BRITISH STANDARD

METHODS OF TESTING VULCANIZED RUBBER

PART A2. DETERMINATION OF TENSILE STRESS-STRAIN PROPERTIES

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BRITISH STANDARDS INSTITUTION

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A complete list of British Standards, numbering over 5000, fully indexed and with a note of the contents of each, will be found in the British Standards Yearbook. The BS Yearbook may be consulted in many public libraries and similar institutions.

This standard makes reference to the following British Standards:

BS 907. Dial gauges for linear measurements.
BS 1610. Methods for the load verification of testing machines.

British Standards are revised, when necessary, by the issue either of amendment slips or of revised editions. It is important that users of British Standards should ascertain that they are in possession of the latest amendments or editions.

The following BSI references relate to the work on this standard:
Committee references RUC/10 and RUC/10/4
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The Rubber Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government department and scientific and industrial organizations:

British Association of Synthetic Rubber Manufacturers
*British Rubber Manufacturers' Association Ltd.
*Department of Trade and Industry
*Natural Rubber Producers' Research Association
*Rubber and Plastics Research Association of Great Britain
Rubber Growers' Association
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BRITISH STANDARD

METHODS OF TESTING VULCANIZED RUBBER

Part A2. Determination of tensile stress-strain properties

FOREWORD

This British Standard has been published under the authority of the Rubber Industry Standards Committee.

The present revision has been undertaken in order to align the method with that described in the second (1968) edition of ISO Recommendation R 37, ' Determination of tensile stress-strain properties of vulcanized rubber '.

Two types of dumb-bell are described, Type 1 and a smaller Type 2. The former is similar to the Type D dumb-bell introduced in the 1956 edition of this standard and the latter to the Type E introduced by the 1961 amendments to that edition. However, it has been found possible to make the dimensional tolerances for these dumb-bells rather less stringent.

METHOD

1. SCOPE

This Part of this British Standard describes a method of test in which standard test pieces, either dumb-bells or rings, are stretched in a tensile testing machine at a constant rate of traverse of the driven grip or pulley.

Readings of force and elongation are taken as required during the uninterrupted stretching of the test piece and when it breaks.

Dumb-bell and ring test pieces do not necessarily give the same values for the stress-strain properties. This is mainly because in stretched rings the stress is not uniform over the cross section. A second factor is the existence of ' grain ', which may cause dumb-bells to give different values according to whether their length is parallel or at right angles to the grain.

The main points to be noted in choosing between rings and dumb-bells are as follows:

(1) *Tensile strength*. Rings give lower, sometimes much lower, values than dumb-bells, the latter being nearer to the true tensile strength of the rubber. The estimation of true tensile strength from ring data involves extrapolation of

the stress-strain curve (see A(1)). Dumb-bells are therefore preferable for determination of tensile strength.

(2) *Elongation at break*. Rings give, on the average, approximately the same values as dumb-bells, provided that (1) the elongation of rings is calculated as a percentage of the initial *internal* circumference and (2) dumb-bells are cut at right angles to the grain if this is present to a marked degree. With some rubbers, however, rings and dumb-bells may be found to differ markedly for reasons not yet clear. Generally there is little to choose between rings and dumb-bells except that the latter must be used if it is desired to study grain effects.

(3) *Elongation at a given stress and modulus*. Rings and dumb-bells give substantially the same values, provided that (1) the elongation of rings is calculated as a percentage of the initial *mean* circumference (see A (2)), and (2) the average value is taken for dumb-bells cut parallel and at right angles to the grain if this is present to a marked degree.

2. DEFINITIONS

For the purposes of this Part of this British Standard the following definitions apply:

(1) *Tensile stress*. A stress applied so as to stretch the test piece. It is calculated as the applied force per unit area of the original cross section of the test length.

(2) *Tensile strain*. The elongation, expressed as a percentage of the original test length, produced in the test piece by a tensile stress.

(3) *Tensile strength*. The maximum tensile stress reached in stretching the test piece to breaking point.

(4) *Elongation at break*. The tensile strain in the test length at breaking point.

