BRITISH STANDARD

BS 903C4: 1983
BS 2782-2: Methods 220 and 221:1983

Methods of testing vulcanized rubber —

Part C4: Determination of electric strength

Methods of testing plastics —

Part 2: Electrical properties — Method 220: Determination of electric strength: rapidly applied voltage method — Method 221: Determination of electric strength: step-by-step method

IMPORTANT NOTE. When using this method in order to test plastics, readers are reminded that the foreword, general introduction and instructions to BS 2782-0:1982 contain important information on the testing of plastics. However, it should be noted that the conditioning requirements given in clause 8 of this Part replace those in Part 0.

UDC 678.01:537.226.7

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Plastics Standards Committee (PLC/-) and the Rubber Standards Committee (RUC/-) to Technical Committee PLC/RUC/9 upon which the following bodies were represented:

British Plastics Federation
British Rubber Manufacturers' Association
Electrical and Electronic and Insulation Association (BEAMA)
Ministry of Defence
Rubber and Plastics Research Association of Great Britain
Telecommunication Engineering and Manufacturing Association (TEMA)

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The following BSI references relate to the work on this standard:
Committee reference PLC/RUC/9
Drafts for comment 76/52548 DC
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Amd. No.	Date of issue	Comments

Contents

Foreword

This revision of this Part of this British Standard which has been published under the direction of the Plastics Standards Committee and the Rubber Standards Committee supersedes the previous edition of BS 903-C4 and methods 201A to 201G of BS 2782, which are being withdrawn.

The standard includes information from IEC 243:1967.

In BS 2782:1970 only the step-by-step methods were described.

In preparing this standard to cover the testing of both vulcanized rubber and plastics, there was some difficulty in reconciling the requirements for the period of conditioning the test pieces prior to testing. The internationally agreed period for vulcanized rubber is a minimum of 16 h (see BS 903-A35) but for plastics a minimum of 88 h is used (see ISO 291). However, for most rubber and plastics, it is considered that 16 h is adequate in the climatic conditions prevailing in the UK.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 10, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

0 Introduction

The electric strength measured in accordance with this standard is not the intrinsic electric strength, i.e. the electric stress at which the material will fail under ideal conditions, but a value which may be considerably less than this and which is usually controlled by such factors as the presence of discharges in the ambient gas or liquid or in gaseous inclusions in the material.

It is meaningless to quote the electric strength of a material without complete details of the test conditions, because the electric strength may be affected by many factors including:

a) the frequency, waveform and time of application of the voltage;

b) the thickness and homogeneity of the test piece and the presence of mechanical strain;

c) the ambient temperature, pressure and humidity;

d) the presence of gaseous inclusions, moisture or other contamination;

e) the dimensions and thermal conductivity of the test electrodes;

f) the electrical and thermal characteristics of the ambient medium.

The results given by different methods are not directly comparable and it should be noted that the electric strength of many materials decreases as the thickness of the test piece between the electrodes increases and with increasing time of voltage application.

Material with a high electric strength measured by the tests described in this standard will not necessarily resist long-term degradation processes such as erosion or chemical deterioration by discharges, or electrochemical deterioration in the presence of moisture, which may cause eventual failure in service at much lower stresses. On the other hand, if discharges in insulation are eliminated by appropriate design and construction, the values obtained by the tests described in the standard may be exceeded.

Thus, these tests are only of limited value to the insulation designer for comparative purposes although they are useful for routine and quality control tests, and as specification tests.

1 Scope

This Part of this British Standard gives two methods of determining the short-time electric strength (breakdown voltage) of insulating vulcanized rubber (including ebonite) and of solid plastics materials using a voltage with a nominal frequency of 50 Hz.

One method of determining electric strength is by rapidly increasing the voltage until breakdown occurs and the other is by a steady increase in the applied voltage step-by-step at 20 s intervals.

Test pieces and electrode systems are specified to provide tests on a variety of materials and forms of material. Tests are carried out normal and parallel to the planes of sheet materials and tubes and parallel to the axes of rods.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this British Standard, the following definitions apply.

