

Winding wires — Test methods —

Part 3: Mechanical properties

The European Standard EN 60851-3:1998, with the incorporation of amendments A1:1997 and A2:2003, has the status of a British Standard

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National foreword

This British Standard is the English language version of EN 60851-3:1996 including amendments A1:1997 and A2:2003. It is identical with IEC 60851-3:1996 and incorporates amendment 1:1997. It supersedes BS 6811-2.3:1992 which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags [A1] <A1>. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment 1 is indicated by [A1] <A1>.

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Foreword

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Annexes designated “normative” are part of the body of the standard.

Annexes designated “informative” are given for information only.

In this standard, Annex ZA is normative and Annex A is informative.

Annex ZA has been added by CENELEC.

Foreword to amendment A1

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Introduction

This part of IEC 60851 forms an element of a series of standards which deals with insulated wires used for windings in electrical equipment. The series has three groups describing:

- a) methods of test (IEC 60851);
- b) specifications (IEC 60317);
- c) packaging (IEC 60264).

1 Scope

This part of IEC 851 specifies the following methods of test:

- Test 6: Elongation;
- Test 7: Springiness;
- Test 8: Flexibility and adherence;
- Test 11: Resistance to abrasion;
- Test 18: Heat or solvent bonding.

For definitions, general notes on methods of test and the complete series of methods of test for winding wires see IEC 60851-1.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60851. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 60851 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of the IEC and ISO maintain registers of currently valid International Standards.

IEC 60851-1:1996, *Winding wires — Test methods — Part 1: General*.

IEC 60851-2:1996, *Winding wires — Test methods — Part 2: Determination of dimensions*.

IEC 61033:1991, *Test methods for the determination of bond strength of impregnating agents to an enamelled wire substrate*.

ISO 178:1993, *Plastics — Determination of flexural properties*.

3 Test 6: Elongation

3.1 Elongation at fracture

Elongation is the increase in length expressed as a percentage of the original length.

A straight piece of wire shall be elongated to the point of fracture of the conductor at a rate of (5 ± 1) mm/s with an elongation tester or with a tensile testing equipment with a free measuring length of between 200 mm and 250 mm. The linear increase at fracture shall be calculated as a percentage of the free measuring length.

Three specimens shall be tested. The three single values shall be reported. The mean value represents elongation at fracture.

3.2 Tensile strength

Tensile strength is the ratio of the force at fracture to initial cross-section.

A straight piece of wire shall be elongated to the point of fracture of the conductor at a rate of (5 ± 1) mm/s with tensile testing equipment with a free measuring length of between 200 mm and 250 mm and which records the force at fracture.

Three specimens shall be tested. The initial cross-section and the three single values of the force at fracture shall be reported. The mean value of the ratio of the force at fracture and the initial cross-section represents the tensile strength.

4 Test 7: Springiness

Springiness is the recoil measured in degrees after the wire is wound in the form of a helical coil or bent through an angle.

4.1 Round wire with a nominal conductor diameter from 0,080 mm up to and including 1,600 mm

4.1.1 Principle

A straight piece of wire is wound five times around a mandrel with a diameter and under a tension applied to the wire as specified in the relevant standard. The reading of the angle by which the end of the five turns recoils is the measure of springiness.

4.1.2 Equipment

Figure 1 shows an example of the test equipment with details of the mandrel given in Figure 2 and Table 1. Figure 2 indicates a helical groove, which may be used to facilitate winding. The provision of this groove, however, is not mandatory. The dial is marked with 72 equally spaced divisions so that with five turns of the wire the reading corresponds to the number of degrees that each turn springs back.

Table 1 — Mandrels for springiness

Mandrel diameter ¹⁾ mm	Dimensions ²⁾ mm					
	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>
5	6,0	7,5	32	0,30	0,05	0,13
7	6,0	9,0	34	0,40	0,07	0,18
10	6,0	9,0	34	0,60	0,10	0,25
12,5	6,0	9,0	40	0,80	0,14	0,35
19	10,0	11,0	45	1,20	0,20	0,50
25	12,5	12,5	45	2,00	0,28	0,70
37,5	12,5	14,5	47	2,40	0,40	1,00
50	12,5	17,5	50	3,00	0,80	2,00

¹⁾ At the bottom of the groove, if provided.

