Aerospace series — Test methods for metallic materials — Constant amplitude force-controlled high cycle fatigue testing

ICS 49.025.01, 49.025.05

National foreword

This British Standard is the UK implementation of EN 3987:2009.

The UK participation in its preparation was entrusted to Technical Committee ACE/61/-/6, Mechanical testing of metallic materials.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2009

ISBN 978 0 580 62413 1

Amendments/corrigenda issued since publication

Date	Comments

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 3987

October 2009

ICS 49.025.01; 49.025.05

English Version

Aerospace series - Test methods for metallic materials - Constant amplitude force-controlled high cycle fatigue testing

Série aérospatiale - Méthodes d'essais applicables aux matériaux métalliques - Essais de fatigue mégacyclique en contrainte imposée

Luft- und Raumfahrt - Prüfverfahren für metallische Werkstoffe - Schwerlastwechselermüdung (HCF) im kraftgesteuerten Versuch

This European Standard was approved by CEN on 11 July 2008.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 3987:2009: E

Contents

Page

Foreword

This document (EN 3987:2009) has been prepared by the Aerospace and Defence Industries Association of Europe - Standardization (ASD-STAN).

After enquiries and votes carried out in accordance with the rules of this Association, this Standard has received the approval of the National Associations and the Official Services of the member countries of ASD, prior to its presentation to CEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2010, and conflicting national standards shall be withdrawn at the latest by April 2010.

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

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This document applies to constant amplitude force-controlled high cycle fatigue (HCF) testing of metallic materials governed by EN Aerospace standards. It defines the mechanical properties that may need to be determined, the equipment, test pieces, methodology of test and presentation of results.

It applies to uniaxially loaded tests carried out on plain or notched test pieces at ambient and elevated temperatures. It is not intended to cover the testing of more complex test pieces, full scale components or structures, although the methodology could well be adopted to provide for such tests.

The purpose of this document is to ensure the compatibility and reproducibility of test results. It does not cover the evaluation or interpretation of results.

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.

EN 10002-2:1991, *Metallic materials — Tensile testing — Part 2: Verification of the force measuring system of the tensile testing machine.*

ASTM E 1012, *Standard practice for Verification of test frame and specimen alignment under tensile and compressive axial force application.* [1)]

3 Principle

The uniaxially loaded force-controlled high cycle fatigue test consists of maintaining a test piece at a uniform temperature and subjecting it to a constant force-amplitude waveform. The magnitude of the applied cyclic force affects the development of microscopic plastic strain within the test section, thus determining the fatigue life. A series of such tests allows the relationship between the applied force and the number of cycles to failure to be established.

The fatigue lives generated are typically in the range 10^4 - 10^8 cycles to failure and the test regime is said to be that of high cycle fatigue (HCF).

4 Terms and definitions

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

4.1
force-control
used to describe tests in which the force acting on a known test section is controlled

4.2
test section
defined as the region of the test piece between the blending fillets into the gripping section, and may be a continuous radius or a parallel sided section

---

1) Published by: American Society for Testing and Materials (ASTM), 1916 Race Street- Philadelphia PA 19103 USA.

4.3
cycle
defined as the smallest section of the force-time function which is repeated periodically. This is shown for a sinusoidal waveform in Figure 1, together with appropriate nomenclature which further defines the force cycle

4.4
failure
defined as complete separation of the test piece within the test section

5 Symbols and abbreviations

See Table 1.

Table 1 — Definitions and symbols relating to force-controlled fatigue testing

Symbol	Units	Term	Definition
F	kN	Force	The force applied to the test section. Tensive forces are considered to be positive and compressive forces negative.
$F_{max.}$	kN	Maximum force	The highest algebraic value of force applied.
$F_{min.}$	kN	Minimum force	The lowest algebraic value of force applied.
ΔF	kN	Force range	The algebraic difference between the maximum and minimum forces. ($F_{max}. - F_{min.}$)
Fa	kN	Force amplitude	Half the algebraic difference between the maximum and minimum forces. ($F_{max.} - F_{min.}$)/2
Fm	kN	Mean force	Half the algebraic sum of the maximum and minimum forces. ($F_{max.} + F_{min.}$)/2
R		Force Ratio	The algebraic ratio of the minimum force to the maximum force. See Figure 2 for examples of different force ratios. (F min./F max.)
σ	MPa	Stress	The force applied divided by the nominal cross-sectional area. The nominal cross-sectional area is that calculated from measurements taken at ambient temperature, and no account is taken for the change in section as a result of elevated temperatures. The above nomenclature for force also applies to stress, with F replaced by σ.
N		Number of force cycles	The number of cycles applied.
f	Hz	Frequency of cycles	The number of cycles applied per second.
N_f		Endurance or fatigue life	The number of cycles to failure.
K_t		Theoretical stress concentration factor	The ratio of the notch tip stress to net section stress, calculated in accordance with defined elastic theory, to the nominal section stress. NOTE Different methods used in determining K_t may lead to variations in reported values.
σ_N	MPa	Fatigue strength at N cycles	The value of the stress amplitude at a stated stress ratio under which the test piece would have a life of at least N cycles with a stated probability.

6 Test equipment

6.1 Test machine

6.1.1 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. In order to minimise the risk of buckling of the test piece, the machine should have great lateral rigidity and accurate alignment between the components used to grip the test piece ends.

The machine loading system shall be a controlled system in which the loading of the test piece is servo-controlled. It may be hydraulic or electromechanical.

During elevated temperature tests, the machine load cell should be suitably shielded and/or cooled such that it remains within its temperature operation range.

6.1.2 Test machine calibration

The force measurement system shall be verified at intervals not exceeding one year. The method to be used is that of EN 10002-2 with the following amendment related to the application of test forces, to cover calibration in tension and compression going through zero (clause 5.4.5 of EN 10002-2:1991).