(5) *Elongation at a given stress*. The tensile strain in the test length when subjected to a given tensile stress.

(6) *Modulus at a given tensile strain*. The tenstile stress in the test length when subjected to a given strain. It should be noted that this is different from Young's modulus or shear modulus.

3. STANDARD TEST PIECES

3.1 Dumb-bells. Dumb-bell test pieces shall have the outline shown in Fig. 1 and the dies with which they are made shall conform to the dimensions given in Table 1 and Fig. 2. The reference length shall be not more than 25 mm for Type 1 test piece and not more than 20 mm for Type 2 test piece. This length shall be equidistant from the ends of the central parallel-sided part of the test piece.

NOTE. In the United Kingdom it is usual to use 25 mm for Type 1 test piece and 20 mm for Type 2 test piece.

TABLE 1. DIMENSIONS OF DUMB-BELL TEST PIECE DIES

	Dimension	Type 1	Type 2
		mm	mm
A	Overall length (minimum)*	115	75
B	Width of ends	25 ± 1	$12{\cdot}5 \pm 1{\cdot}0$
C	Length of narrow parallel portion	33 ± 2	25 ± 1
D	Width of narrow parallel portion†	$6{\cdot}0 \begin{smallmatrix} +\ 0{\cdot}4 \\ -\ 0{\cdot}0 \end{smallmatrix}$	$4{\cdot}0 \pm 0{\cdot}1$
E	Small radius	14 ± 1	$8{\cdot}0 \pm 0{\cdot}5$
F	Large radius	25 ± 2	$12{\cdot}5 \pm 1{\cdot}0$

* *A greater overall length may be necessary to ensure that only the wide parallel-sided* end portions come in contact with the machine grips, thus helping to avoid ' shoulder breaks '.

† The variation within any one die shall not exceed 0·05 mm.

The preferred thickness for both types of dumb-bell shall be $2{\cdot}0 \pm 0{\cdot}2$ mm; the maximum thickness shall be 3·0 mm for Type 1 and 2·5 mm for Type 2.

In any one dumb-bell, the thickness of the narrow part shall nowhere deviate by more than 2 % from the mean. If two groups of dumb-bells are being compared, the mean thickness of each group shall be within 7½ % of the grand mean thickness of the two groups.

Dumb-bells shall be cut from sheet by punching with a die as shown in Fig. 2, using a single stroke of a press. The rubber may be wetted with water or soap solution and shall be supported on a sheet of slightly yielding material (e.g. cardboard, leather or rubber belting) on a flat rigid surface.

Dumb-bells shall be cut with the grain running along their length except that, if grain effects are to be studied, some dumb-bells shall also be cut with the grain running at right angles to their length.

Any dumb-bell test piece showing irregularities or imperfections shall not be used.

3.2 Rings. Ring test pieces shall have a nominal internal diameter of 44·6 mm and a nominal external diameter of 52·6 mm, giving a nominal radial width of 4 mm. The axial thickness shall preferably be $4{\cdot}0 \pm 0{\cdot}2$ mm but in no case greater than 4·2 mm.

NOTE. Results obtained on rings of less than the preferred axial thickness may differ from those obtained on rings of the preferred thickness, due to the ring turning over during the test.

The radial width of a ring shall nowhere deviate from the mean by more than 0·2 mm. In any one ring the axial thickness shall nowhere deviate from the mean by more than 0·2 mm or 2 % whichever is the smaller. If two groups of rings are being compared, the mean thickness of each group shall be within 7½ % of the grand mean thickness of the two groups.

Rings shall be produced (1) from a sheet either by punching or by cutting with revolving knives, (2) from tubes of appropriate wall thickness by cutting in a lathe, or (3) by moulding. In using method (1) or (2) with very soft rubbers it is essential that the knife shall be adequately lubricated with soap solution in order to avoid jagged edges.

Any ring test piece showing irregularities or imperfections shall not be used.

4. APPARATUS

4.1 Dies and knives. The dies and knives used for the preparation of test pieces shall be carefully maintained so that the cutting edges are sharp and free from nicks, to avoid leaving ragged edges on the test piece.

