

INTERNATIONAL STANDARD



**Winding wires – Test methods –
Part 3: Mechanical properties**

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INTERNATIONAL STANDARD



**Winding wires – Test methods –
Part 3: Mechanical properties**

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INTERNATIONAL
ELECTROTECHNICAL
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WINDING WIRES – TEST METHODS –

Part 3: Mechanical properties

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IEC 60851-3 has been prepared by IEC technical committee 55: Winding wires. It is an International Standard.

This fourth edition cancels and replaces the third edition published in 2009, Amendment 1:2013 and Amendment 2:2019. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Clarification of the distance measurement for determining loss of adhesion in 6.6.3, 6.6.4 for fibre-covered wires and 6.6.5 for tape-wrapped wires.

The text of this International Standard is based on the following documents:

Draft	Report on voting
55/1938/CDV	55/1974/RVC

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 60851 series, published under the general title *Winding wires – Test methods*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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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) winding wires – Test methods (IEC 60851);
- b) specifications for particular types of winding wires (IEC 60317);
- c) packaging of winding wires (IEC 60264).

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WINDING WIRES – TEST METHODS –

Part 3: Mechanical properties

1 Scope

This part of IEC 60851 specifies the following test methods for winding wires:

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

For definitions, general notes on test methods and the complete series of test methods for winding wires, IEC 60851-1 applies. This document also provides recommended friction test methods in Annex B.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 60851-1, Winding wires – Test methods – Part 1: General~~

IEC 60851-2:2009, *Winding wires – Test methods – Part 2: Determination of dimensions*

IEC 60851-2:2009/AMD1:2015

IEC 60851-2:2009/AMD2:2019

ISO 178:2019, *Plastics – Determination of flexural properties*

~~Amendment 1:2004~~

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

4 Test 6: Elongation

4.1 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 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.

4.2 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.

5 Test 7: Springiness

5.1 General

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

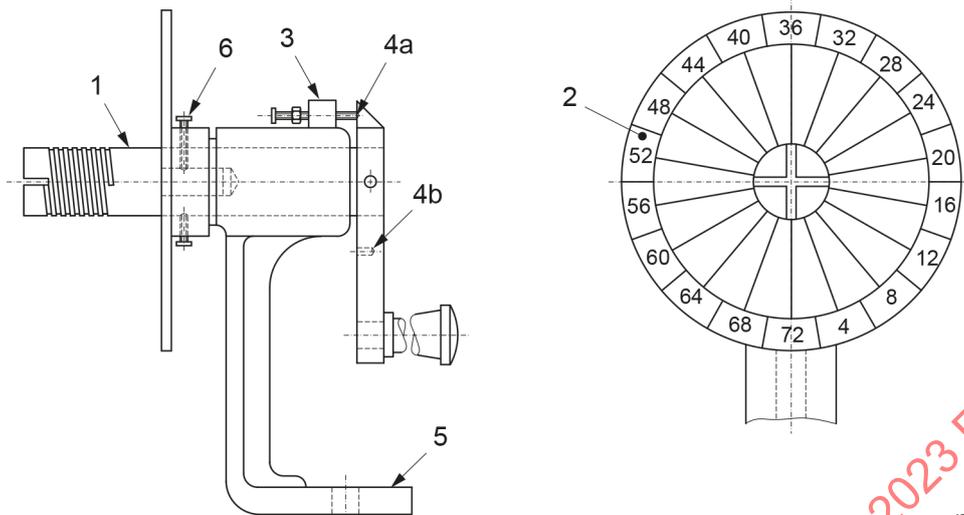
5.2 Round wire with a nominal conductor diameter from 0,080 mm up to and including 1,600 mm

5.2.1 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.

5.2.2 Equipment

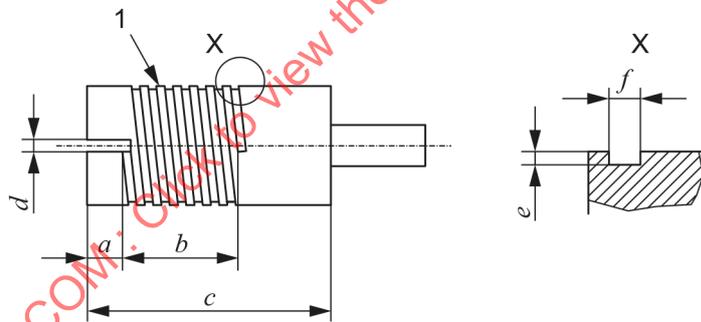
Figure 1 shows an example of the test equipment with details of the mandrel given in Figure 2 and Table 1. Figure 2 indicates a helical groove, which may be used to facilitate winding. The provision of this groove, however, is not mandatory. The dial is marked with 72 equally spaced divisions so that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



Key

- 1 mandrel
- 2 dial
- 3 locking device
- 4 locking device
- 5 base-plate
- 6 mandrel-fixing screw

Figure 1 – Test equipment to determine springiness



Key

- 1 7 threads
- 2 part X enlarged

Figure 2 – Construction and details of the mandrel (see Table 1)

Table 1 – Mandrels for springiness

Mandrel diameter ^a mm	Dimensions ^b mm					
	a	b	c	d	e	f
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

^a At the bottom of the groove, if provided.

^b See Figure 2.

5.2.3 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 counterclockwise (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, it is possible to obtain 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~~ shall 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.

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

5.3.1 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.

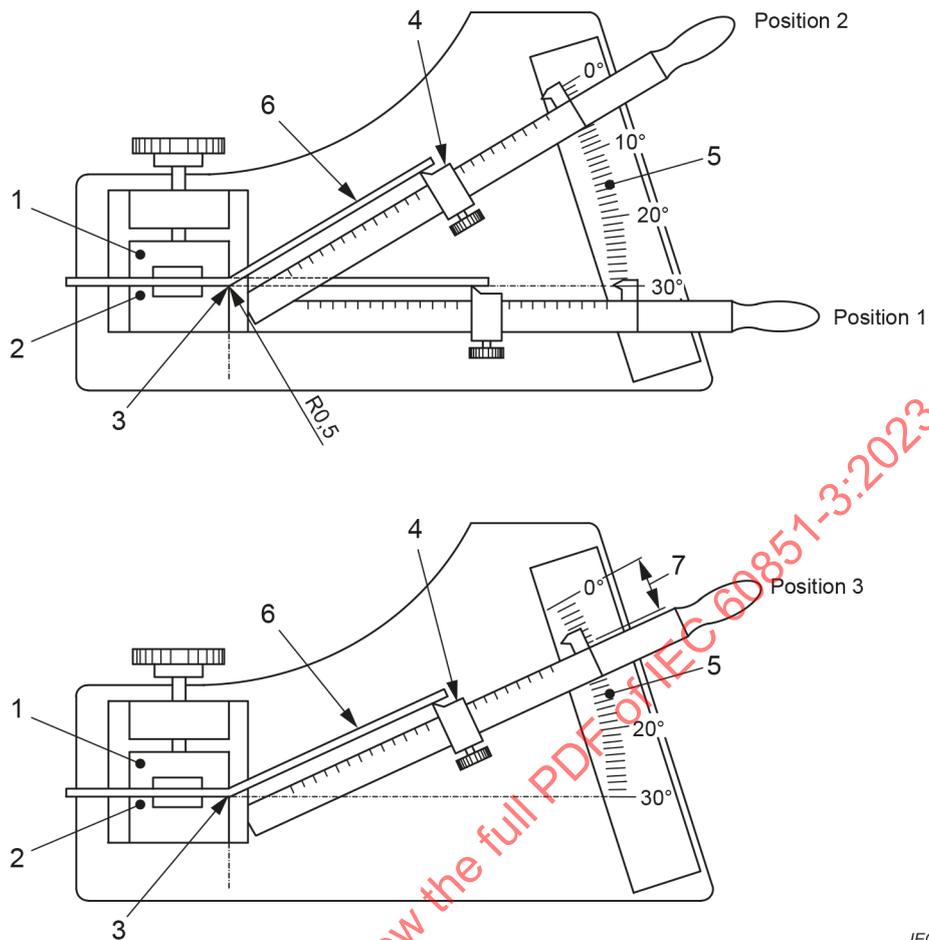
5.3.2 Equipment

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.

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Dimensions in millimetres



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Key

- 1 moveable jaw
- 2 fixed jaw
- 3 centre of graduated sector
- 4 slider
- 5 graduated sector
- 6 wire specimen
- 7 springback

Figure 3 – Test equipment to determine springiness**5.3.3 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.

5.3.4 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~~ All three values shall be reported. The mean value represents springiness.

6 Test 8: Flexibility and adherence

6.1 General

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.

6.2 Mandrel winding test

6.2.1 Round wire

6.2.1.1 General

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 that 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.

6.2.1.2 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 4 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 ^a
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

^a One times magnification expresses normal vision.

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

6.2.1.3 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.

6.2.1.4 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.

6.2.1.5 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.