Three series of measurements shall be carried out. Each series shall comprise at least 20 force steps as follows:

- 5 increasing force steps in tension at regular intervals from 20 % to 100 % of the full scale,
- 10 decreasing force steps at regular intervals from 100 % of the full scale in tension down to the full scale in compression,
- 5 increasing force steps at regular intervals from 100 % of the full scale in compression up to zero.

The relative errors of accuracy, repeatability, reversibility and zero shall be within the limits stated for class 1 of EN 10002-2:1991.

During the calibration process, an initial calibration shall be performed prior to adjustment of the test machine, such that the effect of any errors outside of the grade 1.0 requirement can be understood.

NOTE Modern test machines should readily meet this requirement, however if initial errors are present then the calibration period would need to be reviewed accordingly.

6.2 Cycle counting

The number of cycles applied to the test piece shall be recorded such that the resolution is better than 0,1 % of the indicated life.

NOTE A calibrated timer is a desirable adjunct to the cycle counter. When used to indicate total elapsed time to failure, it provides an excellent check against the cycle counter frequency for a fixed waveform frequency.

6.3 Waveform generation and control

The force cycle waveform shall be constant and is to be applied at a fixed frequency throughout the duration of a test programme. The waveform generator in use shall have repeatability such that the variation in force levels between successive cycles is within the calibration tolerance of the test machine as stated in 6.1.2, for the duration of the test with the total variation in the force level within 1 % of the requested value.

Terms have been identified relative to a sinusoidal waveform in Figure 1. Other waveform shapes may require further parameter definition although nomenclature should be retained where possible.

NOTE The waveform frequency will generally be between 10 Hz and 200 Hz. Although higher or lower frequencies may be used, the effect of frequency and waveform shape on fatigue life can be significant.

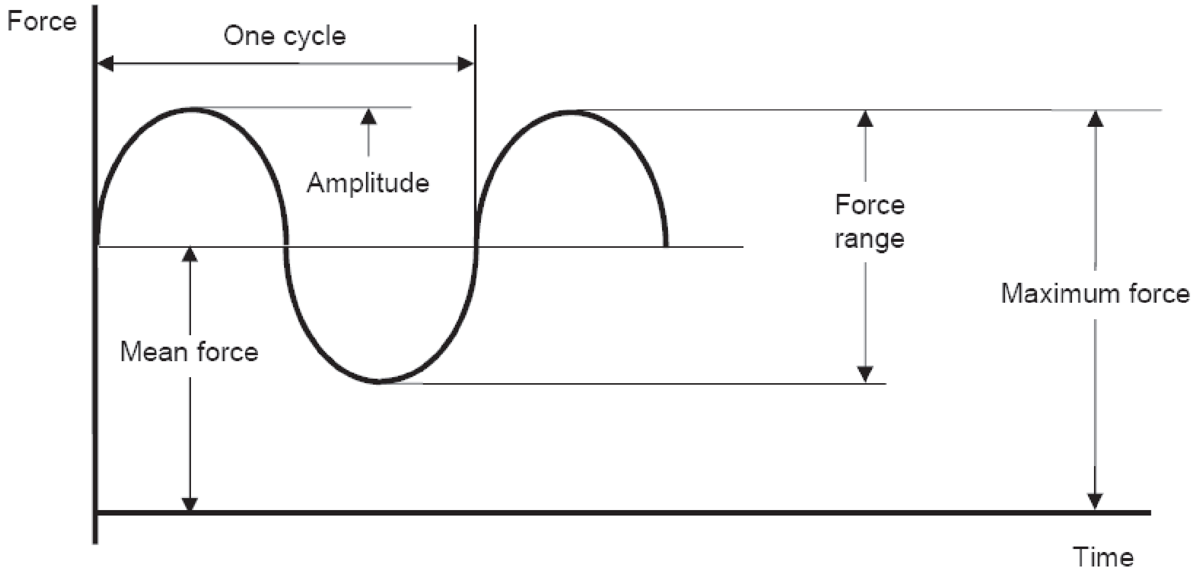


Figure 1 — Fatigue force cycle

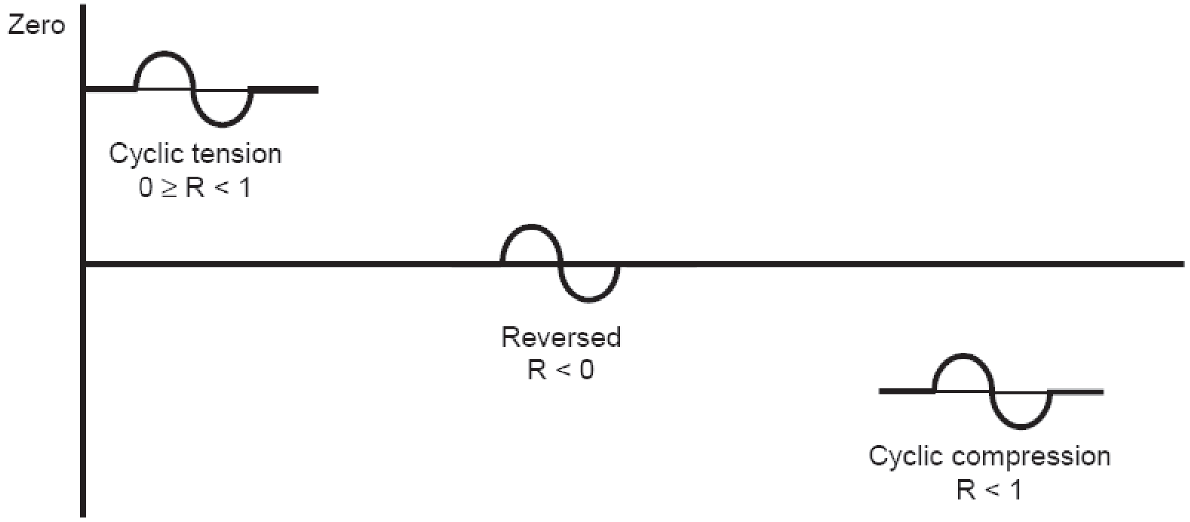


Figure 2 — Varying force ratio

6.4 Test fixtures

6.4.1 General

An important consideration for test piece grips and fixtures is that they can be brought into good alignment consistently from test to test. Good alignment is achieved from very careful attention to design details, i.e. specifying the concentricity and parallelism of critical machined parts.

