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Metallic materials — Fatigue testing — Axial force-controlled method

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

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 1099 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 5, *Fatigue testing*.

This second edition cancels and replaces the first edition (ISO 1099:1975), which has been technically revised.

Introduction

This International Standard is intended to provide guidance for conducting axial, constant-amplitude, force-controlled cyclic fatigue tests on specimens of a metal for the sake of generating fatigue-life data (i.e. stress vs. cycles to failure).

Nominally identical specimens are mounted on an axial force-type fatigue testing machine and subjected to the required loading conditions that introduce any one of the types of cyclic stress illustrated in Figure 1. The test waveform shall be of constant amplitude, and sinusoidal unless otherwise specified.

The force being applied to the specimen is along the longitudinal axis passing through the centroid of each cross-section.

The test is continued until the specimen fails or until a predetermined number of stress cycles has been exceeded. (See Clauses 4 and 13.)

The test is typically conducted at ambient temperature (ideally between 10 °C and 35 °C).

NOTE The results of a fatigue test may be affected by atmospheric conditions, and where controlled conditions are required, subclause 2.1 of ISO 554:1976 applies.

Metallic materials — Fatigue testing — Axial force-controlled method

1 Scope

This International Standard specifies the conditions for carrying out axial, constant-amplitude, force-controlled fatigue tests at ambient temperature on metallic specimens, without deliberately introduced stress concentrations. The object of testing is to provide fatigue information, such as the relation between applied stress and number of cycles to failure for given materials at various stress ratios.

While the form, preparation and testing of specimens of circular and rectangular cross-section are described, component testing and other specialized forms of testing are not included in this International Standard.

NOTE Fatigue tests on notched specimens are not covered by this International Standard since the shape and size of notched test pieces have not been standardized. However, fatigue-test procedures described in this standard may be applied to fatigue tests on notched specimens.

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 554:1976, *Standard atmospheres for conditioning and/or testing — Specifications*

ISO 4287:1997, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters*

ISO 4288:1996, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture*

ISO 4965:1979, *Axial load fatigue testing machines — Dynamic force calibration – Strain gauge technique*

ISO 7500-1:2004, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines – Verification and calibration of the force-measuring system*

3 Terms and definitions

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

3.1
test diameter
d
diametral distance or width of the specimen or test piece where the stress is a maximum

See Figures 3 and 4

3.2
thickness of test section
a
thickness of a rectangular cross-section specimen or test piece

3.3
width of test section
b
width of a rectangular cross-section specimen or test piece

3.4
parallel length
L_c
length in the gauge test section of a specimen or test piece that has equal test diameter or test width and is parallel

See Figures 3 and 4.

3.5
radius
r
curvature at the ends of the test section that starts the transition from the test diameter, d, or test width, b, to the diameter or width of the gripped ends; or the continuous radius between the gripped ends of the specimen or test piece

NOTE The curve need not be a true arc of a circle over the whole of the distance between the end of the test section and the start of the enlarged end for the types shown in Figures 3a) and 4a).

3.6
maximum stress
σ_{max}, S_{max}
highest algebraic value of stress in a stress cycle

See Figure 2.

3.7
mean stress
σ_m, S_m
one-half the algebraic sum of the maximum stress and the minimum stress in a stress cycle

See Figure 2.

3.8
minimum stress
σ_{min}, S_{min}
lowest algebraic value of stress in a stress cycle

See Figure 2.

3.9
stress amplitude
σ_a, S_a
one-half the algebraic difference between the maximum stress and the minimum stress in a stress cycle

See Figure 2.

3.10
stress range
$\Delta\sigma$, ΔS
arithmetic difference between the maximum and minimum stress

$\Delta\sigma = \sigma_{max} - \sigma_{min}$ or $\Delta S = S_{max} - S_{min}$

See Figure 2.

3.11
stress ratio
R_s
ratio of minimum to maximum stress during any single cycle of fatigue operation

$R_s = \sigma_{min}/\sigma_{max}$

See Figure 2.

3.12
stress cycle
variation of stress with time, repeated periodically and identically

See Figure 2.

3.13
number of cycles
N
number of smallest segments of the force-time, stress-time, strain-time, etc., function that is repeated periodically

3.14
fatigue life
endurance
N_f
number of applied cycles to achieve a defined failure criterion

3.15
fatigue strength at N cycles
σ_N
value of the stress amplitude at a stated stress ratio under which the specimen would have a life of N cycles

4 Test plan

4.1 General outline

Before commencing testing, the following shall be agreed by the parties concerned, unless specified otherwise in the relevant product standard:

a) The form of specimen to be used (see 5.1).

b) The stress ratio(s) to be used.

c) The objective of the tests, i.e., which of the following is to be determined:

- the fatigue life at a specified stress amplitude;
- the fatigue strength at a specified “endurance”;
- a full Wöhler or S-N curve.

d) The number of specimens to be tested and the testing sequence.

e) The number of cycles at which a test on an unfailed specimen shall be terminated.

f) The testing temperature if different from the requirements given in 5.2.

Commonly employed “endurances” are, for example, 10^7 cycles for structural steels and 10^8 cycles for other steels and non-ferrous alloys. In the light of recent research, however, it is of importance to note that metals generally do not exhibit an “endurance limit” or “fatigue limit” per se, that is, a stress below which the metal will endure an “infinite number of cycles”. Typically, the “plateau(s)” in stress-life are referred to as the conventional “fatigue limit(s)” or “endurance limit(s)”, but failures below these levels have been reported and do occur. See, for example, References [1] to [3] in the Bibliography.