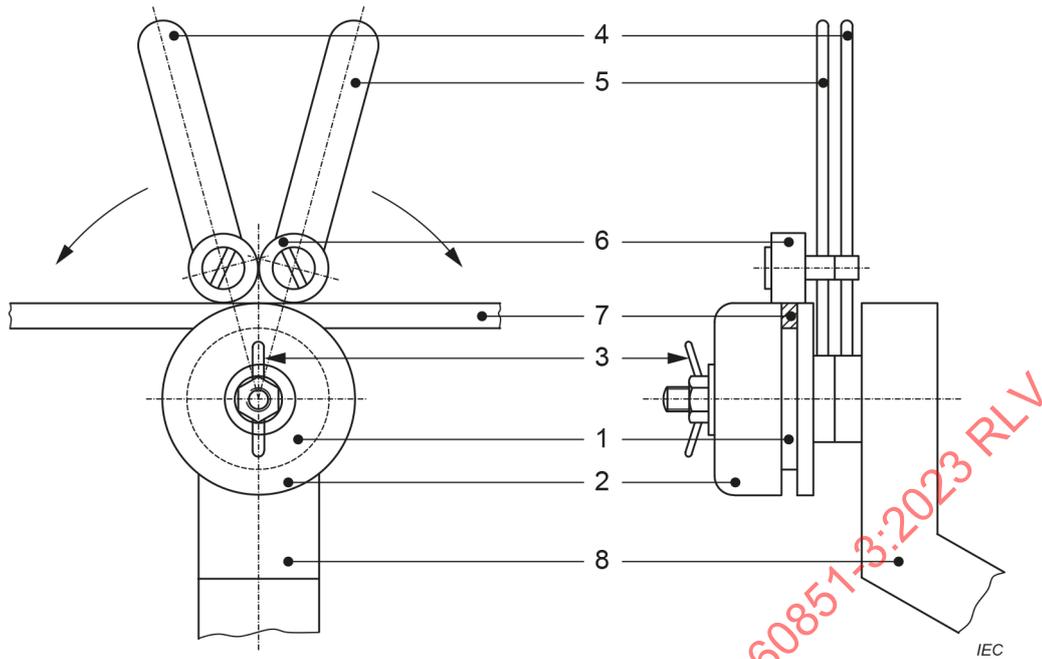
Three specimens shall be tested. Exposure of the bare conductor or any delamination shall be reported.

6.2.2 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 the case of enamelled wire, for exposure of the bare conductor or underlying coating in the case of fibre covered wire and for exposure of the bare conductor and delamination in the 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). If the wire shows cracks or delamination, exposure of the bare conductor or underlying coating, whichever is applicable, this shall be reported.



Key

- 1 mandrel
- 2 mandrel clamping collar
- 3 winding nut
- 4 lever
- 5 lever
- 6 ball bearing
- 7 specimen
- 8 support

Figure 4 – Test equipment for mandrel winding test

6.2.3 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 IEC 60851-2:2009, 3.2.5.3. 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. If the wire does not show the required degree of closeness of the covering, this shall be reported.

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

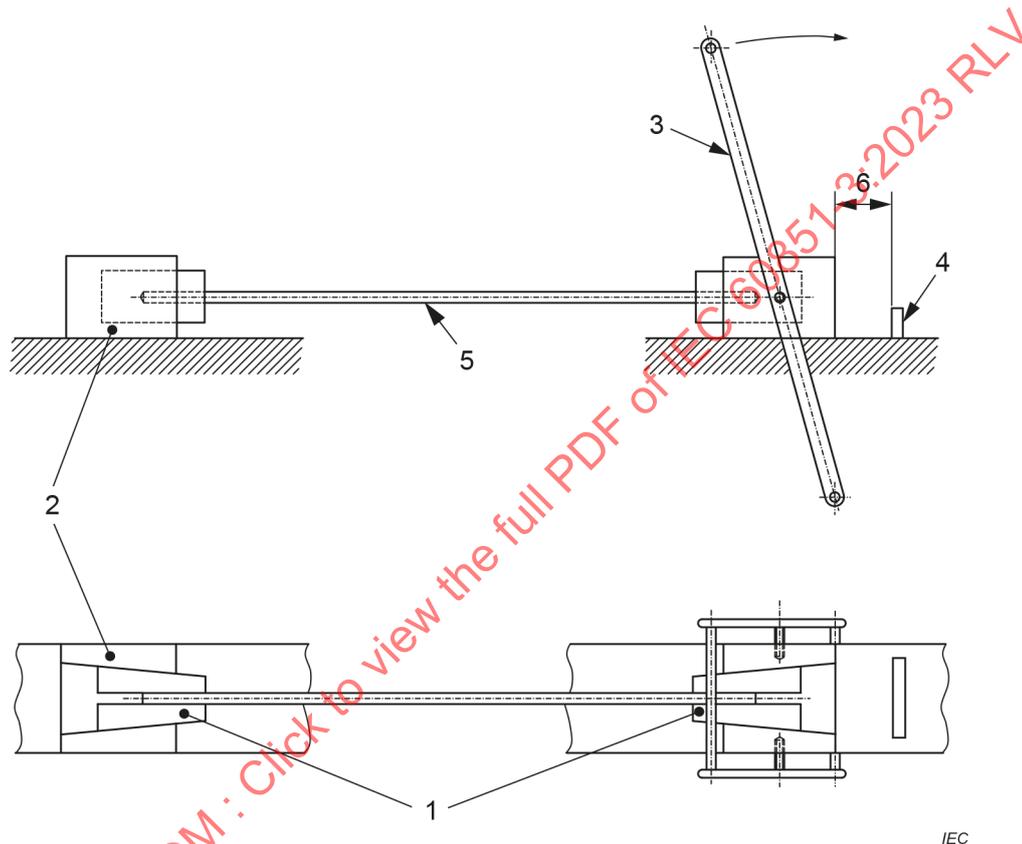
A straight piece of wire shall be elongated according to Clause 4 to the percentage specified in the relevant standard. After elongation, the specimen shall be examined for cracks or loss of adhesion with normal vision or with a magnification of up to six times.

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

6.4 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 with test equipment as shown in Figure 5. A free measuring length of between 200 mm and 250 mm shall be provided. After stretching, 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. If the wire shows cracks and/or loss of adhesion, this shall be reported.



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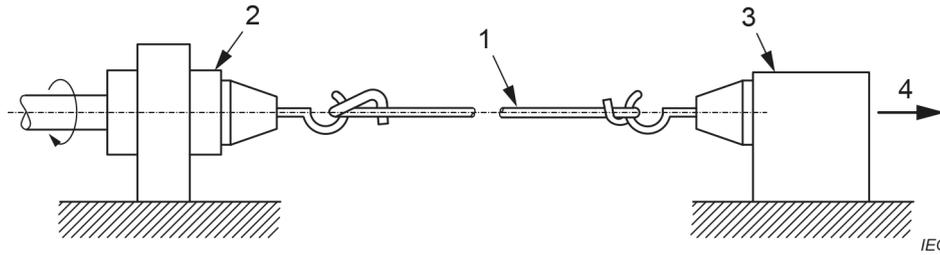
Key

- 1 wedge grips (clamps)
- 2 fixed jaw set
- 3 lever arm
- 4 adjustable stop
- 5 specimen
- 6 specified elongation

Figure 5 – Test equipment for jerk test

6.5 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.



Key

- 1 specimen
- 2 rotary clamp
- 3 fixed clamp
- 4 load

Figure 6 – Test equipment for peel test

Table 3 – Load for peel test

Nominal conductor diameter mm		Load N
Over	Up to and including	
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. If loss of adhesion is observed, this shall be reported.

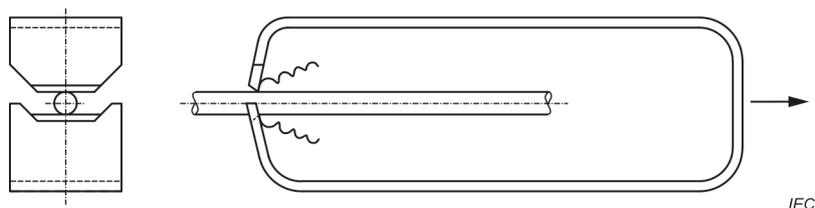


Figure 7 – Scraper

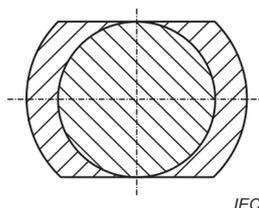


Figure 8 – Cross-section of the wire after removal of the coating

6.6 Adherence test

6.6.1 General

A straight piece of wire of about 300 mm length shall be elongated in accordance with Clause 4 to the percentage specified in the relevant standard.

6.6.2 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. If loss of adhesion is observed, as determined by longitudinal measurement from the cut, it shall be reported. 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, under a magnification of six to ten times.

6.6.3 Impregnated fibre covered round and rectangular wire

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

One specimen shall be tested. If loss of adhesion is observed according to the relevant specification, as determined by longitudinal measurement in one direction from the cut, it shall be reported. The maximum value observed shall be reported after examining all sides of the specimen, under a magnification of six to ten times.

6.6.4 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 specimen through to the conductor. After elongation, the specimen shall be examined for loss of adhesion under a magnification of six to ten times.

One specimen shall be tested. If loss of adhesion is observed according to the relevant specification, as determined by longitudinal measurement in one direction from the cut, it shall be reported. The maximum value observed shall be reported after examining all sides of the specimen, under a magnification of six to ten times.

6.6.5 Tape-wrapped round and rectangular wire (for adhesive tape only)

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 under a magnification of six to ten times. One specimen shall be tested. The maximum value observed shall be reported after examining all sides of the specimen, under a magnification of six to ten times. If loss of adhesion is observed according to the relevant specification, as determined by longitudinal measurement in one direction from the cut, it shall be reported.

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

7.1 General

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.