2.1
voltage

the peak value of the alternating voltage applied to the electrodes divided by $\sqrt{2}$

2.2
breakdown voltage

the voltage at which breakdown occurs in the rapidly applied voltage test or the highest voltage withstood for 20 s in the step-by-step method

2.3
electric strength

the breakdown voltage divided by the dimension of the test piece across which the voltage was applied

2.4
central value

the middle value of an odd number of results, or the mean of the middle two when arranged in order of magnitude

3 Identification of method

Methods are identified according to the mode of applying the voltage and the nature of the material under test as indicated in Table 1.

4 Form of test pieces

4.1 General. If applicable the test piece shall be prepared under the conditions specified in the relevant British Standard for the material. The dimensions shall be as specified in **4.2** to **4.8**; increases in the stated minimum dimensions may be necessary to avoid breakdown through the surrounding medium, i.e. flashover.

4.2 Test pieces for Methods C4.1A, C4.2A, 220A and 221A. The test piece shall be a disc not less than 100 mm in diameter or a square of side not less than 100 mm. Where the material is supplied in sheet form the thickness shall be the thickness of the sheet.

For rigid moulded or cast materials the average thickness of the test piece shall be 3 ± 0.2 mm. In addition, on any one test piece the thickness shall not vary by more than 0.2 mm.

For flexible moulded or cast materials the average thickness of the test piece shall be 1.25 ± 0.2 mm. In addition, on any one test piece the thickness shall not vary by more than 0.1 mm.

4.3 Test pieces for Methods C4.1B, C4.2B, 220B and 221B. The test piece shall be a narrow strip or tape, at least 250 mm long, the width and thickness of the material except when the width needs to be reduced to fit any jig such as that shown in Figure 2.

NOTE For narrow tapes flashover may present difficulties, Flashover may be unavoidable with narrow tapes of some materials so that the maximum width should always be used.

4.4 Test pieces for Methods C4.1C, C4.2C, 220C and 221C. The test piece shall be a rigid tube not less than 100 mm long. The wall thickness of the test piece shall be that of the tube from which it is cut.

4.5 Test pieces for Methods C4.1D, C4.2D, 220D and 221D. The test piece shall be a flexible tube not less than 100 mm in length. The wall thickness of the test piece shall be that of the tube from which it is cut.

4.6 Test pieces for Methods C4.1E, C4.2E, 220E and 221E. The test piece shall be flexible tubing not less than 350 mm in length. The wall thickness of the test piece shall be that of the tube from which it is cut.

4.7 Test pieces for Methods C4.1F, C4.2F, 220F and 221F. The test piece shall be flexible tubing not less than 100 mm in length. The wall thickness of the test piece shall be that of the tube from which it is cut.

4.8 Test pieces for Methods C4.1G, C4.2G, 220G and 221G. The test piece ends shall be parallel smooth planes perpendicular to the plane of the sheet or axis of the rod or tube and 25 ± 0.2 mm apart. The test piece shall be cut from the material without reduction in thickness.

For sheet material the test piece shall be approximately 100 mm long.

For rods and tubes up to 100 mm outer diameter or external side dimension, the test piece shall be a complete ring or length of rod.

For tubes over 100 mm outer diameter or external side dimension, the test piece shall be a portion of a ring approximately 100 mm circumferential length.

5 Number of test pieces

The number of test pieces for the step-by-step method shall be two or as required by the specification for the material. Additional test pieces may be required if some tests are invalid (see **10.3**). The number of test pieces required for the rapidly applied voltage method shall be at least two or as required by the specification for the material, except in reference cases when at least five test pieces shall be tested. In both cases additional test pieces may be required for preliminary tests.

6 Electrodes and test assemblies

6.1 General. The electrodes shall be kept clean and free from pitting including pitting caused by arcing.

Table 1 — Identification of method

Material under test	Mode of applying voltage	Direction of applying voltage	BS 903 reference	BS 2782 reference
Sheet	Rapidly applied	Normal to plane of the sheet or axis of tube	C4.1A	220A
Narrow strip and tape			C4.1B	220B
Rigid tube			C4.1C	220C
Flexible tube including sleeving			C4.1D, E and F	220D, E and F
Rigid sheet, tube and rod		Parallel to the plane of the sheet or axis of tube or rod	C4.1G	220G
Sheet	Step-by-step	Normal to plane of the sheet or axis of tube	C4.2A	221A
Narrow strip and tape			C4.2B	221B
			C4.2C	221C
Flexible tube including sleeving			C4.2D, E and F	221 D, E and F
Rigid sheet, tube and rod		Parallel to the plane of the sheet or axis of tube or rod	C4.2G	221G

The lead to the upper electrode shall not tilt or otherwise move this electrode or affect the pressure on the test piece and the leads to the electrodes shall not appreciably affect the electric field configuration in the neighbourhood of the test piece.

