BRITISH STANDARD

METHODS OF TESTING VULCANIZED RUBBER

PART A.16

PD 2537

Amendment No. 1, published 26 July 1956

to B.S. 903 : Part A.16 : 1956

Methods of testing vulcanized rubber
Part A16. Determination of swelling in liquids

Corrigendum

Clause 5.3 Determination of swelling.
Delete the formula for S_v on page 8 and substitute the following :

$$S_v = \frac{(W_3 - W_4) - (W_1 - W_2)}{(W_1 - W_2)} \times 100$$

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THIS BRITISH STANDARD, having been approved by the Rubber Industry Standards Committee and endorsed by the Chairman of the Chemical Divisional Council, was published under the authority of the General Council on 1st May, 1956.

B.S. 903, first published June, 1940.
B.S. 903, first revision October, 1950.
First published as B.S. 903 : Part A 16, April, 1956.

The Institution desires to call attention to the fact that this British Standard does not purport to include all the necessary provisions of a contract.

In order to keep abreast of progress in the industries concerned, British Standards are subject to periodical review. Suggestions for improvements will be recorded and in due course brought to the notice of the committees charged with the revision of the standards to which they refer.

A complete list of British Standards, numbering over 2500, indexed and cross-indexed for reference, together with an abstract of each standard, will be found in the Institution's Yearbook, price 12s. 6d.

This standard makes reference to the following British Standards:

B.S. 907. Dial gauges for linear measurement.
B.S. 1674. Methods of mixing and vulcanizing rubber test compounds.

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 B.S.I. references relate to the work on this standard:—
Committee reference RUC/10 Draft for comment CV(RUC) 1060

CO-OPERATING ORGANIZATIONS

The Rubber Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and industrial organizations:—

Board of Trade
*British Rubber Producers' Research Association
*Federation of British Rubber and Allied Manufacturers' Associations
*Institution of the Rubber Industry
*Ministry of Supply
Natural Rubber Development Board
*Research Association of British Rubber Manufacturers
*Rubber Growers' Association

The Government departments and scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:—

Admiralty
Air Ministry
Association of British Chemical Manufacturers
British Chemical Plant Manufacturers' Association
British Electrical and Allied Industries Research Association
British Railways, The British Transport Commission
British Rubber Adhesive Manufacturers' Association
Department of the Government Chemist
General Post Office
Institute of Brewing
Institution of Chemical Engineers
Institution of Gas Engineers
Institution of Mechanical Engineers
Institution of Mechanical Engineers (Automobile Division)
Institution of Municipal Engineers
Institution of Water Engineers
London Advisory Committee for Rubber Research (Ceylon and Malaya)
Ministry of Housing and Local Government
Ministry of Works
National College of Rubber Technology
National Physical Laboratory
Royal Institute of Chemistry
Rubber Trade Association of London
Society of Motor Manufacturers and Traders Ltd.

BRITISH STANDARD

METHODS OF TESTING VULCANIZED RUBBER

Part A 16. Determination of Swelling in Liquids

FOREWORD

This British Standard has been published under the authority of the Rubber Industry Standards Committee. In deciding to issue a revision of the 1950 edition, it has also been considered desirable to publish B.S. 903 in separate parts and the present part replaces Part 27 of 1950. The main alteration is the inclusion of the linear change method.

The group of parts in which the prefix letter 'A' is used covers methods of testing the physical properties of rubber. Further parts in this group have been issued as follows:—

Part A 1. Determination of densty and specific gravity.
Part A 2. Determination of tensile stress-strain.
Part A 3. Determination of tear strength.
Part A 10. Determination of flex cracking.
Part A 11. Determination of resistance to crack growth.
Part A 18. Determination of equilibrium water vapour absorption.
Part A 19. Accelerated ageing tests.

SECTION 1 DEFINITIONS

Swelling. The percentage increase in volume or dimensions which a test piece of given dimensions undergoes when immersed in a liquid for a given time and at a given temperature.

Absorption. The volume of a liquid absorbed, expressed as a percentage of the net volume of the test piece (total volume less the volume of matter extractable by the swelling liquid), when a test piece is immersed as stated above. The amounts absorbed from vapour (even saturated vapour) and directly from the corresponding liquid are not necessarily the same.