7.2 Principle

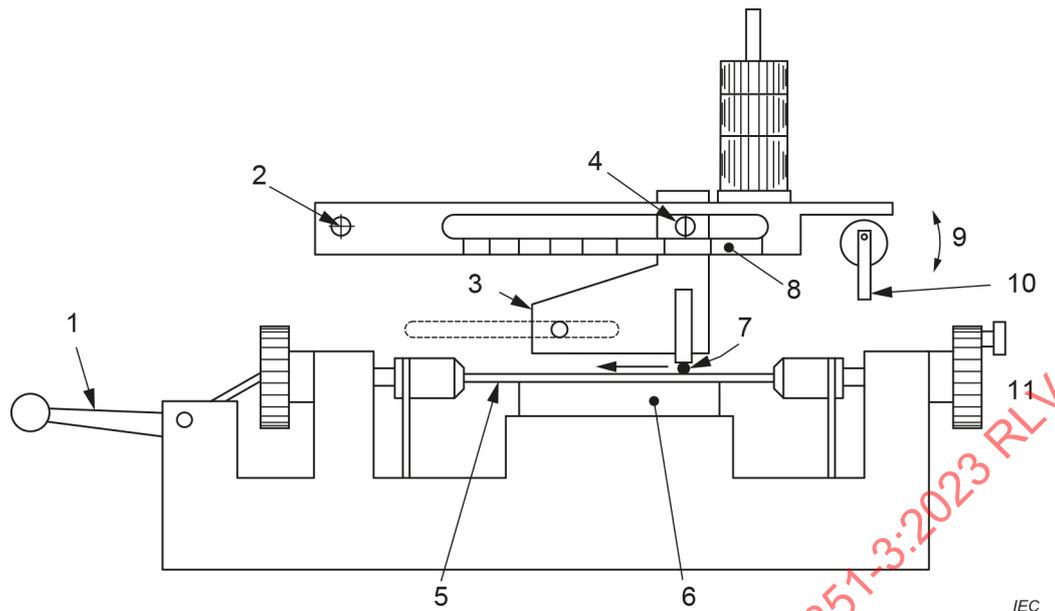
A straight piece of wire is subjected to a unidirectional scrape test, by a needle to which a progressively increasing load is applied and which scrapes along the wire surface. The load that causes an electrical contact of the needle with the conductor is called the load-to-failure.

7.3 Equipment

Test equipment as shown in Figure 9 shall be used. It shall be provided with a mechanism to produce a 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 DC 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.



Weighted scraping device moves from right to left with increasing load on wire

Key

- 1 capstan for straightening specimen
- 2 fixed pivot point
- 3 weighted scraping device
- 4 indexer
- 5 specimen
- 6 anvil with adjustable height for wires with different diameters
- 7 piano wire
- 8 scale, indicating multiplying factor
- 9 reset/operate
- 10 reset lever
- 11 chucks index at 120° increments

Figure 9 – Test equipment for unidirectional scrape test

7.4 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.

8 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 and to enamelled rectangular wire)

8.1 General

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

8.2 Vertical bond retention of a helical coil

8.2.1 General

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.

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

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

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

8.2.3.1 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.

8.2.3.2 Specimen

A straight piece of wire shall be wound on a polished mandrel⁴ 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. A steel mandrel has been found to be satisfactory for larger diameter wires. For smaller wires, copper mandrels have been found to aid in the removal of the coil from the mandrel by stretching the mandrel to reduce its diameter.

The coil on the mandrel shall be positioned vertically as shown in Figure 10 a) 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.

⁴ ~~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.~~

8.2.3.3 Procedure at room temperature

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

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

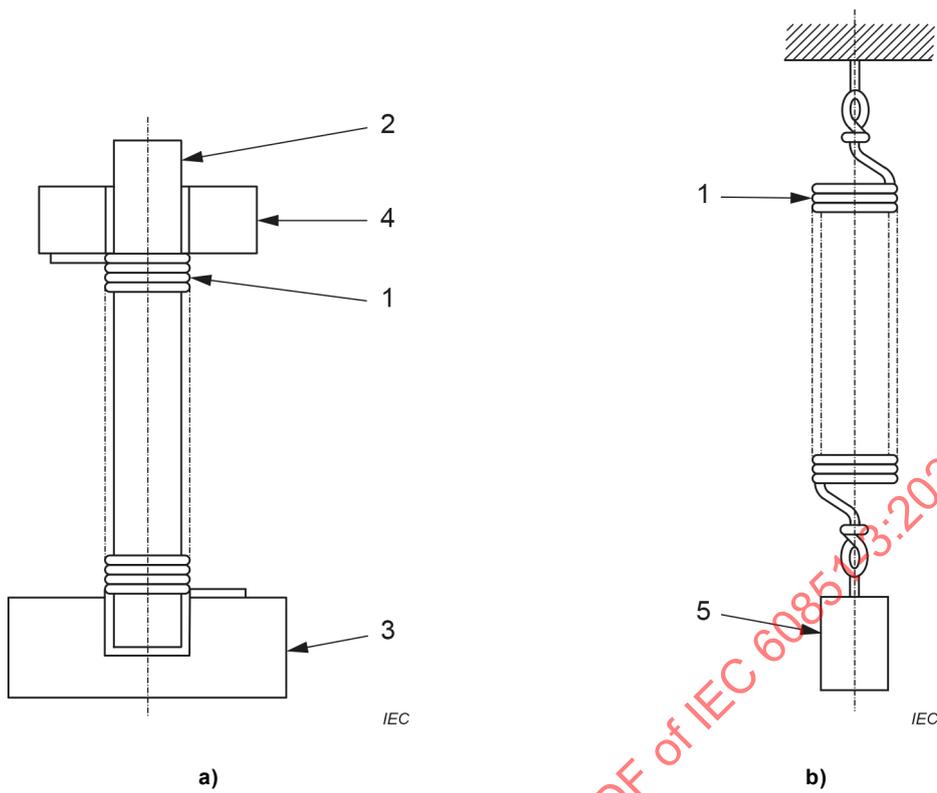
8.2.3.4 Procedure at elevated temperature

A specimen shall be suspended by one of its ends (see Figure 10 b)) and loaded as specified in Table 5. The load shall be applied in a way that 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. If turns other than the first and the last are separated, this shall be reported. The temperature for bonding the specimen shall be reported.

Table 4 – Preparation of helical coils

Nominal conductor diameter mm		Diameter of the mandrel mm	Maximum winding force N	Load on the coil during bonding N
Over	Up to and including			
0,050	0,071	1	0,05	0,05
0,071	0,100	1	0,05	0,05
0,100	0,160	1	0,12	0,15
0,160	0,200	1	0,30	0,25
0,200	0,315	2	0,80	0,35
0,315	0,400	3	0,80	0,50
0,400	0,500	4	2,00	0,75
0,500	0,630	5	2,00	1,25
0,630	0,710	6	5,00	1,75
0,710	0,800	7	5,00	2,00
0,800	0,900	8	5,00	2,50
0,900	1,000	9	5,00	3,25
1,000	1,120	10	12,00	4,00
1,120	1,250	11	12,00	4,50
1,250	1,400	12	12,00	5,50
1,400	1,600	14	12,00	6,50
1,600	1,800	16	30,00	8,00
1,800	2,000	18	30,00	10,00



Key

- 1 coil
- 2 mandrel
- 3 mandrel-holder
- 4 weight
- 5 separating load

Figure 10 – Test equipment for bond retention of a helical coil

Table 5 – Bond retention at elevated temperature

Nominal conductor diameter mm		Load N	Nominal conductor diameter mm		Load N
Over	Up to and including		Over	Up to and including	
0,050	0,071	0,04	0,800	0,900	2,60
0,071	0,100	0,06	0,900	1,000	3,20
0,100	0,160	0,09	1,000	1,120	3,80
0,160	0,200	0,19	1,120	1,250	4,40
0,200	0,315	0,25	1,250	1,400	4,90
0,315	0,400	0,55	1,400	1,600	6,40
0,400	0,500	0,80	1,600	1,800	7,90
0,500	0,630	1,20	1,800	2,000	7,90
0,630	0,710	1,70			
0,710	0,800	2,10			

8.3 Bond strength of a twisted coil

8.3.1 General

Bond strength is the maximum force required to break the twisted coil.

8.3.2 Principle

A random wound coil prepared from the wire is formed to an oval shape, twisted and then bonded by applying a DC current. This specimen produces a rod, which is tested in tensile testing equipment in a horizontal position to obtain the maximum deflection force to break this rod. The test shall be repeated at elevated temperature.

NOTE This test is similar to method A, twisted coil test, given in IEC 61033:1991, 2.1 and IEC 61033:1991/AMD1:2006, 2.1, and is based on the same principle. It differs from method A of IEC 61033 with respect to twisting and bonding the specimen and with respect to wire sizes. It ~~permits~~ facilitates the testing of different wire sizes, whereas method A of IEC 61033 specifies that a wire of a nominal conductor diameter of 0,315 mm shall be used.

8.3.3 Equipment

The following equipment shall be used:

- coil winder in accordance with Figure 11 a) and Figure 11 b);
- coil twister in accordance with Figure 13;
- tensile test equipment in accordance with ISO 178 with a support complying with Figure 13;
- DC supply unit providing a constant current output with a capacity of minimum 50 V and 15 A;
- attached to the tensile test equipment, an oven with forced air circulation, which shall maintain the test temperature within a tolerance of ± 2 °C and which shall allow heating at least five specimens simultaneously within 5 min to 10 min to the test temperature.

8.3.4 Specimen

A random wound coil shall be prepared from the wire using winding equipment according to Figure 11 a) and Figure 11 b). The number of windings shall be calculated as

$$N = \frac{100 \times 0,315^2}{d^2}$$

where d is the nominal conductor diameter of the wire under test.

NOTE 1 For a nominal conductor diameter of $d = 0,315$ mm, N represents 100 turns. For other values of d , the above equation will lead to a number N , which gives the same total conductor cross-section as $N = 100$ and $d = 0,315$ mm.