Details of a suitable die for dumb-bells are shown in Fig. 2.

4.2 Marker. When measurements are made visually, the marker for marking the reference lines on dumb-bell test pieces shall have two parallel knife edges. These shall be ground smooth and true, 0·05 mm to 0·10 mm wide at the edge and bevelled at an angle of not more than 15°.

4.3 Stamp pad. The stamp pad for use with the marker shall use an ink having no deleterious effect on rubber and of contrasting colour to that of the rubber.

4.4 Measuring instruments. The instrument for measuring the thickness of dumb-bell test pieces (and the axial thickness of the ring test pieces) shall consist of a micrometer dial gauge firmly held in a rigid stand over a flat base-plate of diameter at least 50 mm. The gauge shall be graduated in divisions of 0·01 mm, and shall comply with the relevant requirements of BS 907* particularly in respect of accuracy of calibration.

The dial gauge shall be fitted with a flat contact, square to the plunger and parallel to the baseplate, and shall operate with a pressure of 20 ± 3 kN/m². For the most accurate results, the instrument shall be used as a comparator as recommended in BS 907*, which also includes notes on the care and use of dial gauges.

NOTE. It is preferable for the gauge to have a contact of diameter about 4 mm as this may be used on almost all test pieces without any part of the contact overhanging the test piece edge, which would increase contact pressure.

The instrument for measuring the radial width of ring test pieces shall be similar to the above, except that the contact and baseplate shall be shaped to fit the curvature of the ring.

4.5 Tensile testing machine. The tensile testing machine shall be power driven and the power shall be sufficient to maintain the rate of traverse of the driven grip or pulley substantially constant up to the maximum force capacity of the

* BS 907, ' Dial gauges for linear measurements '.

machine. The rate of traverse of the driven grip or pulley shall be 500 ± 50 mm per minute and the traverse shall be adequate to accommodate the elongation of the specimen; a minimum traverse of 1 m is desirable.

For testing dumb-bell test pieces, the machine shall be provided with a type of grip which tightens automatically as the tension increases and which exerts a uniform pressure across the widened end of the dumb-bell. Each grip shall incorporate a means for positioning so that test pieces are inserted symmetrically and in axial alignment with the direction of pull. The depth of insertion shall be such that the test piece is adequately gripped, but leaving a length of approximately 90 mm (Type 1) or 55 mm (Type 2) clear of the grips.

For testing ring test pieces, the machine shall be provided with two pulleys, both of which are free to rotate, whilst one at least is automatically rotated by the machine to equalize the strain in the ring during the test. The pulleys shall be 25 mm in diameter.

The machine shall be equipped to give a continuous indication of the force applied to the test piece. The force measuring device shall preferably be an inertialess dynamometer, e.g. electrical or optical transducer. If the use of a pendulum type dynamometer cannot be avoided the machine shall be of such capacity, or in the case of multi-range machines an appropriate range shall be so selected, that the force required for the test is not greater than 85 % or less than 15 % of the maximum of the scale.

For ring testing the machine shall be equipped to give a continuous indication of the distance between the pulley centres (the internal circumference of the ring = 2 × distance between centres of pulleys + circumference of one pulley) during the uninterrupted stretching of the test piece.

For dumb-bell testing a graduated scale may be used to measure the elongation but preferably the machine shall be equipped with an automatic extensometer operating on a reference length equal to that specified for manual operation.

After the test piece has broken the machine shall give a permanent indication of the maximum force and, where measured automatically, of the maximum elongation.

The calibration of the tensile testing machine shall be as follows:

(1) The force scale shall be calibrated by a convenient method at least once every six months to ensure that the error does not exceed 2 % of the applied force or 0·4 % of the maximum of the scale, whichever is the greater (Grade B machines, BS 1610*).

(2) For a machine equipped with a mechanism for the autographic recording of the stress-strain curve, the force scale and recording mechanism shall be calibrated at least once every three months to ensure that the force scale error does not exceed that specified in (1) above and that the error in the measurements of the elongation does not exceed 2 %.

* BS 1610, ' Methods for the load verification of testing machines '.