6.2 Electrodes for Methods C4.1A, C4.2A, 220A and 221A. For sheet materials the lower electrode shall consist of a solid cylinder of brass or stainless steel 75 ± 1 mm in diameter and approximately 15 mm thick. The upper electrode shall consist of a solid cylinder of brass or stainless steel 25 ± 1 mm in diameter and approximately 25 mm thick. The sharp edges shall be removed from the electrodes, the radius at the edges being approximately 3 mm. (See Figure 1.)

6.3 Electrodes for Methods C4.1B, C4.2B, 220B and 221B. For narrow strips and tapes the electrodes shall be two brass or stainless steel rods, each 6 ± 0.2 mm in diameter mounted vertically one above the other in a jig so that the test piece is held between the ends of the rods. The upper and lower electrodes shall be coaxial. The sharp edges of the ends shall be removed to give a radius of approximately 1 mm. The upper electrode shall weigh 50 ± 2 g. Figure 2 shows a convenient arrangement.

NOTE 1 To prevent flashover around the edges of narrow tapes the test piece may be clamped using strips of tape overlapping the edges of the test piece. Alternatively, gaskets surrounding the electrodes may be used provided there is an annular space between electrode and gasket of about 1.5 mm.

If test pieces are to be tested while extended they shall be clamped in a frame holding them in the required position relative to the assembly shown in Figure 2.

NOTE 2 Wrapping one end of the test piece round a rotatable rod is one convenient way of achieving the required extension.

6.4 Electrodes for Methods C4.1C, C4.2C, 220C and 221C. For rigid round tubes and rigid rectangular tubes, having an internal diameter or minor dimension not exceeding 100 mm, the outer electrode shall be a band of metal foil 25 ± 1 mm wide wrapped tightly around the tube. The inner electrode shall be a closely fitting internal conductor, e.g. rod, tube, metal foil, making good contact with the inner surface. In each case, the ends of the inner electrode shall extend for at least 25 mm beyond the ends of the outer electrode. [See Figure 3(a).]

For round tubes, having an internal diameter exceeding 100 mm, the internal electrode shall consist of a disc of metal foil 25 ± 1 mm in diameter, sufficiently flexible to conform to the curvature of the inner surface of the tube. The external electrode shall consist of a band of metal foil 75 ± 1 mm wide wrapped tightly round the outside of the tube symmetrically with respect to the internal electrode. [See Figure 3(b).]

6.5 Electrodes for Methods C4.1D, C4.2D, 220D and 221D. Straight metal wires or rods shall be used for the inner electrode. The electrode shall be the nearest standard size that will fit snugly without stretching the tube. For the outer electrode a strip of metal foil 25 ± 1 mm wide shall be applied snugly round the tubing.

6.6 Electrodes for Methods C4.1E, C4.2E, 220E and 221E. The inner electrode shall be as specified in **6.5** but shall be approximately 350 mm long and bent into a U-shape by using a mandrel of 50 mm diameter unless otherwise specified for the material. A suitable arrangement is shown in Figure 4.

The U-shaped electrode carrying the test piece shall be placed in a container so that it is immersed in metal shot throughout 250 mm of its length. The shot shall be 0.75 mm to 2.0 mm in diameter and can be stainless steel, solid nickel or nickel plated but any shot of the required dimensions is suitable provided it does not damage the sleeving. The shot shall remain capable of passing a current of not less than 50 mA when a maximum voltage of 200 V a.c. is applied between the U-shaped electrode, without a test piece, but with the curved portion insulated by a sleeve, and the walls of the container or another electrode close to them.