To prevent opening of the coil after removal from the winding equipment, each end of the wire (or short pieces of enamelled wire) shall be wrapped around the coil two or three times at opposite positions. For this purpose, the winding equipment is provided with appropriate notches (see Figure 11 b)).

For winding the coil, the following dimensions shall apply:

- winding diameter: $(57 \pm 0,1)$ mm;
- width of slot: $(5 \pm 0,5)$ mm.

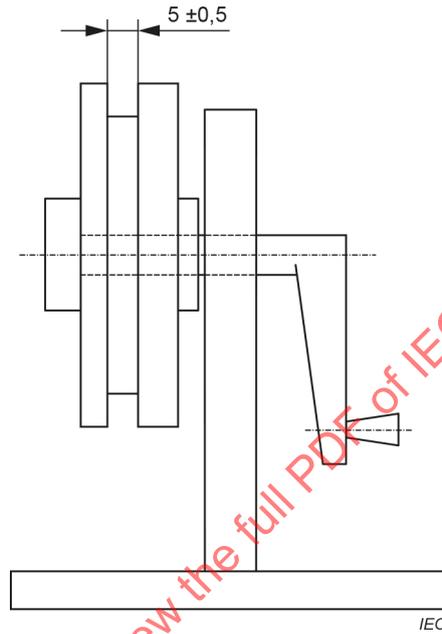
After removal from the winding equipment, the coil shall be formed to an oval shape (see Figure 12) and then twisted in a twisting device around its longitudinal axis according to Figure 13. This device allows application of a mechanical load to be applied to the coil while it

is twisted and subsequently bonded. This load shall be 100 N. The coil shall be twisted for two and a half turns and then half a turn in the reverse direction. While held under a mechanical load in the twisting device, the specimen shall be bonded by applying a constant DC current to the wire. A current shall be chosen that bonds the specimen within a period of 30 s to 60 s.

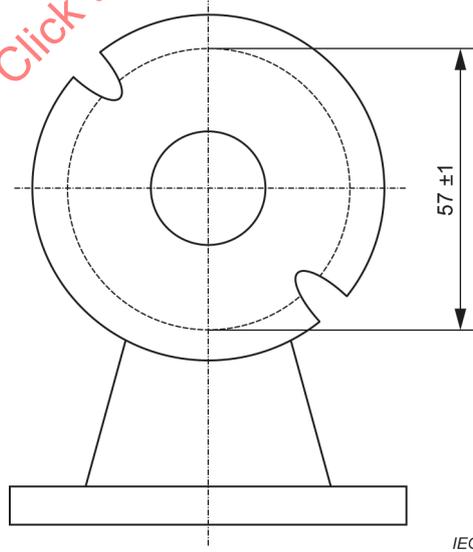
NOTE 2 Since DC current is used, it allows an easy approach to determine the average temperature of the specimen at the end of the heating period (see Annex A).

The specimen is a rod of about 7 mm in diameter and 85 mm to 90 mm in length.

Dimensions in millimetres



a) Coil winder

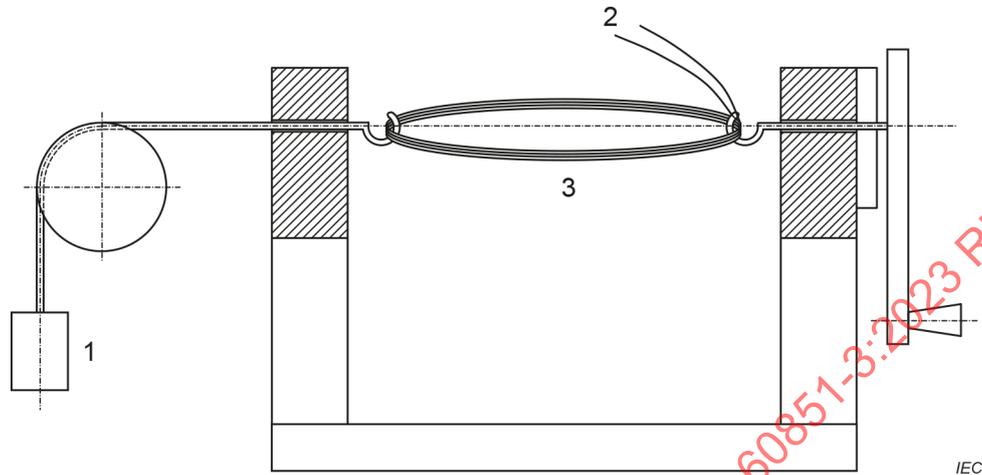


b) Coil winder, front view

Figure 11 – Coil winder



Figure 12 – Oval shape coil



Key

- 1 load 100 N
- 2 DC current
- 3 twisted coil

Figure 13 – Twisting device with a load applied to the twisted coil specimen

8.3.5 Procedure

With the specimen properly positioned on a support according to Figure 14, the bond strength of the specimen shall be determined by adjusting the crosshead speed so that the maximum deflection force is reached in about 1 min.

For tests at elevated temperature, the specimen shall be placed in the oven preheated to the specified temperature. The specimen shall be tested after it has reached the oven temperature but not later than 15 min after being placed in the oven.

8.3.6 Result

For each temperature, five specimens shall be tested. The five single values shall be reported for each test temperature. The mean value represents the bond strength. The nominal conductor diameter, the number of turns of the coil and the bonding conditions of specimens shall also be reported.

Dimensions in millimetres

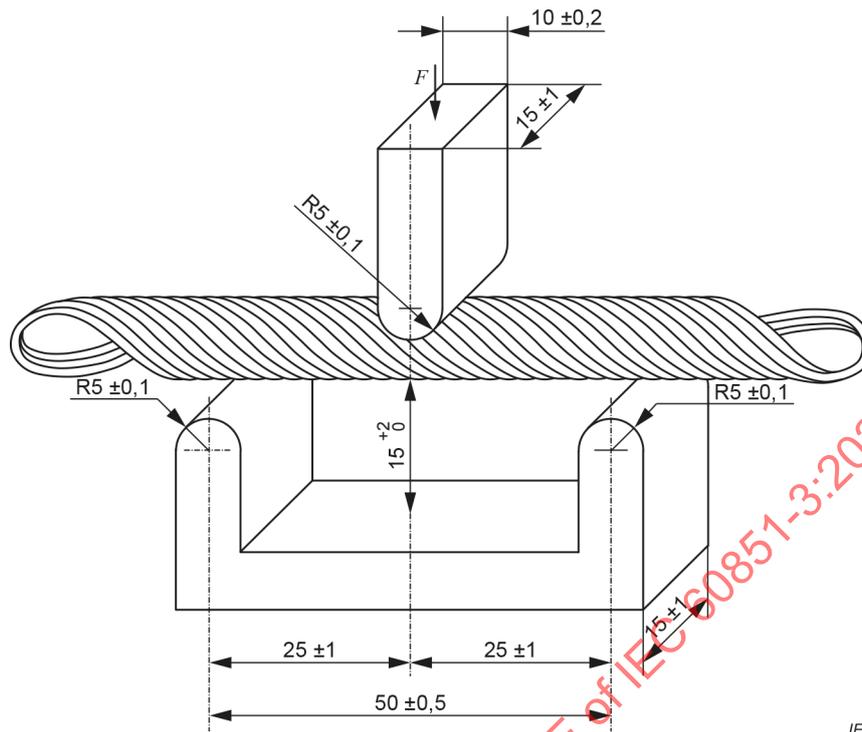


Figure 14 – Arrangement of supports

8.4 Enamelled rectangular wire heat bonding

Five specimens, each composed of two straight pieces of wire of about 100 mm length, are prepared according to Figure 15 and placed in a clamping device with an overlap length (L) (25 ± 5) mm under a pressure of 1,00 MPa. Other overlap lengths and clamping pressures may be agreed upon between user and supplier.

The total length of each specimen between jaws shall be about 125 mm.

The required load (P) for this pressure is calculated as:

$$P = 1,00 \times 25 \times (h - 2R)$$

where

R is the corner radius of the wire (mm);

h is the width of the wire.

The specimens shall be cured in an oven at $(120 \pm 2) ^\circ\text{C}$ for (24 to 24,5) h or as agreed upon between user and supplier.

After being cooled to ambient temperature, the specimens shall be subjected to a lap shear test by applying a gradually increasing load until detachment. The load shall be applied in a way that avoids any additional shock.

Shearing stress (MPa), which shall be as agreed upon between user and supplier, is calculated as:

$$T = \frac{F}{(h - 2 \times R) \times L}$$

where

F is the maximum measured force in N;

H is the width of the wire;

L is the overlap contact length between the wires;

R is the corner radius of the wire (mm);

T is the shearing stress.

The overlap length and the temperature for bonding the specimen shall be reported.

Dimensions in millimetres

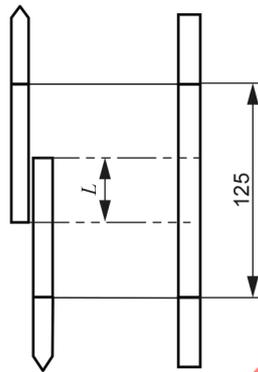


Figure 15 – Samples for heat bonding

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Annex A (informative)

Bond strength of heat bonding wires

A.1 Calculation of the temperature of the twisted coil specimen

A.1.1 Method

While heating the twisted coil by means of DC current, the average temperature of the specimen may be derived from its DC resistance, which is the ratio of the voltage and the constant current applied. Such ratios can be determined at the beginning and at the end of any heating period and allow the calculation of the temperature at the end of the heating period.

A.1.2 Temperature coefficient

For the following calculations, a temperature coefficient of copper of $\alpha = 0,004 \text{ K}^{-1}$ is used.

