

Confirmed

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British Standard Method for
**Determination of the rate of fatigue crack
growth in metallic materials**

Méthode de détermination de la vitesse de propagation des fissurations par fatigue dans
les matériaux métalliques

Verfahren zur Bestimmung des Rißwachstums in metallischen Werkstoffen

Foreword

This British Standard has been prepared under the direction of the Iron and Steel and the Non-Ferrous Metals Standards Committees and describes a method of determining the rate of growth of a fatigue crack as a function of the cyclic range of its stress intensity factor. It is based upon UK experience in this field, but account has also been taken of US practice as embodied in the related document 'Method of test for measurement of fatigue crack growth rates' (ASTM E647-83) published by the American Society for Testing and Materials*.

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.

The 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. However insufficient experience currently exists to justify a British Standard method based on this approach.

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

* Available from the Library, BSI, Linford Wood, Milton Keynes MK14 6LE.



Amendment No. 1
published and effective from 30 April 1991
to BS 6835 : 1988

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

Corrections

AMD 6289
April 1991

Clause 3 Symbols

In the description of R_n , delete ' $0.1 (K_{\max}/\sigma)^2$ (in m)' and substitute ' $100 (K_{\max}/\sigma)^2$ (in mm)'.

AMD 6289
April 1991

Subclause 6.3 Size

In the first line delete ' $5.6 \times 10^{-5} (E/10 \sigma)^2$ ' and substitute ' $5.6 \times 10^{-5} (E/\sigma)^2$ '.

AMD 6289
April 1991

Clause II Test report

In item (f) line 4 delete ' K ' and substitute ' ΔK '.

AMD 6289
April 1991

Table 2. Stress factor function values for SENB3 specimens

Below the title of table 2 delete

'Tabulated values = $(KB \sqrt{W})/P$ ' and substitute

$$\text{'Tabulated values} = \frac{KB}{P} \times \sqrt{\frac{W}{1000}}$$

In the equation after table 2 'Closed form approximation' delete

$$Y = \frac{6 \sqrt{\alpha \{1.99 - \alpha (1 - \alpha) (2.15 - 3.93 \alpha + 2.7 \alpha^2)\}}}{(1 + 2 \alpha) (1 - \alpha)^{1.5}}$$

and substitute

$$Y = \sqrt{1000} \times \frac{6 \sqrt{\alpha \{1.99 - \alpha (1 - \alpha) (2.15 - 3.93 \alpha + 2.7 \alpha^2)\}}}{(1 + 2 \alpha) (1 - \alpha)^{1.5}}$$

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April 1991

Table 3. Stress intensity factor function values for SENB4 specimens

Below the title of table 3 delete 'Tabulated values = $(KB \sqrt{W})/P$ ' and substitute

$$\text{'Tabulated values} = \frac{KB}{P} \times \sqrt{\frac{W}{1000}}$$

In the equation after table 3 'Closed form approximation' delete

$$Y = \frac{3 \sqrt{(2 \tan \theta) \{0.923 + 0.199 (1 - \sin \theta)^4\}}}{\cos \theta}$$

and substitute

$$Y = \sqrt{1000} \times \frac{3 \sqrt{(2 \tan \theta) \{0.923 + 0.199 (1 - \sin \theta)^4\}}}{\cos \theta}$$

Table 4. Stress intensity factor function values for CT specimens

Below the title of table 4 delete

'Tabulated values = $(KB \sqrt{W})/P$ ' and substitute

$$\text{'Tabulated values} = \frac{KB}{P} \times \sqrt{\frac{W}{1000}}$$

In the equation after table 4 'Closed form approximation' delete

$$\text{'Y} = \frac{(2 + \alpha) (0.886 + 4.64 \alpha - 13.32 \alpha^2 + 14.72 \alpha^3 - 5.6 \alpha^4)}{(1 - \alpha)^{1.5}}$$

and substitute

$$\text{'Y} = \sqrt{1000} \times \frac{(2 + \alpha) (0.886 + 4.64 \alpha - 13.32 \alpha^2 + 14.72 \alpha^3 - 5.6 \alpha^4)}{(1 - \alpha)^{1.5}}$$

Table 5. Stress intensity function values for CCT specimens

Below the title of table 5 delete

'Tabulated values = $(KB \sqrt{W})/P$ ' and substitute

$$\text{'Tabulated values} = \frac{KB}{P} \times \sqrt{\frac{W}{1000}}$$

In the equation after table 5 'Closed form approximation' delete

$$\text{'Y} = \sqrt{\theta \sec \theta} (0.707 - 0.007 \theta^2 + 0.007 \theta^4)$$

and substitute

$$\text{'Y} = \sqrt{1000} \times \sqrt{\theta \sec \theta} (0.707 - 0.007 \theta^2 + 0.007 \theta^4)$$

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Method

1 Scope

This British Standard 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 straight front across the thickness of the specimen.