NOTE 1 Care is needed to avoid damage to the test piece by the shot.

NOTE 2 When tests are to be made at a high temperature the metal used should resist degradation at that temperature.

6.7 Electrodes for Methods C4.1F, C4.2F, 220F and 221F. For large bore flexible tubing and sleeving the electrodes shall be as specified in **6.2** and applied to tubing and sleeving cut longitudinally and opened flat.

6.8 Electrodes for Methods C4.1G, C4.2G, 220G and 221G. The electrodes shall be flat brass or stainless steel plates (see Figure 5).

The electrodes shall be of sufficient size to cover the edges of the sheet or the ends of the tube or rod between which the voltage is to be applied, with an overlap at any point of at least 15 mm.

The planes of the electrodes shall be arranged to be perpendicular to the plane of the sheet test piece or to the axis of the test piece of tube or rod.

NOTE It may be necessary to use one or two additional test pieces to support the upper electrode to provide a single test result.

All test pieces shall be discarded after the test. No test piece shall be retested, even if it has not broken down.

7 Electrical apparatus

7.1 *Transformer.* The test voltage shall have a nominal frequency of 50 Hz.

NOTE 1 This may be most conveniently obtained by using a step-up transformer supplied from a variable low-voltage source, having a waveform as nearly sinusoidal as possible.

The transformer and its controlling equipment shall be capable of maintaining the required test voltage up to the instant of breakdown.

With the test piece in circuit, the voltage applied to the material under test shall be of approximately sine waveform; the ratio of the peak value to the root mean square value (i.e. the crest factor) shall be within the limits of $\sqrt{2} \pm 7$ % (1.31 to 1.51).

NOTE 2 The crest factor may be checked either by means of an r.m.s. voltmeter in conjunction with a sphere-gap or a peak voltmeter or by means of an oscillograph, the measurement being made across the material under test.

NOTE 3 A transformer which, with its associated test equipment, is capable of supplying, within the waveform limits specified above, an output current of not less than 40 mA over the voltage range for which the equipment is intended, and at all leading power factors between zero and unity, will usually be found satisfactory.

When the electrodes are not both of the same size, the larger of the two shall be connected to the earthed end of the high voltage winding of the testing transformer, or to the end nearest to earth potential if both poles of the transformer are insulated.

7.2 *Protective resistor.* To protect the test equipment from damage by current or voltage surges following breakdown, a resistor shall be used in series with the specimen. This resistor shall be of the order of several thousand ohms.

7.3 *Circuit-breaker.* In the primary circuit of the high-voltage transformer there shall be a circuit-breaker with arrangements for tripping the breaker at a suitable maximum current and having a no-volt release coil to protect the equipment in the event of restoration of the supply after interruption.

The circuit-breaker shall be well co-ordinated with the characteristics of the test equipment and the material under test, otherwise a false indication of breakdown may occur as a result of flashover, specimen charging, leakage or corona currents, equipment magnetizing current or malfunctioning.

7.4 *Voltage control.* The voltage shall be controlled smoothly by one of the following:

a) a variable ratio auto-transformer;

b) an induction regulator;

c) a resistance-potential divider.

7.5 *Measurement of test voltage*

NOTE 1 For the purposes of this standard, the magnitude of the test voltage is defined as its peak value divided by $\sqrt{2}$ (see **2.1**).

The peak voltage shall be measured in one of the following ways.

a) At the electrodes using a measuring device complying with BS 923.

b) By a voltmeter suitably connected to the input or output side of the test transformer or to a voltmeter winding provided thereon. The instrument shall be calibrated against a sphere-gap up to the full voltage which it is desired to measure.

NOTE 2 The ratio of the voltage derived from the sphere-gap to the voltage indicated on the auxiliary instrument may be dependent upon the presence of the test piece or of the sphere-gap, and it is important that a load equivalent to the test piece is in the circuit during the calibration. The sphere-gap may be disconnected during the actual test if its absence is known to have a negligible influence on the voltage ratio.

8 Conditioning

Conditioning either shall be as required by the specification for the material, or shall comply with the following.

The minimum time between vulcanization and commencement of conditioning of rubber test pieces shall be 16 h. All rubber samples and test pieces shall be protected from the light as completely as possible during the interval between manufacture and testing.