Methods of calibrating the force scales of tensile testing machines are defined in BS 1610*, but a simpler and quicker method is to use steel calibrating springs (see A(3)). This method has the additional advantage that the force scale and the elongation factor of the autographic recording mechanism are both calibrated simultaneously throughout the complete range with the machine movement working under normal operating conditions.

5. PROCEDURE

5.1 Preparation of sample. If fabric is attached to or embedded in the rubber sample, it shall be removed before cutting the test pieces. The method of removal shall preferably avoid the use of a swelling liquid, but a suitable non-toxic volatile liquid may be used, if necessary, to wet the contacting surfaces. Care shall be taken to avoid stretching the rubber during the separation from the fabric, and the liquid, if used, shall be allowed to evaporate completely from the rubber surfaces after separation.

Cloth-marked surfaces shall be made smooth by buffing and a rubber sample which is of uneven thickness, or of thickness above the maximum specified for the test pieces which are to be cut from it, shall also be buffed as necessary. Undue heating of the rubber shall be avoided.

NOTE. The following buffing conditions have been found suitable:

Buffing wheel: Grade C60IP4V or C120GP4V (C = silicon carbide; 60 = medium/fine grit; 120 = fine grit; I = fairly soft wheel; G = soft wheel; P4 = open structure wheel with artificial pores of medium size; V = vitrified).

Peripheral wheel speed: 10–12 m/s.

The surfaces produced by this buffing treatment may lead to slightly lower values of tensile strength and elongation at break than those with a smooth mould finish, the magnitude of the effect depending on the type of rubber. Cloth-marking, if not removed, may have a similar effect on these properties.

5.2 Conditioning of samples and test pieces. Unless otherwise specified for technical reasons, the following requirements shall be observed:

For all test purposes the minimum time between vulcanization and testing shall be 16 hours.

For non-product tests the maximum time between vulcanization and testing shall be 4 weeks and for evaluations intended to be comparable, the tests, as far as possible, shall be carried out after the same time interval.

For product tests, whenever possible, the time between vulcanization and testing shall not exceed 3 months. In other cases tests shall be made within 2 months of the date of receipt of the product by the customer.

Samples and test pieces shall be protected from light as completely as possible during the interval between vulcanization and testing.

Samples, after any necessary preparation, shall be conditioned at 20 ± 2 °C for at least 3 hours before the test pieces are cut. These test pieces may be marked, if necessary, and measured and tested immediately. If not tested immediately,

* BS 1610, 'Methods for the load verification of testing machines'.

they shall be kept at 20 ± 2 °C until tested. If the preparation involves buffing, the interval between buffing and testing shall not exceed 72 hours.

Moulded ring test pieces shall be conditioned at 20 ± 2 °C for at least 3 hours immediately before being measured and tested.

Samples and test pieces of latex rubber shall be conditioned as stated above but at a relative humidity of 65 ± 15 %.

If the test is to be carried out at a temperature other than 20 °C, the test pieces shall be conditioned at the test temperature, immediately prior to testing, for a period sufficient to reach substantial temperature equilibrium.

5.3 Marking of test pieces. For visual measurements of elongation, dumb-bell test pieces shall be marked with reference lines using the marker. The test piece shall be unstrained when it is marked and the resultant lines shall be not more than 0·5 mm wide. They shall be marked on the narrow part of the test piece, as shown in Fig. 1, equidistant from its centre and at right angles to its longitudinal axis.

5.4 Measurement of test pieces. For dumb-bell test pieces, the thickness shall be measured at the centre and at each end of the narrow part with the thickness gauge. The average value of the three measurements shall be used in calculating the area of the cross section. The width shall be taken as the distance between the cutting edges of the die in the narrow part and this distance shall be measured to the nearest 0·05 mm. The distance between the reference lines shall be taken as the distance between the centres of the knife edges of the marker.