²⁾ See Figure 2.

4.1.3 Procedure

The specified mandrel shall be mounted and locked in position with its axis horizontal and with the slot or hole for fastening the wire corresponding with the zero of the dial. The mandrel shall be dusted with powdered talc (French chalk) to prevent the wire clinging to the mandrel.

A tension shall be applied to a straight piece of wire of about 1 m in length by attaching the specified load to one end of the wire. The handle to rotate the mandrel shall be unlatched. The other end of the wire shall be inserted into the slot or hole so that sufficient wire projects on the other side of the mandrel and the wire is in firm contact with the mandrel. The weight shall be slowly lowered with the wire suspended vertically below the mandrel and with the dial zero and the slot or hole pointing downwards.

With the free end of the wire being held securely, the mandrel shall be rotated for five complete turns counter clockwise (looking at the face of the dial) and further until the zero on the dial is vertically upwards. The handle shall then be latched in this position. The load shall be removed while the wire is held in position, and the wire shall then be cut about 25 mm beyond the end of the fifth turn. This end of the wire shall be bent into a vertical position in line with the dial zero to act as a pointer.

A pencil or similar tool shall be placed to the left of this end of the wire to prevent any sudden springback. The coil shall then be allowed to unwind slowly and without jerking.

NOTE If the wire springs back suddenly, erroneous results may be obtained.

The mandrel and the dial shall then be unlatched and rotated clockwise to bring the pointer back into a vertical position. The springback angle is equal to the reading on the dial in line with the pointer. With very springy wires, the pointer may recoil more than one complete revolution. If this is the case, 72 has to be added to the dial reading for each complete revolution of recoil.

Three specimens shall be tested. The three single values shall be reported. The mean value represents springiness.

4.2 Round wire with a nominal conductor diameter over 1,600 mm and rectangular wire

4.2.1 Principle

A straight piece of wire shall be bent through an angle of 30°. After removing the force, the reading of the angle by which the wire springs back is the measure of springiness.

4.2.2 Equipment

Figure 3 shows an example of the test equipment basically consisting of two jaws, one of which is fixed (2) and one is movable (1), and a sector graduated in degrees (5) with the 0° to 10° sector of the scale graduated in 0,5° increments. The graduated sector is an arc placed in a plane at 90° to the clamp faces. Its centre is located at the outer edge of the fixed jaw (3). The lever arm with its fulcrum placed at the centre of the arc can move over the graduated sector in the vertical plane.

The lever arm shall have a pointer or marker to provide a proper reading of the springback angle. On the lever arm with approximately 305 mm length scaled off in millimetres with the origin at the centre of the arc, is a slider (4) with a knife edge.

4.2.3 Specimen

A wire sample of at least 1 200 mm in length shall be removed from the spool with as little bending of the wire as possible. It shall be straightened by hand and cut into three pieces each of 400 mm length. Elongation by tools shall not be used. Unnecessary bending shall be avoided to minimize work hardening.

4.2.4 Procedure

The conductor diameter or thickness, multiplied by 40 determines the position of the slider on the lever arm. The specimen shall be tightened between the jaws with a force just sufficient to prevent slipping. The specimen shall be tightened in such a position as to allow bending the wire in the same direction as it was wound on the spool. The free end of the specimen shall exceed the slider knife edge by (12 ± 2) mm.

By means of the lever arm, starting at the initial position (the 30° scale mark, position 1), the wire shall be bent for 30° (the 0° scale mark, position 2). The total bending shall take between 2 s and 5 s. The specimen shall be held in this position for not more than 2 s and then returned in the reverse direction at the same angular rate at which it was bent, until the slider knife edge moves away from the wire specimen. The lever arm shall be raised again until the slider knife edge just contacts the wire specimen without bending it. In this position, the springback angle equals the reading on the scale of the graduated sector in line with the pointer on the lever arm (position 3).

Three specimens shall be tested. The single values shall be reported. The mean value represents springiness.