NOTE 1 It may also be necessary to protect some plastics materials from the light.

Conditioning shall be at 23 ± 2 °C and 50 ± 5 % r.h. for at least 16 h.

NOTE 2 16 h conditioning is usually sufficient but for some plastics materials a minimum of 88 h may be required particularly in cases of dispute.

9 Conditions of test

The conditions of test either shall be as specified for the material or as follows.

The test shall be carried out at 23 ± 2 °C or 90 ± 2 °C, either in oil, or in air. Sufficient time shall be allowed for the test piece to attain the required temperature, which shall be substantially uniform around the test piece.

Tests in air at elevated temperature shall be made in a well designed oven of sufficient size to accommodate the test piece and the electrodes without flashover occurring during the tests.

Table 2 — Successive voltages to be applied (kilovolts peak/$\sqrt{2}$)

0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.0	1.1	1.2	1.3
1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4
3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.5	6.0	6.5	7.0	7.5	8.0
8.5	9.0	9.5	10	11	12	13	14	15	16	17	18	19	20
22	24	26	28	30	32	34	36	38	40	42	44	46	48
50	55	60	65	70	75	80	85	90	95	100			

The oil shall comply With the requirements of BS 148.

NOTE It is necessary to ensure adequate electric strength and resistivity of the oil as reduction of these may result in an increase in measured electric strength of the test piece. Information is given in BS 5730 on maintenance of insulating oils.

10 Procedure

10.1 General. If the electric strength is to be calculated from the breakdown voltage on the actual thickness of the test piece, measure the dimension of the test piece across which the voltage is to be applied. Record the measurement to the nearest 0.02 mm.

As soon as possible after removal from the conditioning atmosphere (see clause **8**), apply the electrodes to the conditioned test piece (in oil if the test is to be carried out in oil), in accordance with clause **6**, and allow the assembly to attain the specified temperature as given in clause **9**.

10.2 Rapidly applied voltage test. Unless the approximate electric strength of the material is known, carry out a preliminary test or tests to determine it.

Apply the voltage from zero at a uniform rate so that breakdown occurs on an average of between 10 s and 20 s. The test is valid if the average time to breakdown lies within the above limits, even though some of the individual times may be outside these limits.

NOTE Criteria of breakdown are discussed in Appendix A.

10.3 Step-by-step test. Select the nearest voltage to 40 % of the probable rapidly applied breakdown voltage from Table 2 and apply to the test piece.

NOTE If the probable rapidly applied value is not known, it should be obtained by subjecting one additional test piece to a preliminary test consisting of rapidly increasing the voltage at a uniform rate until breakdown occurs.

If the test piece withstands this voltage for 20 s without failure, successively apply the next higher and subsequent voltages given in Table 2 for 20 s until breakdown occurs.

If any test piece breaks down in less than 20 s after the application of the initial voltage discard it and test an additional test piece in its place. In this and any subsequent tests the initially applied voltage shall be appropriately lower than that specified above.

Make the increases of voltage as quickly as possible and include the time spent in raising the voltage in the period of 20 s at the higher voltage. Continue until the required number of valid test results has been obtained.

11 Expression of results

11.1 Rapidly applied voltage test. Express the results in one of the following ways.

a) The results as specified for the material.

b) The breakdown voltage of the material as the mean of the breakdown voltages on two test pieces or the central value[1)] for more than two test pieces (this method of expression shall always be used for methods suffix G).

c) The electric strength of the material as the calculated mean of the electric strengths on two test pieces or the central value for more than two test pieces, calculated on the measured thickness for methods suffix A, B, C, and F and on the nominal wall thickness for methods suffix D and E.

11.2 Step-by-step test. Express the results in one of the following ways.

a) The results as specified for the material.

b) The breakdown voltage of the material as the central value of the breakdown voltages (see **2.2** for definition) of the individual test pieces (this method of expression shall always be used for methods suffix G).

c) The electric strength of the material calculated as the central value of the electric strengths of the individual test pieces calculated from the breakdown voltages (see **2.2**) on the basis of the measured thicknesses for methods suffix A, B, C and F and the nominal wall thicknesses for methods suffix D and E.