A.1.3 Calculation

With this temperature coefficient, the resistance of the test specimen at the end of a heating period is calculated from the equation

$$R_{T_t} = R_{T_o} + \alpha R_{T_o} \times (T_t - T_o)$$

where

R_{T_o} is the resistance in the beginning (at room temperature);

T_t is the temperature at the end of the heating period;

T_o is the temperature at the beginning of the heating period (T_o is normally identical to room temperature, i.e., 23 °C).

Subscript t stands for the end of the heating period.

If the current is constant, the following equation applies:

$$\frac{R_{T_t}}{R_{T_o}} = \frac{U_t}{U_o}$$

where

U_t is the voltage at the end of the heating period;

U_o is the voltage at the beginning of the heating period.

This results in the temperature at the end of the heating period:

$$T_t = T_o + \left[250 \times \left(\frac{U_t}{U_o} - 1 \right) \right] \text{ in } ^\circ\text{C}$$

A.2 Determination of the heating period

A.2.1 Voltage-time graphs

While heating the twisted coil with a constant current, the electrical resistance increases with the temperature. To maintain the current, the voltage output of the constant current transformer increases accordingly. This allows plotting of DC voltage output against time. This provides information about the time t of the heating period. Different graphs may be taken for different currents all plotted on one and the same diagram.

A.2.2 Voltage at maximum temperature

In a specific case one ~~may~~ might wish to bond the specimen up to a certain temperature, but not to exceed this temperature. If this maximum temperature is defined, the last equation as shown in A.1.3 allows the calculation of the voltage required to reach that temperature with a particular heating current:

$$U_t = U_o + 0,004 \times (T_t - T_o) U_o$$

The point of intersection of the voltage-time graph with the Y-axis corresponds to the value of U_o . With this reading, this equation allows the calculation of the voltage to arrive at the temperature of the specimen at the end of the heating period. The corresponding value of the X-axis gives the time length of the heating period required to reach the temperature T_t .

If the same calculation is done with all voltage-time graphs for one and the same temperature T_t , the corresponding entries may be used to produce an isothermic graph that intersects the voltage-time graphs. If this is repeated with different temperatures, it results in a final diagram, which is very helpful in selecting a suitable pair of values for the heating current in amperes and the time in seconds of the heating period to heat the test specimen up to the chosen temperature T_t .

Figure A.1 to Figure A.4 show examples of such complete diagrams for easy reference, based on wire sizes 0,300 mm, 0,315 mm, 0,355 mm and 0,500 mm respectively.

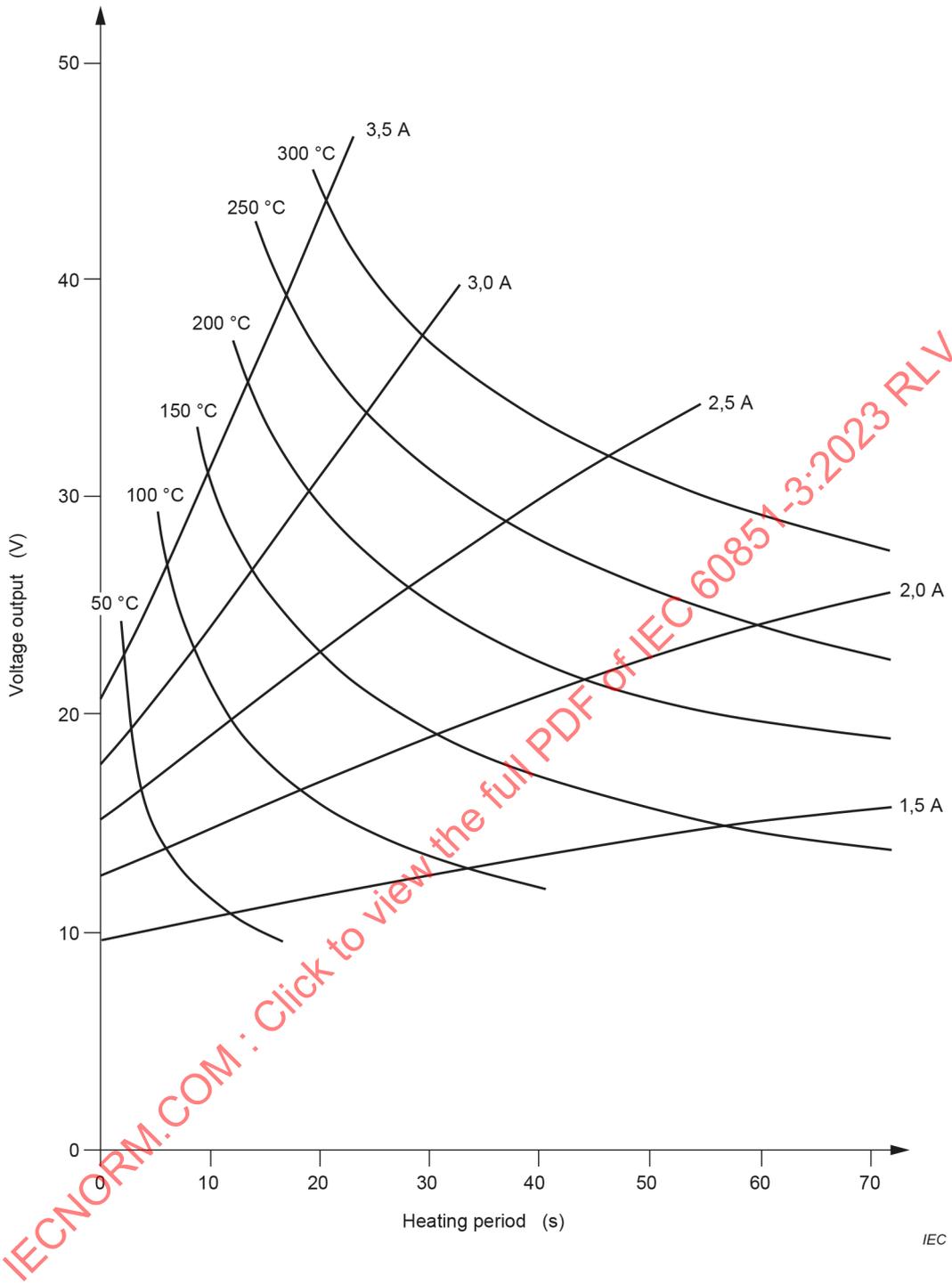


Figure A.1 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,300 mm with isothermic graphs

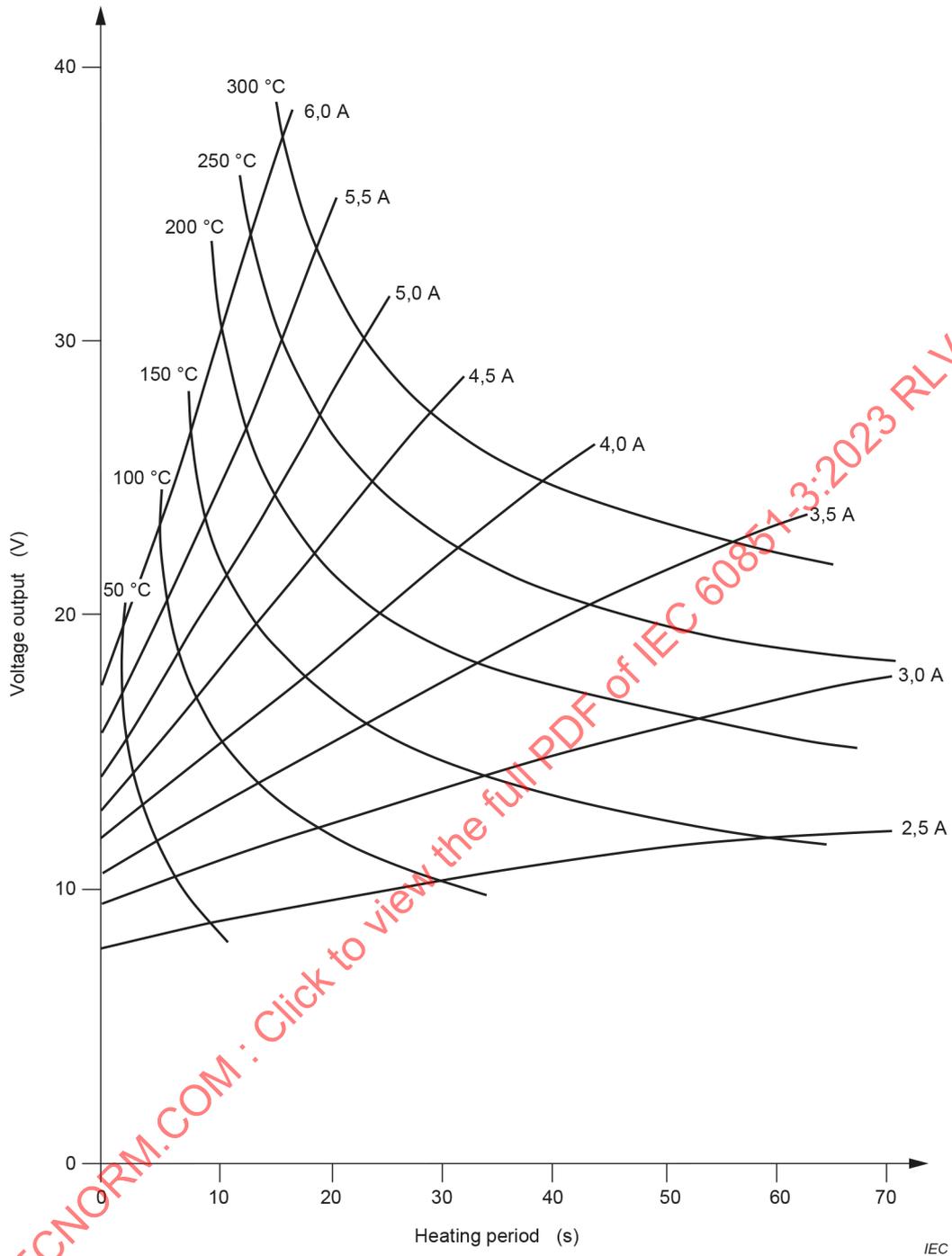


Figure A.2 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,315 mm with isothermic graphs

