

Methods of

Fatigue testing —

Part 1: Guide to general principles

Confirmed
January 2009

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Iron and Steel Standards Policy Committee (ISM/-) and Non-ferrous Metals Standards Policy Committee (NFM/-) to Technical Committee ISM/NFM/4, upon which the following bodies were represented:

- Aluminium Federation
- British Gas plc
- British Non-ferrous Metals Federation
- British Railways Board
- British Steel Industry
- Copper Development Association
- Department of Trade and Industry (National Measurement Accreditation Service)
- Department of Trade and Industry (National Physical Laboratory)
- ERA Technology Ltd.
- GAMBICA (BEAMA Ltd.)
- Ministry of Defence
- Society of British Aerospace Companies Limited
- University College London
- Welding Institute

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

- AEA Technology
- BCIRA
- Electricity Association
- University of Birmingham
- University of Portsmouth

This British Standard, having been prepared under the direction of the Iron and Steel and the Non-ferrous Metals Standards Policy Committees, was published under the authority of the Standards Board and comes into effect on 15 July 1993

© BSI 03-1999
First published July 1962
Second edition July 1993

The following BSI references relate to the work on this standard:
Committee reference ISM/NFM/4
Draft for comment 91/41694 DC

ISBN 0 580 21901 1

Amendments issued since publication

Amd. No.	Date	Comments

Contents

	Page
Committees responsible	Inside front cover
Foreword	ii
1 Scope	1
2 References	1
3 Symbols, terms and definitions	1
4 Preparing a test programme	8
5 Presentation of results	15
Figure 1 — Fatigue stress cycle	2
Figure 2 — Types of stress cycle with algebraic notation	3
Figure 3 — Stress-strain hysteresis loop	6
Figure 4 — Determination of fatigue crack growth rates by the three-point secant method	7
Figure 5 — A portion of the standard sequence “COLOS”	15
Figure 6 — S/N curve (linear stress scale)	17
Figure 7 — S/N curves (logarithmic stress scale)	17
Figure 8 — S/N curves corresponding to particular mean stresses (linear stress scale)	18
Figure 9 — S/N curves corresponding to particular stress ratios (logarithmic stress scale)	19
Figure 10 — Two proposed relationships between the level of mean stress and amplitude resulting in a given life	20
Figure 11 — Experimentally determined relationships between the level of mean stress and the cyclic stress amplitude resulting in given fatigue lives	21
Figure 12 — Strain amplitude versus number of cycles to failure	23
Figure 13 — Strain amplitude versus reversals to failure	23
Figure 14 — Relationship between $\sqrt{(\sigma_{\max} \varepsilon_a E)}$ and cycles to failure	24
Figure 15 — Definition of the cyclic $\sigma - \varepsilon$ curve	25
Figure 16 — Determination of the cyclic hardening coefficient and the cyclic hardening exponent	26
Figure 17 — Illustration of Masing's hypothesis	27
Figure 18 — Schematic da/dN versus ΔK curve for fatigue crack propagation at a fixed value of stress ratio	28
Table 1 — Symbols, terms and definitions relating to stress controlled fatigue testing	4
Table 2 — Symbols, terms and definitions relating to strain controlled fatigue testing	5
Table 3 — Symbols, terms and definitions relating to fatigue crack growth rate testing	8
Table 4 — Guidelines for the selection of the minimum number of test pieces and the minimum degree of replication	9
List of references	Inside back cover

Foreword

This Part of BS 3518 has been prepared under the direction of the Iron and Steel and the Non-ferrous Metals Standards Policy Committees. It is a revision of BS 3518-1:1962, which is withdrawn.

In the interim new methods of predicting fatigue life have been developed and, in parallel with them, new methods of test. Thus whilst as in the previous edition the determination of stress range-life relationships is covered, in addition strain-life tests are considered and also methods of determining the rate of growth of fatigue cracks. Guidance on the selection of test conditions and numbers of specimens is provided, but detailed test procedures are not described. For these the user is referred to the relevant British Standard method.

