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Steel — Tensile testing

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FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO Member Bodies). The work of developing International Standards is carried out through ISO Technical Committees. Every Member Body interested in a subject for which a Technical Committee has been set up has the right to be represented on that Committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the Technical Committees are circulated to the Member Bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 82 was drawn up by Technical Committee ISO/TC 17, *Steel*, and circulated to the Member Bodies in March 1972.

It has been approved by the Member Bodies of the following countries :

Australia	Germany	Spain
Austria	Hungary	Sweden
Canada	India	Switzerland
Chile	Ireland	Thailand
Czechoslovakia	Italy	Turkey
Denmark	Netherlands	United Kingdom
Egypt, Arab Rep. of	New Zealand	U.S.A.
Finland	Romania	U.S.S.R.
France	South Africa, Rep. of	

The Member Bodies of the following countries expressed disapproval of the document on technical grounds :

Belgium
Japan
Norway

This International Standard cancels and replaces ISO Recommendation R 82-1959.

Printed in Switzerland

Steel — Tensile testing

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies requirements for the tensile testing of steel products of diameter equal to or greater than 4 mm (0.16 in) or thickness equal to or greater than 3 mm (0.12 in).

For the tensile testing of particular products, such as sheet, strip, wire and tube, ISO 86, ISO 89 and ISO 375 are applicable.

2 REFERENCES

ISO 86, *Steel — Tensile testing of sheet and strip less than 3 mm and not less than 0,5 mm thick.*

ISO 89, *Steel — Tensile testing of wire.*

ISO 375, *Steel — Tensile testing of tubes.*

ISO/R 147, *Load calibration of testing machines for tensile testing of steel.*

ISO/R 205, *Determination of proof stress and proving test for steel at elevated temperatures.*

ISO/R 377, *Selection and preparation of samples and test pieces for wrought steel.*

ISO/R 783, *Mechanical testing of steel at elevated temperatures — Determination of lower yield stress and proof stress and proving test.*

ISO 2566/I, *Steel — Conversion of elongation values — Part I : Carbon and low alloy steels.*

ISO 2573, *Determination of K-values of a tensile testing system.* [1]

3 PRINCIPLE

The test consists in straining a test piece by tensile stress, generally to fracture, with a view to determining one or more of the mechanical properties enumerated hereafter.

The test is carried out at ambient temperature unless otherwise specified. For tests at elevated temperatures, ISO/R 205 and ISO/R 783 are applicable.

1) At present at the stage of draft.

4 DEFINITIONS

4.1 gauge length : The prescribed part of the cylindrical or prismatic portion of the test piece on which elongation is measured at any moment during the test. In particular, a distinction is to be made between the following :

4.1.1 original gauge length (L_o) : Gauge length before the test piece is strained;

4.1.2 final gauge length (L_u) : Gauge length after the test piece has been fractured and the fractured parts have been carefully fitted together so that they lie in a straight line.

4.2 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. (The length may differ from L_o and may be any value greater than b or d (see clause 5) but less than the parallel length L_c.)

4.3 percentage permanent elongation : Increase in the gauge length of a test piece subjected to a prescribed stress (see 4.12) and after removal of the stress, expressed as a percentage of the original gauge length. If a symbol for this elongation is used, it is to be supplemented by an index indicating the prescribed stress.

4.4 percentage elongation after fracture (A) : Permanent elongation of the gauge length after fracture, $L_u - L_o$, expressed as a percentage of the original gauge length, L_o.

NOTE — If the gauge length is other than $5{,}65\sqrt{S_o}$, where S_o is the original cross-sectional area, A is to be supplemented by a suffix indicating the gauge length used, for example :

A_{10} = percentage elongation on gauge length of $10\sqrt{4S_o/\pi}$.

4.5 percentage reduction of area (Z) : Ratio of the maximum change in cross-sectional area which has occurred during the test, $S_o - S_u$, to the original cross-sectional area, S_o, expressed as a percentage. (S_u = minimum cross-sectional area after fracture.)

