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Metallic materials — Fatigue testing — Axial-strain-controlled method

Matériaux métalliques — Essais de fatigue — Méthode par déformation axiale contrôlée

Reference number
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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 12106 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 5, *Fatigue testing*.

Introduction

The design of mechanical components subjected to fatigue loadings requires, in a number of industrial sectors (nuclear, aeronautical, mechanical engineering), the knowledge of the behaviour of the materials under reversed strain control conditions (referred to as low-cycle fatigue) when cyclic plasticity is present.

In order to ensure reliability and consistency of results from different laboratories, it is necessary to collect all data using test methodologies that comply with a number of key points.

This International Standard concerns both the generation and the presentation of results for fatigue properties of metallic materials.

Metallic materials — Fatigue testing — Axial-strain-controlled method

1 Scope

This International Standard specifies a method of testing uniaxially loaded specimens under strain control at constant amplitude, uniform temperature and strain ratio $R_\varepsilon = -1$.

It can also be used as a guide for testing under other conditions.

2 Normative references

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.

ISO 9513:1999, *Metallic materials — Calibration of extensometers used in axial testing*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.[3 to 9]

3.1
stress
instantaneous force divided by the instantaneous cross-sectional area of the gauge length

$$\sigma = F / A$$

NOTE At strain values less than 10 %, the true stress is approximated by the engineering stress, F_F / A_o.

3.2
gauge length
length between extensometer measurement points

3.3
strain
true total strain

$$\varepsilon = \int_{L_o}^{L} \frac{dL}{L}$$

where L is the instantaneous length of the gauge section

NOTE At true strain values less than 10 %, ε is approximated by the engineering strain $\Delta L / L_o$.

3.4
cycle
smallest segment of the strain-time function that is repeated periodically

3.5
maximum
greatest algebraic value of a variable within one cycle

3.6
minimum
least algebraic value of a variable within one cycle

3.7
mean
one-half of the algebraic sum of the maximum and minimum values of a variable

3.8
range
algebraic difference between the maximum and minimum values of a variable

3.9
amplitude
half the range of a variable

3.10
fatigue life
N_f
number N of cycles that have to be applied to achieve a failure

NOTE Failure criteria are defined, for example, in 7.8. The failure criterion used shall be reported with the results.

3.11
hysteresis loop
closed curve of the stress-strain response during one cycle

4 Symbols

For the purposes of this document, the symbols defined in 4.1 to 4.3 apply.

4.1 Specimens

See Table 1.

Table 1 — Symbols and designations concerning specimens

Specimen	Symbol	Designation	Unit
	L_o	Initial gauge length	mm
	L	Instantaneous gauge length	mm
	A_o	Initial gauge section	mm^2
	A	Instantaneous section with $AL = A_oL_o$	mm^2
	A_f	Minimum area at failure	mm^2
	r	Transition radius (from parallel length into the grip end of the test specimen)	mm
	L_t	Total length of specimen	mm
Cylindrical			
	d	Diameter of cylindrical gauge section	mm
	D	External diameter of specimen	mm
	L_r	Length of reduced section	mm
Flat-sheet			
	B	Width of gauge section	mm
	t	Thickness	mm
	W	Width of grip end	mm

4.2 Fatigue testing

4.2.1 Symbols

E modulus of elasticity, in gigapascals (GPa);

E_T modulus for unloading following a peak tensile stress (see Figure 1), in gigapascals (GPa);

E_C modulus for unloading following a peak compression stress (see Figure 1), in gigapascals (GPa);

N_f number of cycles to failure;

t_f time to failure (= N_f cycles), in seconds (s);

σ true stress, in megapascals (MPa);

ε true strain;

Δ range of a parameter;

$R_{p0,2}$ 0,2 % proof stress;

Rz mean surface roughness, in micrometres (µm);

R_σ stress ratio $\left(= \sigma_{min}/\sigma_{max}\right)$;

R_ε strain ratio $\left(= \varepsilon_{min}/\varepsilon_{max}\right)$;

$\dot{\varepsilon}$ strain rate, in seconds to the power of minus one (s^{-1}).