5 Test 8: Flexibility and adherence

Flexibility and adherence reflect the potential of the wire to withstand stretching, winding, bending or twisting without showing cracks or loss of adhesion of the insulation.

5.1 Mandrel winding test

5.1.1 Round wire

A straight piece of wire shall be wound for 10 continuous and adjacent turns around a polished mandrel of the diameter given in the relevant standard. The mandrel shall be rotated with a rate of 1 r/s to 3 r/s with a tension applied to the wire which is just sufficient to keep it in contact with the mandrel. Elongating or twisting the wire shall be avoided. Any suitable equipment shall be used.

5.1.1.1 Enamelled round wire with a nominal conductor diameter up to and including 1,600 mm

If the relevant standard calls for pre-stretching before winding, the wire shall be elongated according to Clause 3 to the specified percentage. After winding, the specimen shall be examined for cracks with the magnification as given in Table 2.

Table 2 — Magnification to detect cracks

Nominal conductor diameter mm		Magnification *
Over	Up to and including	
—	0,040	10 to 15 times
0,040	0,500	6 to 10 times
0,500	1,600	1 to 6 times

* One time expresses normal vision.

Three specimens shall be tested. Any cracks detected shall be reported.

5.1.1.2 Fibre covered round wire

After winding, the specimen shall be examined for exposure of the bare conductor with normal vision or with a magnification of up to six times.

Three specimens shall be tested. Exposure of the bare conductor shall be reported.

5.1.1.3 Fibre covered enamelled round wire

After winding, the specimen shall be examined for exposure of the bare conductor or underlying coating with normal vision or with a magnification of up to six times.

Three specimens shall be tested. Exposure of the bare conductor or the underlying coating shall be reported.

5.1.1.4 Tape wrapped round wire

After winding, the specimen shall be examined for exposure of the bare conductor or delamination with normal vision or with a magnification of up to six times.

Three specimens shall be tested. Exposure of the bare conductor or any delamination shall be reported.

5.1.2 Rectangular wire

A straight piece of wire approximately 400 mm in length shall be bent through 180° round a polished mandrel of the diameter given in the relevant standard in two directions to form an elongated S-shape. The straight part between the U-shape bends shall be at least 150 mm. Care should be taken to ensure that the specimen does not buckle or depart from a uniform bend. A suitable apparatus is shown in Figure 4.

After bending, the insulation shall be examined for cracks in case of enamelled wire, for exposure of the bare conductor or underlying coating in case of fibre covered wire and for exposure of the bare conductor and delamination in case of tape wrapped wire under a magnification of six to ten times.

Six specimens shall be bent, three flatwise (on the thickness) and three edgewise (on the width). It shall be reported, if the wire shows cracks or delamination, exposure of the bare conductor or underlying coating, whichever is applicable.

5.1.3 Covered bunched wire

A straight piece of wire shall be wound for ten continuous turns around a polished mandrel of the diameter given in the relevant standard and under a tension given in 3.2.5.3 of IEC 60851-2. Care should be taken not to twist the specimen for each revolution.

After winding, the specimen shall be examined by normal vision for openings in the covering.

One specimen shall be tested. It shall be reported, if the wire does not show the required degree of closeness of the covering.

5.2 Stretching test (applicable to enamelled round wire with a nominal conductor diameter over 1,600 mm)

A straight piece of wire shall be elongated according to Clause 3 to the percentage specified in the relevant standard. After elongation, the specimen shall be examined for cracks or loss of adhesion with normal vision or with a magnification of up to six times.

Three specimens shall be tested. It shall be reported, if the wire shows cracks and/or loss of adhesion.

5.3 Jerk test (applicable to enamelled round wire with a nominal conductor diameter up to and including 1,000 mm)

A straight piece of wire shall be rapidly stretched to the breaking point or to an elongation given in the relevant standard, with a test equipment shown in Figure 5 providing a free measuring length of between 200 mm and 250 mm. After elongation, the specimen shall be examined for cracks or loss of adhesion under a magnification as given in Table 2. A distance of 2 mm from the broken ends shall be disregarded.

Three specimens shall be tested. It shall be reported, if the wire shows cracks and/or loss of adhesion.

