INTERNATIONAL STANDARD

ISO 1143

Second edition
2010-11-01

Metallic materials — Rotating bar bending fatigue testing

Matériaux métalliques — Essais de fatigue par flexion rotative de barreaux

Reference number
ISO 1143:2010(E)

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Published in Switzerland

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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 1143 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 1143:1975), which has been technically revised.

Metallic materials — Rotating bar bending fatigue testing

1 Scope

This International Standard specifies the method for rotating bar bending fatigue testing of metallic materials. The tests are conducted at room temperature or elevated temperature in air, the specimen being rotated.

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 376, *Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines*

ISO 1099, *Metallic materials — Fatigue testing — Axial force-controlled method*

ISO 12106, *Metallic materials — Fatigue testing — Axial-strain-controlled method*

ISO 12107, *Metallic materials — Fatigue testing — Statistical planning and analysis of data*

ISO 23718, *Metallic materials — Mechanical testing — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1099, ISO 12106, ISO 12107, ISO 23718 and the following apply.

3.1
fatigue
process of changes in properties which can occur in a metallic material due to the repeated application of stresses or strains and which can lead to cracking or failure

3.2
fatigue life
N_f
number of cycles of a specified character that a given specimen sustains before failure of a specified nature occurs

3.3
S-N **diagram**
diagram that shows the relationship between stress and fatigue life

3.4
bending moment
M
multiplication between force and force arm length

3.5
section modulus
W
ratio of the moment of inertia of the cross-section of a beam undergoing flexure to the greatest distance of an element of the beam from the neutral axis

3.6
machine lever ratio
M_{lr}
ratio between the force applied to the weight hangar and the force applied to the specimen

3.7
force arm length
L
distance between the supporting point and the loading point

See Figures 1 to 7.

NOTE L_1 should equal L_2 for the four-point loading condition.

3.8
endurance stress limit
fatigue limit
cyclic stress range applied to specimens that do not fail upon application of a given number of cycles

NOTE 1 The cycle number limit selected, e.g. 10^7 or 10^8 cycles, shall be specified along with the stress range.

NOTE 2 For a specified fatigue life, “endurance stress limit” has been supplanted by “fatigue limit” as the preferred term.

4 Symbols and designations

Symbols and corresponding designations are given in Table 1, or elsewhere in this International Standard where they appear.

Table 1 — Symbols and designations

Symbol	Designation	Unit
D	Diameter of gripped or loaded end of specimen	mm
d	Diameter of specimen where stress is maximum	mm
N_f	Fatigue life, cycles to failure	cycle
r	Radius at ends of test section which starts transition from test diameter, d	mm

5 Principle of test

Nominally identical specimens are used, each being rotated and subjected to a bending moment. The forces giving rise to the bending moment do not rotate. The specimen may be mounted as a cantilever, with single-point or two-point loading, or as a beam, with four-point loading. The test is continued until the specimen fails or until a pre-determined number of stress cycles have been achieved.

6 Shape and size of specimen

6.1 Forms of the test section

The test section may be

a) cylindrical, with tangentially blending fillets at one or both ends (see Figures 1, 4 and 5),

b) tapered (see Figure 2), or

c) hourglass-type (see Figures 3, 6 and 7).

In each case, the test section shall be of circular cross-section.

The form of test section may be dependent on the type of loading to be employed. While cylindrical or hourglass-type specimens may be loaded as beams, or as cantilevers with either single-point or double-point loading, the tapered form of specimen is used only as a cantilever with single-point loading. Figures 1 to 7 show, in schematic form, the bending moment and nominal stress diagrams for the various practical cases.

The volumes of material subjected to greatest stresses are not the same for different forms of specimen, and they may not necessarily give identical results. The test in which the largest volume of material is highly stressed is preferred.

Experience has shown that a ratio of at least 3:1 between the cross-sectional areas of the test portion and the gripping regions of the specimen is desirable.

In tests on certain materials, a combination of high stress and high speed may cause excessive hysteresis heating of the specimen. This effect may be reduced by subjecting a smaller volume of the material to the specified stress. If the specimen is cooled, the test medium should be reported.

6.2 Dimensions of specimens

All the specimens employed in a test series for a fatigue-life determination shall have the same size, shape and tolerance of diameter.

