भारतीय मानक

Indian Standard

IS 17143 : 2023
ISO 1352 : 2021

धात्विक सामग्रियाँ — बल-आघूर्ण नियंत्रित श्रान्ति परीक्षण

(पहला पुनरीक्षण)

Metallic Materials — Torque-Controlled Fatigue Testing

(First Revision)

ICS 77.040.10

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुर शाह ज़फर मार्ग, नई दिल्ली - 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI - 110002
www.bis.gov.in www.standardsbis.in

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Mechanical Testing of Metals Sectional Committee, MTD 03

NATIONAL FOREWORD

This Indian Standard (First Revision) which is identical to ISO 1352 : 2021 'Metallic materials — Torque-controlled fatigue testing' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of the Mechanical Testing of Metals Sectional Committee and approval of the Metallurgical Engineering Division Council.

This standard was first published in 2019. The first revision of this standard has been undertaken to align with the latest version ISO 1352 : 2021 to harmonize it with the latest developments that have taken place at international level.

The main changes are as follows:

a) Addition of the test apparatus and procedure for the elevated temperature testing; and
b) Addition of measurement uncertainty estimation.

The text of ISO standard has been approved as suitable for publication as in Indian Standard without deviations. Certain terminologies and conventions are, however, not identical with those used in Indian Standard. Attention is especially drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, it should be read as 'Indian Standard'; and
b) Comma (,) has been used as a decimal marker while in Indian Standards the current practice is to use a point (.) as the decimal marker.

The Committee responsible for the preparation of this standard has reviewed the provisions of following International Standards referred in these adopted standards and decided their acceptability for use in conjunction with this standard.

International Standard	*Title*
ISO 554 : 1976	Standard atmospheres for conditioning and/or testing — Specifications
ISO 23788 : 2012	Metallic materials — Verification of the alignment of fatigue testing machines

In reporting the result of a test or analysis made in accordance with this standard, is to be rounded off, it shall be done in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'.

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METALLIC MATERIALS — TORQUE-CONTROLLED FATIGUE TESTING

(First Revision)

1 Scope

This document specifies the conditions for performing torsional, constant-amplitude, nominally elastic stress fatigue tests on metallic specimens without deliberately introducing stress concentrations. The tests are typically carried out at ambient temperature or an elevated temperature in air by applying a pure couple to the specimen about its longitudinal axis.

While the form, preparation and testing of specimens of circular cross-section and tubular cross-section are described in this document, component and other specialized types of testing are not included. Similarly, low-cycle torsional fatigue tests carried out under constant-amplitude angular displacement control, which lead to failure in a few thousand cycles, are also excluded.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 23788, *Metallic materials — Verification of the alignment of fatigue testing machines*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
maximum stress
τ_{max}
highest algebraic value of shear stress at the outer diameter in the stress cycle

Note 1 to entry: See Figure 1.

3.2
minimum stress
τ_{min}
lowest algebraic value of shear stress in the stress cycle

Note 1 to entry: See Figure 1.

3.3
mean stress
τ_m
static component of the shear stress

Note 1 to entry: It is one half of the algebraic sum of the maximum shear stress and the minimum shear stress:

$$\tau_m = \frac{\tau_{max} + \tau_{min}}{2}$$

3.4
stress amplitude
τ_a
variable component of shear stress

Note 1 to entry: It is one half of the algebraic difference between the maximum shear stress and the minimum shear stress:

$$\tau_a = \frac{\tau_{max} - \tau_{min}}{2}$$

3.5
number of cycles
N
number of cycles applied at any stage during the test

3.6
stress ratio
R
algebraic ratio of the minimum shear stress to the maximum shear stress in one cycle

Note 1 to entry: It is expressed as:

$$R = \frac{\tau_{min}}{\tau_{max}}.$$

3.7
stress range
$\Delta\tau$
range between the maximum and minimum shear stresses

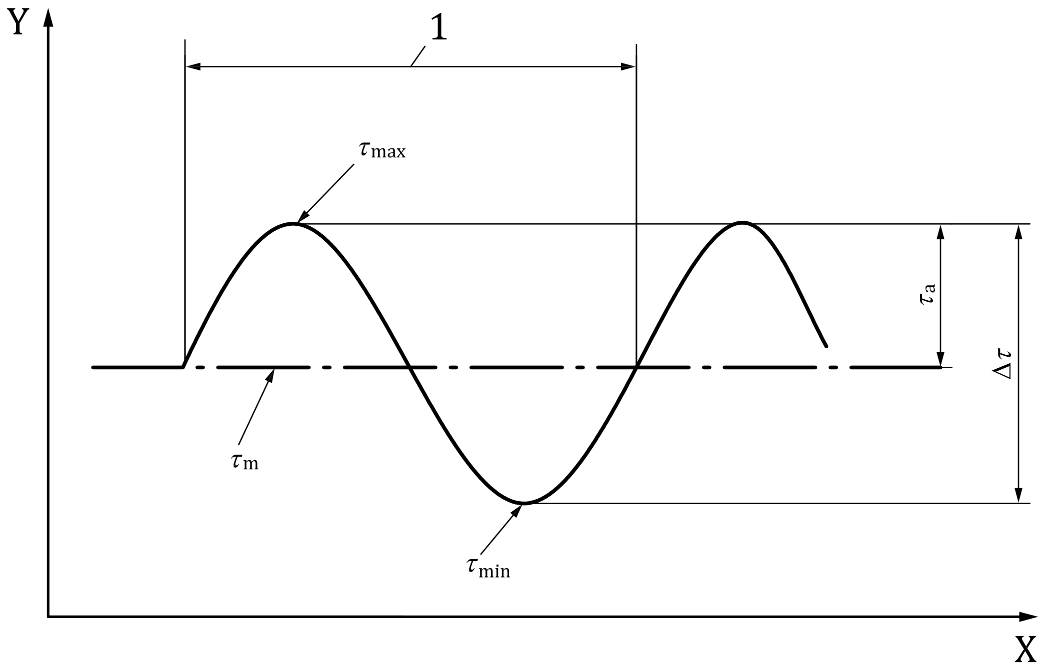
Note 1 to entry: It is expressed as:

$$\Delta\tau = \tau_{max} - \tau_{min}.$$

3.8
fatigue life at failure
N_f
number of stress cycles to failure in a specified condition

3.9
fatigue strength at *N* cycles
τ_N
value of the shear *stress amplitude* (3.4) at a stated *stress ratio* (3.6) under which the specimen would have a life of *N* cycles

3.10
torque
M
twisting couple producing shear stress or twisting deformation about the axis of the specimen



Key

X time

Y stress

1 one stress cycle

Figure 1 — Fatigue stress cycle

4 Symbols and abbreviated terms

D	diameter or width across flats of the gripped ends of the specimen
NOTE 1	The value of D may be different for each end of the specimen.
d	diameter of specimen of circular cross-section
d_o	outer diameter of test section of specimen of tubular cross-section
d_i	inner diameter of test section of specimen of tubular cross-section
L_g	axial separation of strain gauges
L_p	parallel length
r	transition blending radius at ends of test section which starts the transition from d to D (see Figures 3 and 4)
NOTE 2	This 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 specimens of the types shown in Figure 3.
t	wall thickness in the test section of the thin-walled tube specimen
T	specified temperature at which the test should be performed
T_i	indicated temperature or measure temperature on the surface of the parallel length of the specimen

ε_a linear normal strain in the 0° directions of the 45° strain rosette

ε_b linear normal strain in the 45° directions of the 45° strain rosette

ε_c linear normal strain in the 90° directions of the 45° strain rosette

$\varepsilon_{\theta\theta}$ circumferential strain

ε_{zz} longitudinal strain

$\gamma_{\theta z}$ shear strain

5 Principle of test

Nominally identical specimens are mounted on a torsional fatigue testing machine and subjected to the loading condition required to introduce cycles of torsional stress. Any one of the types of cyclic stress illustrated in Figure 2 may be used. The test waveform shall be constant-amplitude sinusoidal, unless otherwise specified.