For natural rubber the curve relating absorption to time of immersion is of the form shown in Fig. 1. It consists of a markedly curved part OA, representing the initially rapid absorption of liquid, and the final part

AB, which is almost straight, with an upward slope representing a slow continuous absorption of liquid, which is termed the swelling increment. With synthetic rubbers, the increment may be so small as to be negligible.

Maximum absorption is defined as the ordinate AC and is independent of the dimensions of the test piece.

The curve relating swelling to time of immersion is of similar form if extraction of soluble matter is small compared with absorption of swelling liquid. Otherwise, the form of this curve will depend on the relative rates of absorption and extraction.

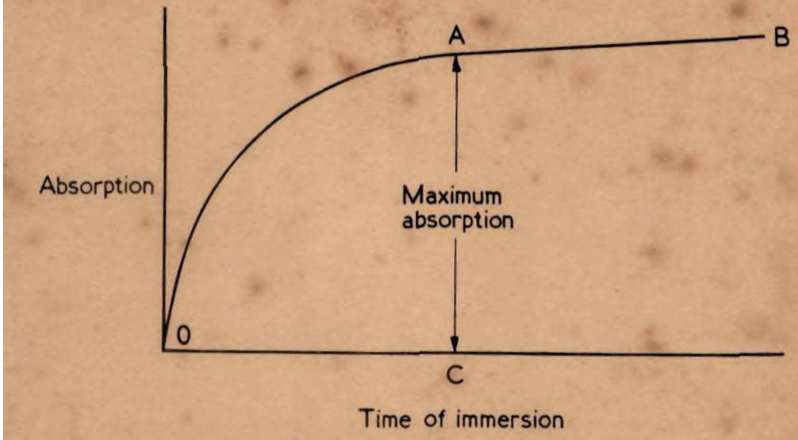

Fig. 1. Time-absorption curve of soft vulcanized rubber

SECTION 2 SUMMARY AND EXPLANATORY NOTE

The tests consist in determining the change in volume or linear dimensions of a vulcanized rubber test piece after it has been immersed in a liquid for a given time, at a constant temperature.

In some instances the liquid may extract a proportion of the plasticizer, or other soluble ingredient of the rubber, and this possibility must be borne in mind when interpreting the results. Oil-resisting rubbers may show a negative swelling, and this is clear evidence that material has been dissolved out of the rubber. When it is suspected that the amount of material dissolved is appreciable it should be determined. The way this is done will depend on the nature of the swelling liquid and the material extracted. If the liquid is readily volatile, the treated test piece may be dried to constant weight and the loss in weight or volume then determined. Alternatively, it may be possible, prior to the test, to extract the plasticizer from the rubber by acetone or other solvent; however, this procedure means that the swelling test is not made on the original material, and accordingly it is not recommended.

Although in some respects swelling tests may simulate service conditions closely, no direct correlation with service behaviour is implied. It does not follow that the rubber giving the lowest swelling value is necessarily the best in service. The measurement of swelling, however, can provide valuable information on the suitability of a rubber for use with a given liquid and, in particular, constitutes a useful control when used comparatively for developing rubber resistant to oil or other liquids.

When information is required on the probable service behaviour of a rubber to be used in contact with a liquid, this liquid should preferably be used in the swelling test. Commercial liquids, however, are not always identical in composition and the test should therefore, whenever practicable, include a control rubber of known swelling characteristics; abnormal results due to unsuspected variations in the swelling liquid will thus be made apparent. It may be found essential to set aside a bulk supply of the liquid for the whole series of tests.

Light mineral lubricating oils and fuel oils are prone to vary appreciably in aromatic content even when supplied to specification. The aniline point of a mineral oil gives an indication of its aromatic content and appears to characterize the swelling action of the oil on rubber. In general, the lower the aniline point the more severe is the swelling action. The report should therefore include the aniline point or the aromatic content of the oil used as the swelling liquid.

The three methods described for the determination of swelling are:

Method A	Volumetric method
Method B	Dimensional change method.
Method C	Linear change method.

