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Fibre-reinforced plastics — Determination of fatigue properties under cyclic loading conditions

Plastiques renforcés de fibres — Détermination des propriétés de fatigue en conditions de chargement cycliques

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 13003 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 13, *Composites and reinforcement fibres*.

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Fibre-reinforced plastics — Determination of fatigue properties under cyclic loading conditions

1 Scope

This International Standard defines the general procedures for fatigue testing of fibre-reinforced plastic composites under cyclic loading conditions of constant amplitude and constant frequency. Although these general procedures are applicable to all modes of testing and test machine control, care will be required in their application in each case. Prior experience has been mainly with tensile and flexural fatigue testing based on the equivalent static (monotonic) test methods. Fatigue tests on unidirectionally reinforced carbon-fibre systems in the fibre direction are particularly difficult to perform.

In some cases, such as fracture toughness crack propagation, specific tests may exist that should be used in preference to this International Standard.

2 Normative references

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

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ISO 291, *Plastics — Standard atmospheres for conditioning and testing*

ISO 527-4, *Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites*

ISO 527-5, *Plastics — Determination of tensile properties — Part 5: Test conditions for unidirectional fibre-reinforced plastic composites*

ISO 1268 (all parts), *Fibre-reinforced plastics — Methods of producing test plates*

ISO 14125, *Fibre-reinforced plastic composites — Determination of flexural properties*

3 Terms and definitions

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

3.1
stress (induced in test specimen)
σ
nominal stress calculated, using the relevant equation given in the monotonic (static) test method used, from the measured load

NOTE It is expressed in megapascals.

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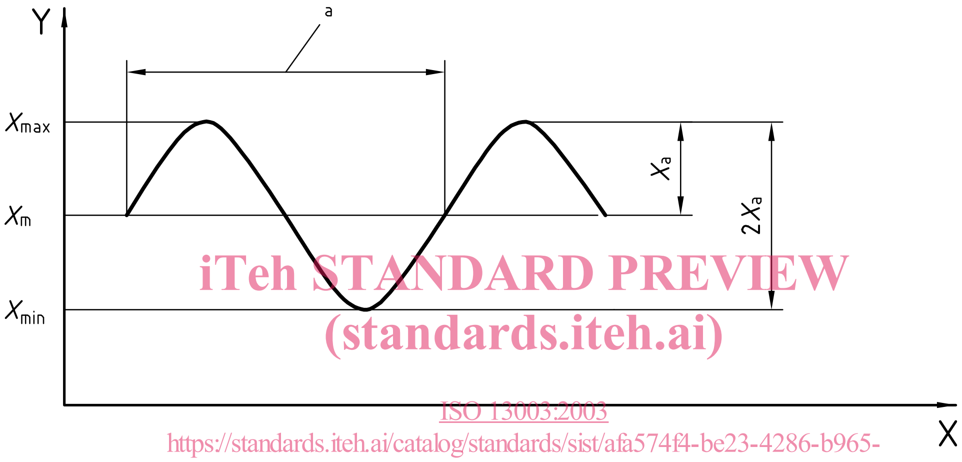
3.2
strain (imposed on test specimen)
ε
fractional elongation of the highest-loaded portion of the test specimen (e.g. the outer surface of a flexure specimen)

NOTE It is calculated from the relevant equation given in the test method used and expressed as a dimensionless ratio.

3.3
waveform
shape of the cyclic variation of the applied stress (load) or strain (displacement) between constant maximum and minimum values

NOTE The default waveform shape is a sine waveform. Figure 1 gives an example of a constant-amplitude, constant-frequency sine wave. Other waveform shapes, such as square, triangular and saw-tooth, are also used.



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Key

X time
Y applied stress or strain X

X_{max} maximum (or peak) value of X
X_m mean value of X [$X_m = (X_{max} + X_{min})/2$]
X_{min} minimum (or trough) value of X
X_a amplitude of X
$2X_a$ extent of variation of X (peak-to-peak amplitude)
[a] 1 cycle

Figure 1 — Example of sine waveform cycle

3.4
cycle
single completed waveform from any point on the waveform (e.g. mean, peak) to the next occurrence of the same point

3.4.1
type of cycle
the type of cycle is defined by the position of the signal in relation to zero stress (load) or strain (displacement)

NOTE Figure 2 gives examples of stress cycles. For strain or deflection displacement cycles, strain or displacement terms replace stress terms.