In order to minimise bending strains the gripping system should be capable of alignment such that the major axis of the test piece coincides closely with the force axis throughout each stress cycle and in the case of tension-compression tests ($R \leq 0$) the gripping system must also be free from backlash effects.

The occurrence of misalignment either due to twist (rotation of the grips) or to a displacement on their axes of symmetry, must be controlled within known limits.

NOTE A parallelism error of less than 0,2 mm/m, and an axial error of less than 0,03 mm for a test space of less than 300 mm, and of less than 0,1 mm for a test space of more than 300 mm, should allow the alignment requirements described in 6.4.2 to be achieved. A further benefit can be realised by minimising the number of mechanical interfaces in the load train and the distance between the machine actuator and crosshead.

6.4.2 Alignment verification

Alignment of the load train assembly shall be checked at intervals not exceeding one year or 100 tests, whichever occurs sooner. In addition, it must be checked following disassembly of the test fixtures, movement of the machine crosshead or following a compressive failure that has caused the two test piece halves to overlap.

It is recommended that the alignment is checked by means of a strain-gauged test piece of geometry identical to that to be tested and that has been manufactured to the same tolerances.

The maximum bending strain determined in accordance with Method 1 of ASTM E 1012 (Standard Practice for the Verification of Alignment Under Tensile Loading) must not exceed 5 % of the mean axial strain induced at the lowest maximum tensile force and the maximum compressive force to be encountered in the test programme. This criterion should be met at each of 4 positions as the test piece is rotated through 90°.

The use of 2 sets of strain gauges in groups of 4, fixed at 90° intervals around the test section is recommended. The gauges should be equally distant from the test piece centre line, 3 of the parallel gauge length apart. Any strains induced into the gauge length due to the gripping mechanism should be minimised to less than 100 $\mu\varepsilon$.

The National Physical Laboratories "Code of Practice for the Measurement of Bending in Uniaxial Low Cycle Fatigue Testing" - NPL MMS 001:1995 is recommended as a good detailed best working practice document.

The use of dial gauge indicators in checking alignment should be avoided. When they are used, the tolerances adopted should ensure an equivalent alignment error to that obtained using strain gauges. However, bending induced by an aligned, but off-centred load train will not be detected by this technique.

6.5 Heating device

6.5.1 General

Testing will generally be conducted in air at ambient or elevated temperatures, although there may be a requirement to test in vacuum or in a controlled atmosphere.

Where additional apparatus is used such as furnaces, chambers etc., it is essential that the full force indicated by the force indicator is being applied to the test piece and is not being diverted through the auxiliary apparatus (e.g. by friction).

For elevated temperature tests the heating device employed shall be such that the test piece can be uniformly heated to the specified temperature, and an indicated temperature gradient along the test section of less than or equal to 4 °C maintained for the duration of the test.

NOTE A resistance furnace with three control zones is recommended. If a direct induction heating system is used, it is advisable to select a generator of medium frequency ($f \leq 100$ kHz) to achieve minimal radial thermal gradient in the test piece.

6.5.2 Verification of temperature uniformity

The uniformity of temperature along the test section shall be verified before every series of tests that introduces a new test piece geometry or test temperature, or in which the cooling, fixturing or heating device mounting arrangement are adjusted.

This verification may be made by means of a dummy test piece of identical geometry to that to be tested, equipped with several thermocouples fixed along and around its test section. The thermocouples should be suitably screened from direct radiant heat from the heating device.

The variation in indicated temperature anywhere on the test section must not exceed 4 °C.

Where temperature uniformity cannot be assured by this technique, for example where it is not possible to correctly position the heating device repeatedly, then an adequate number of temperature sensors must be employed during each test to ensure that the variation in indicated temperature anywhere on the test section does not exceed 4 °C.

6.6 Temperature measurement

The temperature measuring system comprising sensors and readout equipment shall be capable of operating continuously for the duration of the test and have a resolution of at least 1 °C and an accuracy of ± 2 °C. It must be verified over the working temperature range, traceable to National Standards by a documented method.

The use of thermocouples is recommended. Annex A describes their method of use.

The permitted deviations due to instability between the specified test temperature, and the indicated temperature measured at the surface of the test section, are as indicated in Table 2.

Table 2 — Permitted deviations between indicated temperature and specified test temperature

Test temperature	Tolerance
$\theta \leq 600$ °C	± 2 °C
600 °C $< \theta \leq$ 800 °C	± 3 °C
800 °C $< \theta \leq$ 1 200 °C	± 5 °C

NOTE 1 For ambient temperature tests (10 °C to 35 °C) it is not necessary to measure the test piece temperature.

NOTE 2 The effect of compounding errors could result in the real tolerance in temperature from the specified level to be 3 °C greater.

NOTE 3 The temperature rise due to plastic deformation shall be minimised (see 8.3.1) and shall be compensated for within the Table 2 tolerances.

6.7 Data recorders

A data recorder capable of monitoring the indicated test temperature throughout the test, within the accuracy stated in 6.6 must be employed. A temperature observation must be made at least every 5 minutes.

