BS 18 : 1987

UDC [669 : 620.172.24] + 629.7.02-034

British Standard Method for

Tensile testing of metals (including aerospace materials)

Méthode d'essai en traction des métaux (y compris les matériaux pour l'aérospatiale)

Zugprüfung an Metallen (einschließlich solcher für die Luft- und Raumfahrt)

British Standards Institution

Foreword

This British Standard, which has been prepared under the direction of the Iron and Steel and the Non-ferrous Metals Standards Committee, is a revision of BS 18 : Part 1 : 1970 and Parts 2 to 4 : 1971, which are withdrawn. It also incorporates requirements for tensile tests previously given in Section one of Part 1 of British Standard 4A4 : 1966 which is being deleted by amendment.

No new major concepts have been introduced. The appropriate tensile properties have been referred to throughout as strengths rather than stresses. Implicit in these strength definitions is the knowledge that multiaxial loading and/or the presence of notches can change the values of the applied stress at which yield and rupture may occur in a particular material. However, consideration of established and accepted testing practices now in common use, as well as the outcome of the recent work of the International Organization for Standardization (ISO), indicated a sufficient degree of commonality in application to different product forms to allow the standard to revert to one Part. This change has been facilitated by the elimination of the need to determine the K-value (apparent elastic compliance) of the tensile testing system. This has followed a corresponding action in international standards. Attention is drawn to the fact that in ISO 6892 there is no definition of extension and that the definition given for elongation differs from that in BS 18.

Procedures relating to tensile testing of metals at room temperature are described. Testing at elevated temperatures is described in BS 3688 and British Standard 4A4 : Part 1 : Section two : 1967.

Details of procedures that may be specifically applicable to particular metals and alloys are not described.

Provision is not made for testing some forms of product such as very thin foil or products of asymmetrical shape for which demands for accurate measurement of strength are often very limited. Although the procedures described in this standard might be applied to such products, the values obtained would not necessarily be recommended or chosen for use as a basis for acceptance test purposes.

The opportunity has been taken to clarify the significance of some features from earlier Parts of BS 18. Also the greater importance of using unmachined test pieces including those 'as cast' in view of economic considerations has been recognized by the committee. Requirements for tolerances upon measurement of cross-sectional area have been introduced to eliminate any uncertainty regarding the validity of tests carried out on such specimens.

Features that require a decision based fundamentally upon metallurgical considerations, e.g. the position in a product from which a test piece is selected, have been eliminated from this edition.

Testing of metals and alloys complying with the aerospace series of British Standards calls for a small number of special requirements; these requirements have been incorporated into this revision of BS 18 and are referred to in relevant clauses as category 2 requirements.

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

Contents

	Page
Foreword	Inside front cover
Committees responsible	Back cover
Method	
1 Scope	2
2 Definitions	2
3 Symbols and designations	3
4 Principle	3
5 Apparatus	3
6 Shape and dimensions of test piece	5
7 Preparation of test pieces	7
8 Determination of original cross-sectional area (S_o)	7
9 Accuracy of testing equipment	7
10 Temperature of test	8
11 Test procedure	8
12 Test report	10
Appendices	
A Verification of permanent set strength by proving tests	11
B Proving tests for proof strength	11
Tables	
1 Symbols and designations	4
2 Preferred dimensions of circular cross section machined test pieces	5
3 Preferred dimensions of rectangular section test pieces	6
4 Grading of extensometers	8
5 Rate of stressing	8
6 Measurement of gauge lengths for the determination of percentage elongation	10
Figures	
1 Force/extension diagrams illustrating yield	12
2 Force/extension diagram illustrating tensile strength	12
3 Force/extension diagrams illustrating proof strength extension values	13
4 Force/extension diagram illustrating permanent set strength	13
5 Force/extension diagram illustrating proof strength (non-proportional extension)	13
6 Four-point method for the determination of proof strength	14
7 Round and flat test pieces	14
8 Test pieces from tube before and after fracture	15
9 Grip for thin test pieces	16

Method

1 Scope

This British Standard describes the method of tensile testing of metallic materials at room temperature to determine the following properties: yield strength; proof strength; tensile strength; elongation; reduction of area. It incorporates procedures for materials complying with the aerospace series of British Standards. Appendices A and B describe proving tests for the verification of permanent set strength and proof strength. This standard is not applicable to steel wire.

NOTE 1. Steel wire is a major metallurgical product for which tensile and other mechanical tests are normally demanded. The relevant requirements, many of which are specific to steel wire, are described in BS 4545.

NOTE 2. 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 Terms relating to test pieces

2.1.1 test piece. The portion of the test sample on which the tensile test is carried out.

2.1.2 proportional test pieces. Test pieces with gauge lengths having a specified relationship to the square root of the cross-sectional area.

NOTE. As proportionality is related only to cross-sectional area and the specimen gauge length and not to the overall geometry a proportional test piece may have a cross section of any shape.

2.1.3 non-proportional test pieces. Test pieces the gauge length of which does not have any specified relationship to the square root of the cross-sectional area.

2.2 Terms relating to test piece gauge length

2.2.1 gauge length. Length of the cylindrical or prismatic portion of the test piece defined and used for measurement of elongation or extension.

2.2.2 original gauge length (L_o). The test piece gauge length before the application of force.

2.2.3 final gauge length (L_u). The test piece gauge length after rupture, the pieces having been carefully fitted together so that their axes are aligned.

2.2.4 extensometer gauge length (L_e). The length of the parallel portion of the test piece used for the measurement of extension by means of an extensometer. (This length may differ from L_o and is of any value greater than the width (b) or diameter (d or D) of the test piece but less than its overall parallel length (L_c).)

2.3 Terms relating to elongation

2.3.1 elongation. The increase in the original gauge length (L_o) at the conclusion of the test.

2.3.2 percentage permanent elongation. The increase in the original gauge length of a test piece after removal of a specified stress (see **2.6.8**), expressed as a percentage of the original gauge length (L_o).

2.3.3 percentage elongation after fracture (A). The permanent elongation of the gauge length after fracture ($L_u - L_o$), expressed as a percentage of the original gauge length (L_o).

NOTE. In the case of proportional test pieces, if the original gauge length is other than $5.65\sqrt{S_o}$* (where S_o is the original cross-sectional area of the parallel length), the symbol A should be supplemented by an index indicating the coefficient of proportionality (k) used, for example, $A_{11.3}$ is the percentage elongation on a gauge length (L_o) of $11.3\sqrt{S_o}$.

In the case of non-proportional test pieces, the symbol A should be supplemented by an index indicating the original gauge length used expressed in millimetres, for example, $A_{80\ mm}$ is the percentage elongation on a gauge length (L_o) of 80 mm.

2.3.4 percentage total elongation at fracture (A_t). The total elongation (elastic elongation plus plastic elongation) of the gauge length at the moment of fracture, expressed as a percentage of the original gauge length (L_o).

2.3.5 coefficient of proportionality (k). The ratio of the original gauge length (L_o) divided by the square root of the original cross-sectional area (S_o).

2.4 Terms relating to extension

2.4.1 extension. The increase of the extensometer gauge length (L_e) in excess of its original length at any moment during the test.

