

Method for the determination of the rate of fatigue crack growth in metallic materials —

Part 1: Fatigue crack growth rates of above 10^{-8} m per cycle

ICS 77.040.10

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

BSI
Documents



Document Sharing Hub

Committees responsible for this British Standard

The preparation of this British Standard was entrusted to Technical Committee ISE/NFE/4, Mechanical testing of metals, upon which the following bodies were represented:

- British Iron and Steel Producers' Association
- British Non-Ferrous Metals Federation
- British Railways Board
- Copper Development Association
- ERA Technology Ltd.
- Electricity Association
- GAMBICA (BEAMA Ltd.)
- Institute of Materials
- Ministry of Defence
- National Physical Laboratory
- Society of British Aerospace Companies Limited
- United Kingdom Accreditation Service
- University College London
- Welding Institute

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

AEA Technology

This British Standard, having been prepared under the direction of the Engineering Sector Board, was published under the authority of the Standards Board and comes into effect on 15 November 1998

© BSI 1998

Amendments issued since publication

Amd. No.	Date	Text affected
10389 Corr. 1	December 1998	Front cover

The following BSI references relate to the work on this standard:
Committee reference ISE/NFE/4
Draft for comment 95/713844 DC

ISBN 0 580 28610 X

Summary of pages

The following table identifies the current issue of each page. Issue 1 indicates that a page has been introduced for the first time by amendment. Subsequent issue numbers indicate an updated page. Vertical sidelining on replacement pages indicates the most recent changes (amendment, addition, deletion).

Page	Issue	Page	Issue
Front cover	2	3	2
Inside front cover	2	4 to 6	original
a	1	7	2
b	blank	8 to 17	original
i	original	18	2
ii	original	19 to 23	original
1 to 2	original	Back cover	original

Contents

	Page
Committees responsible	Inside front cover
Foreword	ii
1 Scope	1
2 Normative references	1
3 Definitions	1
4 Symbols and units	2
5 Principle	2
6 Testing equipment and measuring accuracy	3
7 Specimens	3
8 Stress intensity factors	7
9 Crack length	7
10 Test procedure	7
11 Data analysis	8
12 Test report	9
Annex A (normative) Grips and fixtures	10
Annex B (informative) Information on methods for measuring crack lengths	13
Annex C (normative) Stress intensity factor functions	15
Annex D (informative) Specimen size recommendations	23
Figure 1 — Three-point single edge notch bend specimen (SENB3)	3
Figure 2 — Four-point single edge notch bend specimen (SENB4)	4
Figure 3 — Compact tension specimen (CT)	4
Figure 4 — Centre-cracked tension specimen (CCT)	5
Figure 5 — Permitted notch geometry	6
Figure A.1 — Test fittings for SENB3 specimens (see A.1)	10
Figure A.2 — Test fittings for SENB4 specimens (see A.2)	11
Figure A.3 — Recommended test fittings for CT specimens (see A.3)	12
Figure A.4 — Recommended test fittings for pin loaded CCT specimens (see A.4)	12
Figure A.5 — Typical steel end-plate design for 250 mm wide aluminium alloy centre-cracked sheet specimen, 100 kN maximum load, $R > 0$	13
Table 1 — Dimensions of specimens	7
Table C.1 — Stress intensity factor function values for SENB3 specimens	15
Table C.2 — Stress intensity factor function values for SENB4 specimens	17
Table C.3 — Stress intensity factor function values for CT specimens	19
Table C.4 — Stress intensity factor function values for CCT specimens	21

Foreword

This part of BS 6835 has been prepared by Technical Committee ISE/NFE/4.

It supersedes BS 6835:1988 which is withdrawn. A number of detailed amendments have been made in the light of the experience of users of BS 6835. In particular, a coherent system of units has been adopted for all the formulae. It is one of a series of standards on fatigue testing and is intended for use in conjunction with BS 3518-1, *General principles*, which gives general guidance relevant to this specialized form of mechanical testing.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

Annexes A and C are normative, annexes B and D are informative.

A British Standard does not purport to include all necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 23 and a back cover.

1 Scope

This part of BS 6835 describes a method for determining the rate of growth of a fatigue crack at ambient temperature as a function of the cyclic range of the crack tip stress intensity factor. It is limited to metal specimens tested in air that remain predominantly elastic, and to constant amplitude, sinusoidal or triangular waveform loadings which only induce crack face displacements perpendicular to the crack plane. Crack growth rates below 10^{-8} m/cycle and threshold stress intensity factor ranges are not covered. The method is restricted to cases where the crack advances on a nominally straight front across the thickness of the specimen.

NOTE 1 In some materials, growth rates in air can be influenced by humidity, waveform and testing frequency.