A British Standard does not purport to include all the 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 28, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This Part of BS 3518 recommends the general principles to be followed in conducting fatigue tests on metallic materials. It gives definitions of recommended terms, guidance on the planning of the tests, and describes effective methods for the graphical presentation of the results. The forms of fatigue testing considered encompass both the use of uncracked and precracked test pieces; the former under either stress or strain control, and the latter under stress control and within the limits imposed by linear elastic fracture mechanics. The general principles are presented initially in terms of the fatigue testing of plain test pieces under a constant amplitude loading in a normal laboratory environment. Subsequently the general principles are extended to include additional concepts and recommendations associated with the testing of notched test pieces or structural components, testing in different environments and testing under variable amplitude loadings. Welded test pieces are not covered.

2 References

2.1 Normative references

This Part of BS 3518 incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on the inside back cover. Subsequent amendments to, or revisions of, any of these publications apply to this Part of BS 3518 only when incorporated in it by updating or revision.

2.2 Informative references

This Part of BS 3518 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Symbols, terms and definitions

3.1 General

In this standard the term “fatigue” relates to the initiation and growth of cracks in metallic materials due to the repeated application of mechanical stresses or strains and any associated changes in mechanical properties. The term stress control is used to describe tests in which the force acting on a known specimen cross-sectional area is controlled, whilst strain control refers to tests in which the displacement of an extensometer of known gauge length is controlled.

A fatigue failure may result from a repeated axial, bending or torsional loading, applied separately or in any combination. For reasons of simplicity, the loadings considered in this standard are assumed to be axial with tension taken as positive and compression taken as negative. However the nomenclature used to describe this simple form of loading is equally applicable to other stress systems.

3.2 Constant amplitude stress controlled testing

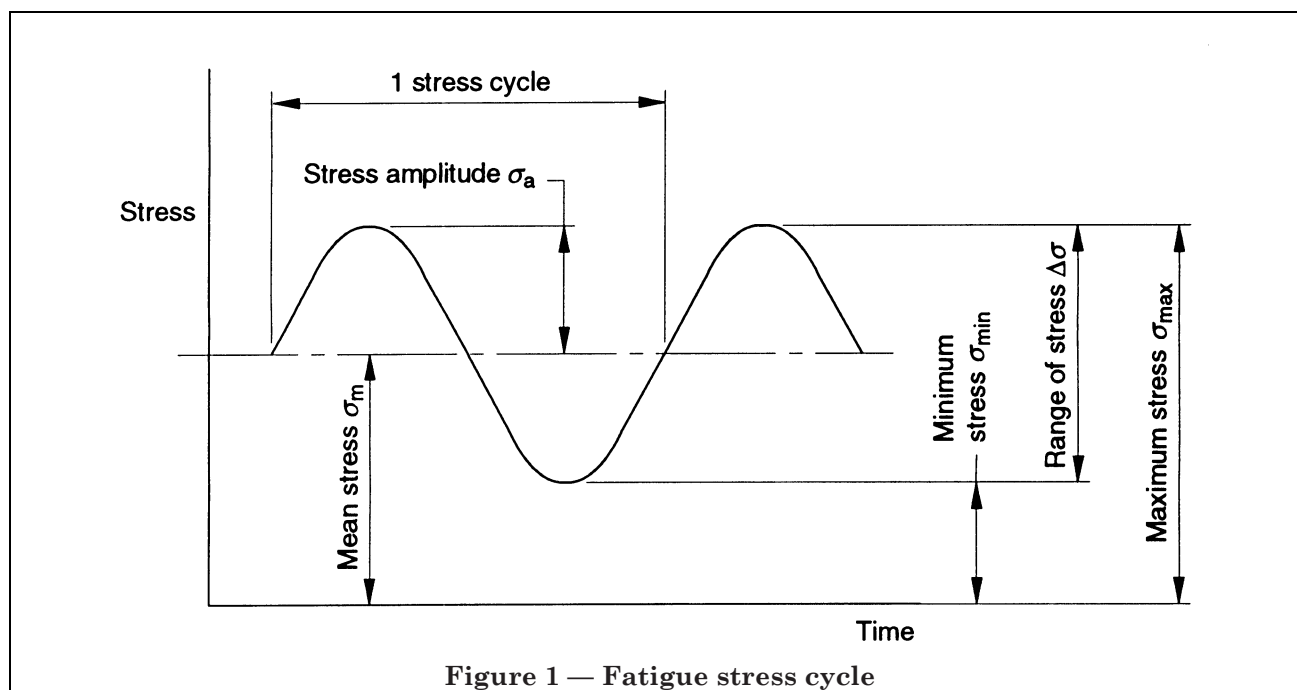
The stresses observed in service or used in testing may be of a simple repetitive form. In general the stresses considered in a fatigue test will be nominal stresses calculated from the measured loads and with reference to the net section under consideration. Conventional elastic formulae will be used. However sometimes they may be calculated from measured strains provided these are within the elastic limit.