In an axially symmetrical specimen, change of mean torque does not introduce a different type of stress system and mean stress in torsion may always be regarded as positive in sign.

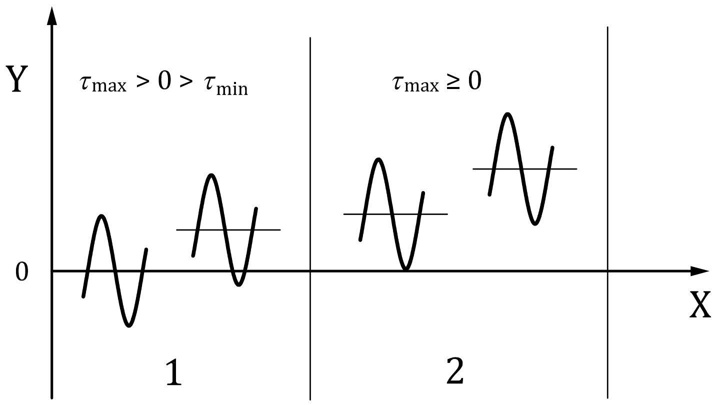
The torque is applied to the specimen about the longitudinal axis passing through the centroid of the cross-section.

The test is continued until the specimen fails or until a predetermined number of stress cycles has been exceeded.

NOTE Typically, cracks produced by torsional fatigue testing are parallel or orthogonal to the longitudinal axis (shear stress driven) or helical at approximately +/-45° to the longitudinal axis (principal stress driven).

Tests conducted at ambient temperature shall be performed between 10 °C and 35 °C unless otherwise agreed with the customer.

The results of fatigue testing can be affected by atmospheric conditions, and where controlled conditions are required, ISO 554:1976, 2.1, applies.



Key

X time

Y stress

1 reversed

2 fluctuating

Figure 2 — Types of cyclic stress

6 Test plan

Before commencing testing, the following shall be agreed by the parties concerned and any modifications shall be mutually agreed upon:

a) the form of specimen to be used (see Clause 7);

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 number of cycles;

— a full Wöhler or S–N curve;

d) the number of specimens to be tested and the test sequence;

e) the number of cycles a specimen is subjected to before the test is terminated.

NOTE 1 Some methods of data presentation are given in Annex A. See ISO 12107[3] for details, including data analysis procedure and statistical presentation.

NOTE 2 Commonly employed numbers of cycles for test termination are:

— 10^7 cycles for structural steels, and

— 10^8 cycles for other steels and non-ferrous alloys.

7 Shape and size of specimen

7.1 Form

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

The specimen may be of:

— solid circular cross-section, with tangentially blending fillets between the test section and the ends (see Figure 3); or

— tubular cross-section, with tangentially blending fillets between the test section and the ends in the outer surface (see Figure 4).

The hourglass specimen is not recommended because the crack under torsional loads may propagate at 45° to the loading axis.

For tubular specimens, the diameter of the inner surface at the ends may be greater than or equal to that at the test section. For a specimen having an inner diameter at the ends greater than that at the test section, crack initiation or failure outside the test section invalidates the test, which should be counted as a discontinued (stopped) test at the number of cycles completed.

Fatigue test results determined using the specimen of tubular cross-section are not always comparable to those obtained from the specimen of solid circular cross-section (due to absence or existence of elastic constraint). Therefore, caution should be exercised when comparing fatigue lives obtained on the same material from specimens having different cross-sections.

Typical specimen ends are shown in Figure 5. It is recommended that ends suitable for meeting the alignment criterion be chosen.