7 Test piece

7.1 Design

The type of test piece used will depend on the objectives of the test programme, the type of equipment, the equipment capacity and the form in which the material is available. The design however must meet certain general criteria as outlined below. (Refer to Figures 3 and 4)

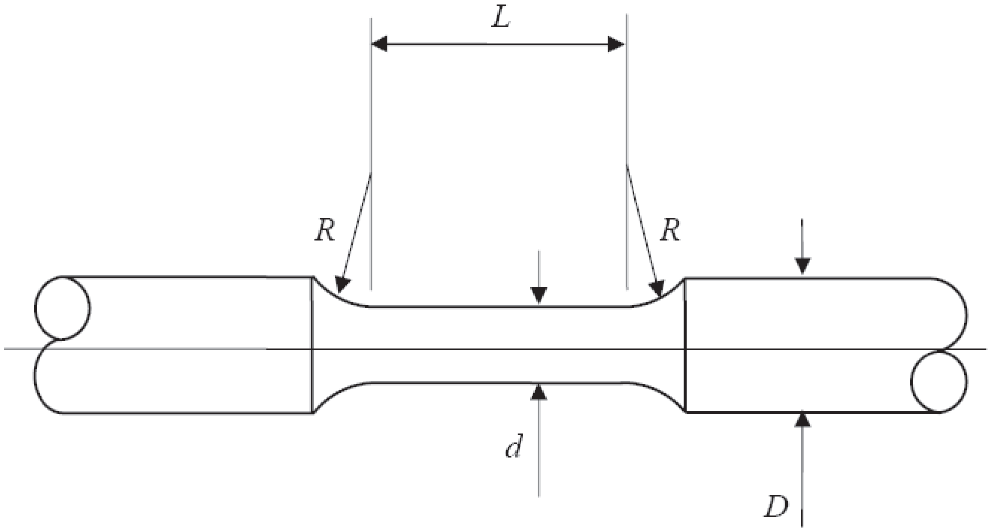
a) Failure must occur within the test section for the test to be considered valid.

b) Test pieces with circular cross sections shall have a blending fillet radius of at least twice the test section diameter to minimise the theoretical stress concentration, K_t, of the test piece. The test section length should be greater or equal to two times the test section diameter Concentricity and parallelism must be less than or equal to 0,03 mm.

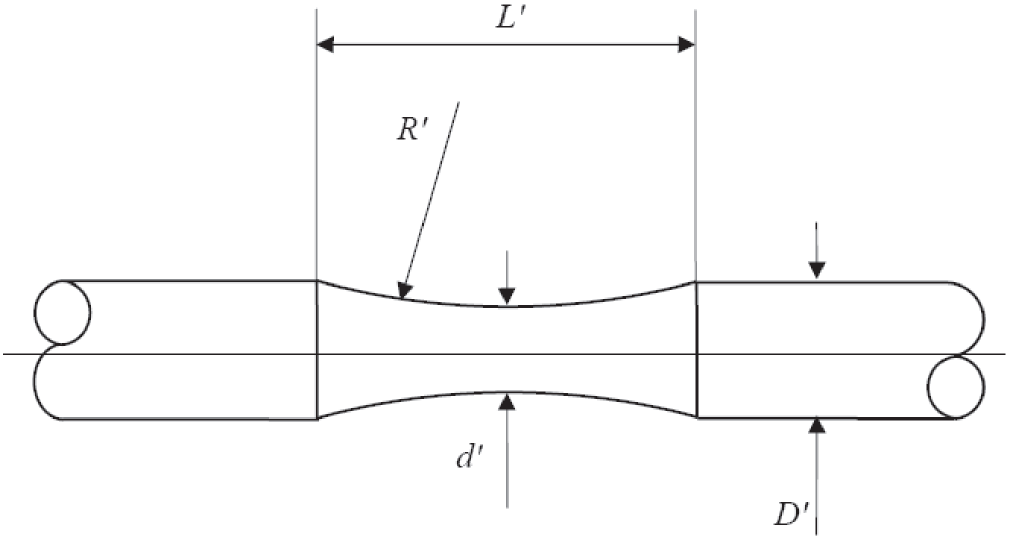
c) Test pieces with rectangular cross sections may have a reduced test cross section along one dimension, generally the width. The test section length should be greater than twice the test section width. The edges of the test piece must be longitudinally polished to prevent premature crack initiation. Errors in flatness must be less than 0,03 mm.

d) Test pieces used for compression should have a test section length less than or equal to twice the test section width or diameter, to avoid buckling.

e) In view of the specialised nature of notched test pieces no restrictions are placed on the design of the notched test piece, other than that it must be consistent with the objectives of the programme. Information on the associated K_t for the notch should have the method and source of its determination reported.



Test pieces with tangentially blending fillets between the test section and the gripping ends



Test pieces with continuous radius between gripping ends

Recommended dimensions:

Test section diameter : d or $d' \geq 4{,}5$ mm

Gripping section diameter : D or $D' \geq 2{,}5\ d$ or $2{,}5\ d'$ (Some materials may require a minimum diameter of $3{,}5\ d$ or $3{,}5\ d'$ to avoid failure within the grip)

