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BSI Standards Publication

Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at room temperature — Determination of fatigue properties at constant amplitude

National foreword

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The UK participation in its preparation was entrusted to Technical Committee RPI/13, Advanced technical ceramics.

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Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at room temperature — Determination of fatigue properties at constant amplitude

Céramiques techniques — Propriétés mécaniques des composites céramiques à température ambiante — Détermination des propriétés de fatigue à amplitude constante

Reference number
ISO 17140:2014(E)

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Foreword

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The committee responsible for this document is ISO/TC 206, *Fine ceramics*.

Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at room temperature — Determination of fatigue properties at constant amplitude

1 Scope

This International Standard specifies the conditions for the determination of properties at constant-amplitude of load or strain in uniaxial tension/tension or in uniaxial tension/compression cyclic fatigue of ceramic matrix composite materials (CMCs) with fibre reinforcement at room temperature.

This International Standard applies to all ceramic matrix composites with fibre reinforcement, unidirectional (1D), bi-directional (2D), and tri-directional (xD, where $2 < x \leq 3$).

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.

ISO 3611, *Geometrical product specifications (GPS) — Dimensional measuring equipment: Micrometers for external measurements — Design and metrological characteristics*

ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system*

ISO 9513, *Metallic materials — Calibration of extensometer systems used in uniaxial testing*

ISO 14544, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at high temperature — Determination of compression properties*

ISO 14574, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at high temperature — Determination of tensile properties*

ISO 15733, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at ambient temperature in air atmospheric pressure — Determination of tensile properties*

CEN/TR 13233, *Advanced technical ceramics — Notations and symbols*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in CEN/TR 13233[1)] and the following apply.

3.1 General

3.1.1
calibrated length
l
part of the test specimen which has uniform and minimum cross-section area

1) Intended to be substituted by a future International Standard.

3.1.2
gauge length
L_0
initial distance between reference points on the test specimen in the calibrated length

3.1.3
initial cross-section area
S_0
initial cross-section area of the test specimen within the calibrated length, at the test temperature

Note 1 to entry: Two initial cross-section areas of the test specimen can be defined:

— apparent cross-section area: this is the total area of the cross-section, $S_{0\ app}$;

— effective cross-section area: this is the total area corrected by a factor to account for the presence of a coating, $S_{0\ eff}$.

3.1.4
longitudinal deformation
A
change in the gauge length between reference points under an uniaxial force

3.1.5
strain
ε
relative change in the gauge length defined as the ratio, A/L_0

3.1.6
stress
σ
force supported by the test specimen at any time in the test, divided by the initial cross-section area

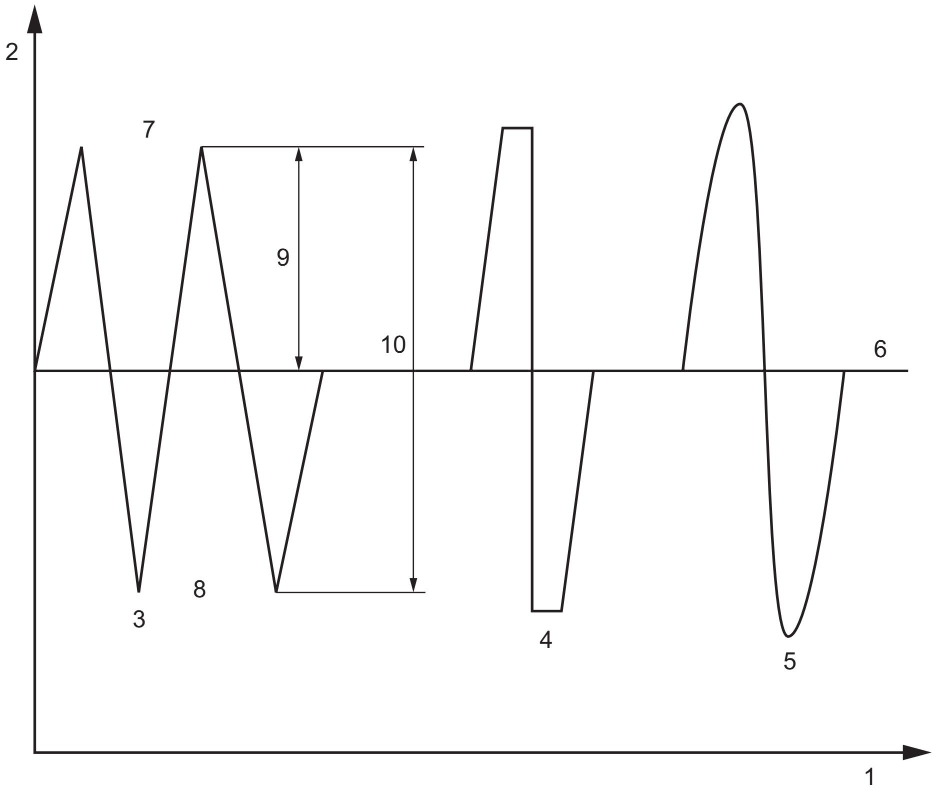
Note 1 to entry: Two stresses can be distinguished:

— apparent stress, σ_{app}, when the apparent cross-section area (or total cross-section area) is used;

— effective stress, σ_{eff}, when the effective cross-section area is used.

Note 2 to entry: Stress can be either in tension or in compression.

3.1.7
constant amplitude loading
in cyclic fatigue loading, constant wave form loading in which the peak loads and the valley loads are kept constant during the test (see Figure 1 for nomenclature relevant to cyclic fatigue testing)



Key

1	time	6	mean
2	control parameter (test mode)	7	peak (maximum)
3	triangular form	8	valley (minimum)
4	trapezoidal form	9	amplitude
5	sinusoidal form	10	range

Figure 1 — Cyclic fatigue nomenclature and wave forms

3.2 Cyclic fatigue phenomena

NOTE Stress-strain curve parameters are defined as given in Figure 2.

3.2.1 Load ratio

3.2.1.1
load ratio
R
in cyclic fatigue loading, the algebraic ratio of the two loading parameters of a cycle

Note 1 to entry: The most widely used ratios are

— R = (minimum load/maximum load), or

— R = (valley load/peak load).

3.2.2 Cyclic fatigue stress

3.2.2.1
maximum stress
σ_{max}
maximum applied stress during cyclic fatigue

3.2.2.2
minimum stress
σ_{min}
minimum applied stress during cyclic fatigue

3.2.2.3
mean stress
σ_m
average applied stress during cyclic fatigue

Note 1 to entry: $\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$

3.2.2.4
stress amplitude
σ_a
difference between the maximum stress and the minimum stress

Note 1 to entry: $\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} = \sigma_{max} - \sigma_m = \sigma_m - \sigma_{min}$

3.2.3 Cyclic fatigue strain

3.2.3.1
maximum strain
ε_{max}
maximum applied strain during cyclic fatigue

3.2.3.2
minimum strain
ε_{min}
minimum applied strain during cyclic fatigue

3.2.3.3
mean strain
ε_m
average applied strain during cyclic fatigue

Note 1 to entry: $\varepsilon_m = \frac{\varepsilon_{max} + \varepsilon_{min}}{2}$

3.2.3.4
strain amplitude
ε_a
difference between the maximum stress and the minimum stress

Note 1 to entry: $\varepsilon_a = \frac{\varepsilon_{max} - \varepsilon_{min}}{2} = \varepsilon_{max} - \varepsilon_m = \varepsilon_m - \varepsilon_{min}$

3.2.4 Fatigue parameters

3.2.4.1
number of cycles
N
total number of loading cycles which is applied to the test specimen during the test

3.2.4.2
cyclic fatigue life
N_f
total number of loading cycles which is applied to the test specimen up to failure

3.2.4.3
time to failure
t_f
time duration required to obtain the number of cycles, N_f

4 Principle

A test specimen of specified dimensions is tested as follows:

— method A: the test specimen is cycled between two constant stress levels at a specified frequency;

— method B: the test specimen is cycled between two constant strain levels at a specified frequency.

The total number of cycles is recorded. If strain is not determined, only the lifetime duration or the residual mechanical properties can be determined. If strain is determined, a number of stress-strain cycles are recorded at specified intervals to determine damage parameters, in addition to the lifetime duration and residual mechanical properties.

NOTE Residual properties can be determined on the test specimens which have not failed during the test using the methods described in the appropriate International Standards.

5 Significance and use

This International Standard enables characterization of the cyclic fatigue behaviour at constant amplitude of CMCs subjected to long duration loading. The simplest way to determine the fatigue properties of a material is to establish lifetime diagrams. In these diagrams, the time to failure (or the cyclic fatigue life) is plotted versus stress (or strain) amplitude.