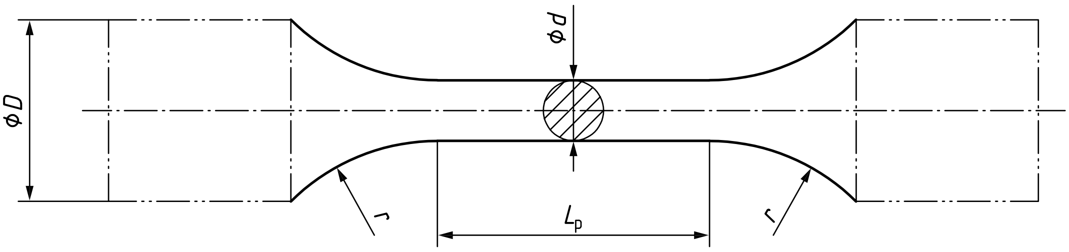


Figure 3 — Specimens with circular cross-section

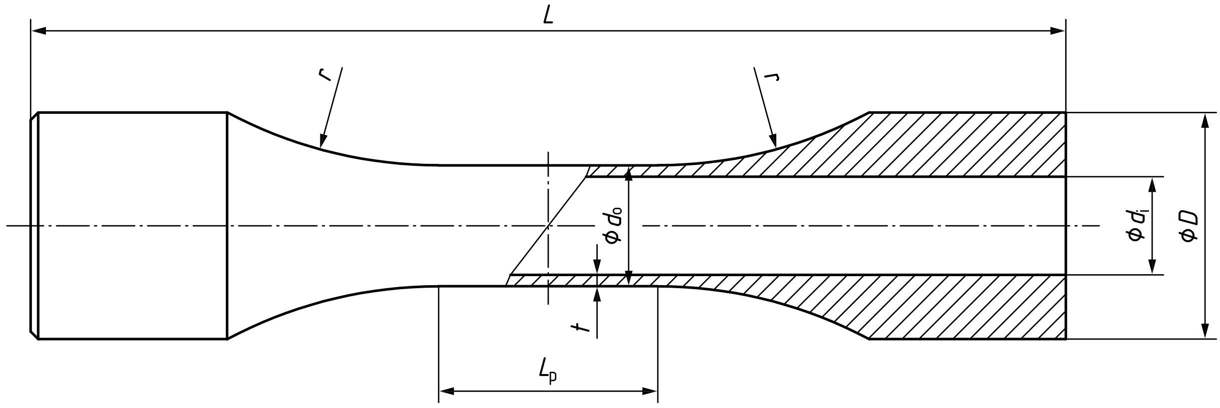


Figure 4 — Specimen with tubular cross-section

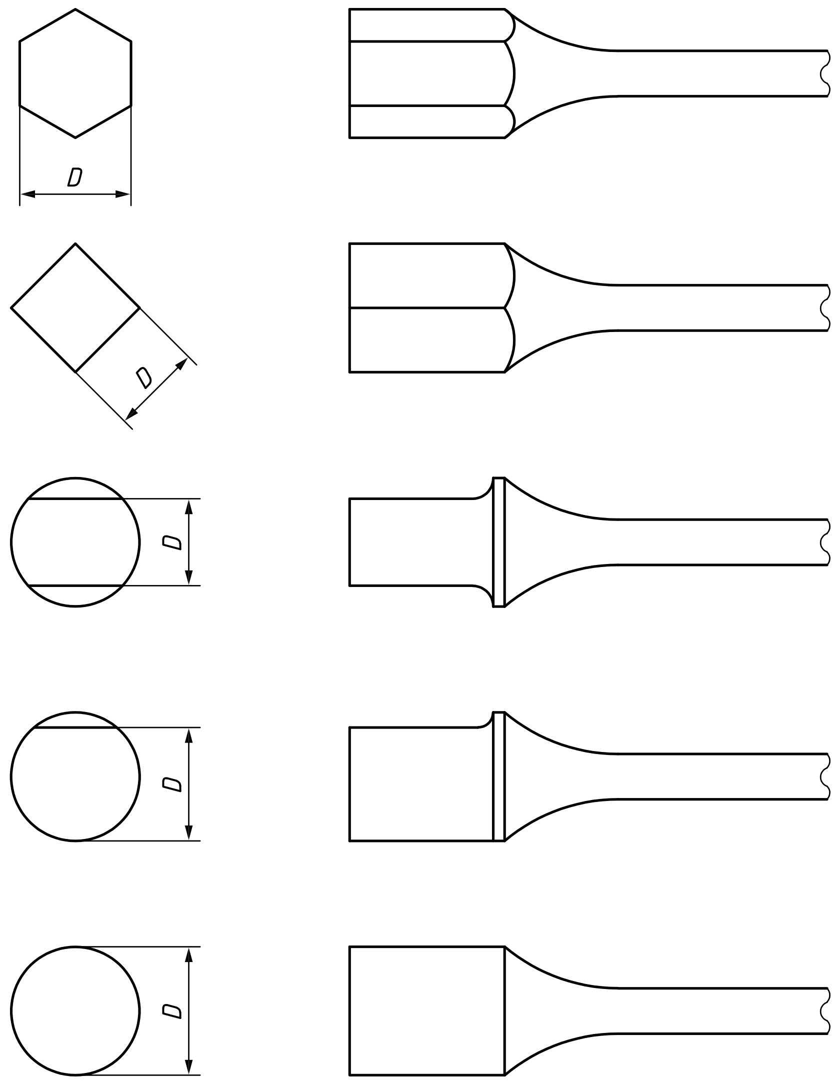


Figure 5 — Typical specimen ends

7.2 Dimensions

7.2.1 Specimens of circular cross-section

It is recommended that the geometric dimensions given in Table 1 be used (see also Figure 3).

Table 1 — Dimensions for specimens of circular cross-section

Diameter of cylindrical parallel length, in millimetres	$5 \leq d \leq 12$
Parallel length	$L_p \leq 5d$
Transition radius (from parallel section to grip end)	$r \geq 3d$
External diameter (grip end)	$D \geq 2d$
The tolerance on d shall be ±0,05 mm.	

To calculate the applied torque loading, the actual diameter of each specimen shall be measured to an accuracy of 0,01 mm. Care should be taken not to damage the surface when measuring the specimen prior to testing.

It is important that general tolerances of the specimen respect the two following properties:

— parallelism: 0,005d or better;

— concentricity: 0,005d or better.

These values are expressed in relation to the axis or reference plane.

7.2.2 Specimens with tubular cross-section

In general, the considerations applicable to specimens of circular cross-section also apply to tests on tubular specimens.

The specimen wall thickness shall be large enough to avoid instabilities during cyclic loading without violating the thin-walled tube criterion, i.e. a mean diameter-to-wall thickness ratio of 10:1 or greater is required.

It is recommended that the geometric dimensions given in Table 2 be used (see also Figure 4).

Table 2 — Dimensions for specimens of tubular cross-section

Wall thickness in test section, t	0,05d_o to 0,1d_o
Outer diameter of test section	d_o
Transition radius (from parallel section to grip end), r	≥ 3d_o
Parallel length, L_p	1d_o to 3d_o
External diameter (grip end)	D ≥ 1,5d_o
Concentricity between the outer diameter, d_o, and the inner diameter, d_i, should be maintained within 0,01t.	

8 Preparation of specimens

8.1 General

In any 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. Deviation from these recommendations is permitted if the test program aims to determine the influence of a specific factor (surface treatment, oxidation, etc.). In all cases, any deviations shall be noted in the test report. Specimens should be machined from normally stress-free material unless otherwise agreed with the customer.

8.2 Machining procedure

Machining the specimens can induce residual stress on the specimen surface that could affect the test results. These stresses can be induced by heat gradients at the machining stage — stresses associated with deformation of the material or microstructural alterations. However, they can be reduced by using an appropriate final machining procedure, especially prior to a final polishing stage. For harder materials, grinding rather than tool operation (turning or milling) may be preferable.

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

— Polishing: remove the final 0,025 mm with papers of decreasing grit size. It is recommended that the final direction of polishing be along the specimen axial direction.

— For tubular specimens the bore should be fine-honed, so that surface finish on the internal surface of the bore is either equal to or better than the surface finish on the external cylindrical surface in the parallel section[4].

Failure to observe the above can result in alteration in the microstructure of the material. This phenomenon can be caused by an increase in temperature and by the strain-hardening induced by machining; it can be a matter of a change in phase or, more frequently, of surface recrystallization. This invalidates the test as the material mechanical properties are changed.

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

8.3 Sampling and marking

The sampling of test materials from a semi-finished product or component can have a major influence on the results obtained during the test. It is therefore necessary to clearly identify the location and orientation of each specimen.

A sampling drawing, attached to the test report, shall indicate clearly:

— the position of each of the specimens;

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

— the marking of each of the specimens.

Specimens shall carry a unique identifying mark throughout their preparation. This may be applied using any reliable method in an area not likely to disappear during machining or to adversely affect the quality of the test.

Identification shall be applied to each end of the specimen before testing.

8.4 Surface conditions of specimen

The surface conditions of the specimens can affect the test results. This is generally associated with one or more of the following factors:

— specimen surface roughness;

— presence of residual stresses;

— alteration in the microstructure of the material;

— introduction of contaminants.

To minimize the impact of these factors, the following is recommended.

The impact of surface roughness on the results obtained depends largely on the test conditions and its effect is reduced by surface corrosion of the specimen or inelastic deformation.

It is preferable, whatever the test conditions, to achieve a mean surface roughness of less than 0,2 µm *Ra* (or equivalent) within the parallel section. This includes both internal and external surfaces for a tubular specimen.

Another important parameter not covered by mean roughness is the presence of localized machining scratches. Finishing operations should eliminate all circumferential scratches produced during turning. Final grinding followed by mechanical polishing is highly recommended. A visual inspection at low magnification (approximately ×20) should only show polishing marks appropriate to the grade of the final polishing medium.

It is preferable to carry out a final polishing operation after heat treatment. If this is not possible, the heat treatment should be carried out in a vacuum or in inert gas to prevent oxidation of the specimen surface. This treatment should not alter the microstructural characteristics of the material under study. The details of the heat treatment and machining procedure shall be reported with the test results.

8.5 Dimensional checks

The dimensions should be measured on completion of the final machining stage using a method of metrology which does not alter the surface condition.

8.6 Storage and handling

After preparation, the specimens should be stored so as to prevent any risk of damage (scratching by contact, oxidation, etc.). If there is any damage on the surface of the specimen during storage, it should be removed by repolishing the specimen. The use of individual boxes or tubes with end caps is recommended. In certain cases, storage in a vacuum or in a desiccator is necessary.

Handling should be reduced to the minimum necessary. Particular attention shall be given to marking of the specimen. Identification shall be applied to each end of the specimen before testing.