2.4.2 percentage yield point extension (Lüders extension) (A_e). The extension between the start of yielding giving localized deformation and the commencement of homogeneous deformation giving smooth work hardening.

NOTE. It can be measured from the force/extension diagram as shown in figure 1, or from a stress-strain diagram.

It is expressed as a percentage of the extensometer gauge length (L_e).

2.4.3 percentage permanent extension. The increase in the extensometer gauge length of a test piece after the removal of a specified stress, expressed as a percentage of the extensometer gauge length (L_e) (see **2.6.8**).

2.4.4 strain. The ratio of extension to original length expressed either as a decimal value or as a percentage.

2.5 Reduction of area

2.5.1 percentage reduction of area (Z). The maximum change in cross-sectional area ($S_o - S_u$) that occurs during the test, expressed as a percentage of the original cross-sectional area (S_o).

2.6 Terms relating to stress

2.6.1 stress. The force at any moment during the test divided by the original cross-sectional area (S_o) of the test piece.

* $5.65\sqrt{S_o} = 5\sqrt{\frac{4}{\pi}S_o} = 5d$.

2.6.2 tensile strength (R_m). The stress corresponding to the maximum force (see figure 2).

2.6.3 yield strength (R_e). The stress at the point reached during the test when plastic deformation occurs without any increase in the force, in material exhibiting a yield phenomenon.

NOTE. A distinction is made between upper and lower yield strength values as described in **2.6.4** and **2.6.5** respectively.

2.6.4 upper yield strength (R_{eH}). The value of stress at the moment when the first decrease in force at yield is observed (see figure 1).

2.6.5 lower yield strength (R_{eL}). The lowest value of stress during plastic yielding, ignoring any transient effects (see figure 1).

2.6.6 proof strength (non-proportional extension) (R_p). The stress at which a non-proportional extension (plastic extension only) is equal to a specified percentage of the extensometer gauge length (L_e) (see figure 3(a) and figure 5). The symbol used is followed by a suffix giving the prescribed percentage of the extensometer gauge length, for example $R_{p0.2}$.

2.6.7 proof strength (total extension) (R_t). The stress at which the total extension (elastic extension plus plastic extension) is equal to a specified percentage of the extensometer gauge length (L_e) (see figure 3(b)). The symbol used is followed by a suffix giving the prescribed percentage of the extensometer gauge length, for example $R_{t0.5}$.

2.6.8 permanent set strength (R_r). The stress at which, after removal of force, a specified permanent extension or elongation, expressed respectively as a percentage of the extensometer gauge length (L_e) or the original gauge length (L_o) has not been exceeded (see figure 4 and appendix A). The symbol used is followed by a suffix giving the specified percentage of the gauge length, for example $R_{r0.2}$.

2.6.9 Young's modulus of elasticity. The ratio of stress to strain during the elastic behaviour of the test piece.

2.7 Materials

2.7.1 category 1. Materials tested in accordance with standards other than the aerospace series of British Standards.

2.7.2 category 2. Materials tested in accordance with the aerospace series of British Standards.

3 Symbols and designations

The symbols and designations used for the purposes of a tensile test shall be as given in table 1 and shown in figures 1 to 8.

4 Principle

The test consists of straining a test piece, by tensile force, generally to fracture, and recording the relationship between force and extension, for the purpose of determining one or more of the tensile properties given in clause **1**.

5 Apparatus

5.1 *Tensile testing machine*, with a force range suitable for the material being tested, calibrated in accordance with **9.1** and **9.2**.

5.2 *Extensometer*, complying with **9.3**, for extension measurements.

5.3 *Wedge grips, screwed or shouldered holders*, or other positive means of holding the test piece (see figure 9) in such a way that the load is applied axially.

NOTE 1. Wires should be held using gripping arrangements that minimize the likelihood of failure of the test piece in or adjacent to the grips.

NOTE 2. The efficiency of the gripping surfaces may be improved, if desired, by fine serrations.

Table 1. Symbols and designations

Symbol	Unit	Designation
Test piece dimensions		
a	mm	Thickness of a flat test piece or wall thickness of a tube
b	mm	Width of the parallel length of a flat test piece or average width of the longitudinal strip taken from a tube or width of flat wire
d	mm	Diameter of the parallel length of a circular test piece, or diameter of round wire or internal diameter of a tube
D	mm	External diameter of a tube
k	—	Coefficient of proportionality
L_o	mm	Original gauge length
L_c	mm	Parallel length
L_e	mm	Extensometer gauge length
L_t	mm	Total length of test piece
L_u	mm	Final gauge length after fracture
r	mm	Transition radius
S_o	mm^2	Original cross-sectional area of the parallel length
S_u	mm^2	Minimum cross-sectional area after fracture
Tensile properties		
A^*	%	Percentage elongation after fracture
A_t	%	Percentage total elongation at fracture
A_e	%	Percentage yield point extension
R_e	N/mm^2	Yield strength
R_{eH}	N/mm^2	Upper yield strength
R_{eL}	N/mm^2	Lower yield strength
R_m	N/mm^2	Tensile strength
R_p	N/mm^2	Proof strength (non-proportional extension)
R_r	N/mm^2	Permanent set strength
R_t	N/mm^2	Proof strength (total extension)
Z	%	Percentage reduction of area

* See **2.3.3**.

NOTE. N/mm^2 = MPa.

6 Shape and dimensions of test piece

6.1 General

NOTE 1. The shape and dimensions of test pieces are dependent on the form and dimensions of the products of which the tensile properties are to be determined. It is not possible to specify a single standard tensile test piece because of the wide variety of forms and dimensions.

NOTE 2. The test piece is usually obtained by machining a sample from the product or a blank or casting. However, products of constant cross section (e.g. sections, bars, wires, tubes) and also cast test bars (e.g. malleable cast iron, white cast iron, non-ferrous alloys) may be subjected to test without being machined.

For the purposes of this standard two types of test piece, proportional and non-proportional are specified.

All test pieces of circular cross section, whether machined or unmachined, shall be regarded as, and tested as, proportional test pieces (see **2.1.2**) unless otherwise specified in the relevant product standard.

Test pieces of rectangular section shall be regarded as non-proportional test pieces (see **2.1.3**) unless the gauge length has the relationship to the cross-sectional area specified for proportional test pieces. Test pieces of square cross section shall be regarded as rectangular test pieces in which the width is equal to the thickness.

NOTE 3. Requirements for proportional and non-proportional test pieces are given in **6.2** and **6.3**, and the shapes and dimensions of test pieces taken from wires and tubes are specified in **6.4** and **6.5**.

NOTE 4. This standard does not specify the size and shape of test pieces to be used for specific types of metallic products. The relevant product standard and/or inspection procedure should specify, where necessary, the type of tensile test piece to be used.

6.2 Proportional test pieces (see 2.1.2)

For proportional test pieces the relationship between gauge length and cross-sectional area is given by:

$$L_o = k\sqrt{S_o}$$

NOTE 1. By international agreement this relationship has been established as $L_o = 5.65\sqrt{S_o}$.

The original gauge length shall be not less than 20 mm and when the cross-sectional area is too small for this requirement to be met a multiple value of k shall be used (e.g. $k = 11.3$).

Test pieces of circular cross section shall have the specified relationship between L_o and S_o, but preferred dimensions are given in table 2.