The first is the most precise, but the second has to be used when it is required to determine directional changes in linear dimensions, because these cannot always be calculated from the volume change owing to grain in the rubber. The third method is especially suitable for rapid comparative tests of swelling when a large number of liquids or rubber compounds is involved. It can also be used to follow the progress of vulcanization of a rubber compound without prior knowledge of the swelling characteristics of that compound (see B.S. 1674*). For this purpose, benzene is a suitable swelling liquid since it produces rapid swelling at room temperature. The maximum absorption value decreases with degree of vulcanization until it reaches a minimum and then remains practically constant unless reversion occurs. The period of vulcanization required to reach this minimum usually corresponds more closely to the time for optimum modulus than to the time for optimum tensile strength.

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* B.S. 1674, ‘ Methods of mixing and vulcanizing rubber test compounds ’.

METHOD A. VOLUMETRIC METHOD

SECTION 3 TEST PIECE

The test piece shall be about 3 ml in volume and the thickness shall not be greater than 3 mm. Test pieces cut from sheet shall be rectangular, about 5 cm long and 2·5 cm wide.

SECTION 4 APPARATUS

This is dependent on the temperature of the test and the volatility of the swelling liquid. For tests at temperatures appreciably below the boiling point of the swelling liquid, a stoppered glass bottle or tube shall be used. The dimensions shall be such that the test piece remains completely immersed in 100 ml of the swelling liquid, and may swell without restraint.

For tests at temperatures near the boiling point of the swelling liquid, the bottle or tube shall be fitted with a suitable reflux condenser.

SECTION 5 PROCEDURE

5.1 Preparation of sample. If fabric is attached to or embedded in the sample, it shall be removed before cutting the test pieces. The method of removal shall preferably avoid the use of a swelling liquid, but benzene, chloroform or carbon tetrachloride may be used to wet the contacting surfaces if necessary. Care shall be taken to avoid stretching the rubber during the separation from the fabric, and swelling 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 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.

5.2 Conditioning of samples and test pieces. The properties of vulcanized rubber change continuously with time, these changes being particularly rapid during the first 24 hours after vulcanization. No tests should therefore be carried out within this period and, for accurate comparisons between different rubbers, it may be necessary to ensure that these are tested at substantially the same interval after vulcanization.

Samples, after any necessary preparation, shall be conditioned at 20 ± 2°C for at least 12 hours before the test pieces are cut. These test pieces may be tested immediately but, if not tested immediately, 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.

Samples and test pieces shall be protected from light as completely as possible.

NOTE. A single temperature for conditioning is not yet practicable for all countries since 20 ± 2°C is difficult to maintain in certain cases. In climates where it is not possible to maintain this temperature a temperature of 27 ± 2°C is permitted provided the temperature of conditioning is stated in the test report.

5.3 Determination of swelling. The test piece shall be weighed in air to the nearest milligramme (W_1), and then in distilled water at 20 ± 2°C (W_2) (see Note 1), care being taken to ensure that all air bubbles are removed; a small camel-hair brush is useful for this purpose.

The test piece shall be blotted dry with filter paper and then placed in the glass container with at least 100 ml of the swelling liquid. If the conditions of test do not necessitate a reflux condenser, the container shall be stoppered and placed in a suitable thermostatically controlled oven or bath for the required length of time. If a reflux condenser is fitted, the container shall be placed in a liquid bath at the required temperature. The rubber shall be shielded from light during the test.

At the end of the immersion period, the test piece shall be cooled to 20 ± 2°C by quickly transferring it to a cool fresh portion of the swelling liquid for a period of not less than five minutes and not more than ten minutes. Surplus swelling liquid shall be removed from the surfaces of the test piece (see Note 2) which shall then be immediately placed in a tared and stoppered weighing-bottle and its weight in air determined (W_3) to the nearest milligramme. It shall then be removed from the bottle and immediately weighed in distilled water (W_4) at 20 ± 2°C.

If the swelling liquid is appreciably volatile at room temperature, it is important that the time for each transference of the test piece, after removal from the swelling liquid, does not exceed 30 seconds.