The smallest section of the stress-time function which is repeated periodically is the stress cycle. This is shown for a sinusoidal cycle in Figure 1.

Figure 1 also shows that any stress varying periodically over a given range ($\Delta\sigma$) between limits $\sigma_{\max}$ and $\sigma_{\min}$ can also be regarded as the sum of a static stress (the mean stress, σ_m) and a cyclic stress of zero mean varying between two values opposite in sign, but equal in magnitude (the stress amplitude, σ_a).

The stress cycles may take any of the forms shown in Figure 2. The stress ratio, that is the algebraic ratio of the minimum stress to the maximum stress in one cycle, has a value which is greater than unity for cycles of fluctuating compression, less than zero for reversed cycles, and between zero and unity for cycles of fluctuating tension.

The recommended symbols, terms and definitions relating to stress controlled fatigue testing are summarized in Table 1. Terms related to stress are also exemplified in Figure 1 and Figure 2.



3.3 Constant amplitude strain controlled testing

When strain cycles are applied to a test piece such that a macroscopic plastic strain is repeatedly developed within the test piece, this has two significant effects. First, the observed fatigue life is greatly reduced compared to that achieved if no significant macroscopic plastic strain repeatedly develops. Typically the fatigue life is less than 100 000 cycles to failure and therefore the test regime is said to be that of low cycle fatigue. Second, a stress-strain hysteresis loop is developed. Frequently it is observed that the shape of the hysteresis loop changes under cyclic loading in response to the processes of cyclic hardening or softening of the material. The initial changes are the greatest, but they progressively decline so that by 20 % to 40 % of the fatigue life of a test piece a stable hysteresis loop is generally established. Figure 3 shows how the total strain range of a hysteresis loop can be divided into the plastic strain range and elastic strain range components by means of simple working definitions. The maximum, minimum and mean strains are defined in an analogous manner to that used previously for defining stress cycles, the same algebraic notation being recommended.

Table 2 summarizes the recommended symbols, terms and definitions which relate to strain controlled fatigue testing.

3.4 Fatigue crack growth rate testing

Direct measurement of fatigue crack growth rates in engineering materials, under conditions where they remain predominantly elastic, has shown that the rate is primarily related to the range of stress intensity factor and not the stress amplitude. The stress intensity factor characterizes the elastic stress field in the vicinity of the crack tip, and also indicates the magnitude of the monotonic plastic zone developed at the crack tip itself. For the opening mode of crack surface displacement, in which the crack surfaces move directly apart, the stress intensity factor (K) is defined by the relationship:

$$K = \frac{PY}{B\sqrt{W}} \quad (1)$$

where

- P is the applied force;
- B is the test piece thickness;
- W is the test piece width;
- Y is the stress intensity factor function (obtained from Table 2 to Table 5 of BS 6835:1988).