NOTE 2. Where $k = 5.65$ the value of $L_o = 5d$.

The following dimensions and tolerances shall apply to all proportional test pieces:

(a) The minimum parallel length (L_c) shall equal 5.5 × the nominal diameter (d);

(b) The tolerance on diameter shall be ± 0.5 % for category 1 materials and ± 0.25 % for category 2 materials;

(c) The minimum transition radius (r) shall be approximately equal to or greater than the nominal diameter (d);

(d) The parallel length shall not vary in diameter by more than 0.03 mm;

(e) The gripped ends of a machined test piece of circular cross section shall be co-axial with the parallel portion within a tolerance of 0.03 mm.

NOTE 3. If a gauge length of $5.65\sqrt{S_o}$ is used, the calculated values of L_o may be rounded off to the nearest multiple of 5 mm provided that the difference between the calculated and marked gauge length is less than 10 % of L_o.

Table 2. Preferred dimensions of circular cross section machined test pieces (see figure 7)

Nominal diameter d	Nominal cross-sectional area S_o	Original gauge length $L_o = 5.65\sqrt{S_o}$	Minimum parallel length $L_c = 5.5d$	Minimum transition radius r	Tolerance on diameter: Category 1 (see **2.7.1**)	Tolerance on diameter: Category 2 (see **2.7.2**)
mm	mm^2	mm	mm	mm	mm	mm
22.56	400	113	124	23.5	± 0.11	± 0.06
15.96	200	80	88	15	± 0.08	± 0.04
13.82	150	69	76	13	± 0.07	± 0.04
11.28	100	56	62	10	± 0.06	± 0.03
10.00	78.5	50	55	9	± 0.05	± 0.03
7.98	50	40	44	8	± 0.04	± 0.02
5.64	25	28	31	6	± 0.03	± 0.02
5.00	19.6	25	28	6	± 0.03	± 0.02
3.99	12.5	20	22	4	± 0.02	± 0.01

6.3 Non-proportional test pieces

NOTE 1. Use of non-proportional test pieces may be required by standards for metallurgical products. They may also be used for convenience when it is required to maintain a constant gauge length between specimens of differing cross-sectional area or where it is impractical to maintain a specified relationship between the gauge length and the cross-sectional area.

Non-proportional test pieces shall have the following dimensions and tolerances, but preferred dimensions of test pieces of rectangular cross section are given in table 3.

(a) The original gauge length (L_o) shall equal at least 4 × the nominal width (b).

(b) The minimum transition radius shall be 25 mm or 2 × the nominal width (b), whichever is the least.

(c) The minimum parallel length shall be $L_o + \frac{b}{2}$.

(d) The tolerance on gauge length (L_o) shall be ± 1 %.

NOTE 2. A test piece may also consist of a strip with parallel sides when specified by the product standard. For products of width equal to or less than 20 mm, the width of the test piece may be the same as that of the product.

NOTE 3. In the case of a parallel sided test piece less than 20 mm wide, and unless otherwise specified in the product standard, the original gauge length (L_o) should be equal to 50 mm. For this type of test piece, the free length between the grips should be not less than 1.5 × L_o.

6.4 Test pieces from bars and sections of diameter or thickness less than 4 mm and non-ferrous wires of diameter or thickness less than 6 mm

NOTE 1. The test piece is generally a parallel-sided unmachined portion of the product.

The original gauge length (L_o) shall be either 200 ± 2 mm or 100 ± 1 mm unless specified otherwise in the product standard. The distance between the grips of the machine shall be at least L_o + 50 mm, i.e. 250 mm and 150 mm, respectively, except in the case of wires where this distance may be equal to L_o.

NOTE 2. In cases where the percentage elongation after fracture is not to be determined, a distance between the grips of at least 50 mm should be used.

6.5 Test pieces from tubes

6.5.1 *General.* The test piece shall consist of one of the following:

(a) a length of tube;

(b) a longitudinal or transverse strip cut from the tube and having the full thickness of the tube wall (figure 8);

(c) a test piece of circular cross section machined from the wall of the tube.

6.5.2 *Length of tube.* Where the test piece consists of a length of tube, the elongation after fracture shall be determined on an original gauge length (L_o) of 50 mm or on a gauge length of 5.65 $\sqrt{S_o}$ if required by the product standard.

NOTE. It should preferably be plugged at both ends to prevent collapse.

The free length between each plug and the nearest gauge marks shall exceed $D/4$. In cases of dispute, the value D shall be used.

6.5.3 *Longitudinal or transverse strip.* For test pieces taken from longitudinal or transverse strips of tube, the elongation after fracture shall be determined on an appropriate original gauge length (L_o) selected from the values given in table 3 or on a gauge length of 5.65 $\sqrt{S_o}$ if required by the product standard.

The parallel length (L_c) shall not be flattened.

NOTE 1. The ends may be flattened for gripping in the testing machine.

NOTE 2. Special precautions should be taken when straightening any test pieces taken from transverse sections of tubes. Such sections are normally taken from large diameter tubes to conserve material.

6.5.4 *Machined circular test piece from a cross section of the tube wall.* The position in the tube from which the test sample is taken shall be as given in the product standard. The dimensions of the circular test piece shall comply with **6.2** but preferred dimensions are given in table 2.

Table 3. Preferred dimensions of rectangular section test pieces (see figure 7)

Nominal width b	Maximum variation in width	Original gauge length L_o	Minimum transition radius r	Approximate total length L_t	Minimum parallel length $L_o + \frac{b}{2}$
mm	mm	mm	mm	mm	mm
50	0.1	200	25	450	225
20	0.1	200	25	450	210
25	0.1	100	25	300	112.5
20	0.1	80	25	250	90
12.5	0.03	50	25	200	56.25
6	0.03	25	12	100	28
3	0.03	12.5	6	50	14

7 Preparation of test pieces

7.1 Machined test pieces

Circular and rectangular machined test pieces shall incorporate a transition curve between the gripped ends and the parallel length. The dimensions of this transition radius are important and shall comply with **6.2** and shall be as given in tables 2 and 3.

NOTE. The gripped ends should be of a shape to suit the grips of the testing machine.

7.2 Unmachined test pieces

When the test piece consists of an unmachined length of the product or of an unmachined or an as-cast test bar, the free length between the grips shall be a minimum of 1.5 × the gauge length (L_o).

NOTE. If a product is delivered coiled, care should be taken when straightening the sample required for the test piece to avoid affecting the properties determined in the subsequent test.

7.3 Separation of test piece from test sample

NOTE 1. The method employed in fabricating the test piece from the test sample should minimize deformation and heating of that part of the test piece to be used for measurements.

Any areas of test pieces that have been hardened during their preparation by flame cutting, shearing or blanking shall be removed by machining.

For routine testing of sheet and strip, test pieces may be produced by blanking, but in cases of dispute the tests shall always be carried out on machined test pieces.

NOTE 2. Care is especially necessary when measurement of the proof strength or permanent set strength is to be made. The best method of cutting is usually by sawing. If the test piece is sheared or flame-cut, adequate allowance on dimensions should be allowed for subsequent machining.