NOTE 1. 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 2. At rates above 10^{-8} m/cycle, growth rates under nominally identical test conditions may differ by a factor of 2 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 3. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

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

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

2.2 range. The difference between the algebraic maximum and minimum values of a variable.

2.3 reference plane. A plane perpendicular to the intended direction of crack extension, used as a datum for the measurement of crack length, and located as shown in figures 1 to 5 inclusive.

2.4 crack length. The distance from the tip of the crack to the reference plane.

2.5 specimen width. The distance from the reference plane to the surface of the specimen in the direction of crack extension.

2.6 specimen thickness. The dimension of the specimen parallel to the line of the notch tip.

2.7 notch length. The distance from the tip of the notch to the reference plane.

2.8 stress intensity factor. A 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.

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

2.10 fatigue crack growth rate. The average crack extension per cycle of force.

2.11 resolution. The minimum change in crack length measurable with the system in use.

3 Symbols

For the purposes of this British Standard the following main symbols apply.

P	is the force (in kN)
$P_{\max}$	is the algebraic maximum value of force during a loading cycle (in kN)
$P_{\min}$	is the algebraic minimum value of force during a loading cycle (in kN)
ΔP	is the force range ($P_{\max} - P_{\min}$) (in kN)
R	is the force ratio ($P_{\min}/P_{\max}$)
a	is the crack length (in mm)
a_0	is the minimum pre-crack length (see figure 5) (in mm)
B	is the specimen thickness (in mm)
W	is the specimen width (in mm)
M	is the notch length (see figure 5) (in mm)
n	is the notch width (see figure 5) (in mm)
Y	is the stress intensity factor function
K	is the stress intensity factor (see clause 7) (in $\text{MN}/\text{m}^{1.5}$)
$K_{\max}$	is the maximum value of K during a loading cycle (in $\text{MN}/\text{m}^{1.5}$)
$K_{\min}$	is the minimum value of K during a loading cycle (in $\text{MN}/\text{m}^{1.5}$)
ΔK	is the stress intensity factor range ($K_{\max} - K_{\min}$) (in $\text{MN}/\text{m}^{1.5}$)
K_{Ic}	is the plane strain fracture toughness determined in accordance with BS 5447 (in $\text{MN}/\text{m}^{1.5}$)
N	is the number of loading cycles

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

da/dN	is the fatigue crack growth rate (in m/cycle)
E	is the Young's modulus (MN/m^2)
σ_Y	is the 0.2 % proof stress of metal, determined in accordance with BS 18 (in MN/m^2)
σ_f	is the arithmetic mean of σ_Y and the ultimate tensile strength (UTS) in accordance with BS 18 (in MN/m^2)
R_p	is an increment of crack extension equal to $0.1(K_{\max}/\sigma_Y)^2$ (in m)
q	is the resolution of crack length measuring system (in mm)
S_p	is the value of $(W - a)$ at which general yielding on the net section is expected (in mm)
R_a	is as defined in BS 1134 : Part 1
T	is the outer diameter of the loading rod thread (in mm)
D	is the hole diameter (in mm)
F, F_1	are the distances between the loading hole centres and the centre line of the notch (in mm)
L	is the overall length (in mm)
G	is the overall width of a compact tension specimen (in mm)
H	is the half-height of a compact tension specimen (in mm)
L_1, L_2	are the distances between the inner and outer loading points on a bend specimen (in mm)
L_3	is the distance between the inner loading points on a four point bend specimen (in mm)

4 Principle

The determination involves the use of 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 standard.

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.