9 Apparatus

9.1 Testing machine

9.1.1 General

The tests shall be carried out on a testing machine having a clockwise/anticlockwise (counter-clockwise) torsional loading capability, with smooth start and no backlash when passing through zero. The test start settings shall allow the required level to be reached without any overload. The time frame for reaching the required level should be as short as reasonably possible.

The machine should have adequate lateral and torsional stiffness and alignment.

The complete machine loading system (including torque cell, grips, and specimen) shall be capable of controlling and measuring torque when the recommended wave cycle is applied. The specimen shall be unconstrained in the axial direction to prevent extraneous forces being introduced.

The testing machine torque measuring system shall be verified statically using a suitable method of calibration and shall be traceable to certified national standards.

It is important to recognize the potential effect of dynamic errors introduced by the inertial mass between the torque cell and the specimen. Inertia torque errors, expressed as a percentage of torque range, can be expected to vary with frequency and are strongly influenced by specimen compliance. For details, see ISO 4965-1 and ISO 4965-2[1,2], which, although intended for axial fatigue testing, gives principles that also apply to torsional fatigue testing.

The machine shall be equipped with a cycle-counting system accurate to 1 % and shall be able to shut down automatically when the specimen fails.

9.1.2 Torque cell

The torque cell shall be fatigue rated. The indicated torque, as recorded at the output from the computer in an automated system, or from the final output recording device in a non-automated system, shall be within specified limits. The torque cell capacity shall be sufficient to cover the range of torque measured during a test to a measurement error of 1 % of the reading or better. The torque cell shall be temperature-compensated and should have a zero drift no greater than 0,002 % of full scale per degree Celsius. Sensitivity variation should not be greater than 0,002 % of full scale per degree Celsius.

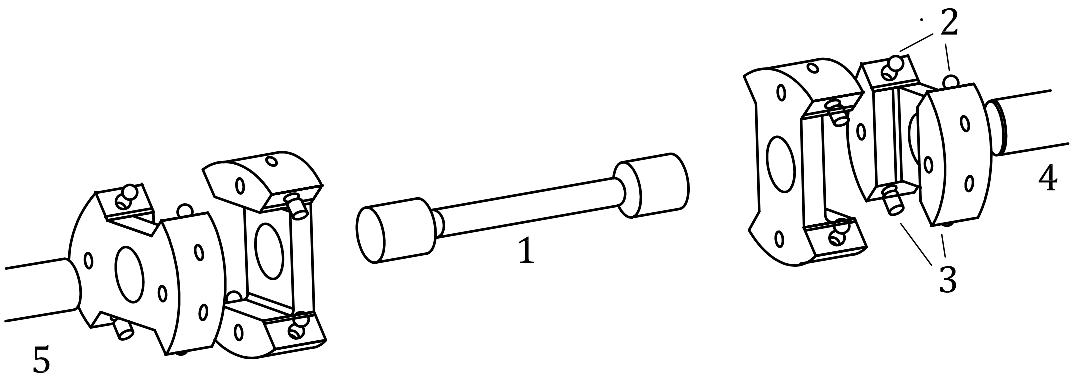
The torque cell shall be calibrated at least once a year.

9.1.3 Gripping of specimen

The gripping device shall transmit the cyclic torques to the specimen without backlash along its circumferential direction for the duration of the test. The geometric qualities of the device shall ensure correct alignment so that it is in accordance with 9.1.4.

The gripping device shall enable repeatable assembly and have surfaces that ensure alignment of the specimen. It shall also allow transmission of reversed torque without backlash throughout the duration of the test.

NOTE The gripping device (for example, collet, chuck style, socket style, wedge, and Morrison grips,[9]) can be chosen appropriate to the specimen ends (See Figure 5 and 6) and testing machine type.



Key

1 specimen
2 standard balls
3 standard rollers
4 reacted torque
5 applied torque

Figure 6 — Example of Morrison torsion grip[8]

9.1.4 Alignment check

It is important that the best uniform stress distribution be obtained for every fatigue test. Axial alignment of the test machine for both axial fatigue machines and torsional fatigue machines shall be measured using ISO 23788. The alignment verification shall be done every time a change is made to the load train.

NOTE 1 Annex B briefly describes the alignment check methodology.

In addition, it is important to document the applied stress distribution in the test section of the fatigue specimen. This applied stress uniformity is controlled by both the test machine and the specimen.

NOTE 2 Annex C describes a procedure for measuring and documenting the applied stress uniformity for torsional tests.

The stress uniformity may be checked before each series of tests or whenever a change is made to the load train.

9.1.5 Axial force

For torsional testing, the axial force on the specimen shall be controlled such that the magnitude of axial stress shall be less than 1 % of magnitude of the maximum cyclic shear stress.

NOTE The axial stress can be calculated or estimated during the alignment verification procedure.

9.2 Heating system

For the elevated temperature tests, the heating system shall be capable of heating the specimen to the temperature, T, specified on the testing program.

Electric furnace, induction heating system or equivalent device may be used for heating system.

The permitted deviations between the specified temperature T and the indicated temperatures T_i, and the maximum permissible temperature difference along the parallel length of the specimen, are given in Table 3.

Table 3 — Permissible deviations between T_i and T and maximum permissible temperature difference along the parallel length of the specimen

Specified temperature T °C	Permissible deviations between T_i and T °C	Maximum permissible temperature difference along the parallel length of the specimen °C
$T \leq 600$	±3	3
$600 < T \leq 800$	±4	4
$800 < T \leq 1\,000$	±5	5
$1\,000 < T \leq 1\,100$	±6	6

For the electric furnace, in order to minimize the temperature gradient along the testing section of the specimen, it is recommended to use three zone control.

The specimen temperature may be measured using thermocouples, pyrometers, RTDs, or other such temperature-measurement devices.

For thermocouples, the thermocouple is recommended to be directly contacted to the specimen without causing incipient failure at the point of contact. Direct contact may be achieved by resistance-spot welding, which should be done outside the gauge length, and by binding or by pressing a sheathed thermocouple against the specimen surface.

The specimen temperature is recommended to be measured using three thermocouples or other appropriate devices, one at each end and one in the middle of the gauge length of the specimen.

The temperature indicator shall have a resolution of at least 0,5 °C and the temperature measuring indicator shall have a maximum measurement error of 1 °C.

9.3 Instrumentation for test monitoring

9.3.1 Recording system

Computerized data collection systems shall have collection rates fast enough to meet this requirement; non-computerized data collection systems may need a high-speed recorder or storage device, which can then be played back at a slower rate to determine the peak and valley torque magnitude for each cycle.

9.3.2 Cycle counter

A cycle counter is essential for recording the number of cycles applied; it shall stop automatically on specimen failure.

9.3.3 Checking and verification

The proper operation of the testing machine and its control and measurement systems should be checked annually or more frequently if required. The time interval between verifications shall not exceed 13 months, except for testing machines being used in long-term tests that exceed this period, in which case the test machine shall be verified upon completion of the test.

Specifically, each transducer and associated electronics shall always be checked as a unit.

The torque measuring system(s) shall be traceable to a national standard.

10 Test procedure

10.1 Mounting of specimen

Care should be taken to ensure that each specimen is located in the driven and stationary (top and bottom, left and right) grips so that the axis of the specimen lies along the axis of torsion of the testing machine and the intended stress pattern is imposed. Care should also be taken to ensure that no (or minimal) axial stress is applied to the specimen during the mounting of the specimen on the testing machine.

10.2 Frequency of testing

The frequency of the torque cycle will depend upon the type of testing machine employed and the test programme requirements. The frequency chosen shall be that suitable for the particular combination of material, specimen and testing machine.