[1)] This term is also called the median (see BS 5324).

12 Test report

The report shall state:

a) the number of this British Standard and the method used, e.g. BS 2782:Method 221A;

b) the result of the test, in kV/mm or V as appropriate, in accordance with clause **11**;

c) the individual results and test piece dimensions across which voltage was applied;

d) the temperature of test;

e) the immersion medium;

f) the moulding, casting or valcanizing conditions of the test piece if applicable;

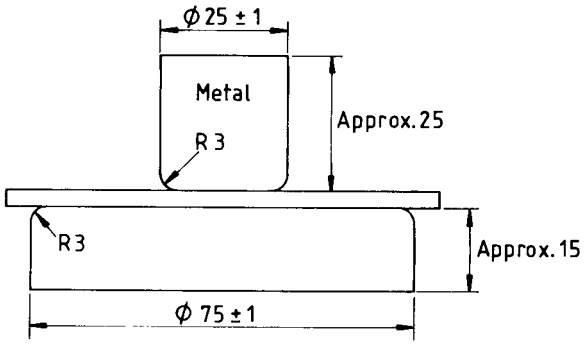
g) the conditioning, if any, of the test piece.

Appendix A Criterion of breakdown

Dielectric breakdown is accompanied by an increase of current flowing in the circuit and by a decrease of voltage across the sample. The increased current may trip a circuit-breaker or blow a fuse. However, tripping of a circuit-breaker may be influenced sometimes by flashover, specimen charging, leakage or corona currents, equipment magnetizing current, or malfunctioning. It is therefore essential that the circuit-breaker is well co-ordinated with the characteristics of the test equipment and the material under test, otherwise the circuit-breaker may operate without breakdown of the specimen, or fail to operate when breakdown has occurred and thus not provide a positive criterion of breakdown. Even under the best conditions, prior breakdowns in the ambient medium may occur, and observations shall be made to detect them during tests. If prior breakdowns in the medium are observed, they shall be reported.

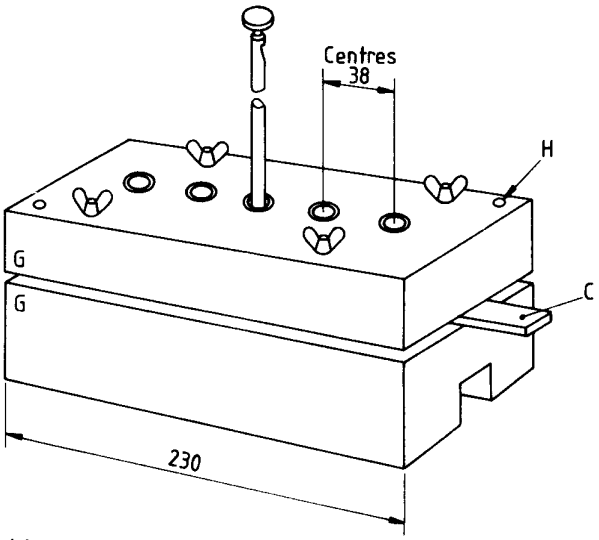
Where tests are made perpendicular to the planes of sheet materials, and axes of rods and tubes, there is usually no doubt when breakdown has occurred and subsequent visual inspection readily shows the actual breakdown channel whether this is filled with carbon or not.

In tests parallel to the planes of sheet materials and axes of rods and tubes, however, it is advisable to confirm breakdown by twice re-applying a voltage less than the first apparent breakdown, to check that subsequent failures occur at lower values. A convenient practice has been found to be the re-application of half the breakdown voltage, followed by increase to failure by the same procedure as in the first test.

