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ISO RECOMMENDATION R 783

MECHANICAL TESTING OF STEEL AT ELEVATED TEMPERATURES

DETERMINATION OF LOWER YIELD STRESS AND PROOF STRESS AND PROVING TEST

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BRIEF HISTORY

The ISO Recommendation R 783, *Mechanical testing of steel at elevated temperatures – Determination of lower yield stress and proof stress and proving test,* was drawn up by Technical Committee ISO/TC 17, *Steel,* the Secretariat of which is held by the British Standards Institution (BSI).

Work on this question by the Technical Committee began in 1961 and led, in 1965, to the adoption of a Draft ISO Recommendation.

In December 1966, this Draft ISO Recommendation (No. 930) was circulated to all the ISO Member Bodies for enquiry. It was approved, subject to a few modifications of an editorial nature, by the following Member Bodies :

Australia	Hungary	South Africa, Rep. of
Austria	India	Spain
Brazil	Israel	Sweden
Canada	Netherlands	Switzerland
Chile	New Zealand	Thailand
Czechoslovakia	Norway	Turkey
Denmark	Poland	U.A.R.
Finland	Portugal	United Kingdom
France	Romania	

Five Member Bodies opposed the approval of the Draft :

Belgium
Germany
Italy
Japan
U.S.A.

The Draft ISO Recommendation was then submitted by correspondence to the ISO Council, which decided, in July 1968, to accept it as an ISO RECOMMENDATION.

ISO Recommendation R 783 July 1968

MECHANICAL TESTING OF STEEL AT ELEVATED TEMPERATURES

DETERMINATION OF LOWER YIELD STRESS AND PROOF STRESS AND PROVING TEST

1. SCOPE

This ISO Recommendation describes the determination of lower yield stress and proof stress of steel in which the test temperature does not exceed 1000 °C.*

2. PRINCIPLE OF TEST

The test consists of heating uniformly a test piece to a prescribed temperature and then subjecting it to tensile stress at that temperature with a view to

(*a*) determining the lower yield stress (R_{eL}) or proof stress (R_p),

(*b*) proving that the proof stress is above a specified minimum value.

3. DEFINITIONS

3.1 *Gauge length.* At any moment during the test, the prescribed part of the cylindrical or prismatic portion of the test piece on which elongation is measured. In particular,

Original gauge length (L_o). Gauge length measured at ambient temperature before the test piece is strained.

3.2 *Extensometer gauge length* (L_e^v). 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.

3.3 *Stress (actually "nominal stress").* At any moment during the test, load divided by the original cross-sectional area of the test piece at ambient temperature.

3.4 *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.

For the purpose of this ISO Recommendation the following definitions apply :

3.5 *Yield stress* (R_e) :

3.5.1 *Upper yield stress* (R_{eH}). The value of stress measured at the commencement of plastic deformation at yield (see clause 12.3 and Fig. 2(b), 2(c), 2(d) and 2(e)).

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.

* This limit of 1000 °C is fixed as a function of the condition of test, particularly for the tolerances on temperature in section 7. In particular, it does not imply that the conception of the proof stress from room temperature up to 1000 °C is equally significant for all steels.

3.5.2 *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 clause 12.3 and Fig. 2(b), 2(c), 2(d) and 2(e)).

3.6 *Proof stress* (non-proportional elongation) (R_p). Stress at which a non-proportional elongation, equal to a specified percentage of the original gauge length, occurs. When a proof stress (R_p) is specified, the non-proportional elongation should be specified (e.g. 0.2 %) and the symbol used for the stress should be supplemented by an index giving the prescribed percentage of the original gauge length (e.g. $R_{p0,2}$).