For ring test pieces, the radial width and axial thickness shall be measured at six positions approximately equally spaced around the ring using the appropriate thickness gauges. The average value of each set of measurements shall be used in calculating the area of the cross section. The internal diameter shall be measured to the nearest 0·1 mm. It may be measured on a suitable cone and the internal circumference and the mean circumference calculated as follows:

Internal circumference = internal diameter × π

Mean circumference = (internal diameter + radial width) × π

5.5 Determination of tensile stress-strain properties. A dumb-bell test piece shall be inserted into the grips of the tensile testing machine as described in 4·5, taking care to adjust it symmetrically so that the tension will be distributed uniformly over the cross section. The machine shall then be started and the distance between the centres of the reference lines measured as required to the nearest mm (in visual measurement taking care to avoid parallax) until the test piece breaks. The force on the test piece shall also be noted as required (see 5.6(3) and 5.6(4)).

A ring test piece shall be placed around the two pulleys with a minimum of tension and the test carried out in the same way as for dumb-bell test pieces except that the internal circumference shall be noted as required.

5.6 Calculation of results (see also Clause 1)

Results on any dumb-bell test piece which breaks outside the narrow part shall be excluded from the calculation of results. In the determination of tensile strength, elongation at break, modulus etc. with either rings or dumb-bells the results obtained shall be treated as though they were independently obtained for each property, i.e. the median shall be separately determined for each property from the results available. An even number of test pieces shall not be used.

(1) *Tensile strength* shall be calculated by dividing the force at break by the initial area of the cross section under test. In the case of rings this is twice the cross-sectional area calculated as in 5.4. The median of at least three results shall be reported.

(2) *Elongation at break* of dumb-bell test pieces shall be calculated by subtracting the initial distance between the reference lines on the dumb-bell test piece from the distance between the lines at breaking point and expressing the result as a percentage of the initial distance. The median of at least three results shall be reported.

For ring test pieces, the result shall be calculated in a similar manner from the initial and final *internal* circumferences of the ring.

(3) *Modulus* shall be determined at one or more tensile strains during the uninterrupted stretching of the test piece. The value may preferably be obtained from a recorded stress-strain curve.

Otherwise, the force on the test piece shall be noted at the instant the required elongation is reached. The tensile stress at this instant is calculated by dividing the noted force by the initial area of the cross section under test.

For dumb-bell test pieces, the distance between the reference lines corresponding to the required elongation (x %) shall be calculated as

$$\frac{x + 100}{100} \times \text{the initial distance}$$

e.g. for 300 % elongation the distance is 4 times the initial distance.

For ring test pieces, the *internal* circumference corresponding to the required elongation (x %) shall be calculated by multiplying the initial *mean* circumference by $x/100$ and then adding the initial *internal* circumference.

The median of at least three results shall be reported.

(4) *Elongation at a given stress* shall be determined during the uninterrupted stretching of the test piece at one or more predetermined stresses. The value may preferably be obtained from a recorded stress-strain curve.

Otherwise, the elongation of the test piece shall be noted at the instant the required tensile stress is reached. The force corresponding to the required tensile stress shall be calculated by multiplying the stress by the initial area of the cross section under test.

For dumb-bell test pieces, the elongation shall be calculated by subtracting the initial distance between the reference lines from the distance between the lines at the required stress and expressing the result as a percentage of the initial distance.

For ring test pieces, the elongation shall be calculated by subtracting the initial *internal* circumference from the internal circumference at the required stress and expressing the result as a percentage of the initial *mean* circumference.

The median of at least three results shall be reported.

6. TEMPERATURE OF TEST

The test shall normally be carried out at 20 ± 2 °C. If another temperature is used, it should preferably be one of the following: −75, −55, −40, −25, −10, 0, +40, +50, +70, +85, +100, +125, +150, +175, +200, +225, +250 °C with a tolerance of ± 1 °C up to 150 °C and ± 2 °C thereafter.

7. TEST REPORT

The test report shall state the following:

(1) Tensile strength (MN/m^2).
(2) Elongation at break (%).
(3) Modulus at x % elongation (MN/m^2). } as required.
(4) Elongation (%) at x MN/m^2. } as required.
(5) Type, thickness and number of test pieces used.
(6) Direction in which dumb-bell test piece if used is cut, relative to grain.
(7) Whether test pieces have been buffed.
(8) Temperature of test, if other than 20 ± 2 °C.