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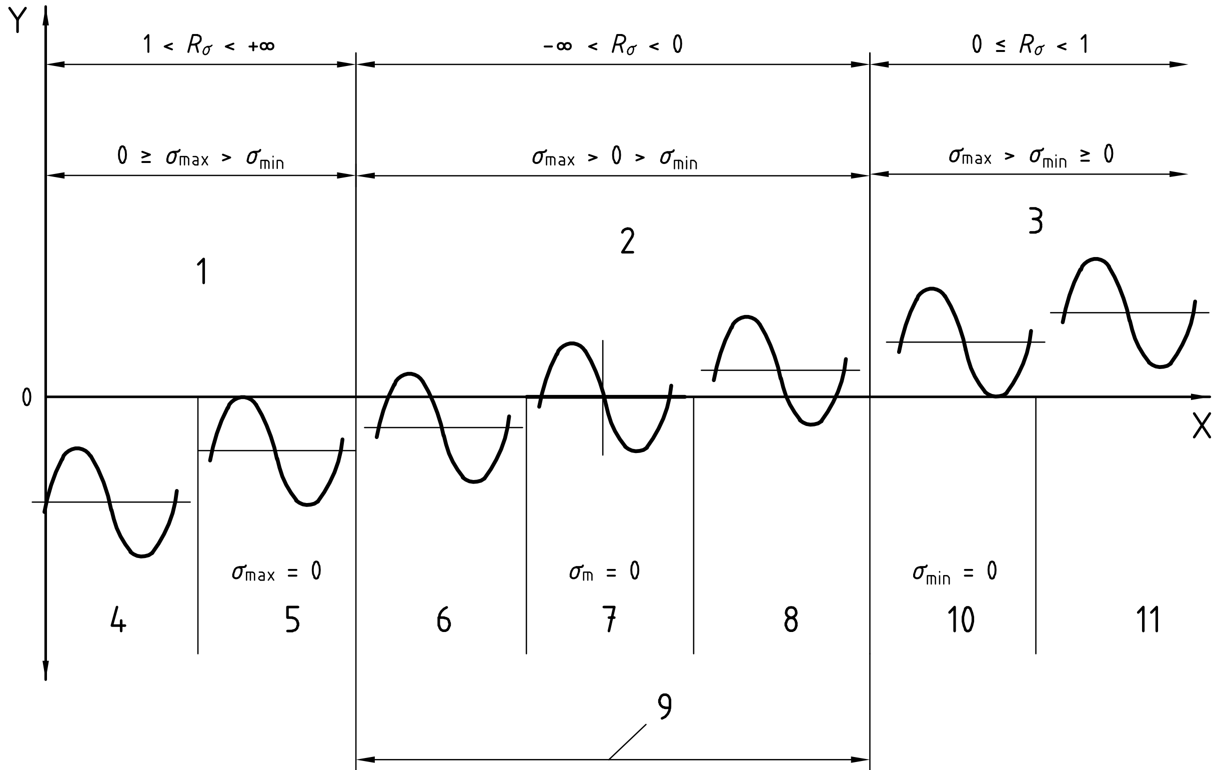

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Key

X time, t

Y stress, σ (or strain, ε)

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1 compression-compression region
2 tension-compression region
3 tension-tension region
4 compression-compression cycle
5 zero-compression alternating cycle
6 compression-dominated alternating cycle
7 fully reversed or fully alternating cycle
8 tension-dominated alternating cycle
9 alternating cycles
10 zero-tension cycle
11 tension-tension cycle

Figure 2 — Examples of cycle types

3.5
frequency
f
number of cycles, or part cycles, completed in 1 s, expressed in hertz

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3.6
stress, strain and displacement values