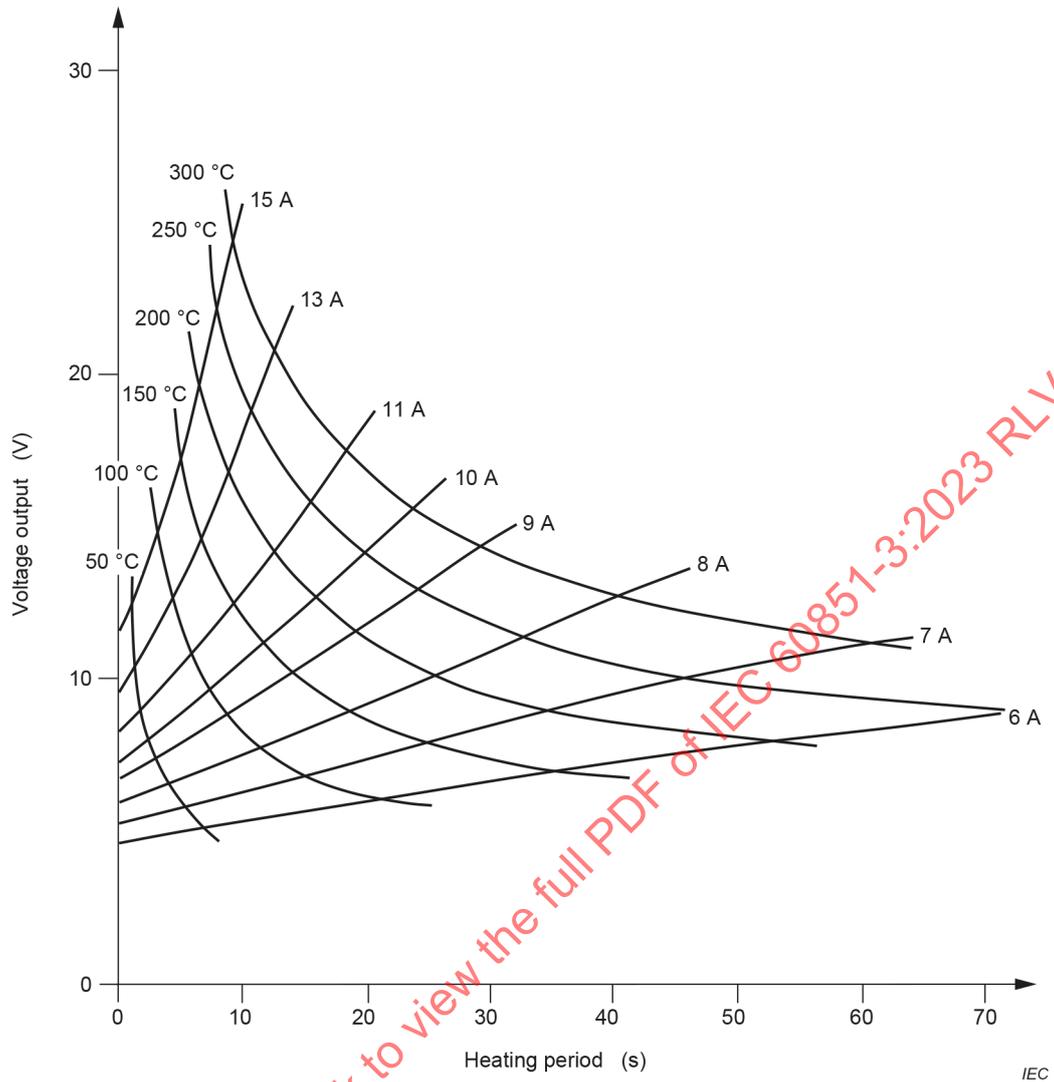


Figure A.3 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,355 mm with isothermic graphs

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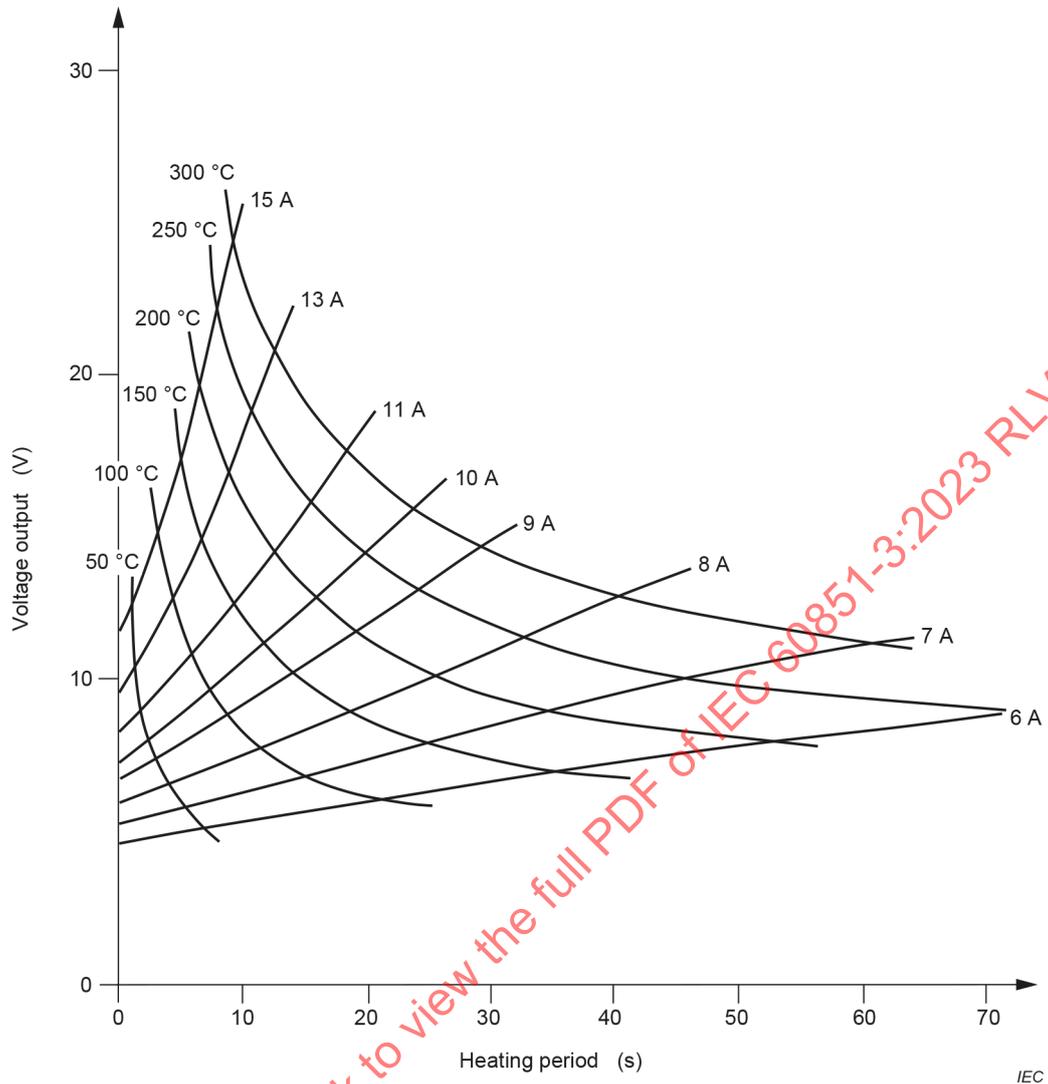


Figure A.4 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,500 mm with isothermic graphs

Annex B (informative)

Friction test methods

B.1 General

This annex provides recommendations to the purchaser and supplier of winding wires with respect to friction test methods to be used for winding wires. The use of additional methods can be agreed upon between purchaser and supplier.

B.2 Test A: Static coefficient of friction test method

B.2.1 Test method (applicable to enamelled round wires with a nominal conductor diameter from 0,050 mm up to and including 1,600 mm)

The static coefficient of friction (μ_s) is determined by measuring the inclining angle (α) of a plane at the moment when a block begins to slip on the track made from the wire specimen. The wire test specimen shall be removed from the delivery spools by de-reeling over the end flange. The top layers of the spool shall be removed before testing when the wire surface is contaminated by dirt or dust. One part of the wire specimen is straightened and then fixed on the inclining plane by means of the two posts and the two clamps constituting the sliding track. The other part of the wire specimen is mounted in a similar way on the sliding block.

The sliding block with the wire specimen is then placed on the track of the plane to be inclined in such a way that the wire on the block and the wire on the plane are crossed at right angles at the point of contact.

The plane is then slowly inclined (approximately 1°/s) until the block starts to slide down the track. At that moment, the angle of inclination (α) is read from the scale.

The static coefficient of friction is calculated as follows:

$$\mu_s = \tan \alpha$$

B.2.2 Test apparatus

The general arrangement of the test apparatus is shown in Figure B.1.

The apparatus consists of a plane (1), which can be inclined to an angle (α) by turning the plane around the axis (8). The support (9) carries a scale (7) marked with the inclination angle (α) or the coefficient of friction ($\tan \alpha$).