The complete lifetime diagram requires the use of a great number of test specimens, which is expensive and time consuming. Hence, it is sufficient to know the cyclic-fatigue under specified stress (or strain) conditions, or to measure the fatigue limit. In any case, the typical fatigue test is defined by cyclic loading, constant amplitude, environment, temperature, and frequency.

To better characterize the mechanical behaviour during a fatigue test, it is possible to determine several mechanical parameters from stress-strain curves. These parameters can then be plotted versus time or versus number of cycles. This displays the damage evolution during the cyclic loading. The following parameters can be considered (see Figure 2):

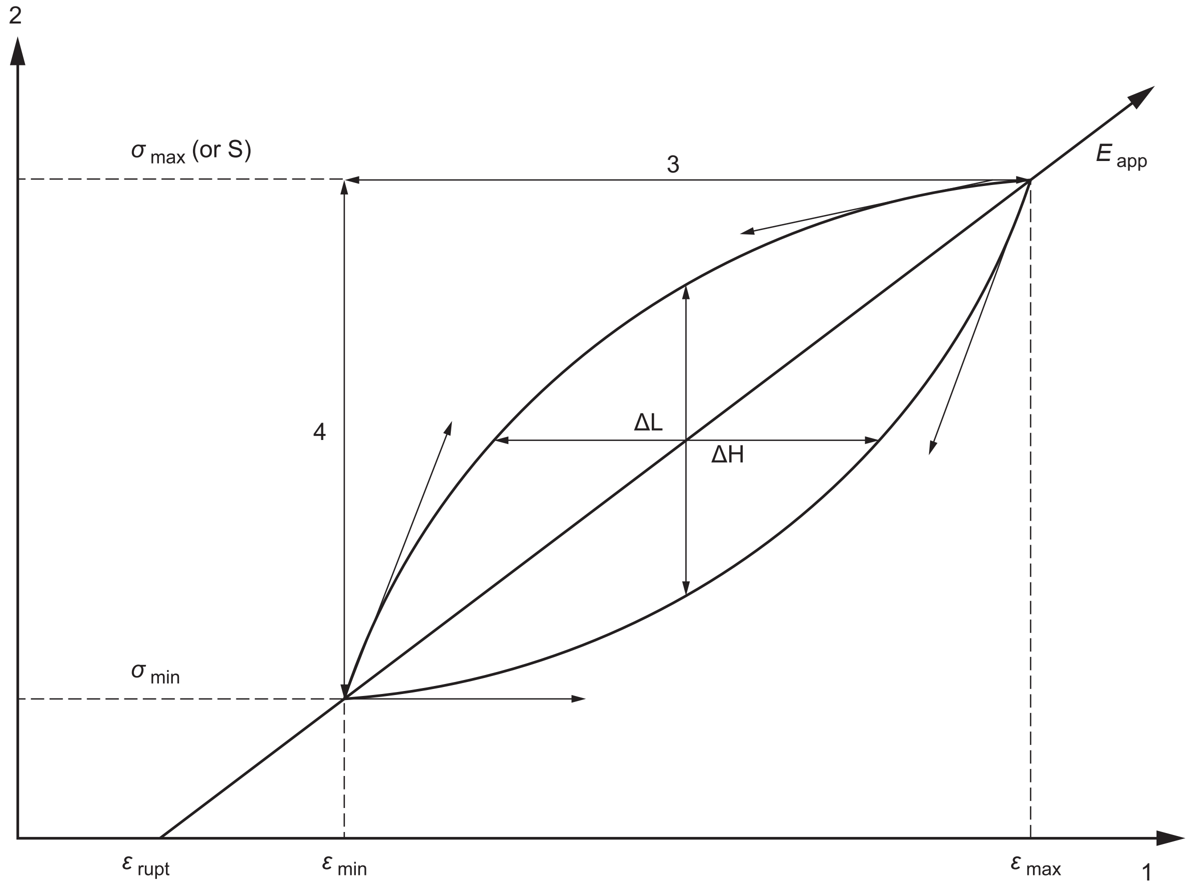
— the residual strain at zero load;

— the secant elastic modulus, or the relative damage parameters;

— the area of the stress-strain hysteresis loop, or the internal friction;

— the maximum strain, the minimum strain, or the difference between them for a selected cycle;

— some specific tangent elastic moduli, for example, at the top or at the bottom of the stress-strain loop.



Key

1 strain (ε)

2 stress (σ)

3 width (L)

4 height (H)

Figure 2 — Parameters that can be considered to assess the cyclic fatigue behaviour

6 Apparatus

6.1 Fatigue test machine

A hydraulic type or electric actuator driven test machine shall be used. It shall be load or strain control operated.