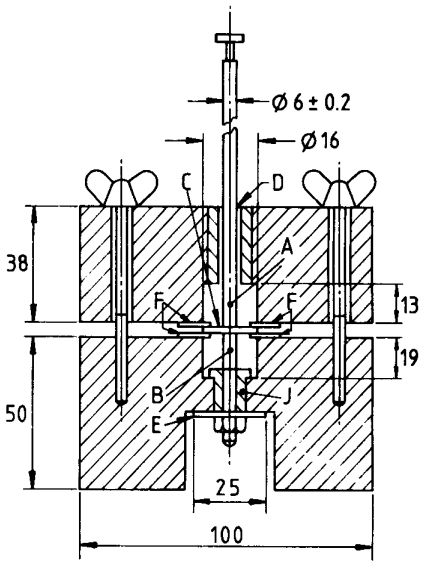


Dimensions are in millimetres

Figure 1 — Electrodes for sheet materials



(a) General arrangement

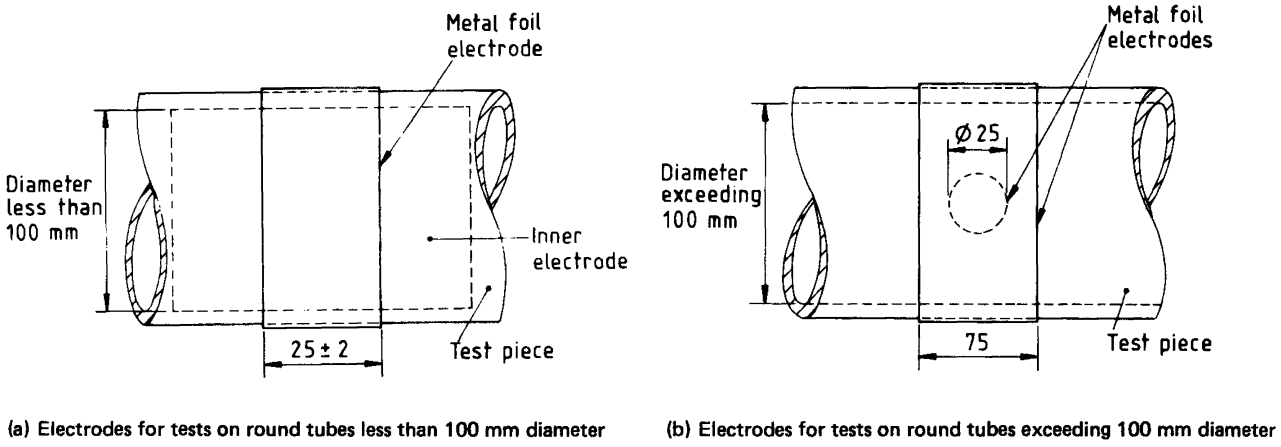


(b) Section of apparatus through electrodes

A = upper electrode to be an easy fit in bush D
B = lower electrode
C = test piece
D = brass bush with inside diameter
E = brass strip 25 mm wide connecting all lower electrodes
F = pieces of strip overlapping edges of narrow test piece
G = blocks of suitable insulation material (e.g. a paper filled laminate)
H = dowel hole
J = brass bushing with internal thread