The plane has means for fixing the wire specimen (3), for example the two posts (5) and the two clamps (6). The parallel parts of the wire shall be 110 mm apart. The parallel parts form a sliding track running from the scale end to the axis on the plane.

On the block (2) clamps and posts are provided to fix the second wire specimen (4). The parallel parts of the specimen shall be 60 mm apart. It is critical that the size of the block ~~must allow~~ allows the clamps and posts to stay clear of the plane (1) to avoid additional friction forces. The block shall have:

- a mass of about 50 g for a wire with a nominal conductor diameter up to and including 0,150 mm;
- a mass of about 500 g for a wire with a nominal conductor diameter over 0,150 mm.

The mass is not critical as it is nonetheless changed by the mass of the second wire specimen.

The angle of inclination shall be changed slowly by means of a motor-operated block and tackle.

B.3 Test B: First dynamic coefficient of friction test method

B.3.1 Principle

The coefficient of friction, μ_d , is determined by measuring the frictional force, C , applied on the wire when moving under the pressure of a known mass, E :

$$\mu_d = \frac{C}{9,81 \times E}$$

B.3.2 Method of test

The general arrangement of the test apparatus is shown in Figure B.2.

The enamelled wire runs via a guide wheel and a brake (4) over a metal plate (2). Via another guide wheel, the wire is lead below this plate (2) and runs back, parallel with the first passage, over this plate again (see Figure B.2). By means of a capstan (1), the wire is drawn with a speed of 0,25 m/s. A mass (5) is placed on the running wire over the plate (2), which is coupled to a force indication meter (3).

The force indication meter can be coupled to a linear recorder (measuring range 1 mV to 250 mV). This linear recorder shows the spread of the smoothness and the level of the wire smoothness over a long distance.

B.4 Test C: Second dynamic coefficient of friction test method (applicable to enamelled round wires with a nominal conductor diameter from 0,050 mm up to and including 1,600 mm)

B.4.1 Test equipment

The design of typical test equipment is illustrated in Figure B.3. Figure B.4 contains detailed drawings of synthetic sapphires and Figure B.5 is a photograph of the load block. The tester is supplied with a wire guiding system and a take-up which pulls the wire over the test bed at 15 m/min as shown in Figure B.6. The test block is aligned parallel with the test bed and the test weights are perpendicular to the wire specimen.

As the wire is pulled under the test block (synthetic sapphires), the friction between the wire surface and the sapphire surface develops a longitudinal force, which is transferred to the measuring system by a shaft supported by two sets of linear ball bearings in contact with the measuring system. The force indicated by the measuring system is divided by the load on the test surface to obtain the dynamic coefficient of friction.

The measuring system in Figure B.3 shows the dynamic coefficient of friction tester with a load cell in place to measure the force. A linear variable differential transformer (LVDT) may also be used to measure the force instead of a load cell. The electrical output from the force measurement device is fed into a computer or into a microprocessor that collects data measurements, usually 1 000 points. Statistics are performed on this data set so that proper interpretation of the results can be made.

NOTE 1 Values for the dynamic coefficient of friction are characteristic of the type of lubrication and the magnet wire specimen surface. The dynamic coefficient of friction values are generally not dependent on wire size.

NOTE 2 Wire lubricated with a mineral oil typically will have a mean dynamic coefficient of friction in the range of 0,9 to 0,16. Wire lubricated with a paraffin wax will typically have a mean dynamic coefficient of friction ranging from 0,03 to 0,06 and will be more consistent in value as evidenced by a lower standard deviation. The mean value, maximum value and standard deviation value can be used to evaluate the application of the lubricant to the wire and smoothness of the wire surface.

The test procedure is designed to provide a measure of the lubrication and the film surface smoothness as a combined value. It is assumed that the wire will be de-reeled from its packaging with minimal contact with surfaces other than those associated with the tester and packaging.

If it is suspected that the presence of dust or dirt may have an effect on the coefficient of friction, one or two outer layers of wire should be removed from the package and the sample retested.

Test surfaces in contact with the wire shall be clean and dry at the start of each separate test. The solvent used to clean the test load surface should remove the various types of lubricants used and should dry without leaving a film residue.

B.4.2 Test specimen

The surface of the wire should be examined for damage, tangles, or excessive dust or dirt. If any of these conditions are present, the top wire specimen layer of the spool should be surfaced off before testing. The wire test specimen should be removed from the shipping package by de-reeling over the end flange or pulling the wire from a pail or drum.

B.4.3 Specimen preparation

The wire specimen is pulled over a test bed surface under a test load (L). A frictional force (F_d) is developed between the wire surfaces and transferred to an appropriate measuring device. The reading (F_d) in grams-force is divided by the test load (L) in grams-force to obtain the dynamic coefficient of friction μ_d .

$$\mu_d = \frac{F_d}{L}$$

A motor should pull the wire specimen at 15 m/min \pm 1,5 m/min across a smooth surface using a motor driven take-up.

Various load weights should be available that will provide 100 grams-force to 1 000 grams-force.

The test block should be comprised of two mounted synthetic sapphires that have a surface roughness of not more than 2,4 μm . The sapphires are described in Figure B.4 and are mounted in accordance with Figure B.5.

There should be a means to guide the wire and a means to maintain a slight tension if needed.

An electrical force measuring device or transducer measures the force due to friction. A force transducer with a range of 0 grams-force to 500 grams-force, a data storage device, and a microprocessor or computer to statistically analyse the data sets should be installed.

A mechanical dampening system consisting of a paddle and a container filled with oil may be used. The electrical signals from the load cell or LVDT can also be dampened electronically.

A cleaning solvent appropriate for dissolving the lubricant being tested should be used for cleaning the sapphires and metal surfaces between tests.

B.4.4 Procedure

The coefficient of friction tester should be level so that the only force being measured by the pressure transducer is that which is perpendicular to the load being applied and so that gravity is not a factor.

Calibrate the pressure transducer by setting the zero without any load and setting the span by hanging a weight of 100 g or a weight of 200 g. Remove the weight and the display should again read zero.

Enter the parameters of the test into the microprocessor or personal computer.

De-reel the wire from its packaging by pulling the wire over the flange, through the tensioning device, through the guides, and onto the take-up spindle.

Adjust the guide pulleys so that the wire is parallel with the test bed. Clean the test bed, any guide pulleys, and the sapphire surfaces with a suitable solvent.

Place the appropriate weight from Table B.1 onto the load block:

Table B.1 – Load block weights for dynamic coefficient of friction testing

Conductor diameter mm	Weight g
0,050 to 0,071	100
0,071 to 0,125	200
0,125 to 0,450	600
0,450 to 1,600	1 000

Adjust the test bed to make the test load parallel with the test surface. Turn the wire take up on and start collecting data after the setup is stable and aligned and continue until the desired number of data points has been stored.

Analyse the data for minimum reading, maximum reading, mean value, and standard deviation.

The dynamic coefficient of friction μ_d should be calculated as follows:

$$\mu_d = \frac{F_d}{L}$$

where

F_d is the force reading in grams force;

L is the test load in grams force.

B.5 Test D: Force of friction by the twisted pair method

B.5.1 Enamelled round wires with a nominal conductor diameter from 0,1 mm up to and including 1,500 mm

From an enamelled wire specimen, a twist is made similar to the one used for test 13 (breakdown voltage) in IEC 60851-5:2008, 4.3 and IEC 60851-1:2008/AMD1:2011, 4.3. The end of the first twist strand is attached to a fixed jaw and a force is applied to the opposite end of the second strand that has been kept free to slide by traction and without rotating, using for example a dynamometer. The force to separate the two strands is the sliding force.

B.5.2 Test method

A specimen of approximately 400 mm in length shall be twisted back on itself for a distance of 125 mm on an apparatus as shown in Figure B.7. The force (weight) applied to the wire pair while the wire pair is being twisted and the number of twists are given in Table B.2.

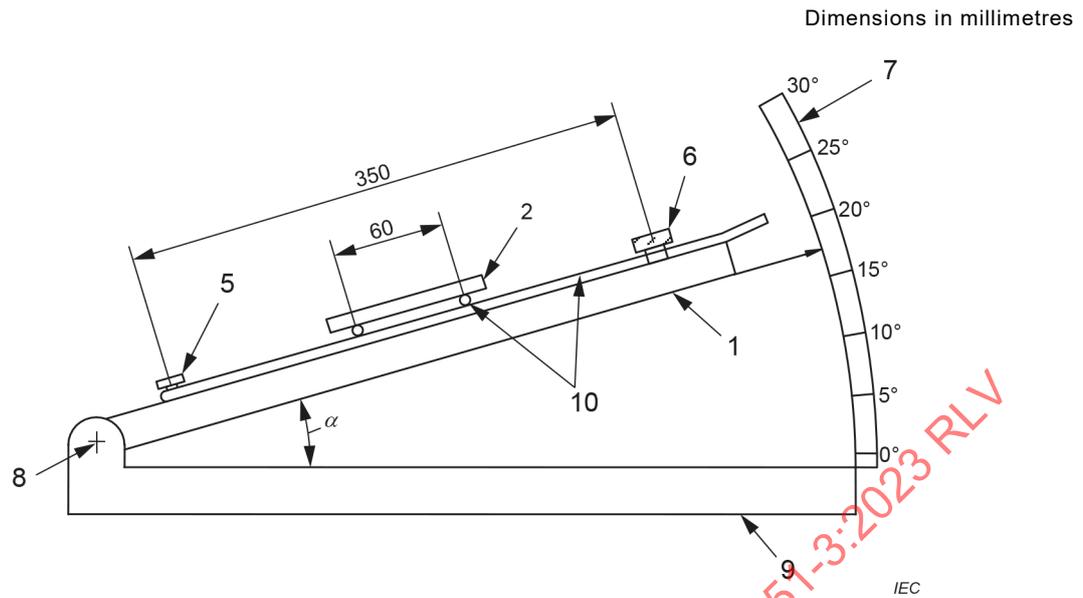
At the twisted end, the loop is cut in two separate places to obtain a maximum separation between these cut ends.