4. SYMBOLS AND DESIGNATIONS

Number	Symbol	Designation
1	d	Diameter of parallel length of test section of test piece of circular cross-section
2	D	External diameter of tube
3	a	Thickness of a flat bar or thickness of tube
4	b	Width of a flat bar or of specimen cut from tube
5	L_o	Original gauge length measured at ambient temperature before application of load
6	L_c	Parallel length of test piece
7	L_t	Total length of test piece
8	L_e	Extensometer gauge length
9	–	Gripped ends of test piece
10	S_o	Original cross-sectional area of gauge length
11	R_p * (e.g. $R_{p0,2}$)	Proof stress (non-proportional elongation) (0.2 % proof stress)
12	R_{eH}	Upper yield stress
13	R_{eL}	Lower yield stress

* Any symbol used should be followed by the temperature at which the test is made.

NOTE. – See Figure 1.

5. TEST PIECE

5.1 The cross-section of the test piece may be circular, square, rectangular, or, in special cases, of some other shape.

5.2 There should be transition curves (fillets) between the gripped ends and the parallel length; the gripped ends may be of any shape to suit the holders of the testing machine.

5.3 The tolerances on the preparation of the test pieces should be in accordance with those given in the Table, Page 8.

5.4 As a general rule, the diameter of the parallel length of machined cylindrical test pieces should be not less than 4.0 mm (0.16 in).