The system for measuring the force applied to the test specimen shall be specially designed for fatigue tests and shall conform to grade 1 or better, in accordance with ISO 7500-1. This shall apply during actual test conditions. The machine shall be equipped with a cycle counter for the chosen test frequency.

6.2 Load train

The load train configuration shall ensure that the load indicated by the load cell and the load experienced by the test specimen are the same.

The attachment fixtures shall align the test specimen axis with that of the applied force.

The grip design shall prevent the test specimen from slipping.

The use of hydraulic grips is recommended.

6.3 Extensometer

If applicable, extensometry shall be capable of continuously recording the longitudinal deformation and compatible with the chosen test frequency. The extensometer shall conform to class 1 or better, in accordance with ISO 9513.

The commonly used type of extensometer is the mechanical type.

In this case, the gauge length is the longitudinal distance between the two locations where the extensometer knife edges are fixed to the test specimen.

NOTE Care should be taken to correct for changes in calibration of the extensometer which can occur as a result of operating under conditions different from those for calibration.

The extensometer performance shall not change because of the test duration.

6.4 Data recording system

A calibrated recorder may be used to record a force-deformation curve. The use of a digital data recording system is recommended.

6.5 Micrometers

Micrometers used for the measurement of the dimensions of the test specimen shall conform to ISO 3611.

7 Test specimens

The lifetime of CMCs depends, among other factors, on stress or strain. Therefore, the configuration of the test specimen shall be designed to obtain a rupture in the gauge length. For this purpose, a dog-bone test specimen shall be used as specified in Figure 3 and Table 1.

In case of 1D composites, dog bone specimens are not recommended. Specimens without shoulders should be used. The sample should be rectangular prismatic with a minimum length of 200 mm.

In addition, the choice of the test specimen geometry depends on the nature of the material and of the reinforcement structure.

The volume in the gauge length shall be representative of the material. The total length, l_t, depends on the gripping system.

In the case of tensile-compressive fatigue tests, the test specimen configuration shall be chosen such as to avoid buckling failure, as defined in ISO 14544.

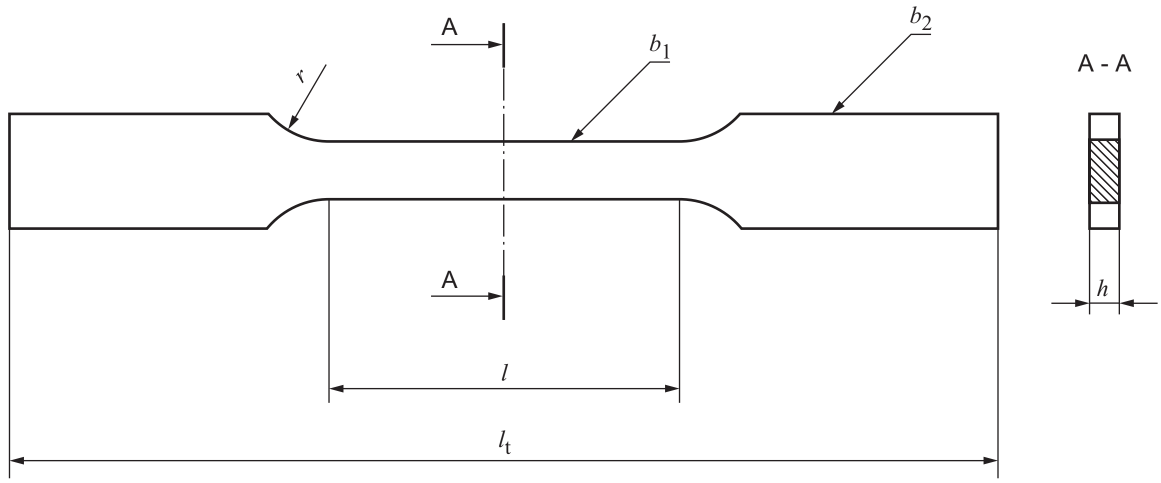


Figure 3 — Test specimen geometry

Table 1 — Recommended test specimen dimensions for 2D or xD (x > 2) reinforcement

Dimensions in millimetres

	1D, 2D, and xD	**Tolerance**
l, calibrated length	30 to 80	±0,5
h, thickness	≥ 2	±0,2
b_1, width in the calibrated length (x ≥ 2)	8 to 20	±0,2
b_2, width	$B_2 = \alpha\ b_1$ with α = 1,2 to 2	±0,2
r, radius (x ≥ 2)	>30	±2
Parallelism of machined parts	0,05	—

8 Test specimen preparation

8.1 Machining and preparation

During cutting out, care shall be taken to align the test specimen axis with the desired fibre related loading axis.