4.6 maximum load (F_m) : The highest load which the test piece withstands during the test.

4.7 stress (actually "nominal stress") : At any moment during the test, load divided by the original cross-sectional area of the test piece.

4.8 tensile strength (R_m) : Maximum load divided by the original cross-sectional area of the test piece, i.e. stress corresponding to the maximum load.

4.9 yield stresses : In a steel which exhibits a yield phenomenon, a point is reached during the test at which plastic deformation, soon after it has been initiated, continues to occur at nearly constant stress.

4.9.1 upper yield stress (R_{eH}) : The value of stress measured at the commencement of plastic deformation at yield (see figure 3);

or

the value of stress measured at the first peak obtained during yielding even when that peak is equal to or less than any subsequent peaks observed during plastic deformation at yield (see figure 4).

4.9.2 lower yield stress (R_{eL}) : The lowest value of stress measured during plastic deformation at yield, ignoring any initial transient effects which might occur. (See figures 3 and 4.)

NOTE — If a steel which usually exhibits a yield phenomenon is in a cold-worked or heat-treated condition, the yield phenomenon may not exist. In such cases a proof stress must be specified. (See 4.10 and 4.11.)

4.10 proof stress (non-proportional elongation) (R_p) : The stress at which a non-proportional elongation, equal to a specified percentage of the original gauge length, occurs. (See figure 7.)

When a proof stress (R_p) is specified, the non-proportional elongation is to be stated (for example 0,2 %) and the symbol used for the stress is to be supplemented by an index giving this prescribed percentage of the original gauge length, for example $R_{p0,2}$.

4.11 proof stress (total elongation) or **proof stress under load (R_t) :** The stress at which a non-proportional elongation plus elastic elongation, equal to a specified percentage of the original gauge length, occurs. (See figure 8.)

When a proof stress (R_t) is specified, or agreed between the interested parties, the total elongation is to be stated and the symbol used for the stress is to be supplemented by an appropriate index, for example $R_{t0,5}$.

NOTE — The value obtained by the total elongation method will only be equivalent to R_p if suitable allowance is made for the measurement of elastic extension.

4.12 permanent set stress (R_r); (stress at permanent set limit) : The stress at which, after removal of load, a prescribed permanent elongation, expressed as a percentage of the original gauge length, occurs. The symbol used for this stress is to be supplemented by an index giving the prescribed percentage of the original gauge length, for example $R_{r0,2}$. (See figure 9.)

5 SYMBOLS AND DESIGNATIONS

Symbols and designations are given in the table below.

Number	Preferred symbol	Designation
1	d	Diameter of parallel length of test section of test piece of circular cross-section (Figure 1)
2	a	Thickness of a flat bar (Figure 1)
3	b	Width of a flat bar (Figure 1)
4	L_o[1]	Original gauge length (Figure 1)
5	L_c	Parallel length (Figure 1)
	L_e	Extensometer gauge length
6	L_t	Total length (Figure 1)
7	—	Gripped ends (Figure 1)
8	L_u	Final gauge length after fracture (Figure 2)
9	$L_u - L_o$	Permanent elongation after fracture (Figure 10)
10	A	Percentage elongation after fracture $\left(\frac{L_u - L_o}{L_o}\right)100$
	(e.g. A_{10})	(Percentage elongation on a gauge length of $10\sqrt{4S_o/\pi}$ mm)
11	S_o	Original cross-sectional area of the gauge length (Figure 1)
12	S_u	Minimum cross-sectional area after fracture (Figure 2)
13	R_{eH}	Upper yield stress or upper yield point [2] (Figures 3, 4 and 5)
14	R_{eL}	Lower yield stress or lower yield point [2] (Figures 3, 4 and 5)
15	R_p (e.g. $R_{p\,0,2}$)	Proof stress (non-proportional elongation) or yield strength (offset)[2] (Figure 7) (0,2 % non-proportional elongation)
16	R_t (e.g. $R_{t0,5}$)	Proof stress (total elongation) or yield strength (total elongation)[2] (Figure 8) (0,5 % total elongation)
17	R_r (e.g. $R_{p0,2}$)	Permanent set stress (Figure 9) (0,2 % permanent set stress)
18	F_m	Maximum load
19	Z	Percentage reduction of area $\left(\frac{S_o - S_u}{S_o}\right)$ 100
20	R_m[1]	Tensile strength $\frac{F_m}{S_o}$ (Figure 10)

1) In correspondence and where no misunderstanding is possible, the symbols L_o and R_m may be replaced by L and R respectively.