NOTE 2 The data produced may be used in the design and evaluation of engineering structures and for establishing, in quantitative terms, the effects of metallurgical and mechanical variables on fatigue crack growth.

NOTE 3 At rates above 10^{-8} m/cycle, growth rates under nominally identical test conditions may differ by a factor of two in replicate tests. This intrinsic variability should be taken account of in determining the number of tests to be undertaken to characterize the crack growth behaviour of a material and also in any engineering application of the data.

NOTE 4 This method does not cover the determination of rates below 10^{-8} m/cycle, nor the determination of threshold stress intensity factor ranges, i.e. ranges below which the rate of growth of a fatigue crack is negligible. For both these purposes a technique involving the smooth reduction of the stress intensity factor range with increasing crack length by automated force control would be preferred. A procedure for conducting such tests is given in DD 186. However, it is anticipated that this will be succeeded soon by BS 6835-2.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of this British Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 1134, all parts, *Assessment of surface texture — Methods and instrumentation*.

BS EN 10002-1:1990, *Tensile testing of metallic materials — Method of test at ambient temperature*.

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

BS 1610-1:1992, *Materials testing machines and force verification equipment — Specification for the grading of the forces applied by materials testing machines*.

3 Definitions

For the purposes of this British Standard the following definitions apply.

3.1

force

force applied to the specimen, considered positive when its direction is such as to cause the crack faces to move apart

3.2

range

difference between the maximum and minimum values of a variable

3.3

reference plane

plane perpendicular to the intended direction of crack extension, used as a datum for the measurement of crack length

NOTE See Figures 1 to 5.

3.4

crack length

distance from the tip of the crack to the reference plane

3.5

specimen width

distance from the reference plane to the surface of the specimen in the direction of crack extension

3.6

specimen thickness

dimension of the specimen parallel to the line of the notch tip

3.7

notch length

distance from the tip of the notch to the reference plane

3.8

stress intensity factor

factor proportional to the magnitude of the stresses near to the tip of a crack in an elastic body

NOTE It has been found that stress intensity factors, calculated assuming that specimens respond purely elastically, correlate the behaviour of real cracked bodies provided that the size of the zone of plasticity at the crack tip is small compared to the crack length and the length of the uncracked ligament.

3.9

stress intensity factor function

function relating the stress intensity factor of a crack to the force, the crack length and the width and thickness of the specimen

3.10

fatigue crack growth rate

average crack extension per cycle of force

3.11

resolution

minimum change in crack length detectable with the system in use

4 Symbols and units

NOTE The equations presented in this standard are in a form which require the use of a coherent set of units, namely: force is MN, length is m, stress intensity factor range is $\text{MPa}\sqrt{\text{m}}$, and growth rate is m/cycle. The units listed in this clause should be used for calculation purposes. It is recognized that other units may be more practical for the measurement of force and length. Indeed for convenience the specimen and fixture dimensions given in this standard are expressed in millimetres (Figures 1 to 10). When such practical units are employed in the test procedure it is necessary to convert the measured values into coherent units in order to calculate the test results.

For the purposes of this British Standard the following symbols and units apply.

Symbol	Quantity	Unit
a	is the crack length	m
a_0	is the minimum precrack length (see Figure 5)	m
B	is the specimen thickness (see Figures 1 to 4)	m
D	is the loading hole diameter	m
da/dN	is the fatigue crack growth per cycle	m/cycle
E	is Young's modulus	MPa
F, F_1	are the distances between the loading hole centres and the notch centre line (see Figures 3 and 4)	m
G	is the overall width of a compact tension specimen	m
H	is the half-height of the specimen (see Figure 3)	m
K	is the stress intensity factor (see clause 7)	$\text{MPa}\sqrt{\text{m}}$
K_E	is a notional value of K used in the estimation of the loading conditions for precracking (see 9.1)	$\text{MPa}\sqrt{\text{m}}$
K_M	is a notional value of K used in the estimation of the loading conditions for precracking (see 9.1)	$\text{MPa}\sqrt{\text{m}}$
$K_{\max}$	is the maximum value of K during a loading cycle	$\text{MPa}\sqrt{\text{m}}$
$K_{\min}$	is the minimum value of K during a loading cycle	$\text{MPa}\sqrt{\text{m}}$
ΔK	is the stress intensity factor range $K_{\max} - K_{\min}$	$\text{MPa}\sqrt{\text{m}}$
K_{Ic}	is the plane strain fracture toughness determined in accordance with BS 7448-1	$\text{MPa}\sqrt{\text{m}}$
L	is the overall specimen length	m
L_1, L_2	are the distances between the inner and outer loading points on a bend specimen	m
L_3	is the distance between the inner loading points on a four-point bend specimen	m