Machining parameters which avoid damage to the material shall be established and documented. These parameters shall be adhered to during test specimen preparation.

8.2 Number of test specimens

At least three valid test results, as specified in 9.3, are required for any condition.

9 Test procedure

9.1 Measurement of test specimen dimensions

The cross-section area shall be determined at the centre of the specimen and at each end of the gauge length.

Dimensions shall be measured to an accuracy of ± 0,01 mm. The arithmetic means of the measurements shall be used for calculations.

9.2 Testing technique

9.2.1 Specimen mounting

Install the test specimen in the gripping system with its longitudinal axis coincident with that of the test machine.

Care shall be taken not to induce flexural or torsional loads in the test specimen.

9.2.2 Setting the extensometer

If used, install the extensometer centrally within the calibrated length.

9.2.3 Measurements

- zero the load cell;
- zero the extensometer, if applicable;
- set the maximum number of cycles, N;
- for method A, set the maximum and minimum stress values;
- for method B, set the maximum and minimum strain values;
- set the frequency and the wave shape;
- start the fatigue test:
  - for method A, in load control mode;
  - for method B, in strain control mode;
- record the number of cycles, N, or N_f;
- if an extensometer is used, record the stress-strain loops up to the total number of cycles.

  A specific computer program is recommended to control the test. Depending on the computerized facilities used, all the loops can be recorded. If this is not possible, the following sequence can be used to record stress versus strain:
  - every cycle for the first 10 cycles;
  - one cycle every 10 cycles between 10 cycles and 100 cycles;
  - one cycle every 100 cycles between 100 cycles and 1 000 cycles;
  - one cycle every 1 000 cycles between 1 000 cycles and 10 000 cycles;
  - etc.

9.3 Test validity

The following circumstances shall invalidate a test for the determination of the lifetime duration:

- failure to specify and record test conditions;
- specimen slippage in the grips.

In addition, the following circumstances shall invalidate a test for the determination of the damage parameter:

- extensometer slippage;

— extensometer drift.

10 Calculation of results

10.1 Time to failure, t_f

Calculate the time to failure in accordance with the following formula:

$$t_f\,(\text{hours}) = \frac{N_f}{f \times 3\,600}$$

where

N_f is the number of cycles required to obtain failure of the test specimen;

f is the frequency, in hertz (Hz).

10.2 Damage parameters

Calculate the damage parameter, D_n, for each recorded cycle, n, in accordance with the following formula:

$$D_n = 1 - \frac{E_{n,app}}{E_{1,app}}$$

where

D_n is the damage parameter at the n^{th} fatigue cycle;

$E_{n,app}$ is the secant modulus at the n^{th} fatigue loop (see Figure 4);

$E_{1,app}$ is the secant modulus at the first fatigue loop (see Figure 4);

$E_{n,app}$ is equal to $\frac{\sigma_{max}}{\varepsilon_{max} - \varepsilon_{nresidual}}$ (see Figure 4).