3.6.1
maximum stress
σ_{max}
maximum strain
ε_{max}
maximum displacement
d_{max}
highest value reached periodically by the stress, expressed in megapascals, or by the strain, expressed in percent, or by the displacement, expressed in millimetres

3.6.2
minimum stress
σ_{min}
minimum strain
ε_{min}
minimum displacement
d_{min}
lowest value reached by the stress, expressed in megapascals, or by the strain, expressed in percent, or by the displacement, expressed in millimetres

3.6.3
mean stress
σ_m
mean strain
ε_m
mean displacement
d_m
algebraic mean of the maximum and minimum stresses, strains or displacements:

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$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \quad (1)$$

$$\varepsilon_m = \frac{\varepsilon_{max} + \varepsilon_{min}}{2} \quad (2)$$

$$d_m = \frac{d_{max} + d_{min}}{2} \quad (3)$$

3.6.4
stress amplitude
σ_a
strain amplitude
ε_a
displacement amplitude
d_a
value equal to half of the difference between the maximum and minimum stresses, strains or displacements:

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} \quad (4)$$

$$\varepsilon_a = \frac{\varepsilon_{max} - \varepsilon_{min}}{2} \quad (5)$$

$$d_a = \frac{d_{max} - d_{min}}{2} \quad (6)$$

NOTE In some cases, the extent of the stress, strain or displacement peak-to-peak variation is quoted (i.e. twice the stress, strain or displacement amplitude).

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3.6.5
stress ratio
R_σ
strain ratio
R_ε
displacement ratio
R_d
ratio of the minimum stress, strain or displacement to the maximum stress, strain or displacement within a cycle:

$$R_\sigma = \frac{\sigma_{\text{min}}}{\sigma_{\text{max}}} \quad (7)$$

$$R_\varepsilon = \frac{\varepsilon_{\text{min}}}{\varepsilon_{\text{max}}} \quad (8)$$

$$R_d = \frac{d_{\text{min}}}{d_{\text{max}}} \quad (9)$$

NOTE For example, $R = 1$ is fully reversed tension and compression of equal magnitude, while $R = 0{,}1$ is tension-tension cycling where the minimum value is 0,1 × the maximum value.

3.7
load
F
the load, measured by a load sensor, on the specimen

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NOTE The maximum and minimum values for each loading cycle are F_{max} and F_{min}, expressed in newtons.

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3.7.1
initial load
F_i
absolute value of the maximum amplitude of the load, measured before the end of the first 100 cycles or when steady conditions are obtained

NOTE Its value can be obtained either by an individual measurement or by sampling over several cycles. It is expressed in newtons.

3.7.2
load ratio
R_F
ratio of the minimum load to the maximum load within a cycle

$$R_F = \frac{F_{\text{min}}}{F_{\text{max}}}$$

3.8
initial stress
σ_i
stress calculated from the initial load (3.7.1)

NOTE It is expressed in megapascals.

3.9
fatigue life
N_f
number of cycles to which a test specimen is subjected until failure occurs or the test is terminated

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NOTE 1 For displacement-controlled tests in which failure does not occur either by separation of the specimen into two or more parts or by excessive general damage (i.e. so that the load can no longer be sustained by the specimen), the end of the test is defined as a damage level (or damage rate) related to a reduction in test specimen stiffness (e.g. 5 % to 20 %). The damage level is normally taken as a 20 % reduction in the absolute value.

NOTE 2 When the test is terminated before either failure or the stiffness limit criterion is reached (i.e. the test duration to obtain failure is considered excessive), the fatigue life is not defined, but is only greater than the duration of the test. These tests are referred to as "run-outs" and the data point is often indicated on plots of stress or strain against the number of cycles by adding an arrow pointing to a higher test duration (e.g. x→, o→).

3.10
ultimate properties

3.10.1
ultimate tensile/fluxural strength at the static (standard) loading rate
UTS^S
UFS^S
parameter given by the test method used, e.g.