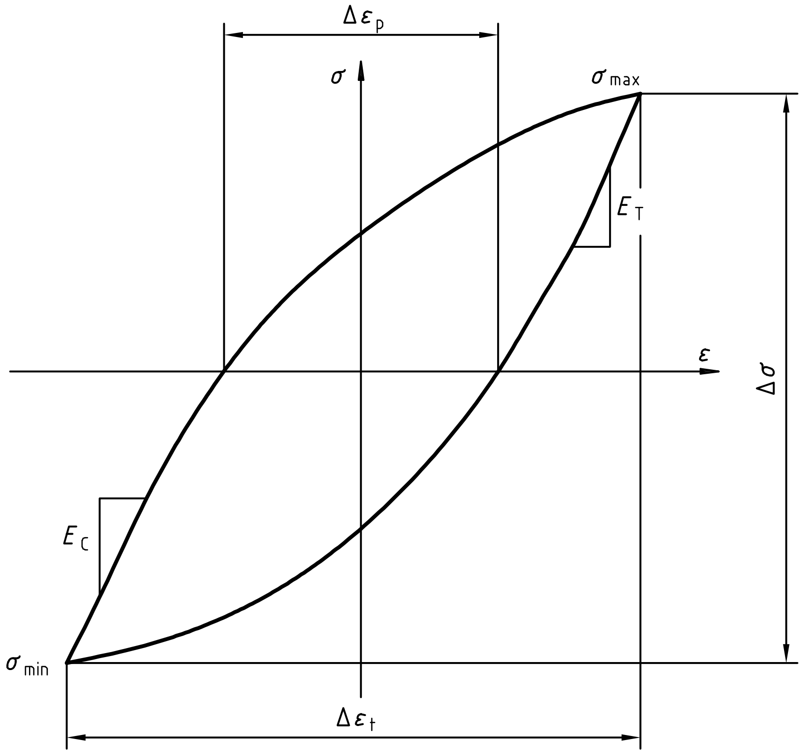


Figure 1 — Stress-strain hysteresis loop

4.2.2 Subscripts

t total;

p plastic;

e elastic;

a amplitude;

m mean;

1/4 related to first 1/4-cycle;

min minimum;

max maximum.

4.3 Expression of results

See Table 2.

Table 2 — Symbols and designations concerning the expression of results

Symbol	Designation	Unit
$\sigma_{y'}$	Cyclic yield strength [a]	MPa
n	Monotonic strain hardening exponent	—
n'	Cyclic strain hardening exponent	—
K	Monotonic strength coefficient	MPa
K'	Cyclic strength coefficient	MPa
$\sigma_{f'}$	Fatigue strength coefficient	MPa
b	Fatigue strength exponent	—
$\varepsilon_{f'}$	Fatigue ductility coefficient	—
c	Fatigue ductility exponent	—

[a] 0,2 % offset is typically used.

5 Apparatus

5.1 Test machine

5.1.1 General

The tests shall be carried out on a tension-compression machine designed for a smooth start-up with no backlash when passing through zero. The machine shall have great lateral rigidity when the crosshead is in the operating position and accurate alignment between the test space support references.

The complete machine-loading system (including load cell, grips and specimen) shall have great lateral rigidity and be capable of controlling strain and measuring force when applying the recommended wave cycle. It may be hydraulic or electromechanical.

5.1.2 Load cell

The load cell shall be designed for tensile-compressive fatigue tests and shall have great axial and lateral rigidity. Its capacity shall be suitable for the forces applied during the test.

The indicated force as recorded at the output from the computer in an automated system or from the final output recording device in any non-automated system shall be within the specified permissible variation from the actual force. The load cell capacity shall be sufficient to cover the range of forces measured during a test to an accuracy better than 1 % of the reading.

The load cell shall be temperature-compensated and shall not have zero drift or sensitivity variation greater than 0,002 % of full scale per degree Celsius.

During high-temperature or cryogenic testing, suitable shielding/compensation may be provided for the cell so it is maintained within its compensation range.

5.1.3 Gripping of specimen

The gripping device shall transmit the cyclic forces to the specimen without backlash along its longitudinal axis. The distance between the grips shall be small to avoid any tendency of the specimen to buckle. The geometric qualities of the device shall ensure correct alignment in order to meet the requirements specified in 5.1.4; it is therefore necessary to limit the number of components of which these gripping devices are composed and reduce the number of mechanical interfaces to a minimum.

The gripping device shall ensure that the way in which the specimen is mounted is reproducible. It shall have surfaces ensuring the alignment of the specimen and surfaces allowing transmission of tensile and compressive forces without backlash throughout the duration of the test. Materials shall be selected so as to ensure correct functioning across the test temperature range.

5.1.4 Alignment check

Bending due to misalignment in rigid-grip systems is generally caused by one or more of the following (see Figure 2): angular offset of the grips, lateral offset of the loading bars (or grips) in an ideally rigid system, an offset in the load-train assembly in a non-rigid system or (in the case of servo-hydraulic machines) an actuator rod with side-play in the bearings.

The alignment shall be checked before each series of tests and any time a change is made to the load train. The bending strains shall be < 5 % of the axial strain at both the maximum and minimum applied strain. Figure 3 shows a recommended strain gauge configuration for checking alignment. There are other techniques for measuring alignment that are adequate for this purpose.[17 to 20] See Annex A for details of methodology. For an example of an alignment check that includes an elastic-plastic method, see [19].