NOTE 3. For relatively thin materials which would deform in machining, it is recommended that strips of identical width are cut and assembled into a bundle with intermediate layers of paper which is resistant to the cutting oil. It is recommended that each small bundle of strips is assembled with a thicker strip on each side, before machining to the final dimensions of the test piece.

8 Determination of original cross-sectional area (S_o)

8.1 General

Calculate the cross-sectional area from measurements of the appropriate dimensions in at least two positions with an error of:

(a) for category 1 materials, not more than ± 0.5 % or 0.01 mm in each dimension, whichever is the greater;

(b) for category 2 materials, not more than ± 0.2 % or 0.005 mm whichever is the greater.

NOTE 1. For test pieces of circular cross section complying with the tolerances given in table 2 the nominal dimensions may be used for calculation of the cross-sectional area.

NOTE 2. For unmachined bar or any specimen that is uniformly parallel, the cross-sectional area may be obtained by dividing the mass of the test piece by the product of its original length and the density of the material, provided the density of the material is known to within an accuracy of ± 1 %.

8.2 Unmachined test pieces from flats

In the case of test pieces prepared from flat products whose width is the same as that of the product, calculate the original cross-sectional area (S_o) from the average of three measurements of both the thickness and the width taken at approximately equidistant positions.

8.3 Tubes

In the case of a length of tube, calculate the original cross-sectional area (S_o) using the following equation:

$$S_o = \pi a\,(D - a)$$

where

D is the nominal external diameter of the tube;

a is the thickness of the tube wall.

For test pieces consisting of a longitudinal strip, calculate the original cross-sectional area S_o using either the following equation, or one that gives a more accurate result.

$$S_o = ab\left[1 + \frac{b^2}{6D\,(D - 2a)}\right]$$

where

a is the thickness of the tube wall;

b is the average width of the longitudinal strip;

D is the nominal external diameter of the tube.

Calculate the original cross-sectional area (S_o) of a test piece consisting of a transverse strip taken from a tube using the following equation:

$$S_o = ab$$

where

a is the thickness of the tube wall;

b is the average width of a transverse strip taken from a tube.

8.4 Tolerance on measurement of cross-sectional area of castings

Determine the transverse cross-sectional area of cast specimens by direct measurement and calculation to an accuracy of ± 1 %.

9 Accuracy of testing equipment

9.1 General

The calibration of measuring apparatus shall be traceable to the National Physical Laboratory either directly or indirectly through a hierarchical chain such as that provided by the British Calibration Service in accordance with the accuracy demanded by the test. This includes automatic equipment used for the determination of any one of the parameters described in clause **11**. The performance of automatic equipment shall be validated by manual methods at appropriate periods.

9.2 Testing machine

The testing machine shall be calibrated in accordance with BS 1610 : Part 1 and maintained to grade 1.0 requirements or better unless otherwise specified in the material specification.

NOTE. If the machine is to be used for the determination of proof strengths, verification of each force range should extend to the lower limit of verification in accordance with BS 1610 : Part 1.

9.3 Extensometers

Extensometers shall be calibrated in accordance with BS 3846 and depending on the property to be determined, shall be as given in table 4.

Table 4. Grading of extensometers

Property	Minimum grade
For testing of category 1 materials	
Measurement of values of strength up to and including 0.1 % proof strength	C
Values of strength above 0.1 % proof strength	D
Values of yield strength	D
% elongation at fracture	E
For testing of category 2 materials	
Measurement of values of strength up to and including 0.2 % proof strength	C
Values of strength above 0.2 % proof strength	D
% elongation at fracture	E

10 Temperature of test

Conduct the tests at room temperature (10 °C to 30 °C). When the product specification demands more stringent conditions tests shall be made at a temperature of 23 ± 5 °C.

NOTE 1. For tests at elevated temperature reference should be made to BS 3688 : Part 1, or to British Standard 4A4 : Part 1 : Section Two for category 2 material.

NOTE 2. Temperature should be monitored with a measuring instrument of demonstrable traceability, e.g. a thermometer manufactured in accordance with BS 593 and marked accordingly.

11 Test procedure

11.1 General

Insert a test piece in the grips of a suitable tensile testing machine and apply an increasing force to strain the test piece.

Test continuously or with interruptions depending upon the tensile properties to be determined.

When measurements of extension are required, fit an extensometer to the test piece at the start of the test.

NOTE 1. The extensometer is generally removed when sufficient data have been acquired, after the onset of plastic deformation and before the test piece is strained to fracture.

Record force and/or extension data either manually or automatically.

NOTE 2. The functions described in this clause may be effected by a suitably programmed computer thus obviating the need to plot a force/extension diagram for each test.

11.2 Determination of yield strength

11.2.1 *General.* When determining both the upper yield strength, R_{eH}, and the lower yield strength, R_{eL}, during the same test, follow the procedure for determining the lower yield strength.

Determine yield strength visually, or by a force/extension diagram (see figure 1).

NOTE. When recording a force/extension diagram, it is permissible to record displacement from the crosshead motion.

11.2.2 *Upper yield strength* (R_{eH}). When determining upper yield strength, ensure that the rate of stressing in the elastic range is within the limits stated in table 5. Fix the rate of stressing by regulating it in the elastic range, the controls of the machine not being further adjusted until the upper yield strength is determined.

Table 5. Rate of stressing

Nominal value of Young's modulus of elasticity	Rate of stressing	
	Min.	Max.
GN/m^2 (kN/mm^2)	(N/mm^2)·min^{-1}	(N/mm^2)·min^{-1}
Up to and including 150	60	600
Greater than 150	180	1800

11.2.3 *Lower yield strength* (R_{eL}). When determining the lower yield strength only, ensure that the rate of straining of the parallel length of the test piece during plastic deformation is between 0.015/min and 0.15/min. On open loop machines this rate cannot be regulated directly; ensure that it is fixed by regulating the rate of stressing just before yield begins, the controls of the machine not being further adjusted until completion of yield.

Ensure that the rate of stressing in the elastic range in no case exceeds the maximum rate given in table 5.

11.3 Determination of proof strength (non-proportional extension) (R_p) and proof strength, (total extension) (R_t)

11.3.1 *General*

11.3.1.1 For category 1 materials in the plastic range of proof strength determination, ensure that the rate of straining of the parallel length of the test piece is no greater than 0.15/min. On open loop machines this rate cannot be regulated directly; ensure that it is fixed by regulating the rate of stressing just before plastic deformation begins.

Ensure that the rate of stressing in the elastic range in no case exceeds the maximum rate given in table 5.

11.3.1.2 For category 2 materials in the plastic range of proof strength determination the rate of straining of the parallel length of the test piece shall be between 0.001/min and 0.005/min.

11.3.2 *Proof strength (non-proportional extension).* Determine the proof strength (non-proportional extension) from the force/extension diagram (see figure 3(a)) by drawing a line parallel to the straight portion and at a distance from this equivalent to the prescribed non-proportional percentage, e.g. 0.2 %. The point at which this line intersects the curve gives the force corresponding to the desired proof strength (non-proportional extension). Obtain the required proof strength by dividing this force by the original cross-sectional area of the test piece.

Accurately draw the force/extension diagram either by an automatic recording device or manual method.