The swelling, S_v, shall be calculated as follows:—

$$S_v = \frac{(W_3 - W_4) - (W_1 - W_2)}{(W_1 - W_2)} \times 100$$

where W_1 = initial weight in air
W_2 = initial weight in water
W_3 = weight of the swollen rubber in air
W_4 = weight of the swollen rubber in water.

If the test is being continued, the test piece shall be at once replaced in the swelling liquid and returned to the thermostatically controlled oven or bath.

Two test pieces shall be taken for each test and they shall be immersed in separate containers. The results shall be averaged.

NOTE 1. The above procedure may not be suitable if the swelling liquid is readily miscible with water or reacts with it. For such a liquid, if it is not too viscous or volatile at room temperature, weighings W_2 and W_4 may be made in the swelling liquid instead of in water and these weights used in the formula for S_v given above. If this is not practicable, the same procedure shall be used as for the water displacement method except that the final weighing in water shall be omitted and S_v calculated from the formula:—

$$S_v = \frac{W_3 - W_1}{L\,(W_1 - W_2)} \times 100$$

where L is the density of the swelling liquid in g/ml at 20°C. This formula may only be approximate if the swelling liquid is a mixture, because the density of absorbed liquid may differ from that of the bulk. Also, the density of any matter extracted from the rubber may differ from that of the swelling liquid.

NOTE 2. The method of removing the surplus liquid from the surfaces of the test piece will vary with the nature of the liquid. When mobile volatile liquids such as *iso*-octane or benzene are used, a quick wipe with filter paper is adequate. Some difficulty may be experienced in completely removing viscous non-volatile oils by this method and it may then be necessary to dip the test piece quickly in a suitable volatile solvent such as acetone and again quickly wipe with filter paper.

SECTION 6 DURATION OF TEST

The large differences in the rate of swelling of rubber in various liquids and in the same liquid at various temperatures precludes the adoption of one standard period of immersion. A period of 24 hours, 48 hours, 96 hours, 168 hours or 30 days may be sufficient but, for a complete investigation, it is recommended that determinations be made and recorded after several periods of immersion, preferably not less than four, so as to indicate the change of swelling with time. The total period should extend well beyond the point of maximum absorption.

SECTION 7 TEMPERATURE OF TEST

The test shall be made at one or more of the following standard temperatures: 25°C, 40°C, 70°C, 100°C, 120°C, or 150°C, with a tolerance of ± 1 Centigrade degree. Whenever possible, the temperature equal to or immediately above that at which the rubber will be used shall be selected. In other cases, 25°C shall be adopted.

SECTION 8 REPORT

The report shall state:

1. The value for swelling, S_v, calculated as described in Section 5.3.
2. Period of immersion.
3. Temperature of test.
4. Description of swelling liquid.
5. Condition of swollen test pieces as judged by visual and manual examination.

6. Appearance of swelling liquid after test; colour, fluorescence, sediment.
7. Initial shape and dimensions of the test piece.

SECTION 9 REPRODUCIBILITY OF RESULTS

The standard deviation of swelling results depends very much upon the swelling liquid and the extent of the swelling, so much so that even the coefficient of variation is not constant. Coefficients of variation range between 4 per cent and 12 per cent, although there are many results around 8 per cent, and this would seem to be a useful value to adopt as a reference level; this includes mixing variation as well as that of testing.

METHOD B. DIMENSIONAL CHANGE METHOD

SECTION 10 TEST PIECE

The test piece shall be rectangular, 5 cm long and 2·5 cm wide. The thickness shall be uniform, preferably not less than 2·5 mm and not greater than 3 mm. The sides shall be cut cleanly and at right angles to the top and bottom surfaces. If the direction of calender grain is known, this shall be parallel to the longitudinal axis of the test piece.

SECTION 11 APPARATUS

This is dependent on the temperature of the test and the volatility of the swelling liquid. For tests at temperatures appreciably below the boiling point of the swelling liquid, a stoppered glass bottle or tube shall be used. The dimensions shall be such that the test piece remains completely immersed in 100 ml of the swelling liquid, and may swell without restraint.

For tests at temperatures near the boiling point of the swelling liquid, the bottle or tube shall be fitted with a suitable reflux condenser.