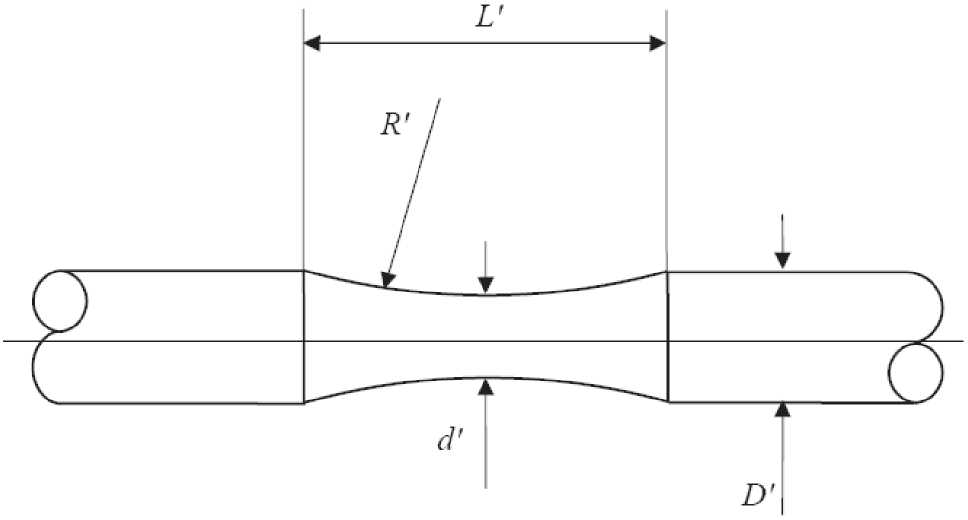
Test section length : $2\ d \leq L \leq 4\ d$ (For compression, $L \leq 2\ d$)

Transition radius : $R \geq 4\ d$ is adequate for most materials)

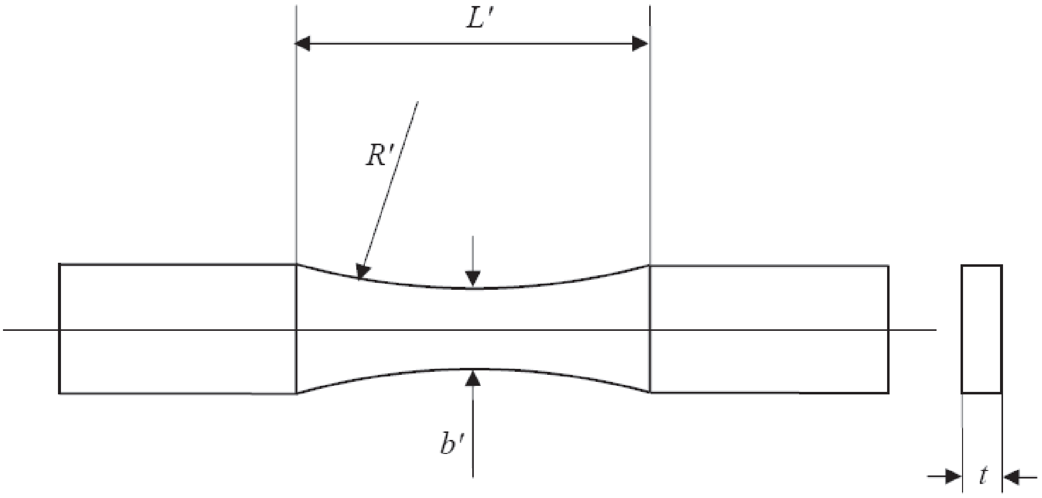
Test section length : $L' > 3\ d'$

Transition radius : $6\ d' \leq R' \leq 8\ d'$

Figure 3 — Test section profile for cylindrical test pieces



Test pieces with tangentially blending fillets between the test section and the gripping ends



Test pieces with continuous radius between gripping ends

Recommended dimensions:

Test section thickness : $t > 3$ mm for finish machined sections

Test section width : b or $b' > t$ and > 5 mm

Test section length : $2\,b \leq L \leq 4\,b$ for tension, $L \leq 2\,b$ for compression

Transition radius : $4\,b \leq R \leq 8\,b$ (Higher values of L and R could cause buckling under high compressive loads)

Test section length : $L' > 3\,b'$

Transition radius : $6\,b' \leq R' \leq 8\,b'$

Figure 4 — Test section profile for flat test pieces

7.2 Sampling, storage and handling

The position and orientation of test piece blanks cut out of components or billets can have a significant effect on the fatigue properties of a material. It is therefore important that their identity is maintained throughout the test piece manufacture process, and that this is traceable to their position in the original material stock. Reference to EN ISO 3785 (Design of test piece axes) is recommended.

Each test piece is blank and ultimately each test piece must therefore be suitably marked in a reliable manner. The test piece should be marked at each end away from the test section, such that the two halves can be identified post-fracture.

Machined test pieces must be stored in a manner that protects them from mechanical damage such as scratching, and environmental effects such as extreme humidity etc.

Throughout the testing process, any special handling requirements for the material under investigation should be adhered to. The use of clean cotton gloves is recommended.

7.3 Test piece preparation

The condition of the test piece and method of preparation are of the utmost importance. Inappropriate methods of preparation, which may be material specific, can greatly bias the test data generated. The effect of contaminants such as cutting fluids and degreasing agents must also be understood. Whilst it may be the purpose of some tests to establish the effect of a particular representative surface finish, for standard test pieces the following guidelines should be adhered to.

The technique established and approved for a specific material and test piece configuration must not be changed without first demonstrating that no bias is introduced by the alternative technique.

The final machining of the test pieces shall be performed in a manner that will consistently produce a smooth surface with low residual compressive stresses. The recommended procedure, for test pieces with circular cross section, comprises a fine turning or low stress grinding sequence followed by longitudinal polishing (see Annex B for example of machining sequence which may be used in the production of test pieces). The final polishing methods used must eliminate all circumferential machining marks or scratches on the test piece gauge length or end transitions. A low-magnification examination (×20) is recommended as a final inspection check.

NOTE Assurance that compressive residual stresses are maintained at a low level throughout the manufacturing route may be achieved by the use of X-ray residual stress measurement techniques. The magnitude of residual compressive stress at the surface of the test piece should be less than 500 MPa. Moreover, after removing 10 µm from the surface of the test piece, the magnitude of residual compressive stress should be less than 200 MPa, and at 50 µm from the surface less than 50 MPa.