2) The latter term is used in the U.S.A. and in Canada.

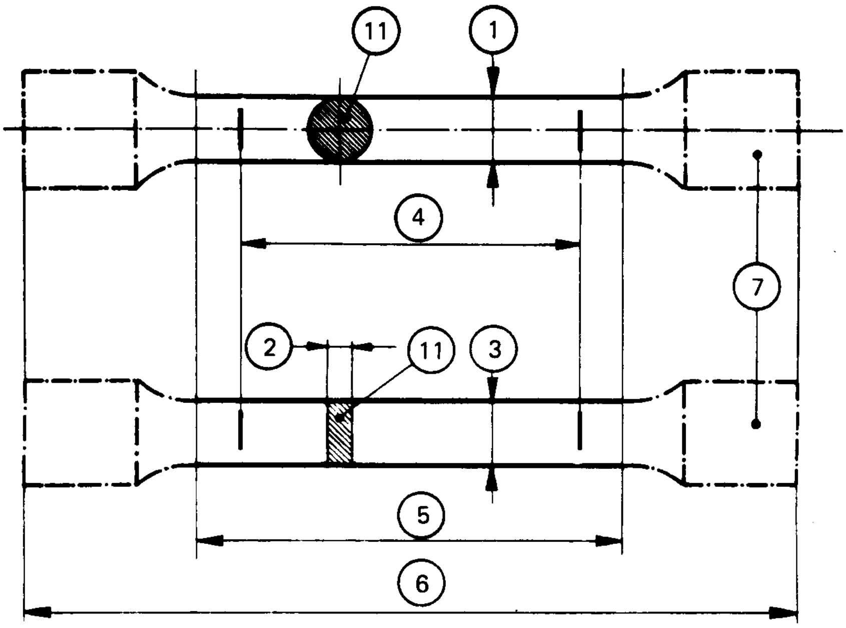

FIGURE 1 – **Test pieces of circular and rectangular cross-section**

NOTE – The form of end of test piece is only intended as a guide.

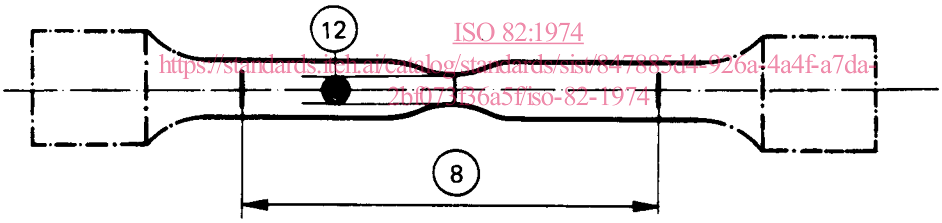

FIGURE 2 – **Test piece of circular cross-section after fracture**

Load/extension diagrams illustrating yield :