The instrument for measuring the thickness of the test pieces shall consist of a micrometer dial-gauge firmly held in a rigid stand over a flat base-plate of diameter at least 2 in. (51 mm). The gauge shall have a scale graduated in unit divisions of 0·001 in. or 0·01 mm and shall comply where relevant with the requirements of B.S. 907* for a Type A gauge, particularly in respect of the accuracy of calibration. The plunger shall be fitted with a flat circular contact of diameter 0·150 ± 0·002 in. (3·81 ± 0·05 mm) which is square to the plunger and parallel to the base-plate. The dial-gauge shall operate under a substantially dead-weight

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* B.S. 907, ' Dial gauges for linear measurements '.

load of 0·85 ± 0·10 oz (24 ± 3 g), nominally equivalent to a pressure on the rubber of 3 lb/sq. in. (210 g/sq. cm). For the most accurate results, the instrument shall be used as a comparator as recommended in B.S. 907* which also includes notes on the care and use of dial-gauges.

SECTION 12 PROCEDURE

12.1 Preparation of sample. If fabric is attached to or embedded in the sample, it shall be removed before cutting the test pieces. The method of removal shall preferably avoid the use of a swelling liquid, but benzene, chloroform or carbon tetrachloride may be used to wet the contacting surfaces if necessary. Care shall be taken to avoid stretching the rubber during the separation from the fabric, and swelling 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 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.

12.2 Conditioning of samples and test pieces. The properties of vulcanized rubber change continuously with time, these changes being particularly rapid during the first 24 hours after vulcanization. No tests should therefore be carried out within this period and, for accurate comparisons between different rubbers, it may be necessary to ensure that these are tested at substantially the same interval after vulcanization.

Samples, after any necessary preparation, shall be conditioned at 20 ± 2°C for at least 12 hours before the test pieces are cut. These test pieces may be tested immediately but, if not tested immediately, 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.

Samples and test pieces shall be protected from light as completely as possible.

NOTE. A single temperature for conditioning is not yet practicable for all countries since 20 ± 2°C is difficult to maintain in certain cases. In climates where it is not possible to maintain this temperature a temperature of 27 ± 2°C is permitted provided the temperature of conditioning is stated in the test report.

12.3 Determination of swelling. The initial length of the test piece, along its centre line, shall be measured to the nearest 0·5 mm; measurements shall be taken along the top and bottom surfaces and the two results averaged. The initial width shall be similarly measured, but taking four measurements in all, one top and one bottom near each end of the test piece. The initial thickness shall be measured with the thickness gauge at four different points along the test piece and the results averaged.

The test piece shall then be placed in the glass container with at least

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* B.S. 907, 'Dial gauges for linear measurements'.

100 ml of the swelling liquid. If the conditions of the test do not necessitate a reflux condenser, the container shall be placed in a suitable thermostatically controlled oven or bath for the required length of time. If a reflux condenser is fitted, the container shall be placed in a liquid bath at the required temperature. The rubber shall be shielded from light during the test.

At the end of the immersion period, the test piece shall be cooled to 20 ± 2°C by quickly transferring it to a cool fresh portion of the swelling liquid for a period of not less than five minutes and not more than ten minutes and surplus swelling liquid removed from the surfaces of the test piece by wiping with filter paper. The length, width and thickness of the test piece shall then be re-measured as described above.

If the swelling liquid is appreciably volatile at room temperature it is important that the measurement shall be completed within one minute of removing the test piece from the swelling liquid.

The percentage change in length, S_L, shall be calculated as follows:—

$$S_L = \frac{L - L_o}{L_o} \times 100$$

where L_o is the initial length and L is the length after immersion.

The percentage change in width, S_W, and change in thickness, S_T, shall be calculated in a similar manner.

If the test is being continued, the test piece shall be at once replaced in the liquid and returned to the thermostatically controlled oven or bath.

Two test pieces shall be taken for each test and they shall be immersed in separate containers. The results shall be averaged.

SECTION 13 DURATION OF TEST

The large differences in the rate of swelling of rubber in various liquids and in the same liquid at various temperatures precludes the adoption of one standard period of immersion. A period of 24 hours, 48 hours, 96 hours, 168 hours or 30 days may be sufficient but, for a complete investigation, it is recommended that determinations be made and recorded after several periods of immersion, preferably not less than four, so as to indicate the change of swelling with time. The total period should extend well beyond the point of maximum absorption.