NOTE 1. It is recommended that the reliability of proof strength determinations is checked using the following method. Since the Young's modulus of elasticity for material to a given specification is nearly constant, the theoretical extension for any given increment of stress within the limit of proportionality may be calculated. If the corresponding strains are calculated for two or three increments of stress at an early stage of the elastic portion of the test it is possible to verify that the test is proceeding satisfactorily by comparing the calculated strain values with those actually being obtained.

NOTE 2. If the straight portion of the force/extension diagram is not clearly defined, so that the parallel line cannot be drawn with sufficient precision, the following procedure should be adopted (see figure 5).

When the presumed proof strength has been exceeded, reduce the force to a value equal to about 10 % of the force obtained. Then increase the force again until it exceeds the value obtained originally. When force elongation data have been plotted a hysteresis loop will be obtained. To determine the desired proof strength, draw a line through the hysteresis loop. Draw another line parallel to the first, at a distance from the origin of the curve, measured along the abscissa, equal to the prescribed value of the non-proportional extension. The intersection of this parallel line and the force/extension curve gives the force corresponding to the proof strength. The required proof strength is obtained by dividing this force by the original cross-sectional area of the test piece.

NOTE 3. If it is desired only to prove compliance with proof strength requirements, the method described in appendix B, which does not necessitate the plotting of a force/extension diagram, may be used.

11.3.3 *Proof strength (total extension).* Determine the proof strength (total extension) from the force/extension diagram (see figure 3(b)) by drawing a line parallel to the y-axis of the diagram and distant from it by the required total extension. Calculate the required proof strength from the force at which the extensometer indicates the total extension required.

11.4 Determination of tensile strength (R_m)

Calculate the tensile strength by dividing the maximum force by the original cross-sectional area (S_o) of the test piece (see figure 2). In the plastic range, after the determination of yield strength or proof strength, the speed of separation of the crossheads of the machine may be increased; however, ensure that the speed of testing does not in any case exceed 0.5 × (L_c) mm per minute.

NOTE 1. For parallel sided test pieces L_c is the total length minus the length in grips.

NOTE 2. If the test does not include the determination of a yield strength (or proof strength) the speed of testing throughout the test may reach 0.5 × (L_c) mm per minute.

11.5 Determination of percentage elongation after fracture

Calculate the percentage elongation after fracture (A) in accordance with the following equation:

$$A = \frac{L_u - L_o}{L_o} \times 100$$

where

L_u is the final gauge length;

L_o is the original gauge length.

To determine the final gauge length, fit the broken pieces of the test piece carefully together so that their axes lie on a straight line, and so that there is proper contact between the broken parts of the test piece when measuring the final gauge length.

NOTE 1. This is particularly important in the case of test pieces having a short gauge length and for materials having low elongation values.

Equipment for the measurement of elongation shall be capable of measuring the distance between gauge marks, both before testing and after fracture with the precision given in table 6.

NOTE 2. If the machines used are capable of measuring elongation automatically, gauge marks are unnecessary. The elongation measured is the total elongation; it is therefore necessary to deduct the elastic elongation in order to obtain the percentage elongation after fracture unless the machine does it automatically.

Table 6. Measurement of gauge lengths for the determination of percentage elongation

Original gauge length L_o	Minimum specified percentage elongation A	Accuracy of measurement required
mm	%	mm
12.5 up to and including 25	Up to and including 5 Over 5 up to and including 10 Over 10	± 0.05 ± 0.1 ± 0.25
Over 25 up to and including 50	Up to and including 5 Over 5 up to and including 10	± 0.1 ± 0.25 ± 0.5
Over 50	Up to and including 5 Over 5	± 0.25 ± 0.5

NOTE 1. This measurement is valid in principle only if the fracture is within the original gauge marks and the distance between the fracture and the nearest gauge mark is not less than one-fifth of the original gauge length. In acceptance testing however, the test results are regarded as valid, irrespective of the position of the fracture, within or outside the original gauge marks, provided that the minimum elongation specified has been obtained.

NOTE 2. When an extensometer is used to measure the elongation after fracture the extensometer gauge length (L_e) has to be equal to the original gauge length (L_o).

NOTE 3. It should be noted that comparisons are valid only when the gauge length and the area of the cross section are the same or when the coefficient of proportionality (k) is the same.

NOTE 4. When elongation has been determined on a gauge length not related to the cross-sectional area (e.g. as given in table 3), the equivalent elongation on a gauge length of $5.65 \sqrt{S_o}$ may be obtained, if permitted by the product standard, by means of the conversion procedure in BS 3894 : Part 1 for carbon and low alloy steels and BS 3894 : Part 2 for austenitic steels.

11.6 Reduction of area (Z)

Calculate the percentage reduction of area (Z) in accordance with the following equation:

$$Z = \frac{S_o - S_u}{S_o}$$

where

S_o is the original cross-sectional area;

S_u is the minimum cross-sectional area after fracture.

For specimens of circular cross section use the average of two diametral measurements taken at right angles to each other.

12 Test report

The test report shall include the following information:

(a) a reference to this British Standard i.e. BS 18 : 1987;

(b) the material being tested and any relevant identifying marks and numbers;

(c) the type (proportional or non-proportional) and major dimensions of the test piece;

(d) if appropriate, the gauge length used or the coefficient of proportionality when this differs from 5.65;

(e) details of appropriate test piece dimensions given in table 1 and required tensile property values calculated as described in clauses **6**, **8** and **11** and appendices A and B.

NOTE. When tests in accordance with this standard have been required by a product standard which specifies the provision of a manufacturer's test certificate, a separate report on tensile tests in accordance with BS 18 is not normally required.

Appendices

Appendix A. Verification of permanent set strength by proving tests (see 2.6.8 and figure 4)

A.1 Apply the force corresponding to the small tensioning stress, stated in the standard for the material, to the test piece. Increase the force to raise the stress to the specified value and maintain it for 10 s to 15 s. Then reduce the force below the initial tensioning stress and finally increase the force to its specified value again.

A.2 Verify that the extensometer gauge length (L_e), has not acquired a permanent extension greater than the specified percentage or that the original gauge length (L_o) has not acquired a permanent elongation greater than the specified percentage, as appropriate.

Appendix B. Proving tests for proof strength

B.1 General

As an alternative to the preparation of a force/extension diagram, when permitted by the relevant testing procedure or specification, one of the following methods may be employed.

B.2 Four-point method

The four-point method of approximate determination of proof strength has the advantage of rapidity. Referring to figure 6, CB is a force/extension curve, and MN is a line drawn parallel to the line of proportionality CE at a distance g from it, where g is equal to the specified non-proportional extension.

(OJ) and (OT) represent the lower and upper limits respectively of the specified proof strength range. If no upper limit is specified and a numerical value of the proof strength is required, assume an arbitrary top limit.

The sequence of operations is as follows.

(a) Apply a very small tensioning force (OC) and set extensometer to zero.

(b) Increase force to a value (OF) where F lies on the straight portion of the force/extension line and (CF) is a convenient fraction of (CJ) and (CT). Record extension e.

NOTE 1. $(CF) = \frac{(CJ)}{x} = \frac{(CT)}{y}$

x and y preferably being whole numbers.

NOTE 2. For any given material $\frac{(CF)}{e} \times \frac{L_e}{S_o}$ (i.e. Young's modulus of elasticity) is nearly constant and obtaining the normal value is a check on the conditions of the test.