5.2 Strain measurement

The strain shall be measured from the specimen using an axial extensometer.

The extensometer used shall be suitable for measuring dynamic strain over long periods during which there shall be minimal drift, slippage and instrument hysteresis. It shall measure directly the axial strain on the gauge section of the specimen.

The strain-measuring system, including the extensometer and its associated electronics, shall be accurate to within 1 % of the range of strain applied. The extensometer shall conform to ISO 9513:1999, Class 1.

The geometry of the contact zones and the pressure exerted by the extensometer on the specimen shall be such that they prevent slippage of the extensometer but do not damage the specimen.

The transducer section of the extensometer shall be protected from thermal fluctuations that give rise to drift.

5.3 Heating device and temperature measurement [10, 14 to 16]

A uniform rise in temperature shall be ensured without the test temperature being exceeded.

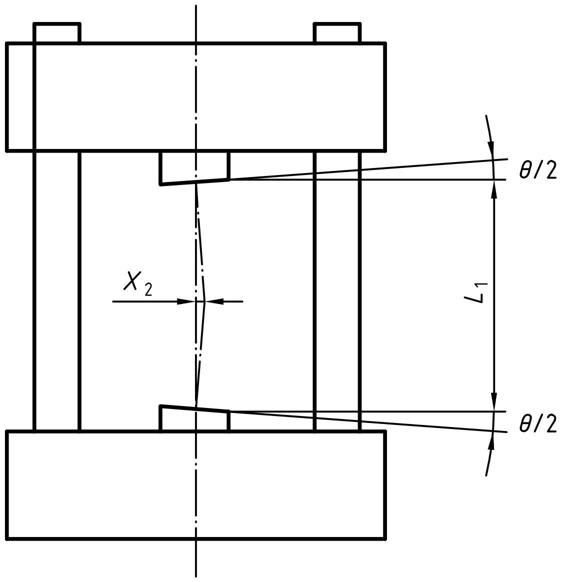
If a direct induction heating system is used, it is advisable to select a generator with a frequency sufficiently low to prevent “skin effects” on heating.

The heating device shall produce a temperature gradient not exceeding 3 °C over the gauge length of the specimen and shall ensure, throughout the test, and with due consideration to all combined sources of error, that deviations between the test temperature and that of the specimen are within 5 °C.

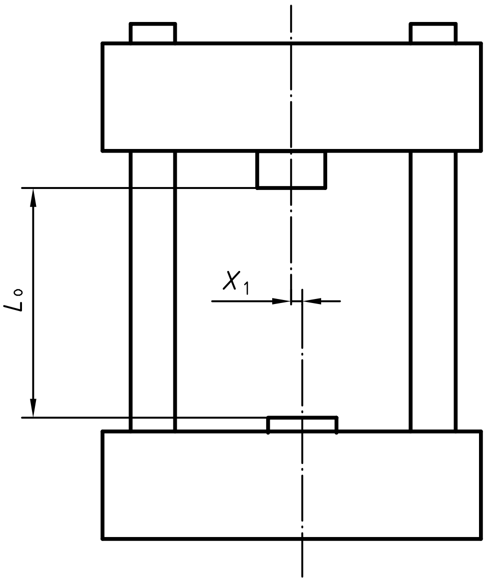
These deviations shall be checked using three thermocouples or other appropriate devices, one at each end and one in the middle of the gauge length of the specimen.

In a test, the specimen temperature may be measured using thermocouples in contact with the specimen surface. Direct contact between the thermocouple and the specimen is necessary and shall be achieved without affecting the test results (e.g. crack initiation at the point of contact of the thermocouple shall be avoided). Commonly used methods of attaching the thermocouples are by binding in place, by pressure or by resistance spot welding.

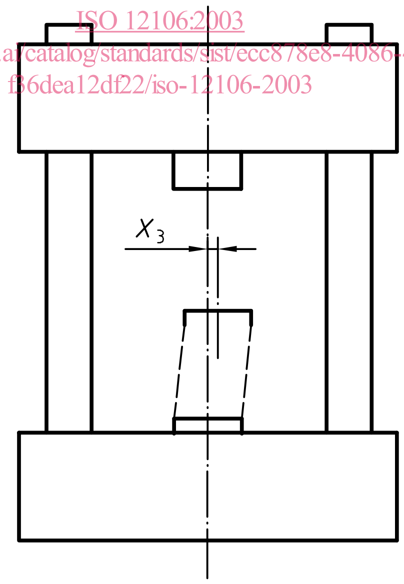
The temperature shall be measured by at least one sensor independently of the one used for control purposes.



a) **Angular offset**



b) **Lateral offset**



c) **Load-train offset in a non-rigid system**

Figure 2 — Bending mechanisms due to misalignment in fatigue test systems