5 Testing equipment and measuring accuracy

5.1 Testing machine

The testing machine shall be verified in accordance with grade 1.0 of BS 1610 : Part 1. 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 ΔP shall not vary by more than 4 % nor $P_{\max}$ by more than 2 % 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 comply with appendix A.

5.2 Crack length measurement

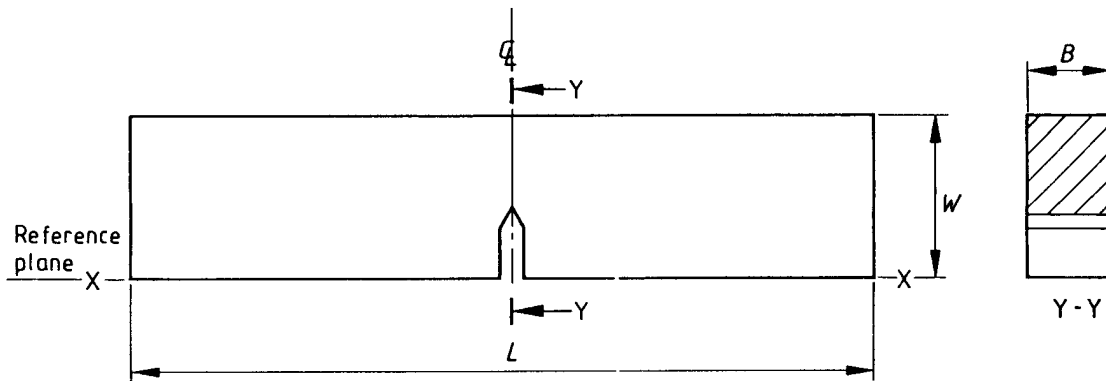
Crack lengths shall be measured to within $0.01W$; changes in crack lengths shall be measured to within $0.003W$.

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 appendix B. Automatic methods of crack length recording are also preferable to minimize the loss of data due to test stoppages (see clause 10).

5.3 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 da/dN is measured in m/cycle. Otherwise individual cycles shall be counted. The measurement of frequency and elapsed time shall not be used.

Example. da/dN is to be determined as a function of ΔK at rates of growth up to 10^{-6} m/cycle. The cycle counting device used shall therefore count in units not greater than 10^{-5} to 10^{-6} , i.e. in tens of cycles.



$$W \geq 10$$

$$0.2W \leq B \leq W$$

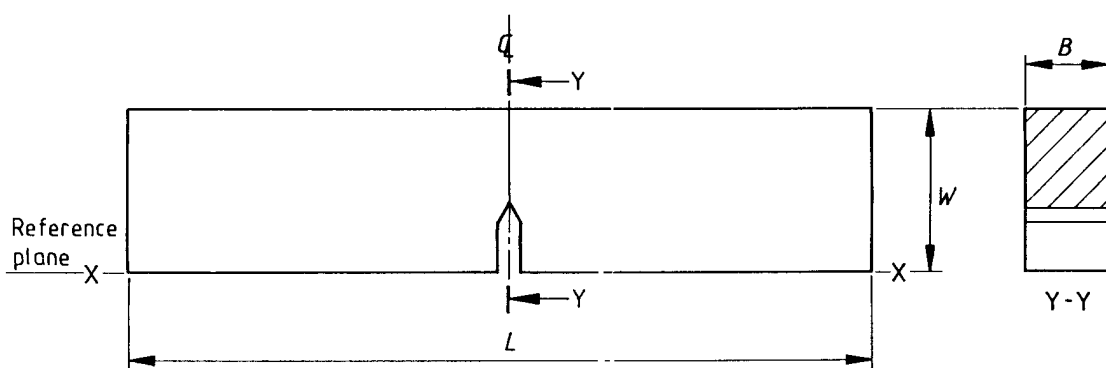
$$L \geq 4W + 10$$

NOTE 1. The crack length is measured from reference plane X-X.

NOTE 2. Specimen is unsuitable for $R \leq 0$.

All dimensions are in millimetres.

Figure 1. Three-point single edge notch bend specimen (SENB3)



$$W \geq 10$$

$$0.2W \leq B \leq W$$

$$L \geq (L_1 + L_2 + L_3 + 10)$$

NOTE. The crack length is measured from reference plane X-X.

All dimensions are in millimetres.

Figure 2. Four-point single edge notch bend specimen (SENB4)