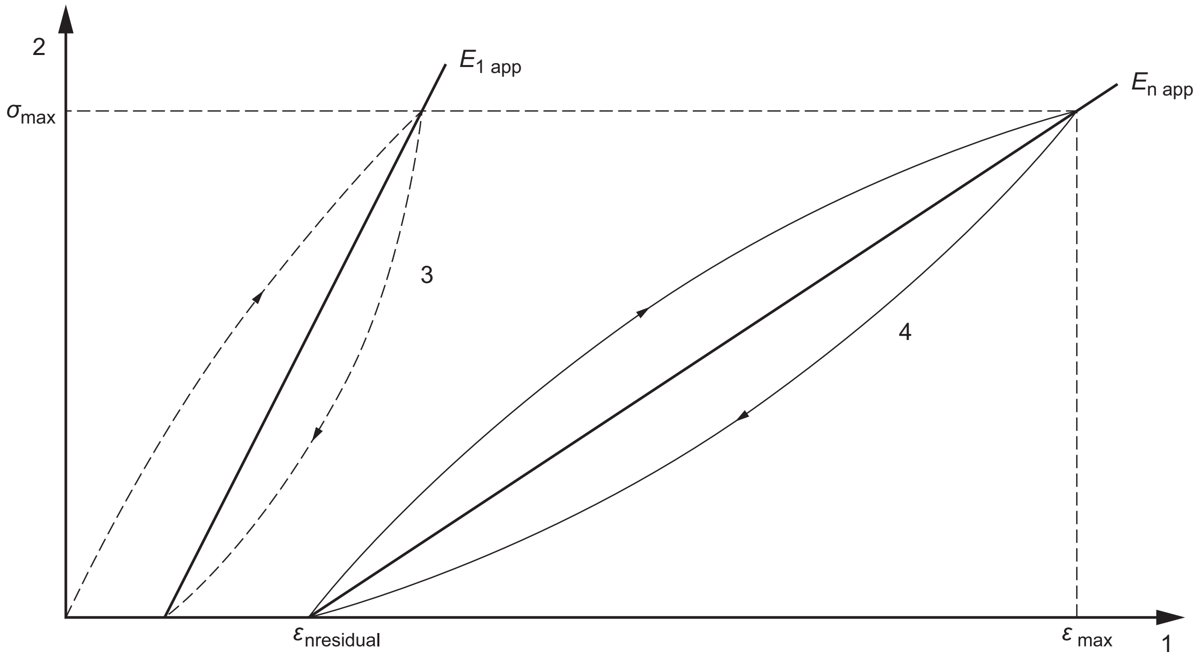
$\varepsilon_{nresidual}$ is equal to $\frac{\varepsilon_{unl} + \varepsilon_l}{2}$ [see Figure 4 b)].

The damage parameters, D_n, ε_{nmax}, $\varepsilon_{nresidual}$, can be plotted versus the number of cycles, N. For N, a log scale is almost always used, although a linear scale can also be used. Figures 4 a) to c) represent three cases of cyclic fatigue of CMCs.

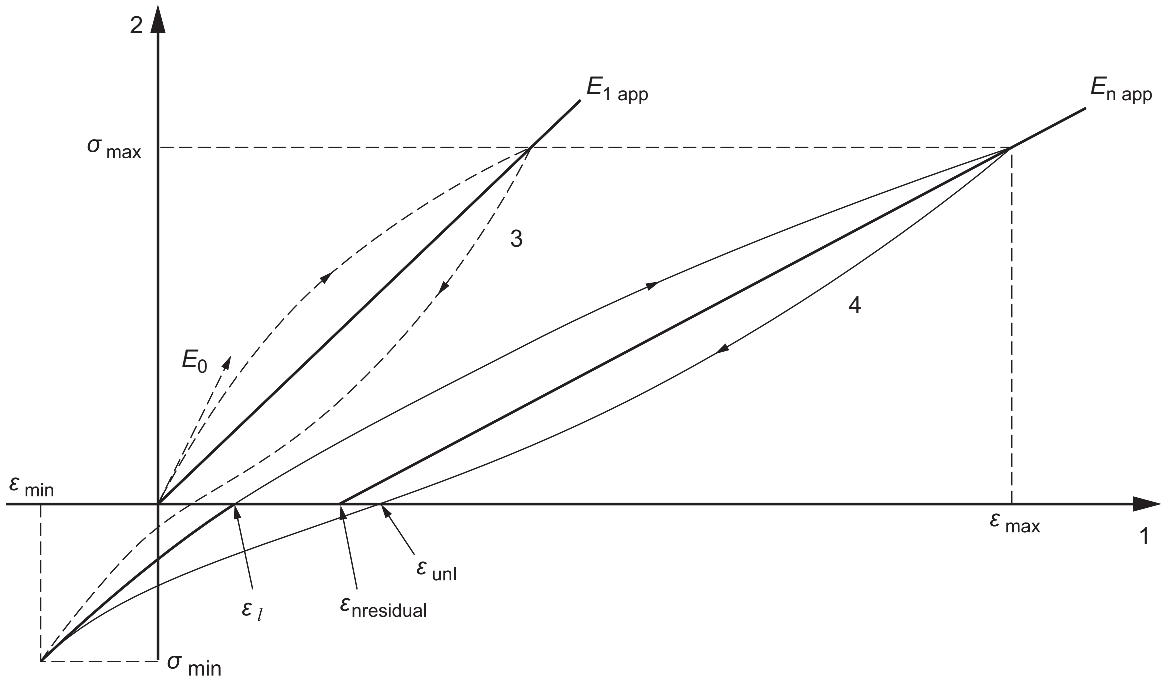
NOTE Annex A shows the schematic evolution of E under different circumstances of damage and creep.