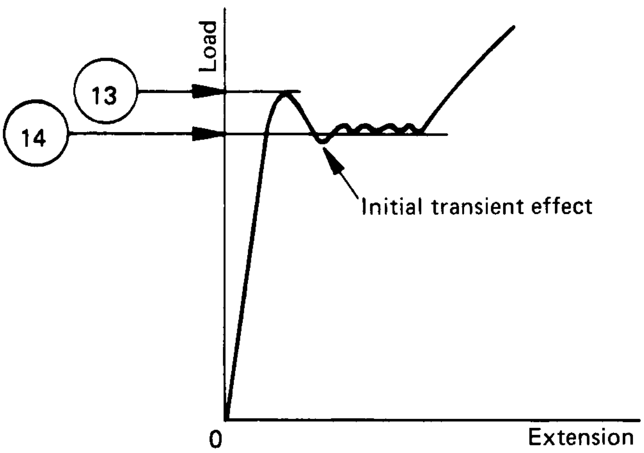

FIGURE 3

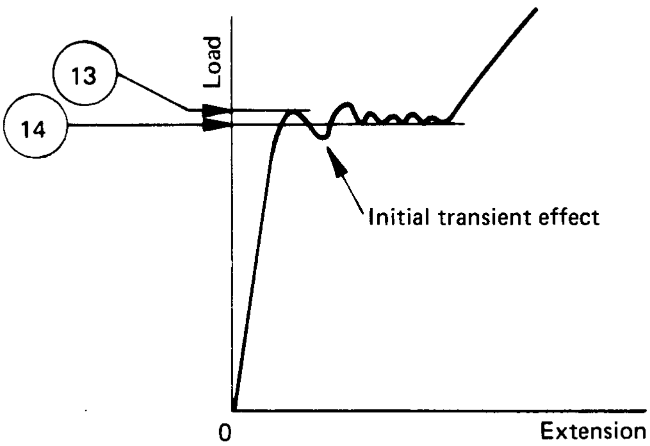

FIGURE 4

Load/extension diagrams :