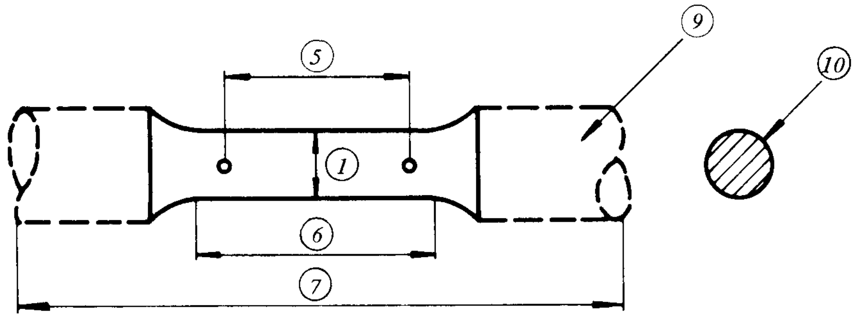

FIG. 1(a) – Test piece of circular cross-section

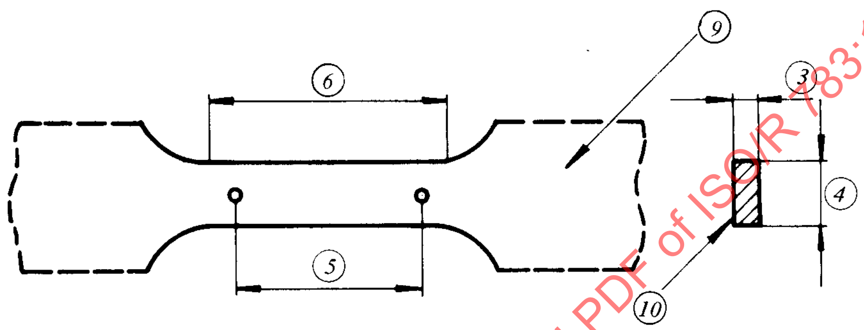

FIG. 1(b) – Test piece of rectangular cross-section

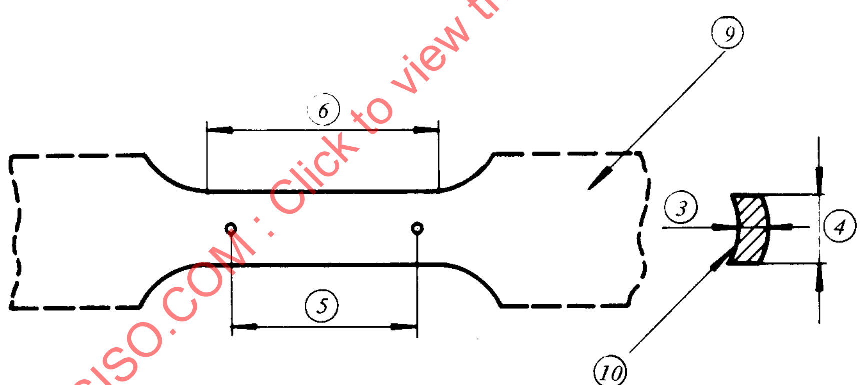

FIG. 1(c) – Strip test piece cut from tube

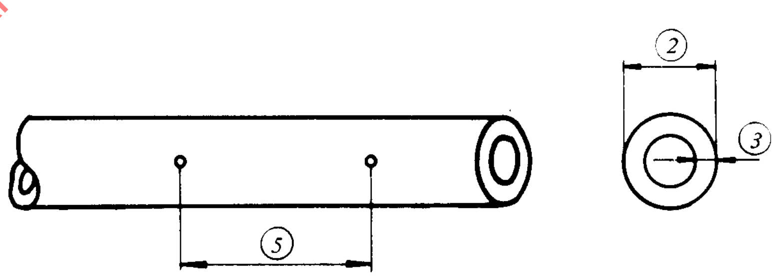

FIG. 1(d) – Tubular test piece

NOTE. – The numerical symbols in Figures 1(a), 1(b), 1(c) and 1(d) are explained in section 4.

TABLE – **Tolerances on dimensions of test pieces**

Designation	Nominal dimensions	Machining tolerance* on nominal dimensions (ISO j_s 12)	Tolerance on form	
			Values	ISO Symbols
Diameter of machined circular-section test piece (metric units)	over 3 mm to 6 mm	± 0.06 mm	0.03 mm	
	over 6 mm to 10 mm	± 0.075 mm	0.04 mm	
	over 10 mm to 18 mm	± 0.09 mm	0.04 mm	
	over 18 mm to 30 mm	± 0.105 mm	0.05 mm	*IT* 9
Diameter of machined circular-section test piece (inch units)	over 0.119 in to 0.237 in	± 0.002 5 in	0.001 in**	
	over 0.237 in to 0.394 in	± 0.003 in	0.001 in**	
	over 0.394 in to 0.709 in	± 0.003 5 in	0.002 in**	
	over 0.709 in to 1.182 in	± 0.004 in	0.002 in**	
Dimensions of cross-section of rectangular-section test piece, machined on the four faces		Same tolerances as for diameter of circular-section test pieces		
Dimensions of cross-section of rectangular-section test piece, unmachined on two opposite faces (metric units)	over 6 mm to 10 mm	–	0.22 mm	
	over 10 mm to 18 mm	–	0.27 mm	
	over 18 mm to 30 mm	–	0.33 mm	
	over 30 mm to 50 mm	–	0.39 mm	*IT* 13
Dimensions of cross-section of rectangular-section test piece, unmachined on two opposite faces (inch units)	over 0.237 in to 0.394 in	–	0.009 in	
	over 0.394 in to 0.709 in	–	0.010 in	
	over 0.709 in to 1.182 in	–	0.012 in	
	over 1.182 in to 1.969 in	–	0.016 in	

* The machining tolerance applies when it is desired to use the nominal cross-section without measurement or calculation.

** Rounded off to 0.001 in.

6. MEASUREMENT OF EXTENSION

The extension should be measured by means of an extensometer. The extensometer should be such that any measurement of extension does not differ from the true value of that extension by more than 0.01 % of the extensometer gauge length, and should be of a type that will take account of the extensions on both sides of the test piece. The parallel length should be not less than 25 mm (1 in) and should preferably be not less than 50 mm (2 in). The extensometer gauge length should be not less than 10 mm and at the centre of the parallel length. Departures from the specified length should not exceed 2 %. The extensometer may be attached to the parallel portion or to the enlarged ends of the test piece; in the latter case, the extension is calculated on the assumption that the observed extension has occurred wholly within the parallel length. When determining lower yield stress, it may not be necessary to measure extension in certain circumstances (see clause 10.4) and an extensometer can be dispensed with.

NOTE. – The additional deformation which occurs between the points of attachment of the extensometer and the ends of the parallel length will lower the proof stress value. This effect is usually so small that it can be ignored.