SECTION 14 TEMPERATURE OF TEST

The test shall be made at one or more of the following standard temperatures: 25°C, 40°C, 70°C, 100°C, 120°C, or 150°C with a tolerance of ± 1 Centigrade degree. Whenever possible, the temperature equal to or immediately above that at which the rubber will be used shall be selected. In other cases 25°C shall be adopted.

SECTION 15 REPORT

The report shall state:

1. The value for percentage change in length, S_L, in width, S_W, and in thickness, S_T, calculated as described in Section 12.3.
2. Period of immersion.
3. Temperature of test.
4. Description of the swelling liquid.
5. Condition of swollen test pieces as judged by visual and manual examination.
6. Appearance of swelling liquid after test; colour, fluorescence, sediment.

SECTION 16 REPRODUCIBILITY OF RESULTS

The standard deviation of swelling results depends very much upon the swelling liquid and the extent of the swelling, so much so that even the coefficient of variation is not constant. Coefficients of variation range between 4 per cent and 12 per cent, although there are many results around 8 per cent, and this would seem to be a useful value to adopt as a reference level; this includes mixing variation as well as that of testing.

METHOD C. LINEAR CHANGE METHOD

SECTION 17 TEST PIECE

The test piece shall be a rectangular strip, 100 mm long and 1·6 mm wide. The thickness shall be uniform, not less than 1 mm and not greater than 3 mm. It shall be cut from sheet by punching with a die using a single stroke of a press. The die used for punching the test pièces shall be carefully maintained so that the cutting edges are sharp and free from nicks to avoid leaving ragged edges on the test piece. 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.

SECTION 18 APPARATUS

Immersion tube. The immersion tube shall be made from straight clear glass tubing, 8 mm internal diameter and approximately 25 cm long. It shall be sealed flat at one end and stoppered at the other.

Tube rack. A suitable rack (see Fig. 2) shall be provided for supporting the tube or a series of tubes at an angle of approximately 45° during the immersion period.

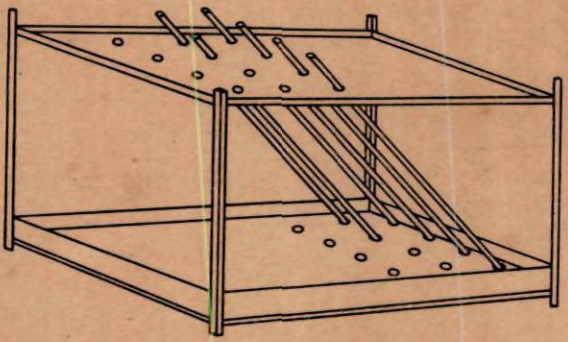

Fig. 2. Rack for swelling test

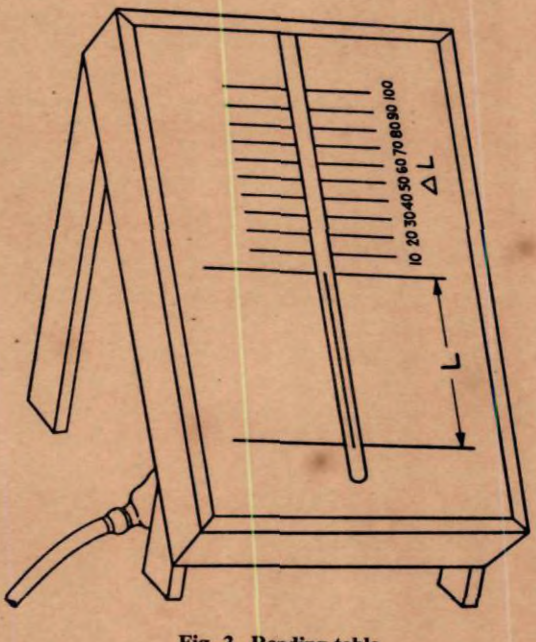

Fig. 3. Reading table

Reading table. The reading table (see Fig. 3) for measuring the length of the test piece without removing it from the tube shall consist essentially of a flat rigid scale, inclined at an angle of 45° and graduated in millimetres, on which the immersion tube may be placed during the measurement. A suitable scale may be constructed from a sheet of 1-mm graph paper supported by a flat glass plate and illuminated from behind.