At high frequencies, substantial heating of the specimen can occur, which could affect the test fatigue life and strength results. In such cases, it is advisable to record the increase in temperature and to include it in the test report. If the test programme allows, the test frequency should be reduced if the specimen temperature increase is excessive for the material.

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

10.3 Heating for the isothermal elevated temperature test

For an isothermal elevated temperature test, the specimen shall be heated to the specified temperature and shall be stabilized for approximately half an hour or more to achieve the steady-state prior to starting the test. Throughout the test, test temperature should be maintained within a permissible deviation and gradient along the test section of the specimen (see 9.2).

If any temperature excursions occur outside the specified limits, then those temperature values should be included in the test report.

Throughout the test, the axial force which may be thermally induced should be minimized.

10.4 Application of torque

The general procedure for attaining full torque running conditions shall be the same for each specimen. The mean torque and torque range shall be maintained within ±1 % of the torque range.

10.5 Calculation of nominal torsional (shear) stress

Torsional (shear) stress, τ, results from the torque, M, applied to the specimens of circular and tubular cross-sections. The torsional stress is always largest at the outer diameter of the test section. Under elastic loading conditions, the nominal torsional stress varies linearly from zero at the axis of twist to a maximum at the outer diameter, and the following calculation of torsional stress, τ, is recommended:

$$\tau = \frac{16M}{\pi d^3}$$ at the outer diameter for solid specimens of circular cross-section;

$$\tau = \frac{16Md_0}{\pi\left(d_o^4 - d_i^4\right)}$$ at the outer diameter for specimens of tubular cross-section.

10.6 Recording of temperature and humidity

The maximum and minimum air temperatures and the humidity shall be recorded daily for the duration of the test.

If specimen self-heating at room temperature testing is of concern, the temperature of the specimen shall be monitored and recorded.

10.7 Failure and termination criteria

10.7.1 Failure

Unless otherwise agreed, the criterion for specimen failure shall be specimen separation.

In particular applications, other criteria (for example, the occurrence of a visible fatigue crack, plastic deformation of the specimen or the rate of crack propagation) may be adopted. Fatigue crack may extend, by helical growth, over a significant portion of the test specimen gauge length, so that the fatigue life, N_f, cannot be precisely determined.

As a result, fatigue life shall be specified as: either cycles to complete separation, or cycles up to X% increase of either the measured rotational amplitude of the test machine actuator or compliance of the specimen above the steady state value.

The failure criterion shall be recorded in the test report together with the values of N_f and, where appropriate, X.

NOTE 1 In a torque testing system, where the torsional stiffness of round loading bars and specimen is proportional to diameter to the power of four, it is reasonable to assume that the measured rotational amplitude of the test machine actuator corresponds closely to the angle of twist applied to the test specimen. An increase in this rotational amplitude is indicative of reducing torsional stiffness of the test specimen due to cracking.

NOTE 2 The preferred value of X is 10.

10.7.2 Termination

The test shall be terminated when either the specimen fails or a predetermined number of cycles is completed, as agreed by the concerned parties.

11 Measurement uncertainty

The test results shall be determined according to the procedure specified in 10.2, and are recommended to be expressed with the measurement uncertainty. The uncertainty can be evaluated according to Annex D.

12 Test report

The test report shall include reference to this document as well as the following information for the test series, if available:

— material tested, its metallurgical characteristics, mechanical properties, and any heat treatment given to the specimen(s);

— location of the specimen(s) in the parent material;

— form and nominal dimensions of the specimen(s);

— surface condition of the specimen(s).

The test report shall include the following for each individual specimen:

a) cross-sectional dimensions;

b) minimum and maximum peak torque applied;

c) applied stress conditions;

d) frequency and fatigue life;

e) a description of the testing machine used, its type and serial number, the torque cell and serial number, number and load train description;

f) temperature of the specimen if self-heating occurs (i.e. greater than 35 °C);

g) maximum and minimum air temperatures and relative humidity;

h) criterion for ending the test, i.e. its duration (e.g. 10^7 cycles), or complete failure of the specimen, or any other criterion;

i) any special observations or deviations from the required test conditions.

Additionally, test results may be presented graphically.

Annex A
(informative)

Presentation of results

A.1 General

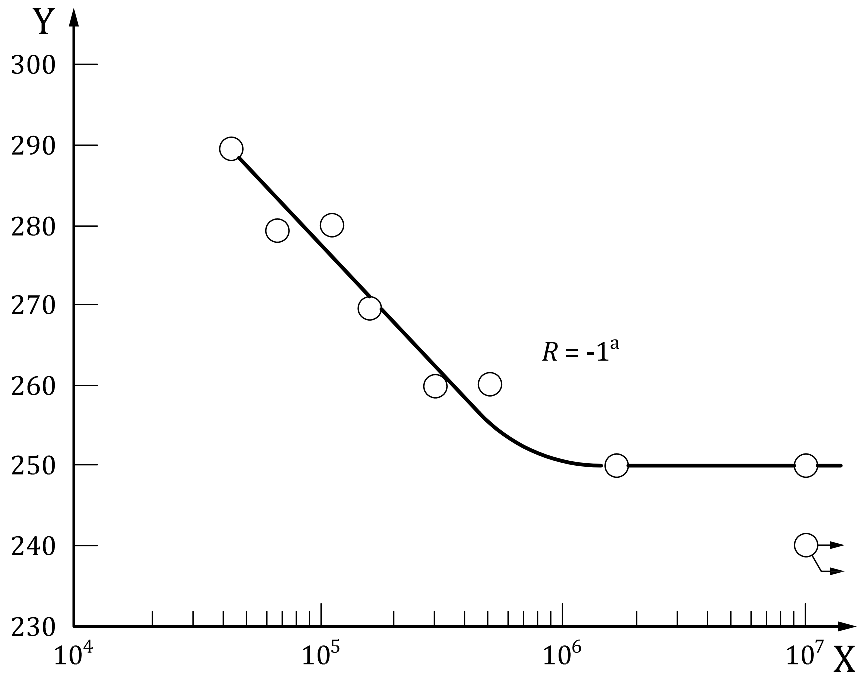
The design of the investigation and the use to be made of the results govern the choice of the most suitable method for presenting the results, graphically or otherwise, from the many available methods. The results of fatigue tests are usually presented graphically. In reporting fatigue data, the test conditions should be clearly defined.

A.2 Wöhler or S–N curve

The most general method of graphically presenting the results is to plot the number of cycles to failure as the abscissa and the values of stress amplitude or (depending on the type of stress cycle) those of any other stress as the 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 using either a linear or logarithmic scale 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 is shown in Figure A.1, where a linear stress scale is used.

A.3 Mean stress diagrams

The fatigue strengths derived from the Wöhler or S–N curve are plotted as 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 A.2 (Haigh diagram), or by plotting the maximum and minimum stresses against the mean stress, as shown in Figure A.3 (Smith diagram). Experimental results may be plotted on the same figure.