7. HEATING APPARATUS

7.1 The heating apparatus for the test piece should be such that the test piece can be heated to a temperature which, at any time throughout the duration of the test and at any point within the gauge length, does not deviate from the specified temperature by more than ± 5 °C for temperatures up to and including 800 °C or ± 6 °C for temperatures over 800 °C up to and including 1000 °C.

7.2 The temperature-measuring equipment should be frequently calibrated.

8. MEASUREMENT OF TEMPERATURE

8.1 Temperature-measuring equipment with a sensitivity of 1 °C should be provided to indicate the temperature of the test piece.

8.2 In general, not less than three thermocouples,* one at each end and one in the middle of the parallel length, should be used. This number may be reduced if the general arrangement of the furnace and the test piece is such that, from experience, it is known that the variation in temperature of the test piece does not exceed the maximum specified in clause 7.1.

9. HEATING OF TEST PIECE AND CONTROL OF TEMPERATURE

The test piece should be heated to the required test temperature and maintained at that temperature, within the tolerances specified in clause 7.1, for the duration of the test. The load should only be applied after the temperature-measuring apparatus and the extensometer, if any, have attained a steady value for at least 10 minutes.

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* Attention is drawn to the necessity of frequently verifying the calibration of the thermocouples.

10. RATE OF TESTING

10.1 The lower yield stress and the proof stress are influenced by the rate of strain, an increase in strain rate usually resulting in higher values. The strain rate of the test piece when these stress values are approached should, therefore, be controlled within the range between 0.001 and 0.003 strain per minute. The time intervals used for estimation of strain rate from measurements of strain should not exceed 6 seconds.

10.2 When serrated yielding occurs (see clause 12.5), it is not practicable to record the effective rate of straining, and the lowest stress value recorded should therefore be taken.

10.3 The test piece should be strained continuously until the lower yield stress or proof stress has been reached.

10.4 If previous measurements of strain rate using an extensometer have established a machine setting which will maintain a strain rate within the permitted range (see clause 10.1) for a particular steel, at a particular temperature, this setting may be used for the tests on the same type of steel of the same shape at this temperature without actual measurement of strain rate.

11. MEASUREMENT OF LOAD

The load should be measured, without interpolation between the graduations of the testing machine, to an accuracy of ± 1 % corresponding to class 1.0 of ISO Recommendation R 147, *Load calibration of testing machines for tensile testing of steel.* An automatic load-extension recorder may be used provided that the load can be determined to the above degree of accuracy.

12. DETERMINATION OF PROPERTIES

12.1 Various shapes of stress-strain curve may be obtained depending on the material and the equipment used, and some typical examples are shown in Figures 2(a), 2(b), 2(c), 2(d) and 2(e).

In these Figures, numerical symbols correspond to the following :

1. Material behaving elastically, i.e. stress proportional to strain.
2. 0.2 % proof stress.
3. Upper yield stress.
4. Lower yield stress.
5. Sudden extension.
6. Lower yield strain.
7. Serrated (i.e. saw-tooth) type of yield, associated with ageing phenomena.
8. Transient effects.

12.2 **Proof stress.** Figure 2(a) shows the curve normally obtained when no yield phenomenon is present. The proof stress should be determined from the stress-strain curve (see Fig. 2(a)) on which a line is drawn parallel to the straight portion and distant from it by an amount corresponding to the required percentage strain. The point at which the line cuts the curve denotes the required stress.

In the case of material exhibiting a yield, if the line cuts the curve where plastic deformation associated with yield is apparent, a proof stress has no meaning and a lower yield stress should be determined (see clause 12.3).

12.3 **Lower yield stress.** When a yield phenomenon is present, Figure 2(b) shows the type of curve that should theoretically be obtained using a testing machine with special apparatus such that the strain rate during the lower yield is constant. Dimension 3 in the Figure is the upper yield stress and this is followed by a sudden extension (dimension 5), the extent of which depends on the characteristics of the testing machine. During this extension, the course of the curve depends, among other things, on the sensitivity and speed of response of the strain- and load-recording mechanism. The sudden extension is followed by a long flat portion on the level of the lower yield stress (dimension 4), terminated by the onset of strain-hardening after an amount of total yield strain (dimension 6).