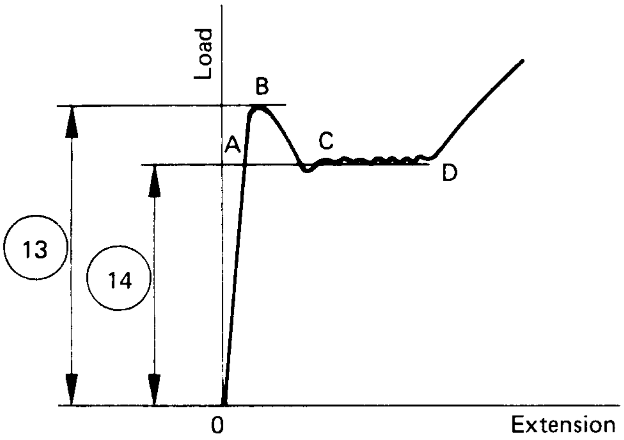

FIGURE 5

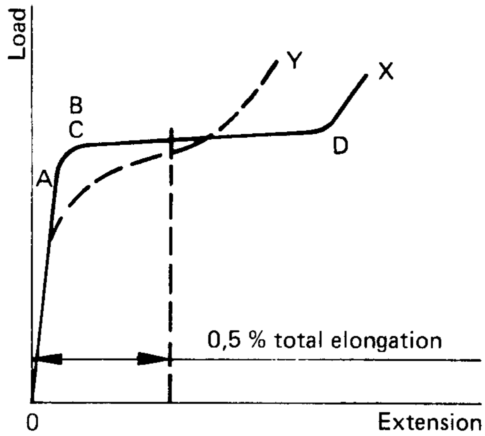

FIGURE 6

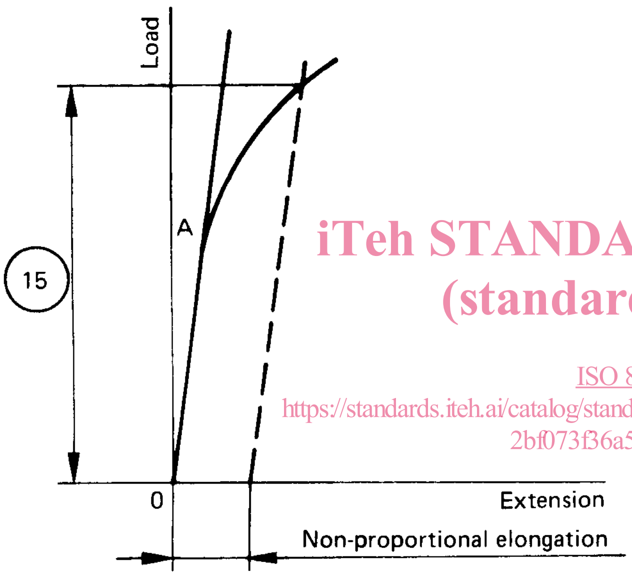

FIGURE 7

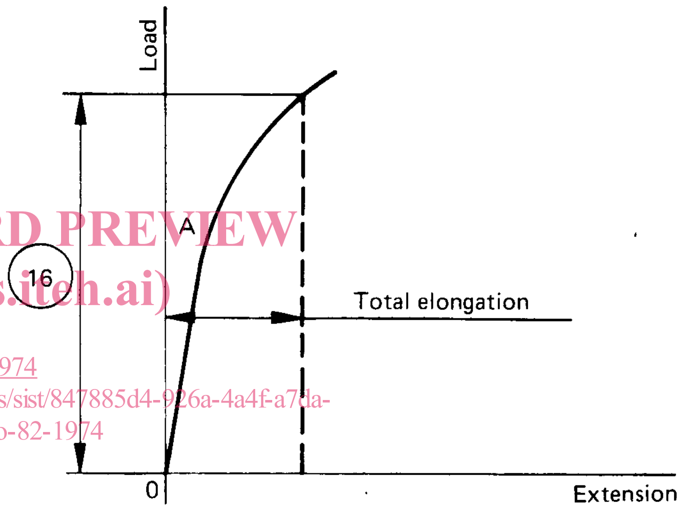

FIGURE 8

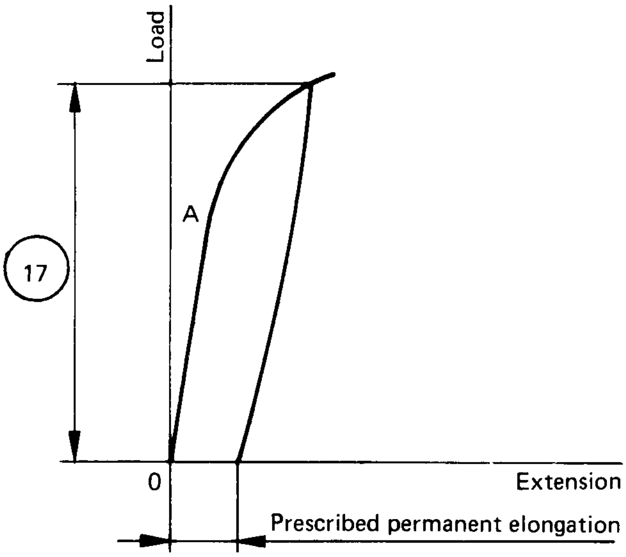

FIGURE 9

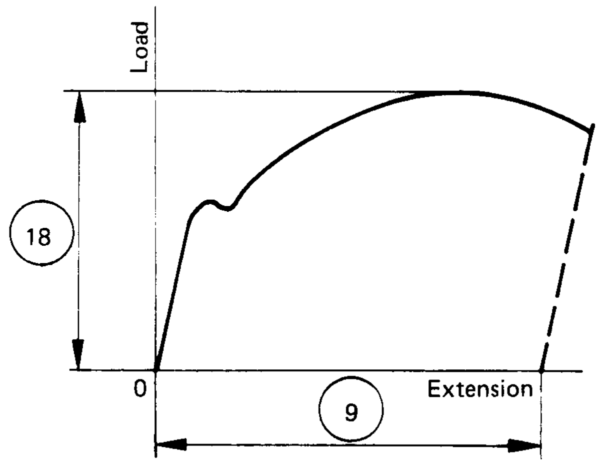

FIGURE 10

A = Elastic limit
B = Upper yield stress
BCD = Yield stress elongation

6 TEST PIECES

6.1 The cross-section of the test piece may be circular, square, rectangular or, in special cases, of other form. For test pieces of rectangular section it is recommended that a ratio of width/thickness of 8 : 1 should not be exceeded.

