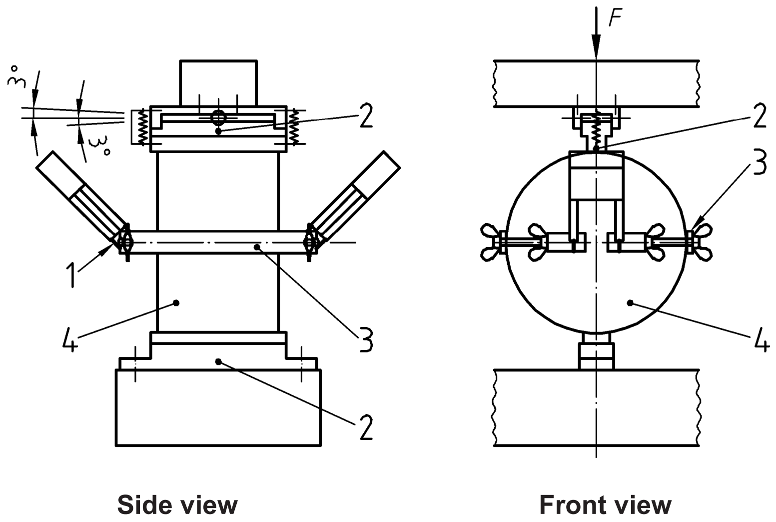
E.2.5.3 Deformation measurement system

Two strips of suitable metal to which the deformation transducers shall be fixed. The strips shall be fixed on opposite sides of the horizontal diametric plan by either glue or springs. The transducers shall be arranged so that the variation in the length of the horizontal diameter during a load cycle can be scanned and captured by the recording equipment.

NOTE 1 The length of the strips depends on the specimen thickness. It is recommended to have sets of strips with different lengths.

NOTE 2 The contact faces of the deformation strips may be concave with a radius to match the nominal radius of the specimen.

NOTE 3 Figures E.1 and E.2 show a suitable system in which the steel strips are 2 mm thick, 10 mm wide and normally 80 mm long.



Key

1 extensiometer
2 loading strips
3 deformation strip
4 asphalt specimen

Figure E.2 — Illustration of loading and deformation strips

E.2.6 Positioning rig

A rig, an example of which is shown in Figure E.3.

NOTE The positioning rig helps positioning and gluing of the deformation strips, as well as assigning the position of the loading strips. The rig illustrated in Figure E.3 is suitable for both 100 mm and 150 mm diameter specimens and for the various lengths of the deformation strips.

NOTE Quick-hardening cyanoacrylate type glue has been found to be suitable.

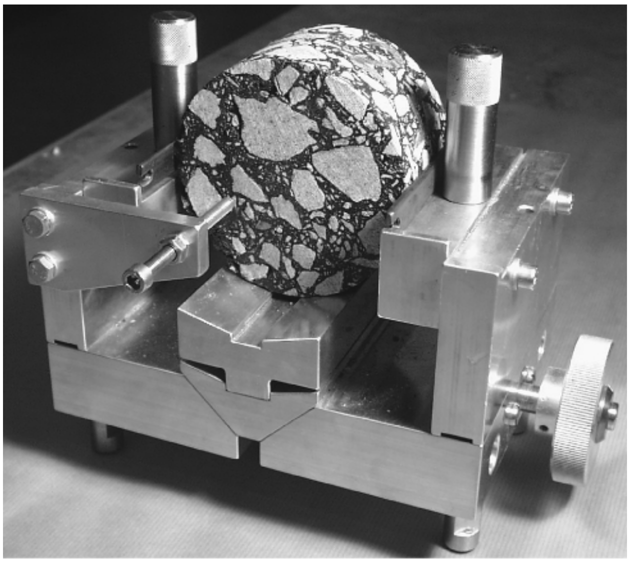


Figure E.3 — Example of positioning rig for both 100 mm and 150 mm diameter specimens

E.2.7 Alternative measurement system:

Alternatively, a LVDT mounting frame according EN 12697-26:2011, Annex C may be used.

E.3 Specimen preparation

E.3.1 Test specimen

10 to 18 specimens shall be prepared (see E.4.2 and NOTE). The cylindrical specimens subject to the test shall be obtained in accordance with:

— test specimen prepared in the laboratory by Gyrator compactor, EN 12697-31;

— test specimen drilled from laboratory-prepared slab of asphalt, EN 12697-33;

— test specimen prepared from drilled core taken from the road, EN 12697-27.