For the purpose of calculating the force to be applied to obtain the required stress, the actual minimum diameter of each specimen shall be measured to an accuracy of 0,01 mm. Care shall be taken during the measurement of the specimen prior to testing to ensure that the surface is not damaged.

On cylindrical specimens subject to constant bending moment (see Figures 4 and 5), the parallel test section shall be parallel within 0,025 mm. For other forms of cylindrical specimen (see Figure 1), the parallel test section shall be parallel within 0,05 mm. For material property determination, the transition fillets at the ends of the test section should have a radius not less than $3d$. For hourglass-type specimens, the section formed by the continuous radius should have a radius not less than $5d$.

Figure 8 shows the shape and dimensions of a typical cylindrical specimen. The recommended values of d are 6 mm, 7,5 mm and 9,5 mm. The tolerance of diameter should be $\leqslant 0{,}005d$. Figure 9 shows a typical hourglass specimen suitable for fatigue testing at elevated temperature.

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

7 Preparation of specimens

7.1 General

In any rotating bar bending fatigue test programme designed to characterize the intrinsic properties of a material, it is important to observe the following recommendations in the preparation of specimens. A possible reason for deviation from these recommendations is if the test programme aims to determine the influence of a specific factor (surface treatment, oxidation, etc.) that is incompatible with the recommendations. In all cases, any deviation shall be noted in the test report.

7.2 Selection of the specimen

The location, orientation and type of specimen shall be taken from the related product standard, or by agreement with the customer.

The sampling of test materials from a semi-finished product or a component may have a major influence on the results obtained during the test. It is therefore necessary for this sampling to be recorded and a sampling drawing be prepared. This shall form part of the test report and shall indicate clearly

— the position of each of the specimens removed from the semi-finished product or component,

— the characteristic directions in which the semi-finished product has been worked (direction of rolling, extrusion, etc., as appropriate), and

— the unique identification of each of the specimens.

The unique mark or identification of each specimen shall be maintained at each stage of its preparation. This may be applied using any reliable method in an area not likely to disappear during machining or likely to adversely affect the quality of the test. Upon completion of the machining process, it is desirable for both ends of each specimen to be uniquely marked so that, after failure of a specimen, each half can still be identified.

7.3 Machining procedure

7.3.1 Heat treatment of test material

If heat treatment is to be carried out after rough finishing of the specimens, it is preferable that the final polishing be carried out after the heat treatment. If that is not possible, the heat treatment should be carried out in a vacuum or in inert gas to prevent oxidation of the specimen. Stress relief is recommended in this case. This treatment shall not alter the micro-structural characteristic of the material under study. The specifics of the heat treatment and machining procedure shall be reported with the test results.

7.3.2 Machining criteria

The machining procedure selected may produce residual stresses on the specimen surface likely to affect the test results. These stresses may be induced by heat gradients at the machining stage or they may be associated with deformation of the material or micro-structural alterations. Their influence is less marked in tests at elevated temperatures because they are partially or totally relaxed once the temperature is attained. However, they should be reduced by using an appropriate final machining procedure, especially prior to a final polishing stage. For harder materials, grinding rather than turning or milling may be preferred.

— Grinding: from 0,1 mm above the final diameter, at a rate of no more than 0,005 mm/pass.

— Polishing: remove the final 0,025 mm with abrasives of decreasing grit size. The final direction of polishing shall be along the test specimen axis.

The phenomenon of alteration in the microstructure of the material may be caused by the increase in temperature and by the strain hardening induced by machining. It may be a matter of a change in phase or, more frequently, of surface re-crystallization. The immediate effect of this is to make the test specimen no longer representative of the initial material. Hence, every precaution should therefore be taken to avoid this risk.

Contaminants can be introduced when the mechanical properties of certain materials deteriorate in the presence of certain elements or compounds. An example of this is the effect of chlorine on steels and titanium alloys. These elements should therefore be avoided in the products used (cutting fluids, etc.). Rinsing and degreasing of specimens prior to storage is also recommended.

7.3.3 Inspection of specimens

The surface condition of specimens has an effect on the test results. This effect is generally associated with one or more of the following factors:

- the specimen surface roughness;
- the presence of residual stresses;
- alteration in the microstructure of the material;
- the introduction of contaminants.

The recommendations below allow the influence of these factors to be reduced to a minimum.