12.4 In actual practice there are many variations from the theoretical type and some of the more common are indicated in Figures 2(c) and 2(d). Where the strain rate over the yield is controlled within the standard range (see clause 10.1) a reasonably flat portion is obtained (except as indicated in clause 12.5) and the lowest value excluding initial transient effects should be taken as the lower yield stress.

12.5 Where there is a yield phenomenon, but the material has also a strong tendency to strain-age hardening, a series of yields may be obtained (see symbol 7 in Fig. 2(e)). The curve then consists of a series of "saw-teeth". This phenomenon is known as a "serrated yield", and the lowest stress obtained (excluding any inertia swing-back) should be taken as the lower yield stress.

13. PROVING TEST

13.1 The requirements of sections 4, 5 and 7 to 10 should be applied.

13.2 The gauge length should be not less than 30 mm (1.182 in); otherwise the extensometer requirements should be in accordance with section 6.

13.3 The test piece should be subjected continuously to a load corresponding to the specified proof stress.

13.3.1 This load is maintained for 10 to 15 seconds. By mutual agreement the time may be extended in certain cases. After removal of the load, it should be verified that the permanent elongation is not greater than the prescribed percentage of the original gauge length.

14. TEST REPORT

The report on each test piece should state

(*a*) the relevant details of the material under test;
(*b*) the temperature of the test (any deviation from the specified limits should be recorded);
(*c*) the approximate time to reach the test temperature and the heating time prior to loading;
(*d*) the original dimensions of the test piece;
(*e*) where possible, the actual rate of straining corresponding to each property determined;
(*f*) the time to reach lower yield stress or, in the case of a proving test, the time for which the load is applied;
(*g*) proof stresses and/or lower yield stress;
(*h*) whether an extensometer was attached to the parallel length, the gauge length or the enlarged ends of the test piece.

NOTES

1. This ISO Recommendation imposes no limitation on the strain rate during the major part of the elastic range. However, due to the stiffness of the tensile machine (hardness or softness) the strain rate at the time when yield occurs will increase considerably compared to the strain rate during the elastic range. It is recommended, therefore, that, before yield occurs, the strain rate should be adjusted, if necessary, to not more than 0.0005 strain per minute.

2. Instability during the yield extension can occur where the upper yield stress is high compared to the lower yield stress. The magnitude of the upper yield stress may be reduced by the use of smaller transition radii on the test piece. If instability is experienced during the lower yield extension, the extensometer gauge length should be increased.

3. **Axiality of loading.** Poor axiality of loading may cause low values of yield stress or proof stress to be recorded, due to yield fronts being generated on one side of the test piece before the other. This condition may be recognized by the occurrence of a low limit of proportionality, and a pronounced bending of the stress-strain curve before the upper yield stress is reached. In such cases a repeat test may be taken.

4. **Yield front.** This is the boundary between plastically deformed (yielded) material and material that is still elastic.

5. **Multiple yield fronts**

   (*a*) The presence of stress raisers in the test piece may result in the initiation of numerous yield fronts. These stress raisers may be in the form of scratches, reference marks or excessive marking caused by the attachment of an extensometer to the parallel portion. Under these conditions, the average strain rate will be reduced and the value of the yield stress lowered.

   (*b*) The yield phenomenon is known to occur by initiation and movement of these fronts through the volume of the material under test.

6. **Hardness ratio.** From the type of information referred to in clause 10.4 (i.e. the measurement of strain rate from an extensometer for a given machine setting), the hardness ratio for a given test piece and gripping assembly can be obtained. For a given test piece, machine and gripping assembly, the hardness ratio can be defined as the strain rate during the lower yield extension divided by the strain rate during the initial elastic loading, provided that the rate of movement of the cross-head of the machine remains sensibly constant for the period during which these rates are measured. A fuller explanation of the determination of the hardness ratio of a tensile testing machine is given in ISO Recommendation R 82 (2nd edition*), *Tensile testing of steel.*

* At present Draft ISO Recommendation No. 1356.