5.4 Peel test (applicable to enamelled round wire with a nominal conductor diameter over 1,000 mm)

A straight piece of wire shall be placed in the test equipment shown in Figure 6 consisting of two fixing devices 500 mm apart on the same axis. One of these is free to rotate. The other is not but can be displaced axially and is loaded according to Table 3 to apply a tension to the rotating wire.

Table 3 — Load for peel test

Nominal conductor diameter mm		Load
Over	Up to and including	N
1,000	1,400	25
1,400	1,800	40
1,800	2,240	60
2,240	2,800	100
2,800	3,550	160
3,550	4,500	250
4,500	5,000	400

By means of a scraper as shown in Figure 7, the coating shall be removed on opposite sides of the wire and along the wire axis down to the bare conductor as shown in Figure 8. The pressure on the scraper shall be sufficient to remove the coating and leave a clean smooth surface at the coating/conductor interface without scraping off a significant quantity of conductor material. The removal of the coating shall commence about 10 mm from the fixing devices. The rotating device shall be driven at a speed of between 60 r/min and 100 r/min until the number of revolutions R as specified in the relevant standard has been reached.

After peeling and rotating, the specimen shall be examined for loss of adhesion. If the coating can be removed from the wire without difficulty (for example with the thumbnail), it shall be considered to have lost its adhesion even if it has not become completely detached from the wire.

One specimen shall be tested. It shall be reported, if loss of adhesion is observed.

5.5 Adherence test

A straight piece of wire of about 300 mm length, shall be elongated in accordance with Clause 3 to the percentage specified in the relevant standard.

5.5.1 Enamelled rectangular wire

Before elongation, the coating shall be cut circumferentially through to the conductor at a point approximately in the centre of the measured length. After elongation, the specimen shall be examined for loss of adhesion.

One specimen shall be tested. It shall be reported, if loss of adhesion is observed, measured longitudinally from the cut. If so, the length of loss of adhesion shall be measured in one direction from the cut. The maximum value observed shall be reported after examining all sides of the specimen.

5.5.2 Impregnated fibre covered round and rectangular wire

Before elongation, the insulation shall be removed from all but the central 100 mm of the wire piece. After elongation, the specimen shall be examined for loss of adhesion.

One specimen shall be tested. It shall be reported, if loss of adhesion is observed with the insulation sliding along the conductor in case of round wire or being detached in case of rectangular wire.

5.5.3 *Fibre covered enamelled round and rectangular wire*

Before elongation, the insulation shall be cut circumferentially at two places 100 mm apart in the centre of the wire piece through to the conductor. After elongation, the specimen shall be examined for loss of adhesion.

One specimen shall be tested. It shall be reported, if loss of adhesion is observed.

5.5.4 *Tape wrapped round rectangular wire (only for adhesive tape)*

Before elongation, the insulation shall be cut circumferentially through to the conductor at a point approximately in the centre of the measured length. After elongation, the specimen shall be examined for loss of adhesion.

 *Text deleted* 

6 Test 11: Resistance to abrasion (applicable to enamelled round wire)

Resistance to abrasion is determined as the maximum force which can be sustained when a needle scrapes along the wire under a progressively increasing force.

6.1 Principle

A straight piece of wire is subjected to a unidirectional scrape test, by a needle to which a progressively increasing load is applied and which scrapes along the wire surface. The load which causes an electrical contact of the needle with the conductor is called the load-to-failure.

6.2 Equipment

Test equipment as shown in Figure 9 shall be used. It shall be provided with a mechanism to produce scraping action in one direction at a rate of (400 ± 40) mm/min. The scraping device shall contain a polished piano wire or a needle of $(0,23 \pm 0,01)$ mm diameter, located between two jaws which hold the piano wire or needle rigidly, without sagging or curvature and at right angles to the direction of stroke which shall be in the direction of the axis of the wire under test. For placing the specimen, the test equipment shall be provided with two clamping jaws over a supporting anvil which can be lowered while a wire is inserted into the jaws and straightened.