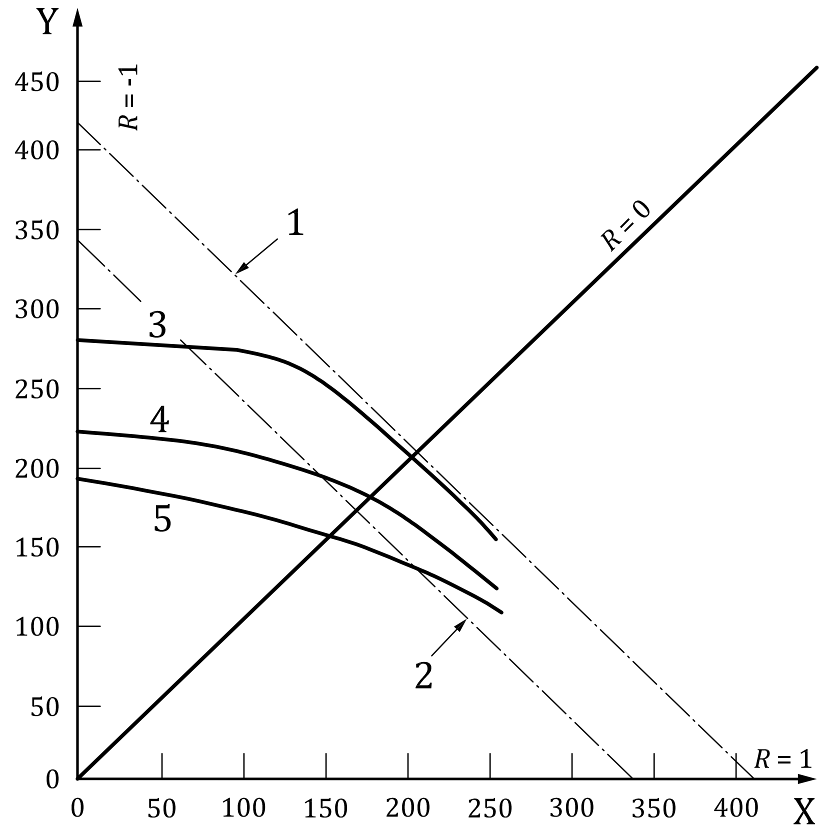
Key

X number of cycles to failure, N

Y stress amplitude, τ_a, MPa

[a] Ambient temperature.

Figure A.1 — Wöhler or S-N curve



Key

X mean stress, τ_m, MPa

Y stress amplitude, τ_a, MPa

1 shear strength

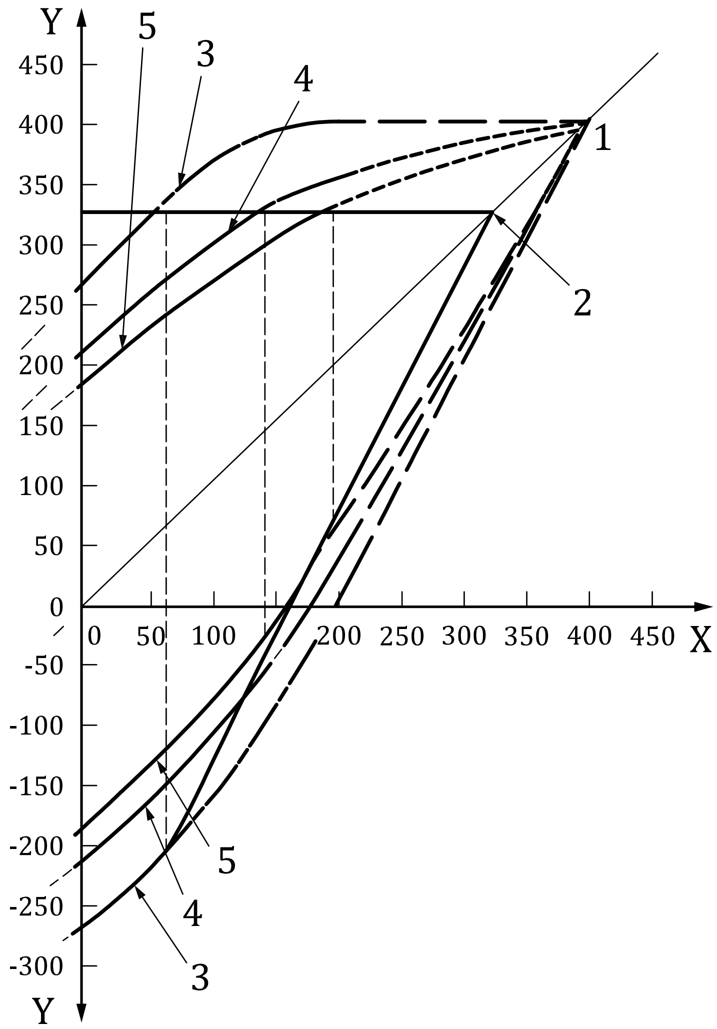
2 0,2 % torsional proof stress

3 10^5 cycles

4 10^6 cycles

5 10^7 cycles

Figure A.2 — Stress amplitude against mean stress — Haigh diagram



Key

X mean stress, τ_m, MPa

Y maximum and minimum stresses, τ_{max} and $\tau_{min,}$ MPa

1 shear strength

2 0,2 % torsional proof stress

3 10^5 cycles

4 10^6 cycles

5 10^7 cycles

Figure A.3 — Maximum and minimum stresses against mean stress — Smith diagram

Annex B
(informative)

Verification of alignment of torsional fatigue testing machines

B.1 The alignment check shall be carried out using a standard axial alignment specimen or bar alignment device. The bar alignment device is illustrated in Figure B.1, and the axial alignment specimen, shown in Figure B.2, should be of a geometry similar to the specimens being tested. It is recommended that the alignment specimen be made from a hardened heat-treated steel.

B.2 The bar alignment device, as a non-strain-gauged device, may be useful for checking the alignment in the test system both qualitatively and relatively quickly. The device, as illustrated in Figure B.1, should consist of a split bar and a sleeve, both made to precise tolerances. It is recommended that the sleeve and bar be made of the same materials.

B.3 In order to check the misalignment due to angular offset, lateral offset and/or load train offset, the axial strain-gauged alignment specimen should have resistance strain gauges secured at the locations illustrated in Figure B.2. 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 be made. At this time, the alignment specimen should be gripped in both the upper and lower grips.

B.4 The gauged specimen should be loaded in torsion to a maximum tensile strain of 0,4 %, or to a torque corresponding to the maximum torsional strain to be imposed on specimens in the test series if this value does not exceed 0,4 % strain of the gauge specimen. The maximum bending strains are calculated according to the scheme described in ISO 23788, in which the bending strains are separated into the machine contribution and the specimen contribution. If the maximum bending strain for the machine contribution exceeds 50 microstrains in one or more of the two instrumented planes, adjustments should be made in the test frame actuator or fixtures and/or force transducer, followed by a repetition of the procedure until 50 microstrains is achieved.

It is recommended that the general procedure for preparation of the alignment specimen and checking of the alignment follow that described in ISO 23788.

Care should be taken when applying a series of torsional loads or torsional strains to the specimen because the axial strain gauges cannot sense the torsional strain or deformation imposed on the specimen. Therefore, it is recommended that the torsional loads to be imposed on the specimen be pre-determined using another specimen with the same dimension and material as the gauged specimen.