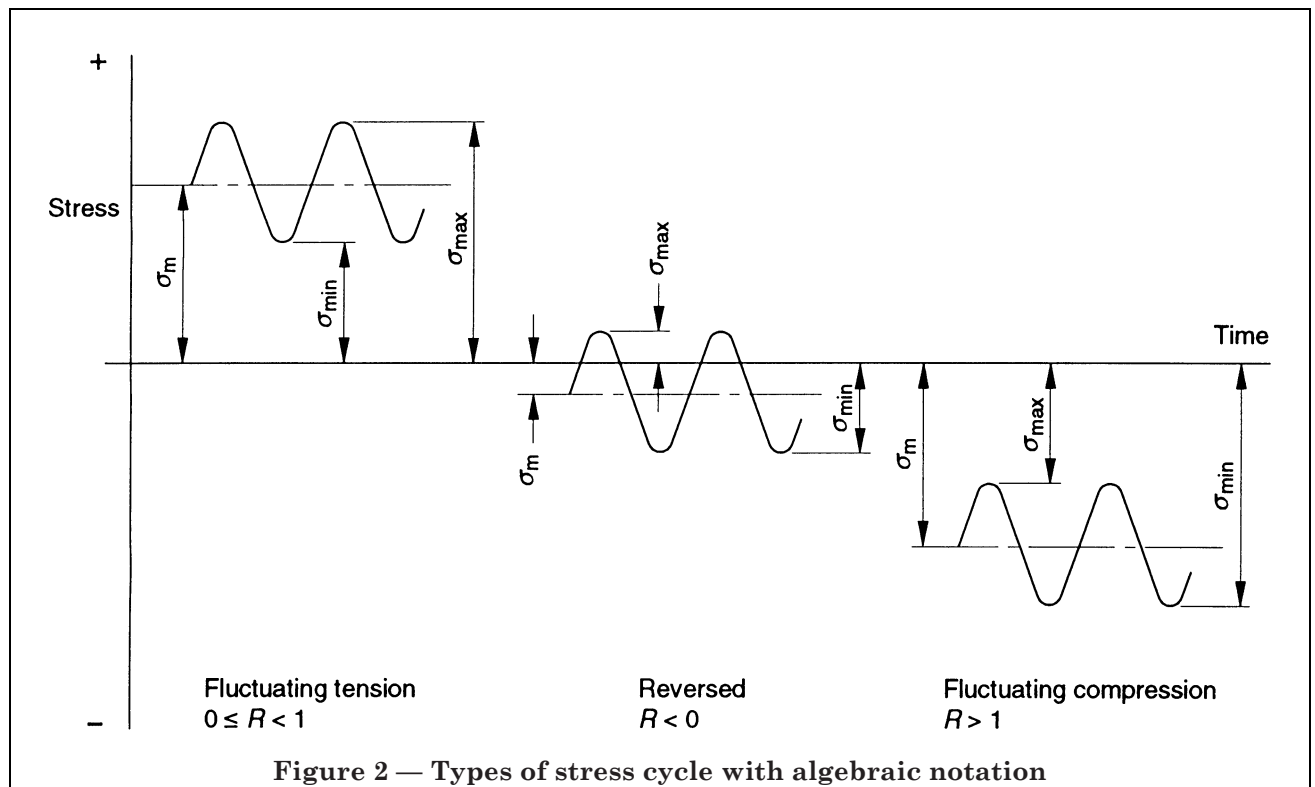
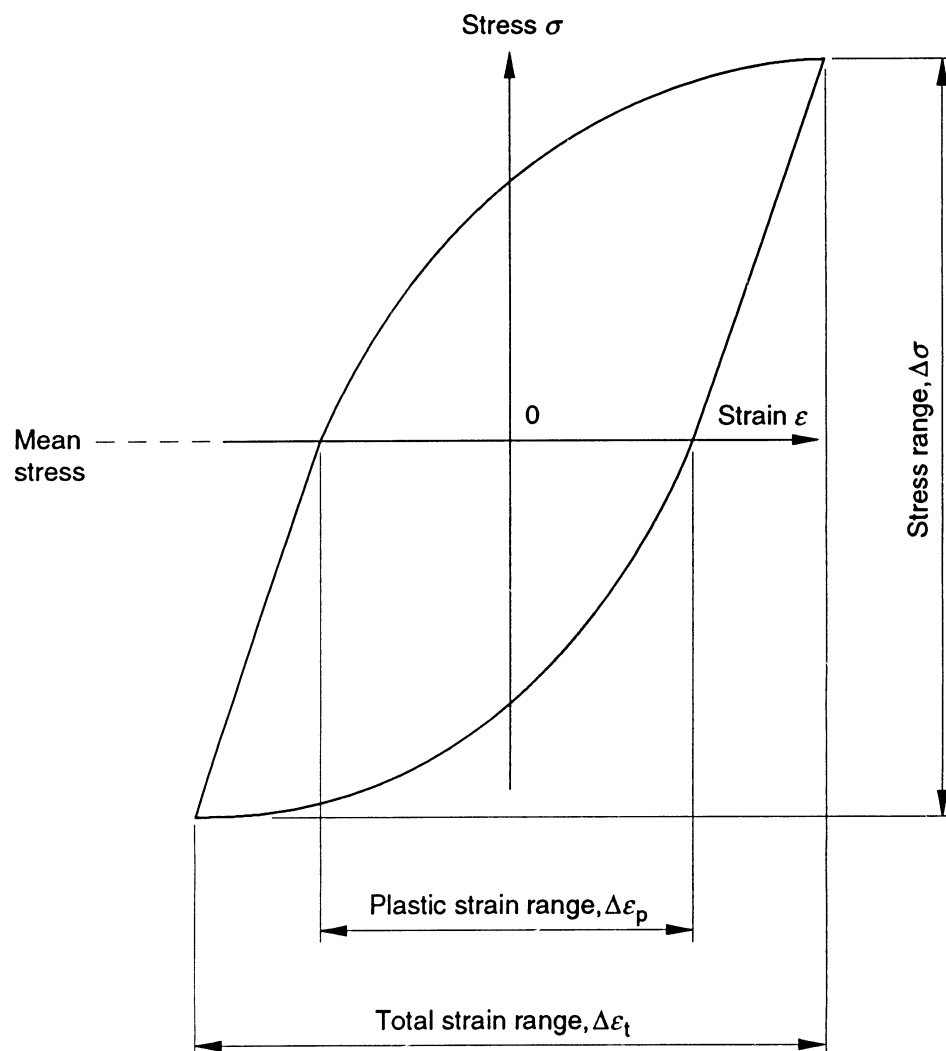