(c) Increase force until recorded extension is $ex + g$ (where $\frac{(CJ)}{(CF)} = x$).

(d) Increase force until recorded extension is $ey + g$ (where $\frac{(CT)}{(CF)} = y$).

NOTE 3. If the force (OG) is above the lower limit (OJ) and force (OH) is below the upper limit (OT) of the material specification, the material is deemed satisfactory in respect of proof strength.

An approximate proof strength value (OP) may be obtained by using the equation:

$$(OP) = (OJ) + f$$

where $f = \frac{\{(OG) - (OJ)\} \times \{(OT) - (OJ)\}}{\{(OG) - (OJ)\} + \{(OT) - (OH)\}}$

B.3 Three-point method

If it is desired merely to verify that the material will withstand the specified minimum proof strength, apply the four-point method with the omission of operation (d).

NOTE. If the stress corresponding to the force (OG) recorded at operation (c) is not less than the specified minimum value, the material is deemed satisfactory in respect of proof strength.

B.4 Alternative three-point method

Although the procedure given in **B.3** is suitable for tensile machines of the indicating type, it may present some difficulty with machines of the lever type where it is necessary to maintain the beam in a horizontal position. With the latter type of machine, therefore, the following alternative procedure may be adopted.

After proceeding as described in (a) and (b) of the four-point method (see **B.2**), increase the force until the stress in the test piece is equal to the specified minimum proof strength.

NOTE. If the extensometer reading is not greater than $ex + g$, the material is deemed satisfactory in respect of proof strength.

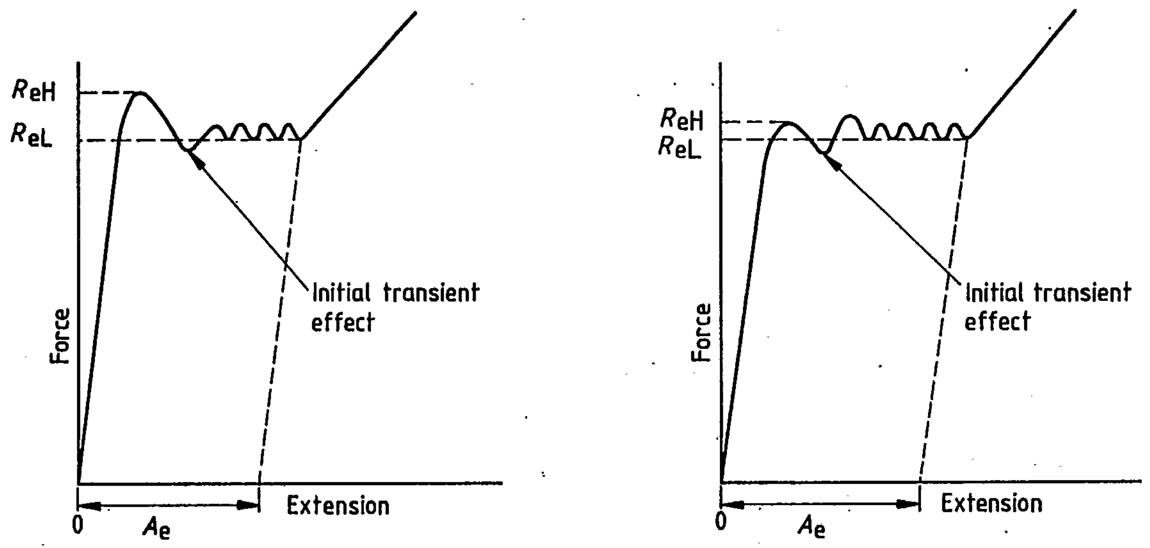


Figure 1. Force/extension diagrams illustrating yield

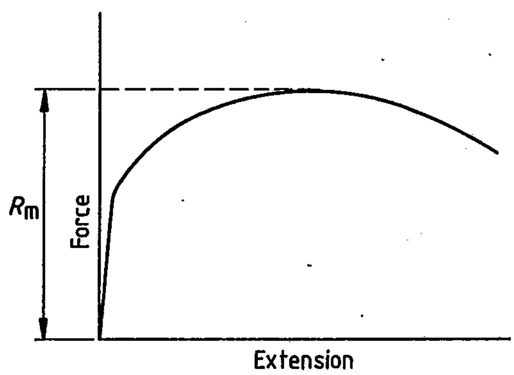
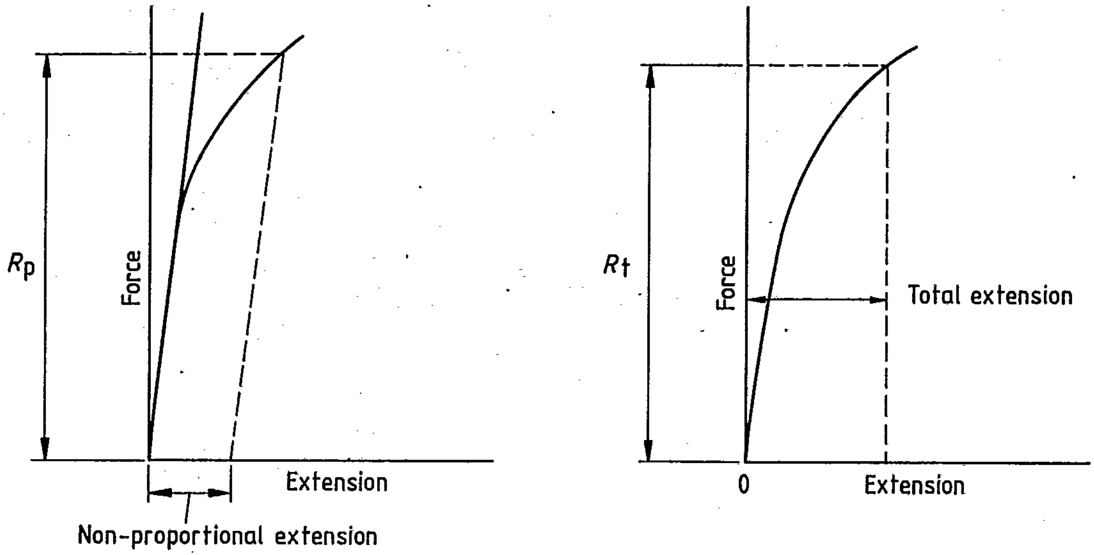