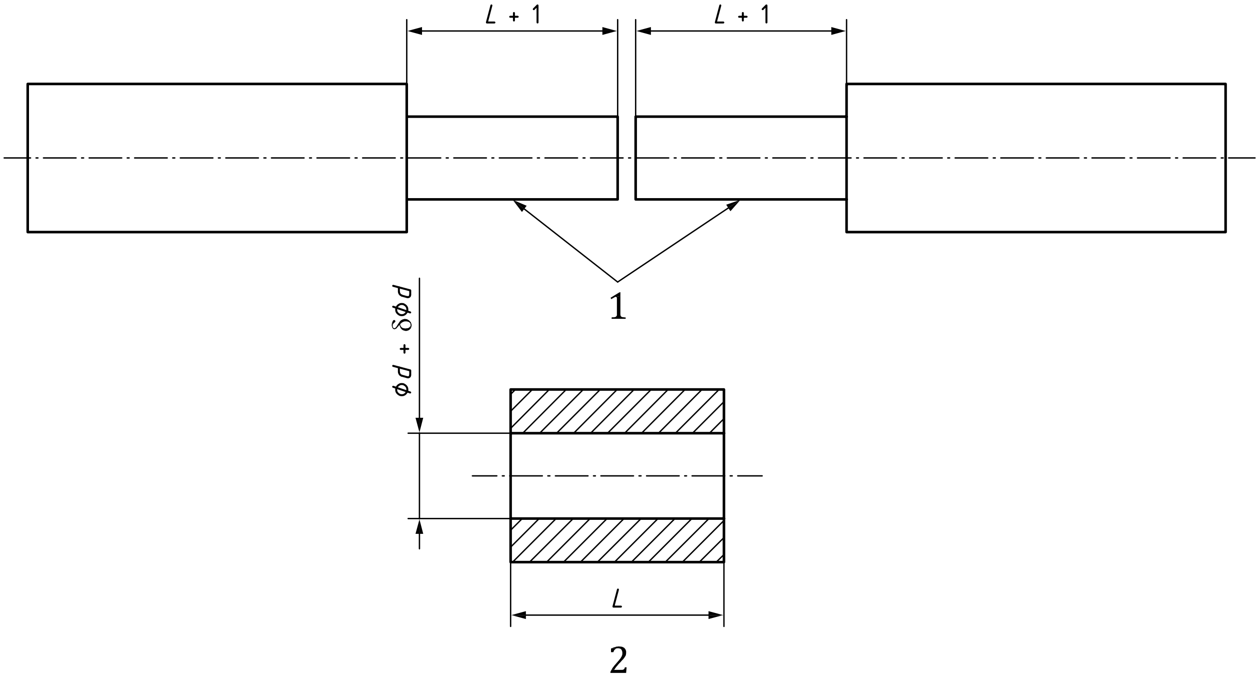
B.5 The procedure should be repeated in reversed torsion to ascertain that the alignment is within that specified (i.e. < 5,0 %).

B.6 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; and

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



Key

1 split bar

2 sleeve

Figure B.1 — Example of alignment bar

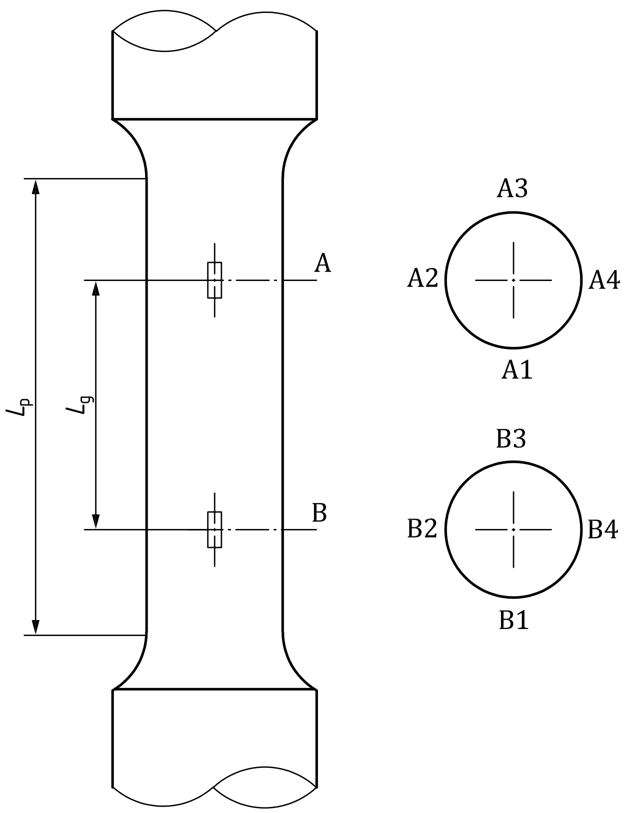


Figure B.2 — Strain-gauged specimen

Annex C
(informative)

Measuring uniformity of torsional strain (stress) state

C.1 It is important for any fatigue test that the best possible uniform stress distribution in the test section of every fatigue specimen be obtained prior to the actual fatigue test. Fatigue life is typically controlled by a combination of the highest stress and the largest defect within the specimen. The failure location is most likely not the location of the highest stress nor at the largest defect; but the actual failure location is controlled by a combination of both stress and defect size. By testing specimens with uniform stress distributions, all defects will be subjected to the same stress and failure will occur at the most critical defect. Fatigue scatter is reduced when the test section is increased and when the stress is uniform.

The uniformity of the applied stress is controlled by both the test machine and the specimen. To measure the uniformity of the applied torsional stress, the strain gauges need to be at 45° to the specimen axis, which is the direction of the applied principal stress.

C.2 It is always better to select one representative specimen from the group of actual test specimens to be strain-gauged so that the machine contribution and the specimen contribution to the uniformity of the applied stresses can be measured at the same time. For torsional testing, it is recommended that either the strain gauges be oriented at 45° to the specimen axis or an array of four 45° strain gauge rosettes be used, as illustrated in Figure C.1 a). The principal stress direction for a pure torsion specimen is 45° to the specimen axis. Therefore, single gauges orientated 45° to the specimen axis or rosettes will measure the principal stress. The strain gauges shall be equally spaced, 90° apart, around the circumference of the specimen in the same cross-sectional plane. The axial directions of the rosettes should be aligned to within ±2° of the longitudinal axis of the specimen.

In case four-gauge rosettes cannot be arranged in the same cross-sectional plane, they may be arranged in two sets of two-gauge rosettes as shown in Figure C.1 b).

It is recommended that all the strain gauge rosettes be matched and have active lengths of approximately 0,1 L_p or less.

C.3 The temperature during checking should be allowed to equilibrate and the zero reference adjustments to the bridge amplifiers should be accomplished with the top or bottom (not both) of the rosette-gauged specimen secured in the gripping arrangement. At this time, the specimen should be gripped in both the upper and lower grips.