Table 1 — Symbols, terms and definitions relating to stress controlled fatigue testing

Symbol	Term	Definition
σ or S	Stress	The force applied divided by the original cross-sectional area; tensile stress is considered positive and compressive stress negative.
$\sigma_{\max}$	Maximum stress	The highest algebraic value of stress in the stress cycle.
$\sigma_{\min}$	Minimum stress	The lowest algebraic value of stress in the stress cycle.
σ_m	Mean stress	Half of the algebraic sum of the maximum and minimum stresses.
σ_a	Stress amplitude	Half of the algebraic difference between the maximum and minimum stresses.
$\Delta\sigma$	Range of stress	The algebraic difference between the maximum and minimum stresses.
R	Stress ratio	The algebraic ratio of the minimum stress to the maximum stress in one cycle.
n	Number of stress cycles	The number of cycles applied.
f	Frequency of cycles	The number of cycles applied per second.
N or N_f	Endurance or fatigue life	The number of stress cycles to failure. NOTE This is generally stated as decimal fractions or multiples of 10^6 .
σ_N	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. NOTE If no probability is stated 50 % is implied. If no stress ratio is stated a value of -1 is implied.
σ_D	Fatigue limit	The value of the stress amplitude below which the test piece would be expected to endure an infinite number of stress cycles with a stated probability. NOTE Certain materials do not show a fatigue limit. Others only show a fatigue limit in certain environments.
K_t	Theoretical stress concentration factor	The ratio of the notch tip stress, calculated in accordance with elastic theory, to the net section stress.
K_f	Fatigue strength reduction factor	The ratio of the fatigue strength at a specified life for a plain polished test piece to that of a test piece with a stress concentration, expressed in terms of net section stress. NOTE The values of K_f commonly quoted usually refer to the fatigue limit.
FLF	Fatigue life factor	The ratio of the mean fatigue life at a specified stress amplitude of samples of treated test pieces to that of untreated test pieces. NOTE Treated test pieces are those to which a thermal or mechanical process has been applied in order to assess the effect of that process on fatigue behaviour.