SECTION 19 PROCEDURE

19.1 Preparation of sample. If fabric is attached to or embedded in the sample, it shall be removed before cutting the test pieces. The method of removal shall preferably avoid the use of a swelling liquid, but benzene, chloroform or carbon tetrachloride may be used to wet the contacting surfaces if necessary. Care shall be taken to avoid stretching the rubber during the separation from the fabric, and swelling 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 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.

19.2 Conditioning of samples and test pieces. The properties of vulcanized rubber change continuously with time, these changes being particularly rapid during the first 24 hours after vulcanization. No tests should therefore be carried out within this period and, for accurate comparisons between different rubbers, it may be necessary to ensure that these are tested at substantially the same interval after vulcanization.

Samples, after any necessary preparation, shall be conditioned at 20 ± 2°C for at least 12 hours before the test pieces are cut. These test pieces may be tested immediately but, if not tested immediately, 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.

Samples and test pieces shall be protected from light as completely as possible.

NOTE. A single temperature for conditioning is not yet practicable for all countries since 20 ± 2°C is difficult to maintain in certain cases. In climates where it is not possible to maintain this temperature a temperature of 27 ± 2°C is permitted provided the temperature of conditioning is stated in the test report.

19.3 Determination of swelling. The test piece shall be inserted in the immersion tube so that it is straight and one end rests on the sealed flat end of the tube. The tube shall be placed on the reading table and the initial length of the test piece measured to the nearest 0·5 mm.

The tube shall then be placed in the rack, 10 ml of the swelling liquid poured in, the stopper inserted and the assembly placed in a thermostatically controlled oven or bath for the required length of time.

At the end of the immersion period, the tube and contents shall be cooled to 20 ± 2°C by quickly transferring it to a water bath for a period of not less than five minutes and not longer than 10 minutes. The length of the test piece shall then be re-measured on the reading table as described above.

The change in length shall be calculated as follows:—

$$\text{Change in length, } \Delta L \text{ (mm)} = L - L_o$$

where L_o is the initial length and L is the length after immersion.

The percentage increase in volume or swelling, S_v, may then be determined from the value of ΔL using Table 1 which is based on the assumption that the swelling is isotropic.

If the test is being continued, the tube shall be at once returned to the rack in the thermostatically controlled oven or bath.

Four test pieces shall be taken for each test and they shall be immersed in separate tubes. Two shall be cut parallel to one edge of the sheet, the other two being cut in a direction at right angles to the first pair. The results for each pair shall be averaged. If the rubber is known to be free from grain, the percentage increase in volume may be determined from the value of ΔL, taking the average for all *four* test pieces, by using Table 1. This procedure is not permissible if grain is present, i.e. if the values of ΔL for the test pieces cut in the two perpendicular directions are different. When it is desired to show the effect of grain the apparent increase in volume may be determined from the value of ΔL taking the average for each pair of test pieces by using Table 1.

SECTION 20 DURATION OF TEST

The large differences in the rate of swelling of rubber in various liquids and in the same liquid at various temperatures precludes the adoption of one standard period of immersion. A period of 24 hours, 48 hours, 96 hours, 168 hours or 30 days may be sufficient but, for a complete investigation, it is recommended that determinations be made and recorded after several periods of immersion, preferably not less than four, so as to indicate the change of swelling with time. The total period should, if possible, extend well beyond the point of maximum absorption.

SECTION 21 TEMPERATURE OF TEST

The test shall be made at one or more of the following standard temperatures: 25°C, 40°C, 70°C, 100°C, 120°C, or 150°C, with a tolerance of ± 1 Centigrade degree. Whenever possible, the temperature equal to or immediately above that at which the rubber will be used shall be selected. In other cases 25°C shall be adopted.

This method of test is only suitable for use at temperatures appreciably below the boiling point of the swelling liquid.