Symbol	Quantity	Unit
M	is the notch length (see Figure 5)	m
n	is the notch width (see Figure 5)	m
N	is the number of loading cycles	
P	is the force applied to the specimen	MN
$P_{\max}$	is the cyclic maximum value of P	MN
$P_{\min}$	is the cyclic minimum value of P	MN
ΔP	is the force range $P_{\max} - P_{\min}$	MN
q	is the resolution of the crack length measuring system	m
R	is the force ratio $P_{\min}/P_{\max}$	MN
R_a	is a measure of the surface roughness as defined in BS 1134	μm
r_p	is a dimension equal to $(K_{\max}/\sigma_Y)^2$	m
T	is the outer diameter of the loading rod thread	m
S_p	is the value of $(W-a)$ at which net section yielding is expected	m
W	is the specimen width (see Figures 1 to 4)	m
Y	is the stress intensity factor function	
σ_Y	is the 0.2 % proof strength of a metal, determined in accordance with BS EN 10002-1	MPa
σ_f	is the arithmetic mean of σ_Y and the tensile strength, determined in accordance with BS EN 10002-1	MPa

5 Principle

The test is performed on a notched specimen. A fatigue crack is induced at the root of the notch by cyclic loading and its growth is monitored by a suitable method. As the crack grows the force range applied to the specimen is maintained or reduced in a controlled manner until the crack is of sufficient length for the influence of the notch to be negligible and ΔK reaches the lowest level of interest. The force range is then maintained constant and the crack length recorded as a function of elapsed cycles. These data are then subjected to numerical analysis, enabling da/dN to be determined as a function of ΔK .

Crack growth rates presented in terms of ΔK are generally independent of the geometry of the specimen used except that they may be influenced by specimen thickness. However variations with thickness are not expected within the range of thicknesses covered by this part of BS 6835.

NOTE Residual stresses can markedly affect the observed behaviour. Thermal stress relief should therefore be considered prior to testing, but if this is not acceptable, the possibility of an effect should be recognized in the interpretation of the results.



6 Testing equipment and measuring accuracy

6.1 Testing machine

The testing machine shall have smooth start up and backlash free operation if passing through zero force.

The testing machine shall be verified in accordance with class 1.0 of BS EN 10002-2 for tensile forces and grade 1.0 of BS 1610-1 for compressive forces throughout the full range of forces to be used in the test. Friction at loading pins, rollers and knife-edges shall be minimized. Lubricants shall be used on all the interfaces between the specimen and the loading system at which movement could occur. During testing the indicated value of ΔP shall not vary by more than 2 % nor the indicated value of $P_{\max}$ by more than 1 % of their desired values.

NOTE With some testing systems significant inertial forces, additional to those applied to the specimen, may be applied to the force measuring system under dynamic conditions. Correction should be made for this if necessary.

Test fixtures shall conform to annex A.

6.2 Crack length measurement

Crack lengths shall be measured to within 0.01W; changes in crack lengths shall be measured to within 0.003W.

NOTE Whilst checks on the surface lengths of a crack are called for during the early stages of the determination, a method that measures the average crack length across the thickness of the specimen is generally preferable. Suitable techniques are described in annex B. Automatic methods of crack length recording are also preferable to minimize the loss of data due to test stoppages (see clause 11).

6.3 Cycle counting

The number of applied load cycles shall be accurately counted. When da/dN is less than 10^{-5} m/cycle the unit of counting shall not exceed $10^{-5}/da/dN$ where the da/dN is measured in m/cycle. Otherwise individual cycles shall be counted. Calculation based on nominal frequency and elapsed time is not permitted.

NOTE For example, if da/dN is to be determined as a function of ΔK at rates of growth up to 10^{-6} m/cycle, then the cycle counting device used should count in units not greater than 10^{-5} divided by 10^{-6} , i.e. in tens of cycles.

7 Specimens

7.1 Geometry

One of the following types of specimen shall be used:

- three-point single edge notch bend (SENB3);
- four-point single edge notch bend (SENB4);
- compact tension (CT);
- centre-cracked tension (CCT).

The geometries of the specimens shall be in accordance with Table 1 and Figures 1 to 5.

7.2 Specimen preparation

7.2.1 Marking out and extraction

The notch direction and material identity shall be clearly shown. Sufficient allowance for the removal of all material affected by the process of cutting out shall be made. In all cases the blank shall be not less than 2 mm oversize.

NOTE 1 A method for crack plane identification is given in BS EN ISO 3785.

NOTE 2 Cold or semi-cold methods should be used to extract the blank, e.g. sawing or spark erosion to minimize the amount of machining subsequently required.