— UTS^S for tensile strength by ISO 527-4 or ISO 527-5;

— UFS^S for flexural strength by ISO 14125

3.10.2
ultimate tensile/fluxural strength at the fatigue loading rate
UTS^F
UFS^F
parameter given by tests at the fatigue loading rate, e.g. UTS^F for tensile strength and UFS^F for flexural strength

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NOTE 1 The fatigue loading rate is taken as that resulting in failure in a time equivalent to 0,5 × the cycle time, i.e.

Test duration (s) = 0,5 × frequency (Hz)

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NOTE 2 It can be set at the same frequency as the fatigue tests using a triangular waveform with an amplitude sufficient to cause ultimate failure. N.B. For a rate-dependent material, such as continuously reinforced glass-fibre-reinforced plastic, this may be significantly higher (> 40 %) than the static strength.

4 Principle

A continuously alternating mechanical load or applied displacement is applied at constant frequency to the test specimen. The test may be carried out at a constant stress (load) amplitude, a constant strain amplitude or a constant displacement amplitude.

The test method, specimen dimensions and calculations used are the same as those used in the equivalent test mode under static (monotonic) loading conditions.

NOTE 1 For example, tensile fatigue tests use ISO 527-4 or ISO 527 5 (N.B. these specimens are not suitable for fully reversed loading without support against buckling in compression, cf. ISO 14126, *Fibre-reinforced plastic composites — Determination of compressive properties in the in-plane direction*). Flexural fatigue tests use ISO 14125.

NOTE 2 There are no major differences between the operation of the fatigue machine in the different control modes (e.g. load, displacement) but there are major differences in the definition of the end-point of the test (see 3.9).

Recommendations for particular test modes are given in Annex A (flexural tests) and Annex B (tensile tests).

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5 Apparatus

5.1 Test machine

A test machine suitable for the test mode selected (e.g. tension, flexure) shall be used. The equipment shall be suitable for applying the required number of cycles for several tests (e.g. $\geqslant 10^8$ cycles), in the required waveform(s) (e.g. sine, square, triangular, saw-tooth). The number of cycles applied shall be measured directly or obtained from a knowledge of the applied frequency and test duration.

5.2 Sensors and associated electronics

This equipment shall be capable of measuring continuously the variation in load, displacement or other parameters, such as strain, to within 2 % of full scale, depending on the control mode in use.

NOTE The choice of the force sensor and its full-scale range is linked to the desired measurement sensitivity and to the characteristics of the moving element of the sensor (i.e. its dimensions and mass will affect the frequency response and the magnitude of inertia effects).

The use of fatigue-rated sensors is recommended.

6 Preparation and checking of test specimens

6.1 Preparation of the test specimens

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Test specimens as specified by the test method standard used shall be cut from test panels prepared in accordance with the relevant part of ISO 1268 or from flat areas of the product under test.

The mechanical properties of components or sub-components are directly linked to the structure of the material and therefore directly dependent on the processing conditions. It is recommended that testing is on test specimens which, if not taken from actual components or sub-components, are produced under conditions that are close to the actual production conditions.

6.2 Shape and dimensions

These shall be as given in the standard for the chosen test method.

6.3 Checking

Specimens shall be checked in accordance with the test method standard used. Particular care shall be taken to ensure good-quality specimens free of machining defects that could initiate premature failure.

7 Number of test specimens

For the determination of the lifetime diagram, five specimens shall be tested at a minimum of four levels of imposed stress/strain, etc., unless otherwise specified (see Note 1).

Test the five specimens monotonically to failure to measure the static (monotonic) strength for the chosen test method. Repeat tests are recommended at the fatigue loading rate for loading rate dependent materials.

NOTE 1 If it is intended to analyse the results statistically, it is advisable to increase the number of test specimens [e.g. for Weibull-type failure curves or for generating design data (e.g. 24 to 30 specimens preferred)]. To reduce the cost of preliminary or exploratory investigations, 6 specimens, and for materials research 12 specimens, may be sufficient depending on the scatter found in the test results.

NOTE 2 For loading rate sensitive materials (e.g. glass-fibre-reinforced systems), it is advisable also to measure the ultimate strength at a loading rate equivalent to the fatigue test conditions (see 3.10.2).

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