The surface condition is commonly quantified by the mean roughness or equivalent (e.g. 10 point roughness or maximum height of irregularities). The importance of this variable on the results obtained depends largely on the test conditions, and its influence is reduced by surface corrosion of the specimen or plastic deformation.

It is preferable, whatever the test conditions, to specify a mean surface roughness, Rz, of less than 0,2 µm (or equivalent).

Another important parameter not covered by mean roughness is the presence of localized machining scratches. A low-magnification check (at approximately ×20) shall not show any circumferential scratches or abnormalities.

7.3.4 Dimensional checks

The diameter shall be measured on each specimen. In the case of specimens with a parallel gauge length, the diameter shall be measured at a minimum of three positions along the gauge length. The measurement shall be performed using a method that does not damage the specimen.

7.4 Sampling and marking

The sampling of test materials from a semi-finished product or a component may have a major influence on the results obtained during the test. It is therefore necessary for this sampling to be recorded and a sampling drawing to be prepared. This shall form part of the test report and shall indicate clearly

- the position of each of the specimens removed from the semi-finished product or component,
- the characteristic directions in which the semi-finished product has been worked (direction of rolling, extrusion, etc., as appropriate), and
- the unique identification of each of the specimens.

The unique mark or identification of each specimen shall be maintained at each stage of their preparation. This may be applied using any reliable method in an area not likely to disappear during machining or likely to adversely affect the quality of the test. Upon completion of the machining process, it is desirable for both ends of each specimen to be uniquely marked so that, after failure of a specimen, each half can still be identified.

7.5 Storage and handling

After preparation, the specimens shall be stored so as to prevent any risk of damage (scratching by contact, oxidation, etc.). The use of individual boxes or tubes with end caps is recommended. In certain cases, storage in a vacuum or in a dessicator containing silica gel may be necessary.

Handling shall be reduced to the minimum necessary. In all instances, the gage length or test section should not be touched. However, if this happens, cleaning the specimen with alcohol is allowed.

8 Accuracy of the testing apparatus

A number of different types of rotating bending fatigue machine are used. Figures 1 to 7 show the principles of the main types of machine. Figure 11 shows the schematic of a kind of rotating bend fatigue machine. Its operation shall satisfy the following requirement: the accuracy of the applied bending moment shall be within 1% (see Annex A).

9 Heating device and temperature measurement

9.1 The specimen is heated with a furnace or equivalent device.

9.2 The temperature of the furnace shall be kept uniform throughout the test, complying with the limits defined in 10.5.3. The temperature gradient along the test section of the specimen in the furnace shall not be greater than 15 °C.

9.3 To measure or record temperature, the thermocouple, compensating wire, and controlling and measuring temperature meter that are used shall be calibrated together as a system. The calibration interval shall be in accordance with the product standard, customer requirements and good metrological practice.

9.4 The temperature indicator shall have a resolution of at least 0,5 °C and the temperature measuring equipment shall have an accuracy of ±1 °C.

10 Test procedure

10.1 Mounting the specimen

Each specimen shall be mounted in the test machine such that stresses at the test section (other than those imposed by the applied force) are avoided. If the bearings transmitting the force are secured to the specimen by means of split collets, in certain cases it may be desirable for these to be positioned and fully tightened before the specimen is mounted in the test machine, in order to prevent an initial torsion strain being imparted. A similar practice may be necessary if the method of securing is by means of an interference fit.

To avoid vibration during the test, alignment of the specimen and the driving shaft of the test machine shall be maintained within close limits. Permissible tolerances are ±0,025 mm at the chuck end and ±0,013 mm at the free end for single-point and some types of two-point loading test machines. For other types of rotating bending fatigue test machines, the permissible tolerance on eccentricity measured at two places along the actual test section is no greater than ±0,013 mm. The required degree of alignment shall be established before applying any force.

NOTE These measurements are typically made using a dial gauge.

10.2 Application of force

The lever ratio shall be calibrated according to Annex A. The test stress is calculated according to Table 2.