10.3 Residual properties

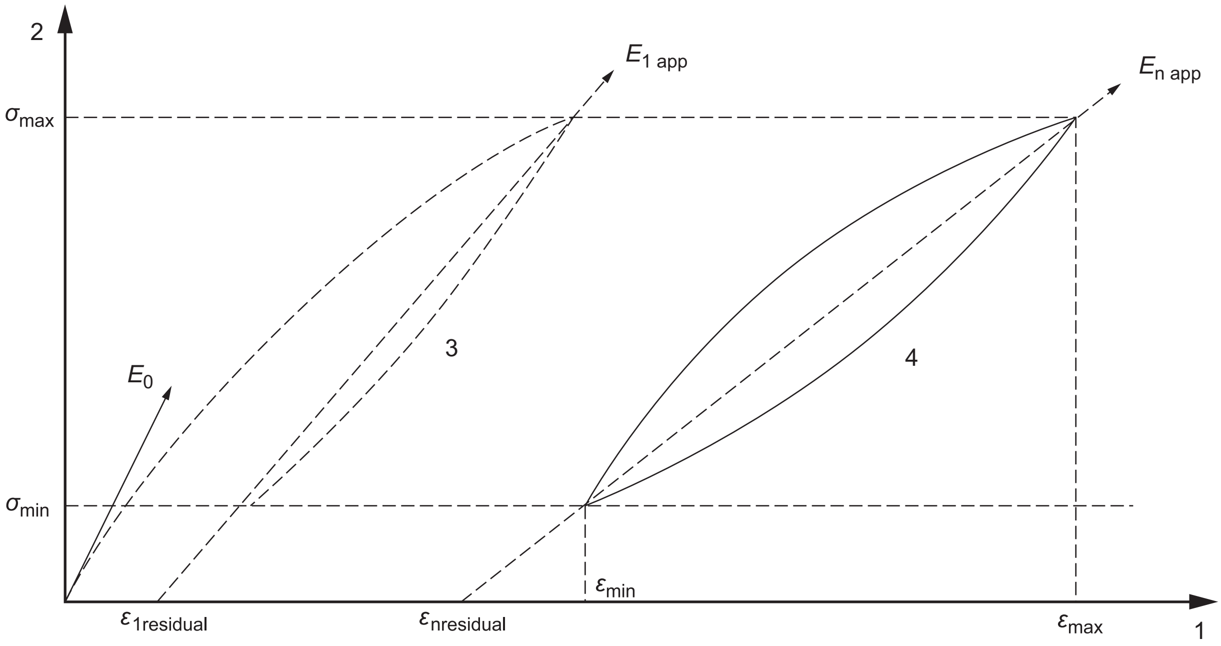
When rupture does not occur before the end of the test, the test specimen shall be tested to rupture in accordance with ISO 14574 or ISO 15733.


2
$E_{1\ app}$
$E_{n\ app}$
σ_{max}
3
4
$\varepsilon_{nresidual}$
ε_{max}
1

a) *R* = 0


2
$E_{1\ app}$
$E_{n\ app}$
σ_{max}
3
4
E_0
ε_{min}
ε_{max}
1
ε_{unl}
ε_{l}
$\varepsilon_{nresidual}$
σ_{min}

b) *R* < 0



c) *R* > 0

Key

1 strain (ε)

2 stress (σ)

3 cycle 1

4 cycle n

ε_l loading

ε_{unl} unloading

Figure 4 — Fatigue stress-strain curves with a) *R* = 0, b) *R* < 0, and c) *R* > 0

11 Test report

The test report shall contain the following information:

a) name and address of the testing establishment;

b) date of the test, unique identification of report and of each page, customer's name, address, and signature;

c) a reference to this International Standard (i.e. ISO 17140);

d) test specimen drawing or reference;

e) description of the test material (material type, manufacturing code, batch number);

f) description of the test set up: extensometer, gripping system, load cell;

g) frequency in hertz;

h) wave form;

i) maximum and minimum stress (method A);

j) maximum and minimum strain (method B);

k) number of cycles to failure; if test is stopped at a specified number of cycles without failure occurring, it shall be registered;

l) residual properties (if applicable);

m) number of tests carried out and number of valid results obtained;