Figure 2. Force/extension diagram illustrating tensile strength



(a) Non-proportional extension

(b) Total extension

Figure 3. Force/extension diagrams illustrating proof strength extension values

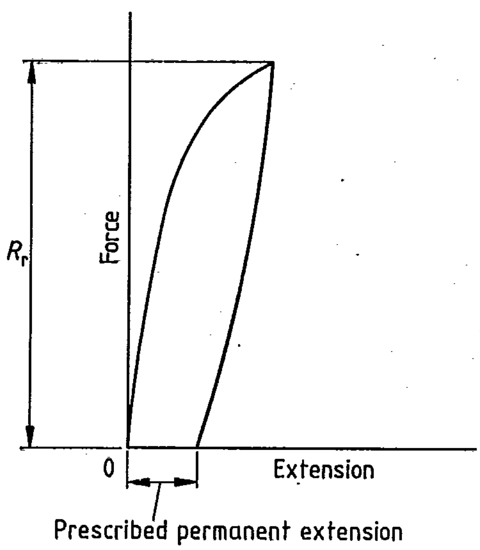


Figure 4. Force/extension diagram illustrating permanent set strength

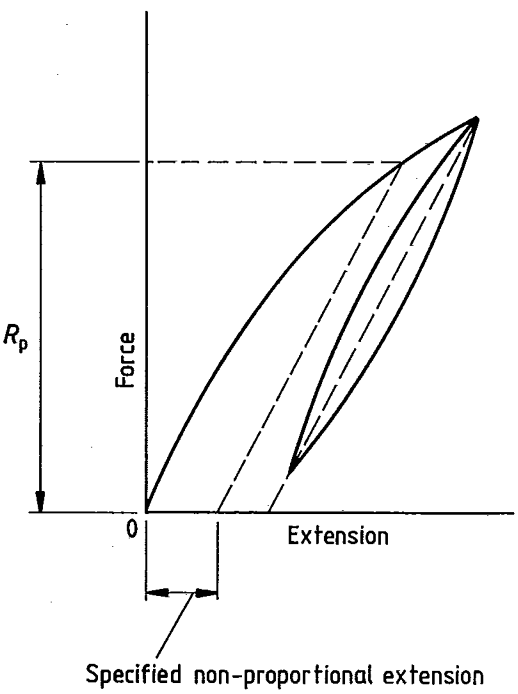


Figure 5. Force/extension diagram illustrating proof strength (non-proportional extension)