6.1.1 There shall be a transition curve between the gripped ends and the parallel length. The dimensions of this transition curve are important and it is recommended that the radius be stated in the material specification. The gripped ends may be of any shape to suit the holders of the testing machine. Sections, bars, etc., may however, be tested without being machined.

6.1.2 The tolerances on the dimensions of the test pieces shall be in accordance with those given in tables 3 and 4 in annex A.

6.2 In general, the diameter of the measured portion of the machined cylindrical test pieces shall be not less than 4 mm (0.16 in).

6.3 Test pieces which are geometrically similar and have a specified relationship between gauge length and cross-sectional area are known as proportional test pieces. By international agreement this relationship has been established as $L_o = 5{,}65\sqrt{S_o}$, which, for test pieces of circular cross-section, gives a value of $L_o = 5\ d$.

6.4 Test pieces other than proportional test pieces as defined in 6.3 may, for technical or economical reasons, be used.

6.5 It is recommended that the parallel length (L_c) of test pieces of circular cross-section be between $L_o + 2\ d$ and $L_o + d/2$ and of test pieces of rectangular cross-section between $L_o + 1{,}5\sqrt{S_o}$ and $L_o + 2{,}5\sqrt{S_o}$.

Provided that there is sufficient material, a parallel length (L_c) to be used for arbitration purposes shall be $L_o + 2d$ for test pieces of circular cross-section and $L_o + 2\sqrt{S_o}$ for test pieces of rectangular cross-section.

6.6 If test pieces with rectangular cross-section are machined together from a batch of samples of different thicknesses, the uniform parallel length should be between $L_o + 1{,}5\sqrt{S_o}$ and $L_o + 2{,}5\sqrt{S_o}$, where S_o refers to the test piece with the largest cross-section.

6.7 The test pieces shall be obtained and prepared in accordance with the requirements of ISO/R 377. (See also A.3.3 in annex A.)

7 DETERMINATION OF CROSS-SECTIONAL AREA

For test pieces of circular cross-section complying with the tolerances given in table 3, the nominal dimensions may be used for calculation of the cross-sectional area. For all other test pieces the cross-sectional area shall be calculated from measurements of the appropriate dimensions with an error of not more than ± 0,5 % on each dimension. (See also A.2 in annex A.)

8 MARKING THE ORIGINAL GAUGE LENGTH

8.1 For proportional test pieces, the value of L_o calculated in accordance with clause 6 can be rounded off to the nearest multiple of 5 mm (0.2 in) provided that the difference between the calculated and marked gauge length is less than 10 % of L_o.

8.2 Each end of the gauge length may be marked by means of a fine mark or a scribed line. An alternative method is first to paint the test piece with a quick-drying ink, and mark the gauge length by fine scribed lines. Incised markings are not recommended for notch-sensitive material as premature failure may occur at such a marking.

8.3 It may be useful to mark on the surface of the test piece a line parallel to the longitudinal axis. For test pieces with flat faces, the line shall be at the middle of one of the wider faces.

8.4 If the parallel length is much in excess of the gauge length, as for instance with an unmachined test piece, a series of overlapping gauge lengths, some extending into the gripped portions, shall be marked on the bar. (See also A.4 in annex A.)

9 METHOD OF GRIPPING

9.1 Test pieces shall be held by suitable means, for example wedges, screwed holders, shouldered holders, etc., as most convenient.

9.2 Every endeavour must be made to ensure that test pieces are held in such a way that the load is applied as axially as possible. This is of particular importance when testing brittle material or when determining proof stress or yield stress.

10 ACCURACY OF TESTING EQUIPMENT

10.1 The testing machine shall be calibrated in accordance with ISO/R 147, and shall be maintained to grade 1,0 except when grade 0,5 is required by the standard for the material.

10.2 Where appropriate, (see also 12.2), the apparent elastic compliance (K) of the tensile testing system shall be determined in accordance with ISO 2573.

10.3 The instrument error of an extensometer or proof stress indicator shall not exceed 5 % of the value of the elongation for which the stress value is obtained.