The test equipment shall provide a d.c. voltage of $(6,5 \pm 0,5)$ V to be applied between the conductor and the piano wire or the needle scraper. The short-circuit current shall be limited to 20 mA, for example by means of a series resistor or a relay. The circuit shall be designed to detect a short circuit and stop the equipment after the scraper is in contact with the conductor of the wire for about 3 mm.

The test equipment shall be provided with a graduated scale over the lower edge of the lever, which indicates the factor by which the initial load applied to the piano wire or to the needle has to be multiplied to determine the force-to-failure.

6.3 Procedure

A straight piece of wire shall be wiped clean, placed in the apparatus and straightened by a maximum of 1 % elongation. The specimen shall then be secured in the clamping jaws and the supporting anvil adjusted to contact the specimen. The initial force applied to the scraping device shall not exceed 90 % of the minimum force to failure specified in the relevant standard and shall lead to short circuit between scraper and conductor at a point between 200 mm and 150 mm from the fixed pivot point. The weighted scraping device shall be lowered slowly to the surface of the wire and the scraping action started.

The value at which the scraper stops shall be read on the graduated scale on the lower edge of the lever. The product of this value and the initial load applied shall be recorded.

The procedure shall be repeated twice on the same specimen, indexing around the periphery of the wire, once at 120° and once at 240° from the original position and the same information recorded.

One specimen shall be tested. The three single values shall be reported. The mean value represents the average force-to-failure.

7 **Test 18: Heat bonding** (applicable to enamelled round wire with a nominal conductor diameter over 0,050 mm up to and including 2,000 mm)

Heat bonding is the potential of the windings of a coil to bond together under the influence of heat. 

7.1 Vertical bond retention of a helical coil

Vertical bond retention of a helical coil is the potential of the bonded coil to maintain its coherence when a load is applied to its lower end.

7.1.1 Nominal conductor diameter up to and including 0,050 mm

The method of test is to be agreed upon between purchaser and supplier.

7.1.2 Nominal conductor diameter over 0,050 mm up to and including 2,000 mm

7.1.2.1 Principle

The turns of a helical coil of the wire wound on a mandrel are pressed together by applying a load and then bonded by means of heat or solvent. After bonding, the specimen is removed from the mandrel and suspended in a vertical position with a load applied at the lower end to determine whether the specimen withstands a specified load or not. This procedure is repeated at an elevated temperature.

7.1.2.2 Specimen

A straight piece of wire shall be wound on a polished mandrel²⁾ of a diameter according to Table 4. The coil shall have a minimum length of 20 mm. The winding rate shall be between 1 r/s and 3 r/s with an applied winding force not exceeding the values in Table 4. In order to allow the coil to relax freely, the ends of the wire shall not be fastened. The coil on the mandrel shall be positioned vertically as shown in Figure 10a with a load applied as specified in Table 4. The weight shall not stick to the mandrel, and there shall be a clearance between the weight and the mandrel. This arrangement shall then be placed in an oven with forced air circulation at a temperature specified in the relevant standard for a period of:

- 30 min for wires with a nominal conductor diameter up to and including 0,710 mm;
- 1 h for wires with a nominal conductor diameter over 0,710 mm up to and including 2,000 mm, unless otherwise agreed upon between purchaser and supplier.

After cooling to room temperature, the coil shall be removed from the mandrel.

7.1.2.3 Procedure at room temperature

A specimen shall be suspended by one of its ends (see Figure 10b) and loaded as required in the relevant standard. The load shall be applied in a way which avoids any additional shock.

Three specimens shall be tested. It shall be reported, if turns other than the first and the last are separated. The temperature for bonding the specimen shall be reported.

7.1.2.4 Procedure at elevated temperature

A specimen shall be suspended by one of its ends (see Figure 10b) and loaded as specified in Table 5. The load shall be applied in a way which avoids any additional shock. The specimen with its load shall be placed in an oven with forced air circulation for 15 min at a temperature as specified in the relevant standard.

Three specimens shall be tested. It shall be reported, if turns other than the first and the last are separated. The temperature for bonding the specimen shall be reported.

¹⁾  footnote deleted 

²⁾ A steel mandrel is satisfactory for larger diameter wires. For smaller wires, copper mandrels may assist in the removal of the coil from the mandrel by stretching the mandrel to reduce its diameter.