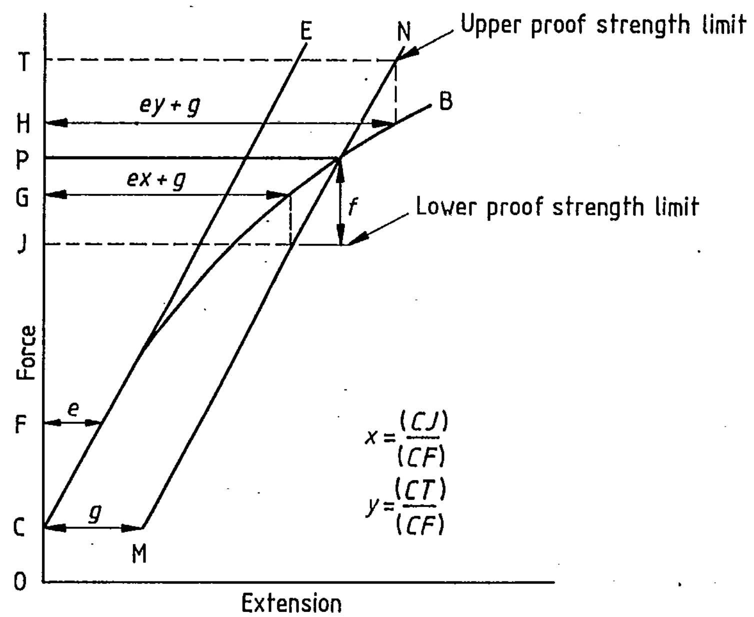


Figure 6. Four-point method for the determination of proof strength

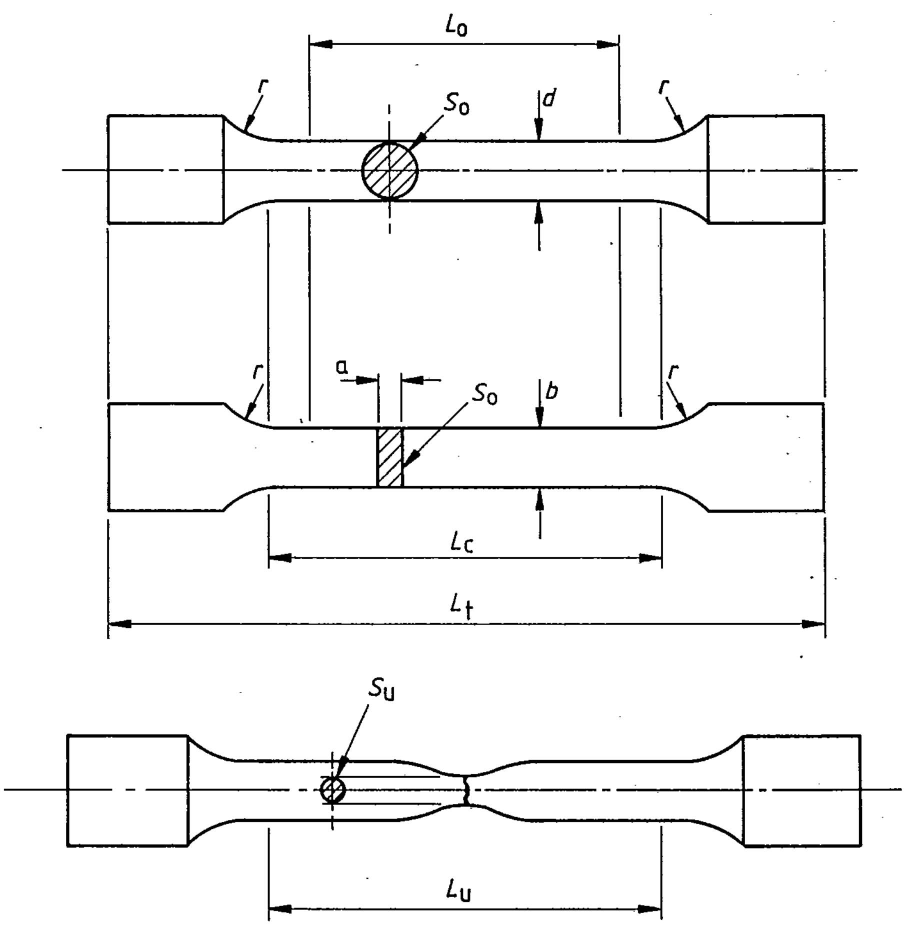


Figure 7. Round and flat test pieces

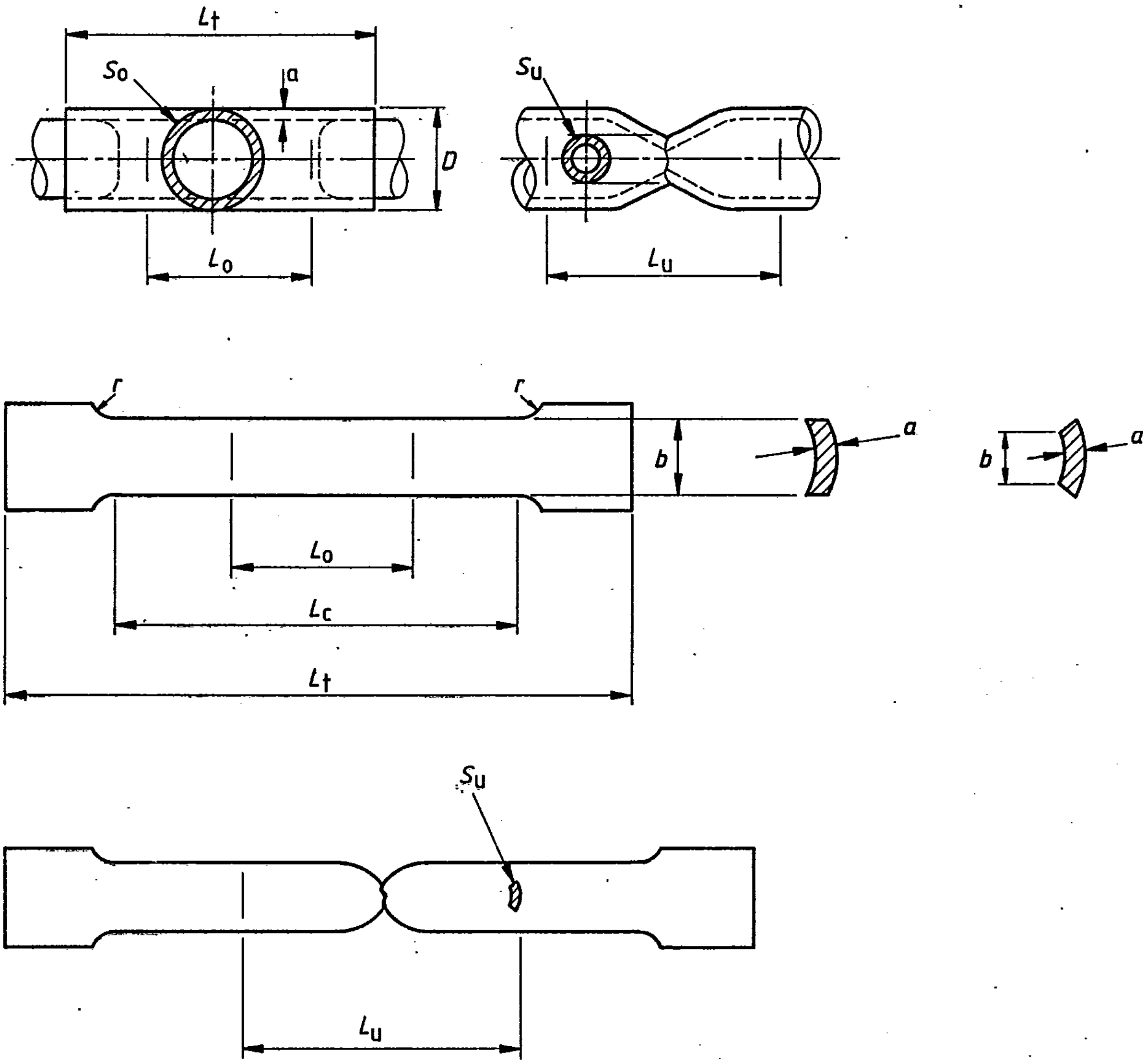


Figure 8. Test pieces from tube before and after fracture

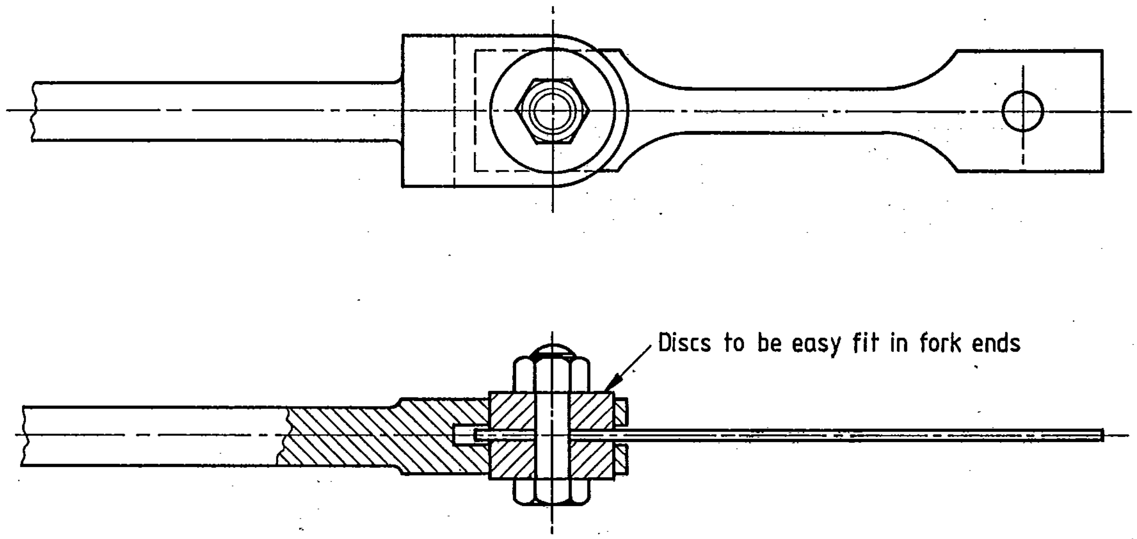


Figure 9. Grip for thin test pieces

Publications referred to

BS 593	Specification for laboratory thermometers
BS 1610	Materials testing machines and force verification equipment Part 1 Specification for the grading of the forces applied by materials testing machines
BS 3688	Methods for mechanical testing of metals at elevated temperatures Part 1 Tensile testing
BS 3846	Methods for calibration and grading of extensometers for testing of metals
BS 3894	Method for converting elongation values for steel Part 1 Carbon and low alloy steels Part 2 Method of conversion for application to austenitic steels
BS 4545*	Methods for mechanical testing of steel wire
British Standard 4A4	Specification for test pieces and test methods for metallic materials for aircraft Part 1 : Section Two. Tensile tests — elevated temperature. Metric units
ISO 6892*	Metallic materials — tensile testing

* Referred to in the foreword only.

BS 18 : 1987

This British Standard, having been prepared under the direction of the Iron and Steel and the Non-ferrous Metals Standards Committee, was published under the authority of the Board of BSI and comes into effect on 30 June 1987.

First published June 1904
First revision June 1907
Second revision November 1910
Third revision December 1938
Fourth revision May 1950
Fifth revision December 1956
Sixth revision October 1962
Seventh revision, Part 1, February 1970
Seventh revision, Parts 2, 3 and 4 July 1971
Eighth revision June 1987.

ISBN 0 580 15916 7

The following BSI references relate to the work on this standard:
Committee reference ISM/NFM/4 Draft for comment 85/42664 DC

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Iron and Steel Standards Committee (ISM/–) and Non-ferrous Metals Standards 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 Engineering Laboratory)
Department of Trade and Industry (National Physical Laboratory)
ERA Technology Ltd.
GAMBICA (BEAMA Ltd.)
Ministry of Defence
Society of British Aerospace Companies Limited
Welding Institute

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

Association of Consulting Scientists
BCIRA
British Industrial Fasteners Federation
Civil Aviation Authority (Airworthiness Division)
Department of Trade and Industry (National Measurement Accreditation Service)
Institute of Sheet Metal Engineering
Light Metal Founders' Association
Magnesium Industry Council
Process Plant Association

BS 18 : 1987

Amendments issued since publication

Amd. No.	Date of issue	Text affected

British Standards Institution · 2 Park Street London W1A 2BS · Telephone 01-629 9000 · Telex 266933

8708–7–2k–B

ISM/NFM/4