Table 2 — Derivation of weight to be applied to test machine loading system

Machine type	Loading system	S	F	Conversion of F to applied mass
Single-point bending	Direct load	$S = \frac{M}{W} = \frac{16F(L-x)}{\pi d^3}$	$F = S\frac{\pi d^3}{16(L-x)}$	× 1,0
Single-point bending	Fixed ratio lever	$S = \frac{M}{W} = \frac{16F(L-x)}{\pi d^3}$	$F = S\frac{\pi d^3}{16(L-x)}$	Divide by the lever ratio, M_{lr}.
Single-point bending	Lever and poise	$S = \frac{M}{W} = \frac{16F(L-x)}{\pi d^3}$	$F = S\frac{\pi d^3}{16(L-x)}$	Set to F on the load scale on the lever.
Two-point bending	Direct load	$S = \frac{M}{W} = \frac{16FL}{\pi d^3}$	$F = S\frac{\pi d^3}{16L}$	× 1,0
Two-point bending	Fixed ratio lever	$S = \frac{M}{W} = \frac{16FL}{\pi d^3}$	$F = S\frac{\pi d^3}{16L}$	Divide by the lever ratio, M_{lr}.
Two-point bending	Lever and poise	$S = \frac{M}{W} = \frac{16FL}{\pi d^3}$	$F = S\frac{\pi d^3}{16L}$	Set to F on the load scale on the lever.
Four-point bending	Direct load	$S = \frac{M}{W} = \frac{32FL}{\pi d^3}$	$F = S\frac{\pi d^3}{32L}$	× 1,0
Four-point bending	Fixed ratio lever	$S = \frac{M}{W} = \frac{32FL}{\pi d^3}$	$F = S\frac{\pi d^3}{32L}$	Divide by the lever ratio, M_{lr}.
Four-point bending	Lever and poise	$S = \frac{M}{W} = \frac{32FL}{\pi d^3}$	$F = S\frac{\pi d^3}{32L}$	Set to F on the load scale on the lever.

where

- S is the required test stress;
- M is the bending moment;
- F is the applied force;
- L is the force arm length (see A.4.2);
- d is the specimen diameter;
- W is the section modulus;
- M_{lr} is the machine lever ratio (see also A.4.3);
- x is the distance along the specimen axis from the fixed bearing face to the stress measurement plane.

The general procedure for attaining full-force running conditions shall be the same for each specimen. The test machine shall be switched “ON” and the desired speed attained before application of force is commenced. The force shall then be applied incrementally or continuously until the required value is attained, without shock or impact, and as quickly as is convenient. Small adjustments in operating speed can then be made if a particular frequency is required.[1)]

10.3 Frequency selection

The frequency chosen shall be suitable for the particular combination of material, specimen and test machine. The testing speed should be the same for the given test series. It is necessary to avoid abnormal vibration of the specimen when testing.

Tests are normally performed at a frequency between 15 to 200 Hz (i.e. from 900 to 12 000 rev/min).

At high frequencies, self-heating of the specimen can occur and could affect the resulting fatigue life. If self-heating occurs, it is advisable to decrease the test frequency. In room temperature testing, self-heating of the specimen should be monitored and recorded. The specimen temperature, T_{H}, in Kelvin (K), should not exceed:

$$0{,}3T_{\mathrm{H}} = \frac{T_{\mathrm{test}}}{T_{\mathrm{melt}}}$$

NOTE If the influence of the environment is significant, the test result is likely to be frequency-dependent.

10.4 End of test

The test is continued until specimen failure or until it has reached the required number of cycles (e.g. 10^7 or 10^8). Where the failure location is outside the specimen gauge length, the test result is considered invalid.

10.5 Procedure for testing at elevated temperature

10.5.1 Due to the nature of rotating bar bending fatigue testing, direct temperature measurement may not be possible. If this is the case, it is essential to use indirect temperature measurement, calibrated in a static manner.

10.5.2 To measure the temperature of the specimen two approaches are possible.

The first approach, which is the preferred method, uses indirect measurement, i.e. the tip of the thermocouple is not directly in contact with the specimen surface, but kept about 1-2 mm distance from it. When using this method, the laboratory shall establish a relationship between the specimen surface temperature and that shown by the measuring thermocouple. This relationship shall be used to derive a correction factor for establishing the specimen temperature.

The second approach uses direct measurement, i.e. the thermocouple tip is directly in contact with the specimen surface. Use of this approach requires the test machine to be stopped periodically, the load to be removed and then the temperature of the specimen surface to be measured.

NOTE Self-heating of the specimen is not considered in this procedure.

1) It is recognized that plasticity is present in the low-cycle region. For details, see Reference [2], Chapter 7 and references thereto.