11 DETERMINATION OF PROPERTIES

The appropriate properties to be determined are to be stated in the specification for the material and determined in accordance with the procedures described in clauses 12 to 19.

NOTE — Attention is drawn to 4.9, 4.10 and 4.11 regarding the appropriate yield stresses and proof stresses to be stated. (See also A.3 in annex A.)

12 TESTING TECHNIQUES

12.1 Factors affecting the rate of straining

It is necessary to take into account the wide variation of actual strain rate which can occur during a tensile test and which may affect the results obtained. The rate of straining during plastic deformation may be measured directly if suitable equipment is available. However, for most practical purposes the straining rate may be assessed in terms of loading rate, taking into account the following factors :

1) the apparent elastic compliance (K) of the testing machine and test piece assembly (see 12.3);

2) the area of cross-section of the test piece;

3) the parallel length of the test piece.

The first of these factors has to be established before testing.

12.2 Determination of testing system characteristics

The value of K is to be determined in accordance with ISO 2573. The value thereby obtained on the type of test piece normally used can be regarded as applicable to all tensile tests performed in the testing machine using the same type of attachments and under generally similar testing conditions.

12.3 Application of K

12.3.1 *Measurement of upper and lower yield stress*

For the measurement of upper and lower yield stress, a rate of strain during plastic deformation not exceeding 0,002 5/s is recommended. This is the strain rate during the yield extension normally obtained in a number of testing machines in common use when a proportional round test piece is tested with the controls of the machine set to give a nominal rate of application of stress of 30 $N/mm^2 \cdot s$ (1.9 $tonf/in^2 \cdot s$).

In addition to the recommended rate of straining, an upper limit of 30 $N/mm^2 \cdot s$ (1.9 $tonf/in^2 \cdot s$) on the elastic stress rate is imposed to avoid, amongst other things, errors due to inertia effects.

Tables 1 and 2 give the values of the maximum permitted initial stress rate for different test pieces and different K-values for use when the required plastic strain rate (not exceeding 0,002 5/s) cannot be achieved by direct control.

A stressing rate not less than one-tenth of the elastic stressing rate determined from tables 1 and 2 is permitted. This will result in a slightly lower value of yield stress being obtained.

In those cases where the K-value of the tensile testing system cannot be determined in accordance with ISO 2573, a K-value of 0,000 3 mm/N may be used subject to agreement between the interested parties.

NOTE — A "hard" machine having a low K-value will permit a larger range of test piece cross-sectional areas to be tested at the maximum permitted elastic stressing rate without exceeding the straining rate of 0,002 5/s.

12.3.2 *Measurement of proof stress*

When a yield phenomenon is not present the strain rate imposed on the test piece in the vicinity of the proof stress may not be markedly dependent upon the value of K or the dimensions of the test piece. In proof stress determination a single maximum rate of application of stress of 30 $N/mm^2 \cdot s$ (1.9 $tonf/in^2 \cdot s$) is, therefore, recommended.

NOTE — Within this limit, it is not practical to specify closely the corresponding strain rate as this would dictate the type of extensometer used.

13 OBSERVATIONS ON LOAD/EXTENSION DIAGRAMS

13.1 One of a variety of diagrams may be produced (for example figures 5 to 9). For many materials the initial part of such a load/extension diagram is straight (OA of figures 5 to 9). (Observations of extension made at a sequence of increasing loads during a tensile test may be used to derive corresponding values of stress and strain.)

13.2 As the load increases beyond point A in figure 5, the relationship between load and extension ceases to be linear. In some cases the load may attain a maximum, then decrease and remain sensibly constant while the extension increases markedly (BCD of figure 5). In other cases a maximum value is not obtained initially at the point where plastic deformation commences, and in such cases the level remains sensibly constant during yield while the extension increases markedly (CD of figure 6, curve X).

13.3 After yield is completed, further extension results only from increase in load.

13.4 Where the material does not show the yield type phenomenon, the extension will continue to increase non-proportionally to load after point A in figures 7, 8 and 9 has been reached. In such cases a proof stress or a permanent set stress should be measured (see clauses 15 and 16).