E.3.2 Specimen dimensions

The specimen shall have either

— a thickness of at least 40 mm and a diameter of (100 ± 3) mm for a maximum aggregate size of 25 mm; or

— a thickness of at least 60 mm and a diameter of (150 ± 3) mm for a maximum aggregate size of 38 mm.

Position of the deformation and loading strips.

If deformation strips are used, these strips shall be positioned and glued (if springs are not used) at the opposite sides of the horizontal diametral plane using the positioning rig. The loading strips shall be positioned on the vertical diametral plane.

E.3.3 Conditioning

The specimens shall be placed in the thermostatic chamber and exposed to the specified test temperature for at least 4 h prior to testing.

E.4 Procedure

E.4.1 Fatigue tests shall be carried out over an initial dynamic tensile strain range of approximately 100 µm/m to 400 µm/m. The resultant fatigue life of the tested material shall fall within a range between 10^3 and 10^6 per number of load applications.

For cyclic tests, the initial strain amplitude shall be between 50 µm/m and 200 µm/m.

NOTE In the case of materials with high stiffness modulus, the load capacity of the test machine may mean that it is not possible to achieve the higher end of the recommended range of initial dynamic tensile strains. Higher dynamic strains can, where possible, be achieved however by reducing specimen thickness.

E.4.2 The specimens shall be tested at three levels of stress, with at least three specimens at each level for laboratory-manufactured specimens and at least five specimens for cores taken from the road.

NOTE Cores taken from the road should be selected at random in order to be representative for the test section (see also the NOTE to E.5.5).

E.4.3 The specimen shall be positioned in the loading device so that the axis of the deformation strips is (90 ± 5)° to the axis of the loading strips.

E.4.4 The deformation transducers or the LVDT mounting frame shall be mounted and adjusted to almost the end of their calibrated stroke so that they remain within their calibrated range as the specimen deforms horizontally.

E.4.5 The test shall start at a loading amplitude of 250 kPA. A haversine load shall be applied repeatingly with 0,1 s loading time and 0,4 s rest time. If the deformation shown on the monitor during the first 10 applications is outside the strain range (100 to 400) µε, the test shall be stopped immediately and the load level adjusted.

NOTE 1 In almost every case, 250 kPa has been found to be a practical stress level. Experienced operators can choose a suitable stress level with regard to the stiffness of the tested material.

NOTE 2 As an alternative, a cyclic force signal can be applied without any rest periods defined by the frequency f.

E.4.6 During the test, the load and horizontal deformation shall be monitored continually and recorded at the pre-selected intervals. To enable the calculation of the initial stiffness modulus, the first 200 load cycles should be measured continuously.

E.4.7 When obvious cracking is shown on the vertical axis or the dynamic tensile strain increases to twice its initial value, the test shall be stopped.

E.5 Calculation and reporting of results

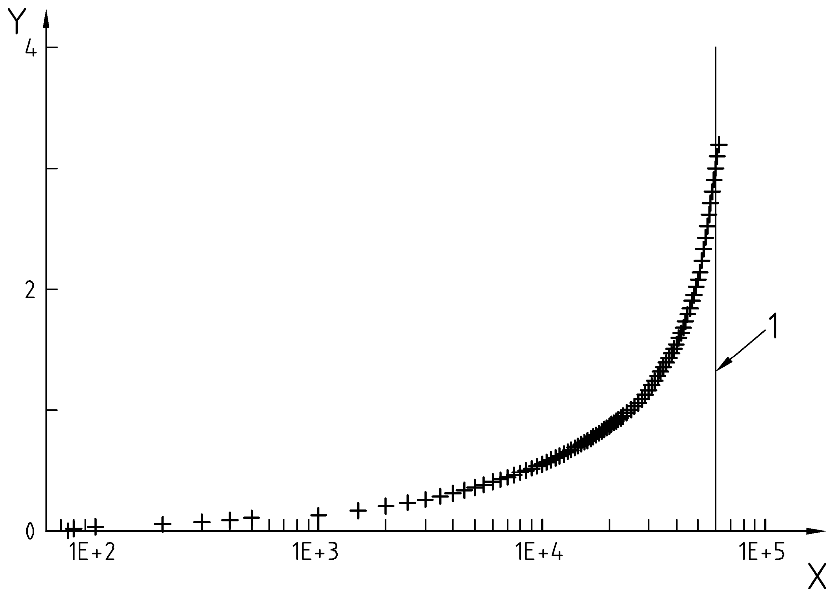
E.5.1 The procedure in E.5.2 to E.5.5 shall be carried out for each specimen tested.

E.5.2 The fracture life shall be determined as the total number of load applications that causes a complete fracture of the specimen. The fracture life is obvious from the relationship between log number of load applications and the total horizontal deformation (see Figure E.4).