4.2 Presentation of fatigue results

The design of the investigation, and the use to be made of the results, govern the choice of the most suitable method of presenting the results from the many available, graphically and otherwise. The results of fatigue tests are usually presented graphically. In reporting fatigue data, the test conditions should be clearly defined. In addition to graphical presentations, tabulated numerical data are desirable where the presentation format permits.

4.2.1 Wöhler or S-N curve

The most general method of presenting the results graphically is to plot the number of cycles to failure, N, as abscissa and the values of stress amplitude or, depending on the type of stress cycle, those of any other stress, as ordinate. The curve drawn smoothly as an approximate middle line through the experimental points is called a Wöhler or S-N curve. A logarithmic scale is used for the number of cycles and the choice of whether a linear or logarithmic scale is used for the stress axis lies with the experimenter. Individual curves are plotted for each set of tests for each R-ratio. Experimental results are usually plotted on the same figure. An example of these graphical representations is shown in Figure 5, where a linear stress scale is used.

4.2.2 Mean stress diagrams

The fatigue strengths derived from the Wöhler or S-N curve are plotted in fatigue strength diagrams. The results can be represented by a graph giving directly, for particular “endurances”, the stress amplitude against the mean stress, as shown in Figure 6 (Haigh diagram); or by plotting the maximum and minimum stresses against the mean stress, as shown in Figure 7 (Smith diagram); or by plotting the maximum stress against the minimum stress, as shown in Figure 8 (Ros diagram). Experimental results may be plotted on the same figure.

4.2.3 Alignment

The alignment check shall be carried out using a standard calibration specimen. The alignment specimen illustrated in Figure 9 should be of a geometry similar to the specimens being tested. It is suggested that the alignment specimen be made from a hardened heat-treated steel or similar material capable of totally elastic strains up to at least 0,4 % or the force corresponding to the maximum strain imposed on the specimen used in the test series.

In order to check the misalignment due to angular offset, lateral offset and/or load-train offset, the alignment specimen should have resistance strain gauges secured at the locations A, B and C illustrated in Figure 9. With the top **or** bottom (not both) of the strain-gauged specimen secured in the gripping arrangement, the temperature should be allowed to equilibrate and the zero reference adjustments to the bridge amplifiers accomplished. At this time, the alignment specimen should then be gripped in both the upper and lower grip.

The gauged specimen should then be loaded in **tension** to a maximum strain of 0,4 % or the force corresponding to the maximum strain to be imposed on the specimens in the test series, if this value does not exceed 0,4 % strain on the gauge specimen. The force shall be applied to the gauged specimen four (4) times, corresponding to the specimen positions of 0, 90, 180, 270 degrees. The percent bending is calculated for each of the four specimen positions according to the scheme in Figure 9. If the percent bending exceeds 5 % on one or more of the three instrumented planes for any of the four specimen positions, adjustments should be made in the test frame actuator or fixtures and/or force transducer, followed by repeating the procedure until the less than 5 % limit on percent bending is achieved.

The procedure should be repeated in **compression** to ascertain that the alignment is within that specified (i.e. $\leqslant$ 5 %).

If the check is not satisfactory:

— The reproducibility of the measurements shall be verified by carrying out the process several times.

— It shall be established that the results are attributable to the test assembly and not to the specimen.

— The elements making up the gripping train (instruments, cell, machine) shall be checked for their geometric accuracy.

5 Shape and size of specimen

5.1 Form of specimens

Generally, a specimen having a fully machined test section of one of the types shown in Figures 3 and 4 shall be used.

The specimens may be of the following:

— circular cross-section, with tangentially blending fillets between the test section and the ends [Figure 3 a)], or with a continuous radius between the ends [Figure 3 b)];

— rectangular cross-section of uniform thickness over the test section with tangentially blending fillets between the test section and the gripped ends [Figure 4 a)], or with a continuous radius between the ends [Figure 4 b)].

It is important to mention that, for specimens of rectangular cross-section, it may be necessary to reduce the test section in both width and thickness. If this is necessary, then blending fillets will be required in both the width and thickness directions. Also, for a rectangular-section specimen, where it is desired to take account of the surface condition in which the metal will be used in actual application, then at least one surface of the test section of the test piece should remain unmachined. It is often the case, for fatigue tests conducted using a rectangular-section piece, that the results are not always comparable to those determined on cylindrical specimens, because of the difficulty in obtaining an adequate surface finish or because fatigue cracks initiate preferentially at the corner(s) of the rectangular test piece.

For either form of specimen where the test section is formed by a continuous radius, this radius shall be at least $3d$ (or $3b$) and the elastic stress concentration factor shall be included in the test report.

5.2 Specimen temperature measurement

The test is typically conducted at ambient temperature (ideally between 10 °C and 35 C). In a high or low temperature test, the specimen temperature may be measured using thermocouples in contact with the specimen surface, or other appropriate devices accurate to within ± 2 °C. The specimen temperature, T, must be documented if it is considered “high” (H), that is, greater than or equal to 0,3 × homologous temperature of the metal [i.e. $\geqslant 0{,}3T_{\mathrm{H}} = T_{\mathrm{test}}\,(K) / T_{\mathrm{melt}}\,(K)$].