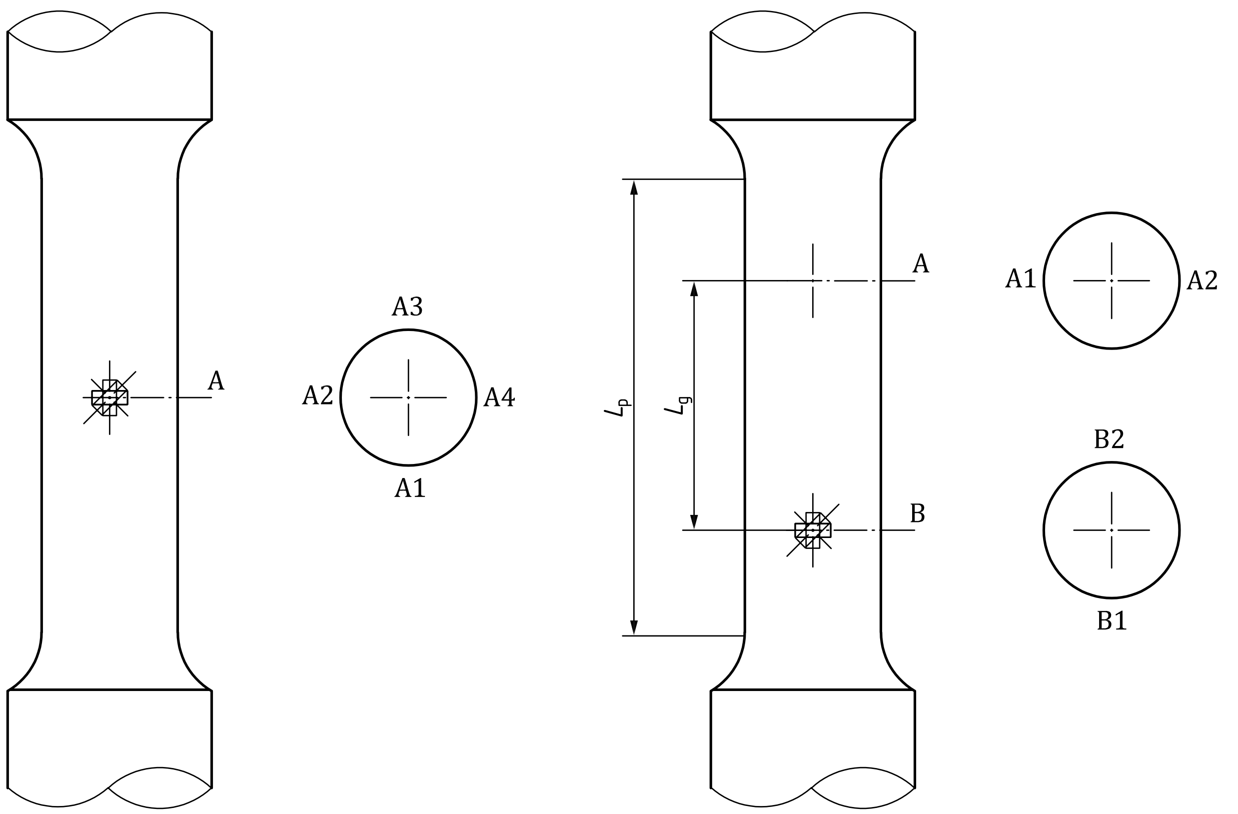
The strain-measuring equipment and data acquisition systems shall have a resolution of at least 1 microstrain and an accuracy to within ±0,5 % of the indicated reading or ±3 microstrains, whichever is the greater.

C.4 The gauged specimen should be loaded in torsion to the torque corresponding to the maximum torsional strain to be imposed on specimens in the test series, if this value does not exceed 0,4 % strain of the gauged specimen. If strain gauge rosettes are used, then the normal strain components [normal strains in the axial, circumferential and shear (45°) strain directions] are determined according to the analysis of strain gage rosette data. The procedure should be repeated in reversed torsion and the normal strain components in the three directions (0°, 45° and 90°) and at the four instrumented points should be reported. If only 45° strain gauges are used, report the normal strain component measured by the 45° gauges.

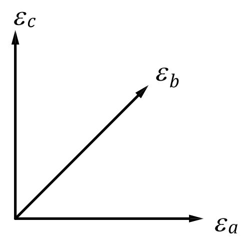
C.5 Once the procedure given in C.4 has been completed, the strain-gauged specimen is removed from the testing machine and rotated 180°, installed in the test machine, and the C.4 procedure repeated. At the completion of these two sets of torque application, the strain gauge data can be separated using the equations given in ISO 23788 into the machine contribution for non-uniform stress state and the specimen contribution for non-uniform stress state. If rosette strain gauges are used, then those equations will need to be used for each of the three-strain gauges within the rosette to separate the machine contribution from the specimen contribution. After separation, the direction and magnitude of the uniformity of the applied stress can be determined for both the machine contribution and specimen contribution using standard analysis for strain gauge rosette data.

C.6 Ideally, if every specimen could be strain-gauged, then the results calculated according to C.5 could be used to rotate the specimen to a position within the test machine to obtain the best uniform stress distribution prior to testing. Unfortunately, this would be very costly and is therefore not typically done. However, the information obtained from one representative specimen does provide important information on the quality of the specimen fabrication and how uniform the stress distribution would be for a perfect specimen (machine contribution for non-uniform stress state). If the specimen contribution to the non-uniform stress state is large, then more care is needed during specimen fabrication. If the machine contribution to the non-uniform stress state is large and the axial alignment is relatively good, then the axis of rotation of the torque actuator is not aligned with the rest of the machine.

C.7 In summary, it is critical to obtain the best uniform stress distribution within the test section of every possible specimen.



a) Four-gauge rosettes b) two sets of two-gauge rosettes



Key

$\varepsilon_{\theta\theta} = \varepsilon_a$

$\varepsilon_{zz} = \varepsilon_c$

$\gamma_{\theta z} = 2\varepsilon_b - \varepsilon_a - \varepsilon_c$

0° −45° −90° strain gauge rosette

Figure C.1 — Strain-gauged specimen

Annex D
(informative)

Estimation of measurement uncertainty

D.1 General

D.1.1 ISO/IEC 17025[5] requires all calibration and testing laboratories to provide the uncertainty estimates or the procedure for estimating the uncertainty associated with their test results. A customer may also demand requirements for measurement uncertainty information or the testing laboratory itself may want to gain a better understanding of which aspects of the test procedure have the greatest effect on results so that these may be monitored more closely or improved.

D.1.2 Where information is available, it is recommended that the uncertainty is estimated in accordance with the ISO/IEC Guide 98-3:2008[6]. All the terminology used should be in accordance with ISO/IEC Guide 98-3:2008[6] and ISO/IEC Guide 99:2007[7].

D.1.3 Measurement uncertainty is defined as "non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand".

D.1.4 According to the ISO/IEC Guide 98-3:2008, measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. All the other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations and evaluated from probability density functions based on other information.

For a given set of information, it should be understood that the measurement uncertainty is associated with a stated quantity attributed to the measurement. A modification of this quantity value will result in a modification of the associated uncertainty.

D.2 Guidelines for evaluation of uncertainty in torsional stress-controlled testing

D.2.1 It is recommended to identify, rank and list all the significant sources that contribute (either directly or indirectly) to the uncertainty of the fatigue life, N_f, result (or results) being reported. It should be noted that the list is uniquely associated with the testing procedure, specimen, apparatus, laboratory environment and possibly operator. This means that the list should be carefully reconsidered each time a source changes.

D.2.2 For torsional stress-controlled fatigue testing, it is envisaged that significant sources of input uncertainties identified in D.2.1 relating to fatigue life will (in order of significance) include:

a) uncertainty due to superimposed bending in the specimen resulting from misalignment between the direction of the applied force and the specimen's axis;

b) uncertainty in controlling the applied torsional stress;

c) uncertainty in the test temperature (in elevated testing);

d) uncertainty associated with the chosen definition of failure.

D.2.3 Where information is available, it is recommended that uncertainty is estimated in accordance with a protocol based on ISO/IEC Guide 98-3:2008. The protocol should include all the parameters identified in D.2.2. It should also be agreed before undertaking the work between the testing laboratory and the client. Examples of protocols for estimating measurement uncertainty in fatigue testing can be found in Reference [8].

D.2.4 Evaluating uncertainty may necessitate performing specific measurements and/or additional fatigue tests. It may also involve performing Monte Carlo simulations. Considerations for such requirements should be agreed with the client before undertaking the work.

D.2.5 The reported uncertainty should also include the level of confidence and a statement describing how the calculations were made.

D.2.6 It should be recognized that there will be situations where a reliable uncertainty estimate cannot be obtained due to lack of information needed for the uncertainty calculation.

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