NOTE 1 For estimating the fatigue life, the conventional failure criterion $N_{f/50}$ can be applied.

NOTE 2 Alternative failure criteria can be defined according dissipated energy approaches.

Dimensions in millimeters



Key

Y horizontal deformation in millimetres (mm)
X number of load applications
1 fracture life

Figure E.4 — Determinations of the fracture life of a specimen

E.5.3 The tensile strain and stress at the centre of the specimen shall be calculated using the following formulae:

$$\sigma = \frac{2F}{\pi \times t \times \Omega} \quad \text{(E.1)}$$

$$\varepsilon = \left(\frac{2\ \Delta H}{\Omega}\right) \times \left[\frac{1 + 3\nu}{4 + \pi \times \nu - \pi}\right] \quad \text{(E.2)}$$

$$\varepsilon_o = 2{,}1 \frac{\Delta H}{\Omega} \quad \text{(E.3)}$$

$$S_{mix} = \frac{\sigma_s}{\varepsilon_s} \times (1 + 3\nu) \quad \text{(E.4)}$$

where

σ is the horizontal tensile stress at specimen centre, in megapascals (MPa);

F is the measured force, in Newtons (N);

t is the specimen thickness, in millimetres (mm);

Ω is the specimen diameter, in millimetres (mm);

ε is the horizontal strain, in microns per metre (µm/m);

ΔH is the horizontal deformation, in millimetres (mm);

σ_o is the maximum tensile stress value during the load impulse, in megapascals (MPa);

σ_a is the stress amplitude during cyclic loading, in megapascals (MPa);

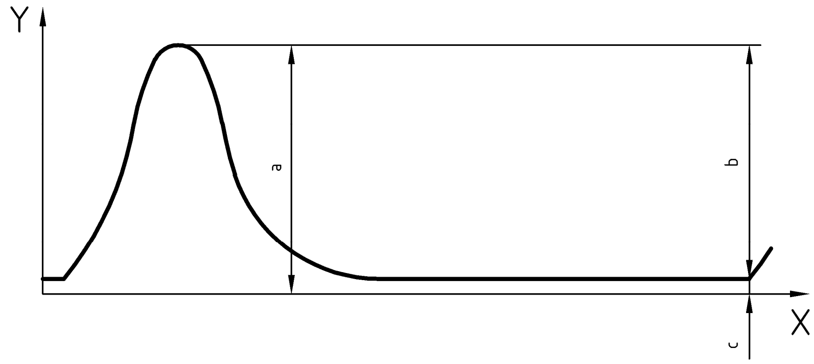
ε_o is the resilient horizontal tensile strain between load impulses, in microns per metre (µm/m);

ε_a is the strain amplitude during cyclic loading, in microns per metre (µm/m);

S_{mix} is the stiffness modulus, in megapascals (MPa).

E.5.4 The initial RESILIENT strain $\varepsilon_{o,in}$ shall be calculated according to Formula (E.3) from the total horizontal deformation at the 100th load application, which is illustrated in Figure E.5.

If cyclic loading is applied, the initial strain amplitude $\varepsilon_{a,in}$ shall be calculated from the measured deformation amplitude of the 100th load cycle.



Key

Y horizontal deformation
X time

a total horizontal deformation
b resilient deformation
c plastic deformation

Figure E.5 — Definition of the total horizontal deformation

E.5.5 The fatigue criterion for an individual bituminous material shall be determined from the tested specimens. The least-squares regression relationship shall be fitted to the data of the logarithm of the initial strain as an independent variable and the data of the logarithm of the fracture life as a dependent variable according to Formulae (E.5) and (E.6).

$$\lg(N_f) = k + n \times \lg(\varepsilon_0) \quad \text{(E.5)}$$

$$N_f = k \times \left(\frac{1}{\varepsilon_o}\right)^n \quad \text{(E.6)}$$

where

N_f is the number of load applications;

k, n are material constants;

ε_o is the tensile strain in $\mu\varepsilon$ at the centre of the specimen.

NOTE Usually, if the R^2 is less than 0,9, increase the number of test specimens.

E.6 Test report

The test report shall refer to the items listed in Clause 9, together with:

a) a graphical and mathematical presentation of the fatigue criterion;

b) the correlation coefficient, R^2.

NOTE 1 test result comprises measurements on 10 to 18 individual specimens.

E.7 Precision

Based on testing cores the average of the 95 % confidence interval of the strain corresponding with $0,5 \times 10^6$ loading cycles is 13 $\mu\varepsilon$.

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