SECTION 22 REPORT

The report shall state:

1. The value for swelling, S_v, calculated as described in Section 19.3.
2. Period of immersion.
3. Temperature of test.
4. Description of the swelling liquid.
5. Condition of swollen test pieces as judged by visual and manual examination.
6. Appearance of swelling liquid after test; colour, fluorescence, sediment.

SECTION 23 REPRODUCIBILITY OF RESULT

The standard deviation of swelling results depends very much upon the swelling liquid and the extent of the swelling, so much so that even the coefficient of variation is not constant. Coefficients of variation range between 4 per cent and 12 per cent, although there are many results around 8 per cent, and this would seem to be a useful value to adopt as a reference level; this includes mixing variation as well as that of testing.

TABLE 1. RELATION OF ΔL TO S_v

ΔL	S_v	ΔL	S_v	ΔL	S_v	ΔL	S_v	ΔL	S_v
mm	per cent	mm	per cent	mm	per cent	mm	per cent	mm	per cent
0·5	1·5	20·5	75·0	40·5	177	60·5	314	80·5	488
1·0	3·0	21·0	77·2	41·0	180	61·0	317	81·0	493
1·5	4·5	21·5	79·4	41·5	183	61·5	321	81·5	498
2·0	6·1	22·0	81·6	42·0	186	62·0	325	82·0	503
2·5	7·6	22·5	83·8	42·5	189	62·5	329	82·5	508
3·0	9·2	23·0	86·1	43·0	192	63·0	333	83·0	513
3·5	10·8	23·5	88·4	43·5	196	63·5	337	83·5	518
4·0	12·5	24·0	90·7	44·0	199	64·0	341	84·0	523
4·5	14·1	24·5	93·0	44·5	202	64·5	345	84·5	528
5·0	15·8	25·0	95·3	45·0	205	65·0	349	85·0	533
5·5	17·4	25·5	97·5	45·5	208	65·5	353	85·5	538
6·0	19·1	26·0	100	46·0	211	66·0	357	86·0	544
6·5	20·8	26·5	102	46·5	214	66·5	362	86·5	549
7·0	22·5	27·0	105	47·0	218	67·0	366	87·0	554
7·5	24·2	27·5	107	47·5	221	67·5	370	87·5	559
8·0	26·0	28·0	110	48·0	224	68·0	374	88·0	564
8·5	27·7	28·5	112	48·5	227	68·5	378	88·5	570
9·0	29·5	29·0	115	49·0	231	69·0	383	89·0	575
9·5	31·3	29·5	117	49·5	234	69·5	387	89·5	580
10·0	33·1	30·0	120	50·0	238	70·0	391	90·0	586
10·5	34·9	30·6	122	50·5	241	70·5	396	90·5	591
11·0	36·8	31·0	125	51·0	244	71·0	400	91·0	597
11·5	38·6	31·5	127	51·5	248	71·5	404	91·5	602
12·0	40·5	32·0	130	52·0	251	72·0	409	92·0	608
12·5	42·4	32·5	133	52·5	255	72·5	413	92·5	613
13·0	44·3	33·0	135	53·0	258	73·0	418	93·0	619
13·5	46·1	33·5	140	53·5	262	73·5	422	93·5	624
14·0	48·2	34·0	141	54·0	265	74·0	427	94·0	630
14·5	50·0	34·5	143	54·5	269	74·5	431	94·5	636
15·0	52·1	35·0	146	55·0	272	75·0	436	95·0	642
15·5	54·1	35·5	149	55·5	276	75·5	440	95·5	647
16·0	56·1	36·0	152	56·0	280	76·0	445	96·0	653
16·5	58·1	36·5	154	56·5	283	76·5	450	96·5	659
17·0	60·2	37·0	157	57·0	287	77·0	454	97·0	664
17·5	62·2	37·5	160	57·5	291	77·5	461	97·5	670
18·0	64·3	38·0	163	58·0	294	78·0	464	98·0	676
18·5	66·6	38·5	166	58·5	298	78·5	469	98·5	682
19·0	68·5	39·0	169	59·0	302	79·0	474	99·0	688
19·5	70·6	39·5	172	59·5	306	79·5	478	99·5	694
20·0	72·8	40·0	174	60·0	310	80·0	483	100·0	700

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