7.4 Test piece measurement

7.4.1 General

The dimensions used for calculating the cross-sectional area of the test piece shall be measured prior to the test on individual test pieces, to an accuracy of 0,2 % or 0,005 mm, whichever is the greater value. The integrity of the surface finish must not be jeopardised during this activity.

NOTE The use of projection measurement methods is advised in these cases.

Applied stresses shall be calculated based on ambient temperature measurements and no compensation will be made for the change in section and effective stress due to heating for elevated temperature tests, or due to deformation of the test section during the test.

7.4.2 Circular or rectangular sections

The diameter or width and thickness of the gauge section shall be measured at three positions on the gauge length. The averages of these values are used to calculate the cross-sectional area. For continuous radius test sections the minimum diameter shall be used.

7.4.3 Notched test pieces

In the case of rectangular sections, the average thickness of the test piece measured at three equidistant positions in the plane of the notch root, and the average value of the notch root separation measured at each side of the test piece, shall be used in calculating cross-sectional area. Projection measurement equipment should be used in determining the notch separation.

In the case of circular notched sections, the minimum diameter shall be determined by a projection measurement method from at least two directions with an angular separation of 90°. The average of these values will be used in calculating the cross-sectional area.

For both geometry's the average notch root radius should be similarly measured.

The K_t value quoted may be affected to varying degrees by variations in the notch dimensions, depending on the method used to calculate it.

The accuracy of the value of the K_t should be reported if the tolerance on machining the notch geometry affects the average K_t value by more than ± 5 %. If the variability of the K_t value exceeds ± 5 % then the notch geometry should be measured and reported with each test piece.

8 Test method

8.1 Test piece insertion

The method employed to insert the test piece into the test fixture shall not jeopardise the alignment mechanisms, surface finish integrity or material properties. Excessive twisting should be avoided and compressive forces limited to a maximum of 50 % of yield strength.

8.2 Test piece heating

The test piece shall be heated to the specified temperature at a rate not exceeding 50 °C per minute and shall be maintained at that temperature for a sufficient period to ensure that the temperature has fully stabilised. In general a period of 30 seconds per mm^2 cross-sectional area should be allowed, with a minimum period of 15 minutes. If the total time to reach and stabilise at the test temperature exceeds 12 hours, then the actual soak time should be reported.

During the heating process, the temperature of the test piece shall not exceed the specified temperature within the tolerances outlined in 6.6.

Expansion during the heating process must not result in compressive forces being applied to the test piece. The force applied to the test piece shall therefore be controlled throughout the heating process and shall not exceed 10 % of the yield stress.

8.3 Test commencement

8.3.1 Waveform optimisation

The same waveform should be retained throughout the whole test programme unless the aim of this programme is to study the effect of the waveform on the behaviour of the material.

The frequency shall be such that it does not cause any temperature rise more than 2 °C in the test piece.

Unless the purpose of the test is to assess the effect of this parameter, the initial loading shall be in the tensile direction.

Prior to commencing cycling the waveform generator should be set such that the achieved maximum and minimum forces are between 95 % and 100 % of the intended force range.

On commencing cycling, the specified force should not be adjusted in order to achieve the precise intended force cycle. Actual forces and R ratios should be recalculated based on the measured values. If the test piece is overloaded during the start of the test, the force range or maximum force must not be reduced. However, in the cases where the specified maximum and minimum forces are mandatory, the specified force should be adjusted so that the correct maxima and minima are achieved within the first 10 cycles. This should be stated in the test report.

The achieved frequency must be within ± 10 % of the specified frequency.

The sinusoidal waveform shall be smooth and free from discontinuities.

8.3.2 Data recording

Monitoring of the indicated test temperature throughout the test must be employed in order to ensure that the test temperature has remained within the limits specified in 6.6.

NOTE It is recommended that a monitor of achieved force maxima and minima is also kept. This may be achieved in part by the setting of machine force limit trips which will indicate if an overload or underload has occurred.

8.4 Test termination

Tests should be continued without interruption until the test piece fails or a predetermined number of cycles have been exceeded.

The criterion for failure will generally be complete separation of the test piece. The cycle count attained is the fatigue life.

It should not be assumed that tested but unbroken test pieces have not suffered fatigue damage. Those test pieces therefore should not be resettled at a different stress amplitude.

9 Post-test checks

9.1 Accuracy of control parameters

In order to validate the test, the test temperature record must be consulted to ensure that there were no deviations outside the limits specified in 6.6.

NOTE If a record of achieved force maxima and minima has been kept then this should also be consulted. This may be achieved by checking that the set force trips have not been exceeded.

9.2 Examination of fracture surface

The failure position along the length of the test section should be noted. Failure of the test piece at a transition radius or outside the test section must be considered an invalid result, as must failure caused by initiation at the corner of a rectangular section test piece.

Examination of the fracture surface should also be made to establish whether the crack initiated from a surface blemish or other obvious feature.

NOTE A more thorough examination, using a scanning electron microscope, may be necessary to see if the crack initiated from surface scratches generated by poor machining or handling procedures, or thermocouple interference and to identify the initiation site (inclusion, porosity, ...).