Table 2 — Symbols, terms and definitions relating to strain controlled fatigue

Symbol	Term	Definition
ϵ	Strain	The extension of the gauge length divided by the original gauge length. It is taken to be positive when the gauge length increases in length and negative when it contracts.
$\epsilon_{\max}$	Maximum strain	The highest algebraic value of strain in the strain cycle.
$\epsilon_{\min}$	Minimum strain	The lowest algebraic value of strain in the strain cycle.
ϵ_m	Mean strain	One-half the algebraic sum of the maximum and minimum strain.
$\Delta\epsilon_t$	Total strain range	The algebraic difference between the maximum and minimum strain in one strain cycle.
$\Delta\epsilon_p$	Plastic strain range	The width of the hysteresis loop of stress plotted against strain, determined at the mean stress.
$\Delta\epsilon_e$	Elastic strain range	The difference between the total strain range and the plastic strain range.
ϵ_a or $\Delta\epsilon_t/2$	Strain amplitude	Half the total strain range.
$\Delta\epsilon_p/2$	Plastic strain amplitude	Half the plastic strain range.
$\Delta\epsilon_e/2$	Elastic strain amplitude	Half the elastic strain range.
$2N_f$	Fatigue life in reversals	The number of reversals, or half cycles, to failure (see 5.2).
b	Fatigue strength exponent	The slope of the “elastic” line obtained by plotting the logarithm of the elastic strain amplitude at half-life as the ordinate and the logarithm of the number of reversals to failure as the abscissa, the mean stress being zero (see 5.2.1).
σ'_f	Fatigue strength coefficient	The stress amplitude corresponding to a life of one reversal, obtained by extrapolating the “elastic” line (see above).
c	Fatigue ductility exponent	The slope of the “plastic” line obtained by plotting the logarithm of the plastic strain amplitude at half-life as the ordinate and the logarithm of the number of reversals to failure as the abscissa, the mean stress being zero (see 5.2.1).
ϵ'_f	Fatigue ductility coefficient	The plastic strain amplitude corresponding to a life of one reversal obtained by extrapolating the “plastic” line (see above).
n'	Cyclic hardening exponent	The slope of the line obtained by plotting the logarithm of the stress amplitude at half-life as the ordinate and the logarithm of the half-life plastic strain amplitude as the abscissa, the mean stress being zero (see 5.2.2).
K'	Cyclic hardening coefficient	The stress amplitude corresponding to a plastic strain amplitude of unity; obtained by plotting the logarithm of the stress amplitude at half-life as the ordinate and the logarithm of the half-life plastic strain amplitude as the abscissa, the mean stress being zero (see 5.2.2).



$$\text{Elastic strain range, } \Delta\epsilon_e = \Delta\epsilon_t - \Delta\epsilon_p$$

NOTE In general in a strain controlled fatigue test the mean stress tends to be zero. In some materials, e.g. grey cast iron, the mean stress may not be zero.

Figure 3 — Stress-strain hysteresis loop

For a constant amplitude fatigue loading, the stress intensity factor range (ΔK) is given by:

$$\Delta K = K_{\max} - K_{\min} \quad (2)$$

this parameter being indicative of the size of the small cyclic plastic zone which is located at the crack tip and contained within the monotonic plastic zone.

By simultaneously measuring values of crack length and the number of cycles applied to a precracked specimen, the fatigue crack growth rate may be obtained. Figure 4 shows the three-point secant construction used to estimate the fatigue crack growth rate from any three consecutive points having the co-ordinates (N_{j-1}, a_{j-1}) , (N_j, a_j) and (N_{j+1}, a_{j+1}) . According to this method, the growth rate is given by the gradient of the line connecting the first and the third of these three points. Thus:

$$\left(\frac{da}{dN}\right)_j = \frac{a_{j+1} - a_{j-1}}{N_{j+1} - N_{j-1}} \quad (3)$$

and the corresponding value of ΔK is calculated using the value of Y for the test piece employed and a crack length of a_j . The values of N_j and a_j are recorded at equal intervals of a .

Table 3 summarizes the recommended symbols, terms and definitions which relate to fatigue crack growth rate testing.