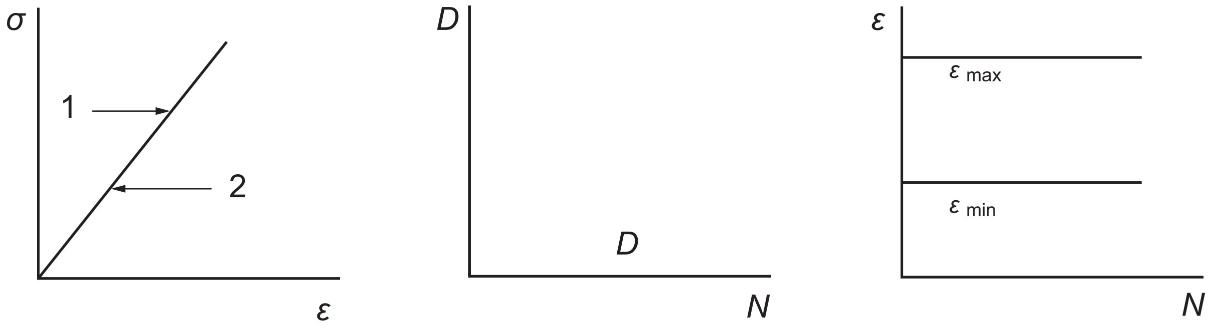
n) damage parameter, if applicable;

o) failure location in all the specimens used for obtaining the above results, if applicable.

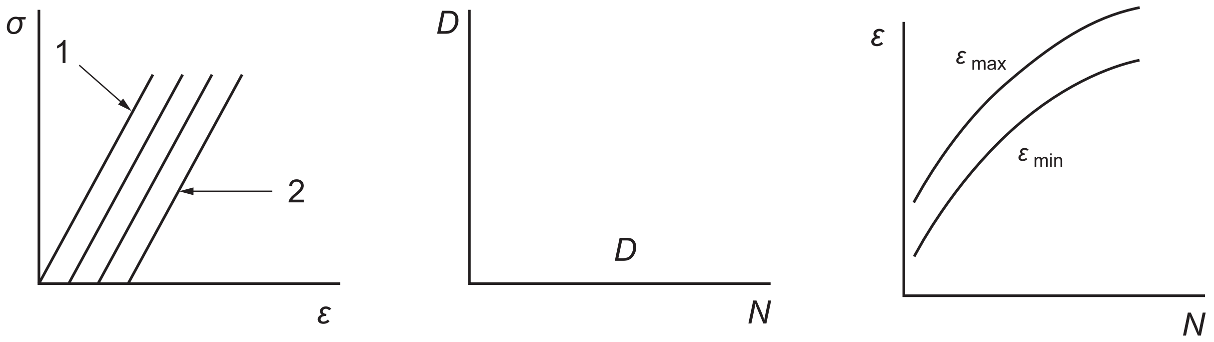
Annex A
(informative)

Schematic evolution of *E*

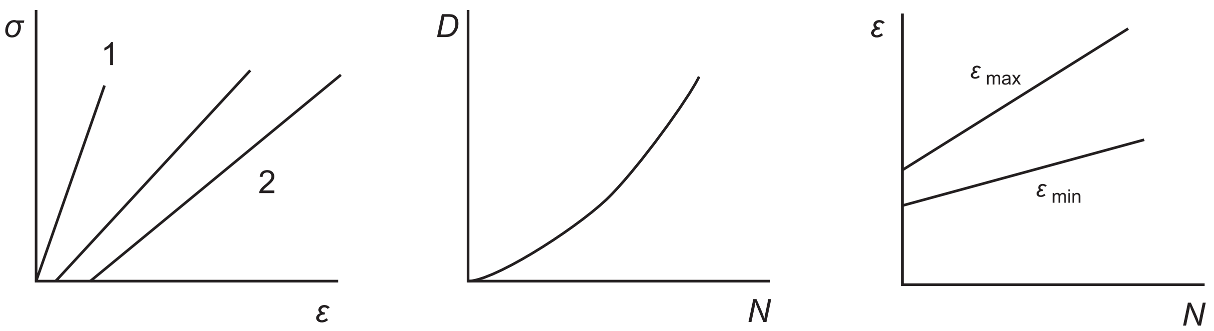
Figure A.1 shows a schematic evolution of *E* where there is a) no damage, b) creep but no fatigue damage, and c) fatigue damage and eventual creep.



a) No damage



b) No fatigue damage (only creep)



c) Fatigue damage plus eventual creep

Key

1 first cycle

2 last cycle

Figure A.1 — Schematic evolution of *E* with a) no damage, b) creep but no fatigue damage, and c) fatigue damage and eventual creep

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