10 Test report

10.1 Essential information

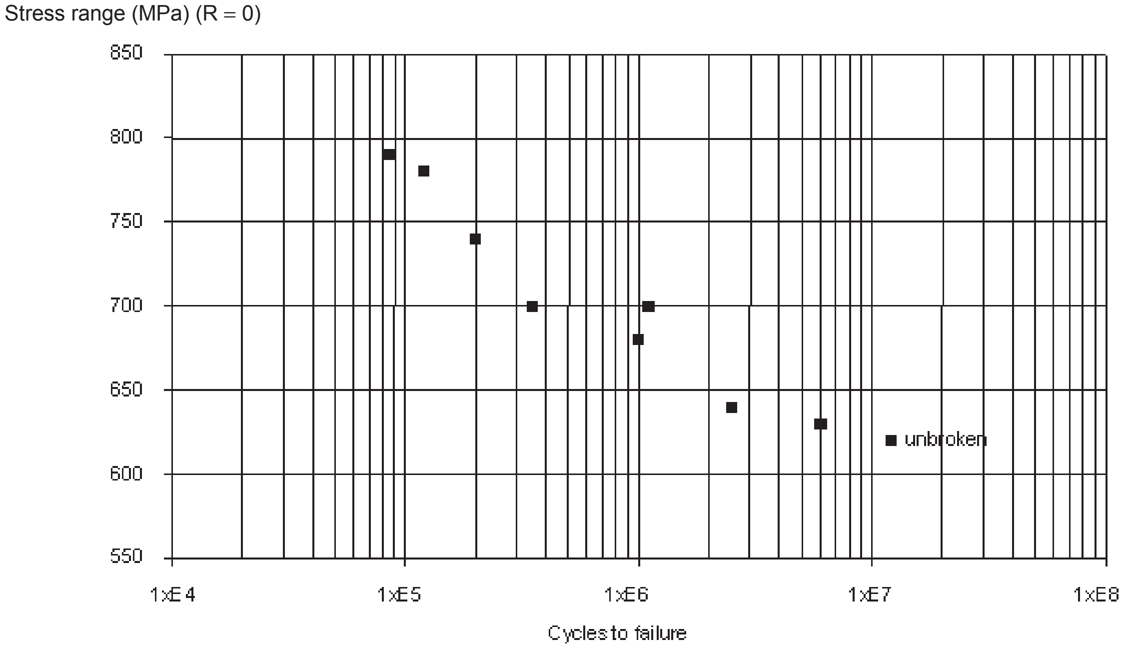
- Reference to this standard;
- test piece identity, drawing number, dimensions and reference to a documented method of preparation;
- stress concentration factor plus method and source of its determination for notched test pieces;
- temperature of the test plus any deviation from the specified limits;
- waveform, shape of load cycle, frequency of application and R ratio;
- total stress range, noting any initial adjustments made;
- cycles to failure and position of failure;
- any other occurrences that may affect the test result e.g. test suspensions, etc.

10.2 Additional information

The following information should be included in the test report:

- material composition, heat treatment, microstructure;
- complete identification of the part or half-finished product from which the test pieces are taken;
- precise position and orientation of each test piece;
- fractographic examination of the two fracture surfaces to identify the initiation site and to determine any unusual causes of failure that might invalidate the test result.

NOTE The most popular presentation of data for a series of related tests is via a graphical S-N diagram. Its construction involves plotting the number of cycles to failure as the abscissa and the stress range as the ordinate. A logarithmic scale is commonly used for the number of cycles and a linear scale for the stress axis (see Figure 5).



Key

A	Cycles to failure
B	unbroken

Figure 5 — Typical S-N diagram

Annex A
(informative)

Use of thermocouples

A.1 Calibration

Thermocouples shall be made batches of wire that have been calibrated over the whole working range against the recognized fixed points for thermocouple calibration or by comparison with a similarly calibrated and carefully maintained secondary standard reference thermocouple.

A.2 Use

For short sections (< 25 mm), two thermocouples equally spaced along the test section are generally sufficient to guarantee uniformity of the temperature of the test piece unless prior verification has been performed according to 6.6. For longer test sections at least three thermocouples should be used.

The thermocouple junctions should be maintained in close thermal contact with the surface of the test piece and be suitably screened from direct radiant heating caused by the heating system. However they must not be welded to the test section or affect the surface of the test section in any way.

NOTE 1 The accuracy of thermocouples may be affected by radio interference from induction coils. It is therefore recommended that they are not used as the only measurement system when induction heaters are used.

NOTE 2 It is recommended that heat resistant string be used to tie the thermocouple to the test section.

Due to the time-temperature dependent nature of degradation of thermocouple performance they should be periodically checked in order to ensure that measurement accuracy is not impaired, in line with good calibration practice.

Annex B
(informative)

Test piece preparation

B.1 General

In order to determine basic material properties, it is essential that the roughness of the surface contributes as little as possible to the fatigue failure and that the surface residual stresses microstructural modifications are minimised.

B.2 Machining the test piece blank

Machine test pieces in the fully heat-treated condition. For test pieces that cannot easily be machined in this condition, give the final heat treatment prior to finish machining.

NOTE The fatigue properties of metals are often sensitive to microstructure, which can depend on the cross-section at the time of heat treatment. The user should assure themselves that the microstructure of the test piece is similar to the component in question.

In all other cases, take steps to ensure that any cutting or rough turning operation does not alter the metallurgical structure of the test piece, i.e. remove metal in cuts of decreasing depth to minimise work hardening of the surface.

B.3 Machining of the test piece

The gauge length of the test piece and its transition radii shall be machined following a procedure that will minimise the residual stresses at the surface of the test piece.

During the finish machining stage, at least 0,5 mm from the test piece diameter shall be removed. The test piece diameter shall be decreased to 0,025 mm over the final diameter, the final 0,025 mm in diameter being removed by polishing.

Low stress grinding followed by longitudinal polishing is the procedure that is used in most of the cases. However, particularly for titanium and aluminium alloys, turning may be an alternative to grinding. The chosen method should adhere to one of the following procedures.

a) Turning

Remove metal by cuts of progressively decreasing depth. No single cut shall exceed 0,4 mm and the final pass should not exceed 0,05 mm. The following sequence would be suitable:

0,4 mm, 0,25 mm, 0,125 mm, 0,075 mm, 0,05 mm

NOTE Cuts of less than 0,08 mm may result in squeezing rather than cutting in some cases, especially if the cutting edge is not renewed; this must be avoided.

b) Grinding

A suitable lubricant shall be used and its flow shall be sufficient to prevent heating of the surface. The abrasive particles shall be continuously removed from the lubricant.