Dimensions are in millimetres

Figure 2 — Typical example of electrode apparatus for tests on tape

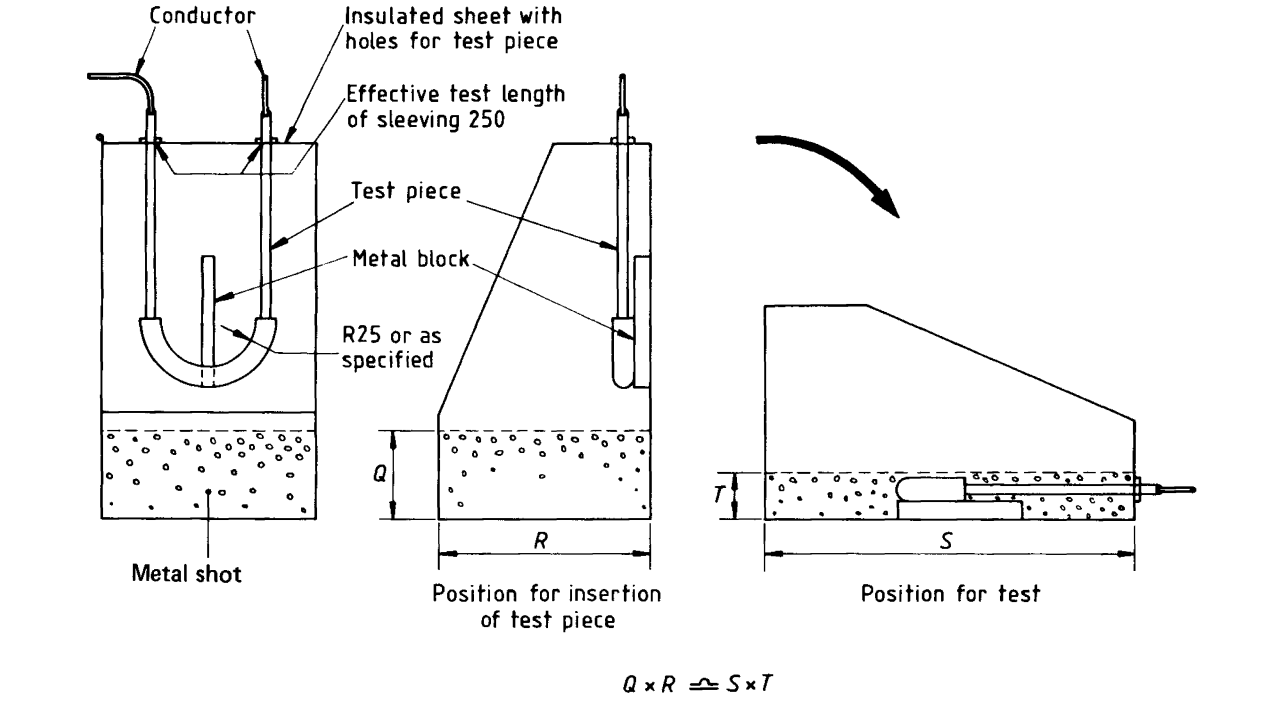


(a) Electrodes for tests on round tubes less than 100 mm diameter

(b) Electrodes for tests on round tubes exceeding 100 mm diameter

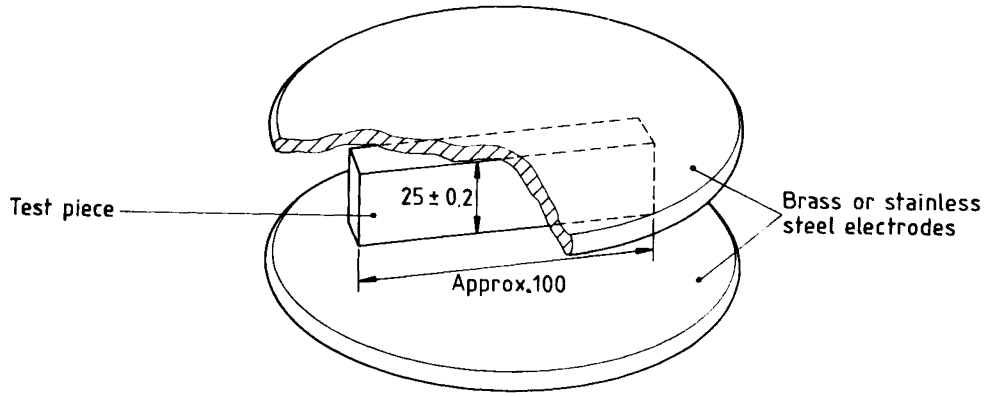
Dimensions are in millimetres

Figure 3 — Electrodes for tests on round tubes



Dimensions are in millimetres

Figure 4 — Typical electrode arrangement for tests parallel to the surface



Dimensions are in millimetres

Figure 5 — Typical electrodes for tests on flexible tube including sleeving

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Publications referred to

BS 148, *Insulating oil for transformers and switchgear.*

BS 903, *Methods of testing vulcanized rubber.*

BS 903-A35, *Standard temperatures, humidities and times for the conditioning and testing of test pieces*[2)].

BS 923, *Guide on high-voltage testing techniques.*

BS 2782, *Methods of testing plastics.*

BS 2782-0, *Introduction.*

BS 5324, *Guide to application of statistics to rubber testing.*

BS 5730, *Code of practice for maintenance of insulating oil.*

IEC 243, *Recommended methods of test for electric strength of solid insulating materials at power frequencies*[2)].

ISO 291, *Plastics — Standard atmospheres for conditioning and testing*[2)].

[2)] Referred to in the foreword only.

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