APPENDIX A

REFERENCES

(1) Reece, W. H. *I.R.I. Trans.*, 1935, **11**, 312.
(2) Scott, J. R. *J. Rubber Res.*, 1949, **18**, 30.
(3) Stafford, R. L. *I.R.J.*, 1953, **125**, 8–10.

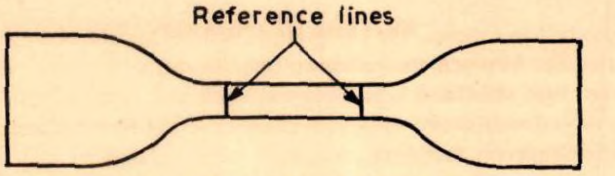

Fig. 1. Shape of dumb-bell test pieces

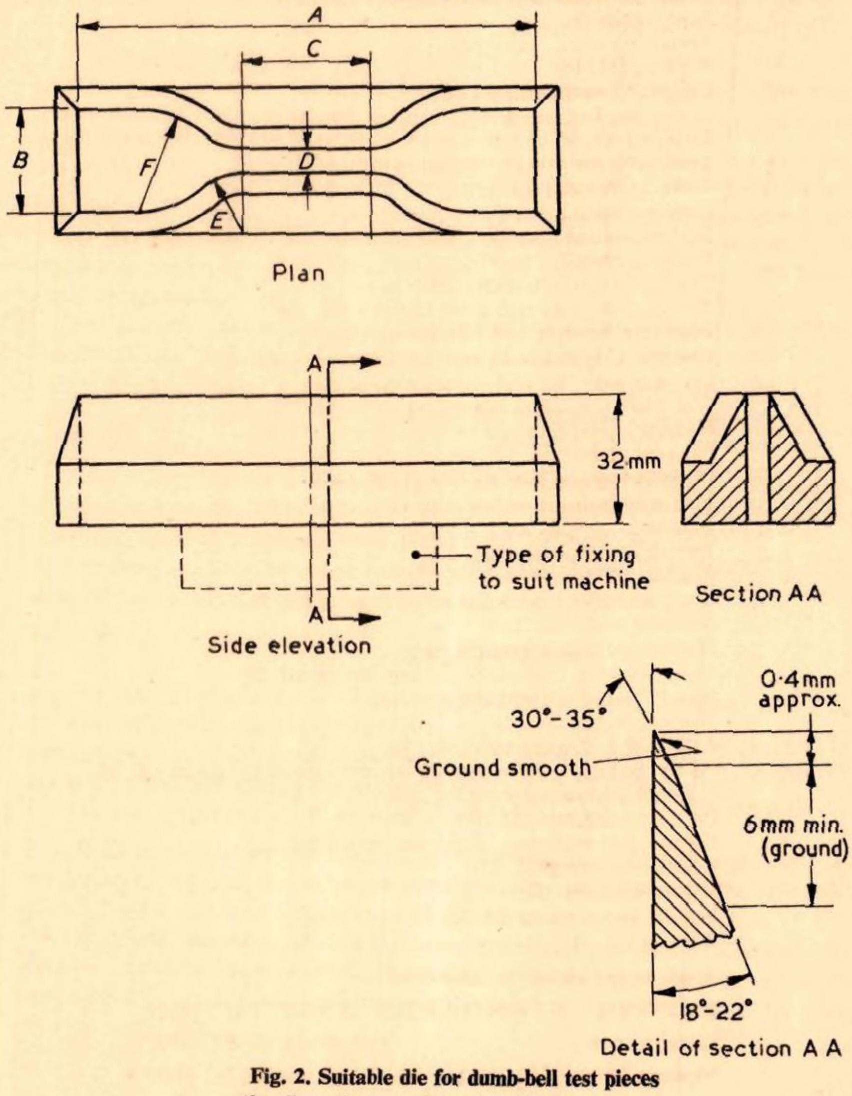

Fig. 2. Suitable die for dumb-bell test pieces
(for dimensions *A* to *F*, see Table 1)

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