The diameter of the test piece shall be reduced at a rate of no more than 0,5 µm per turn (plunge grinding) or 0,005 mm per pass (traverse grinding) for the last 0,025 mm.

The grinding wheel shall be frequently dressed.

The characteristics of the wheel and maximum grinding speed shall be selected as a function of the alloy to be machined : a silicon carbide abrasive is suitable for titanium and aluminium alloys whereas aluminium oxide abrasive is suitable for steels, nickel or cobalt base alloys.

c) Milling

This method may be used to machine blanks of a rectangular cross-section to their finish size. Choose cutting speeds and depths of cut to minimise work hardening of the surface and produce a surface finish after longitudinal polishing in accordance with B.4.

B.4 Polishing of the test section

The final 0,025 mm in diameter shall be removed by longitudinally polishing the test piece.

The polishing paper shall be renewed periodically. The force applied to the polishing paper shall be constant and low (2 N to 5 N). An automatic polishing device is recommended.

Recommended metal removals and paper grit are as follows:

- 0,012 mm with P800 paper (particle size: 20 µm to 30 µm);
- 0,008 mm with P1 000 paper (particle size: 15 µm to 25 µm);
- 0,005 mm with P1 200 paper (particle size: 10 µm to 2 µm).

All grinding or turning marks must be removed with the P800 paper before using a finer grit. Polish with each finer grit paper until all marks left by the previous paper are removed, and to impart a maximum surface roughness of 0,2 µm R_a in the test piece axis direction.

NOTE Extreme caution should be exercised in polishing to ensure that material is being properly removed rather than merely smeared to produce a smooth surface.

Annex C
(informative)

Guidelines on test piece handling and degreasing

Unless otherwise specified by the customer or where special surface treatments have been applied, the following guidelines should be adhered to:

Steels

Degrease by full submersion in an acetone bath immediately prior to testing. The use of an ultrasonic bath is recommended. Test pieces that are degreased and then not tested for some reason should be retreated with an anti-corrosion fluid.

No special handling requirements are necessary subsequently.

Thread lubricants should not be necessary at the test temperatures encountered.

Nickel and cobalt base alloys

Degrease the test section with acetone and wipe dry with a clean soft cloth.

No special handling requirements are necessary subsequently.

For tests at temperatures greater than 650 °C, a thread lubricant should be used sparingly. Any excess evident once the test piece has been inserted should be removed.

Titanium based alloys

Degrease the test section with acetone and wipe with a clean soft cloth.

Once degreased, the test section must not be touched other than with clean cotton gloves. In addition, everything which touches the test section (extensometer probes, string used to tie on thermocouples, etc.) should be clean and should be handled with gloves (to prevent any transfer of salt from the skin to the test piece).

Thread lubricants must not be used.

Aluminium and magnesium alloys

Degrease the test section with acetone and wipe dry with a clean soft cloth.

No special handling requirements are necessary subsequently.

Thread lubricants should not be necessary at the test temperatures encountered.

Annex D
(informative)

Guidelines on producing an S-N curve

A good S-N curve has an even distribution of data points between the low and high endurance extremes. Where information on a particular material/condition is unavailable then the following guidelines may be used in order to produce an acceptable curve from the minimum number of test pieces.

1) Conduct an initial test at a peak stress level likely to produce a failure in approximately 1×10^5 cycles. Base this on results from similar materials, customer information etc. (If no other information is available and tensile test data exists, an initial test at a stress of ((UTS + 0,2 % PS)/2) will produce a failure).

2) Reduce the peak stress level by 40 MPa for the next test, which should now produce a life in the order of 1×10^7 stress-cycles unbroken.

3) If test '2' fails before attaining 1×10^7 stress cycles, reduce the peak stress level by a further 20 MPa and repeat to provide an unbroken test result at 1×10^7 stress cycles.

4) Conduct the next test at a peak stress level up to 40 MPa higher than that used for the initial test '1'. This should fail at a test endurance of around 1×10^4 stress-cycles.

5) If '4' above fails at an endurance level in excess 1×10^4 stress cycles, increase the peak stress by a further 20 MPa and carry out a repeat test.

6) Conduct further tests to fill in any obvious gaps in the S-N curve so that an even distribution of points is obtained when the S-N curves is plotted on 4 cycles log/linear paper.

NOTE The above details are only a guide for use when more suitable information and/or experience is unavailable. Precise details will depend on the materials under test and test conditions. (e.g. Nickel based alloys may have a quite different slope S-N curve to Titanium based alloys).

Bibliography

[1] NPL MMS 001:1995, *Code of Practice for the Measurement of Bending in Uniaxial Low Cycle Fatigue Testing*

[2] EN ISO 3785, *Metallic materials — Designation of test specimen axes in relation to product texture (ISO 3785:2006).*

This page has been intentionally left blank

BSI - British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001. Fax: +44 (0)20 8996 7001 Email: orders@bsigroup.com You may also buy directly using a debit/credit card from the BSI Shop on the Website http://www.bsigroup.com/shop

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact Information Centre. Tel: +44 (0)20 8996 7111 Fax: +44 (0)20 8996 7048 Email: info@bsigroup.com

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: +44 (0)20 8996 7002 Fax: +44 (0)20 8996 7001 Email: membership@bsigroup.com

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsigroup.com/BSOL

Further information about BSI is available on the BSI website at http://www.bsigroup.com.

Copyright

Details and advice can be obtained from the Copyright and Licensing Manager. Tel: +44 (0)20 8996 7070 Email: copyright@bsigroup.com

BSI Group
Headquarters 389
Chiswick High Road,
London, W4 4AL, UK
Tel +44 (0)20 8996 9001
Fax +44 (0)20 8996 7001
www.bsigroup.com/
standards