Any bending of the wires, at the cut end or at the other untwisted end, to ensure adequate separation between the wires, shall avoid sharp bends or damage to the insulation.

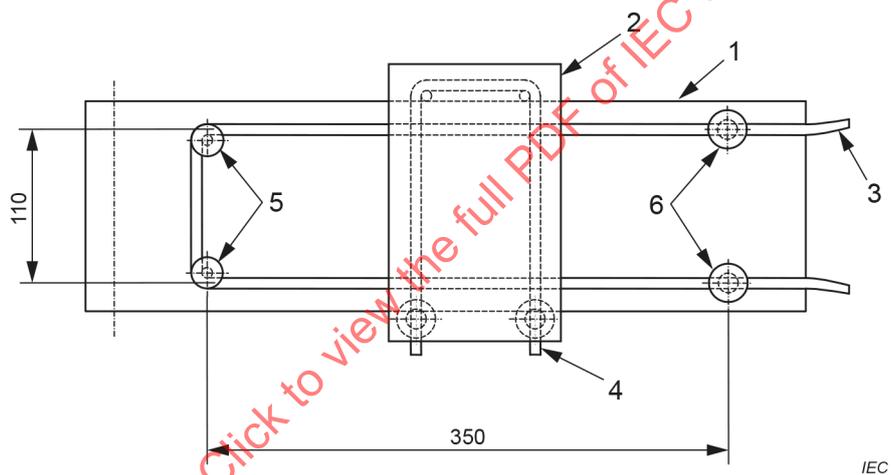
One end of one wire shall be attached firmly to a jaw, while at the opposite end of the other wire a force (weight) is applied to let that wire slide without any rotation. Three specimens shall be tested.

Table B.2 – Twisted pair method

Nominal conductor diameter mm		Force applied to wire pairs N	Number of twists per 125 mm
Over	Up to and including		
0,10	0,25	0,85	17
0,25	0,315	1,40	15
0,315	0,40	2,40	13
0,40	0,50	3,40	12
0,50	0,71	6,00	11
0,71	0,80	8,50	10
0,80	0,90	10,00	9
0,90	1,00	12,50	8
1,00	1,12	15,00	7
1,12	1,25	20,00	6
1,25	1,50	27,00	5



a) Side view

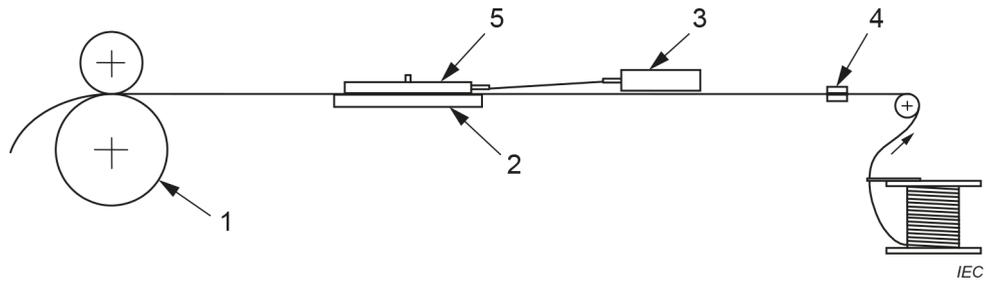


b) Top view

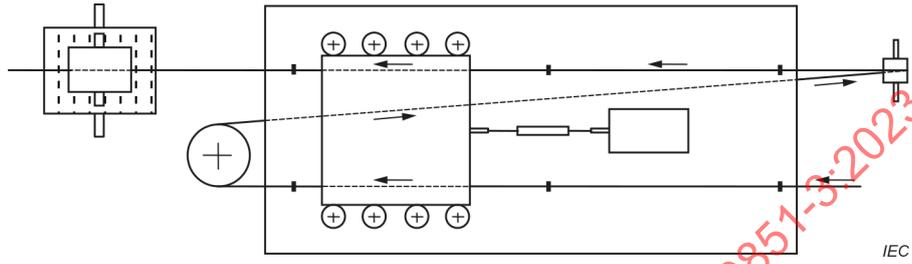
Key

- 1 plane
- 2 block
- 3 wire specimen
- 4 wire
- 5 posts
- 6 clamps
- 7 scale
- 8 axis
- 9 support
- 10 winding wire specimen

Figure B.1 – Static coefficient of friction test apparatus



a) Side view



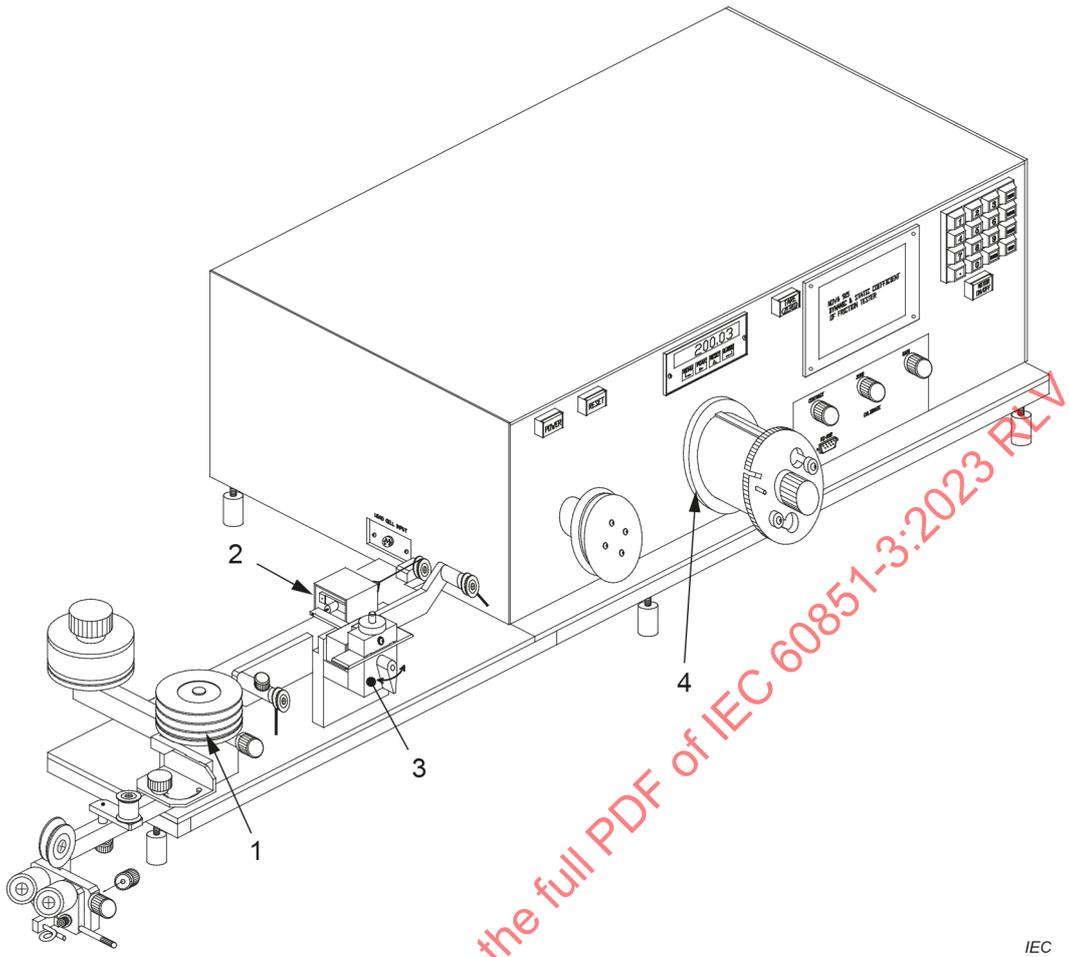
b) Top view

Components

- 1 capstan
- 2 plate
- 3 force indication meter
- 4 brake
- 5 mass

Figure B.2 – Dynamic coefficient of friction test apparatus

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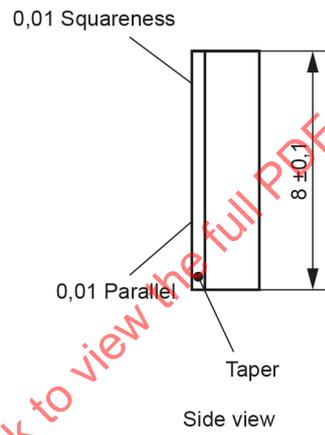
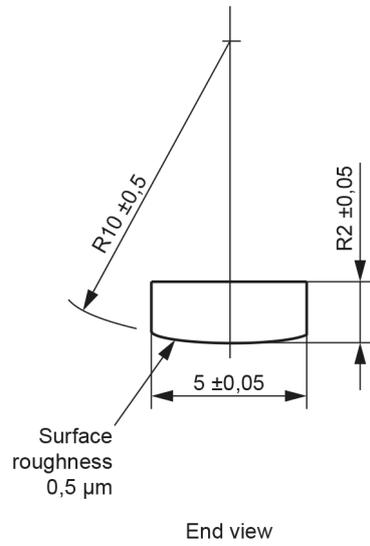
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Key

- 1 wire tensioner
- 2 load cell assembly
- 3 sapphire test head and support block assembly
- 4 wire take-up mandrel

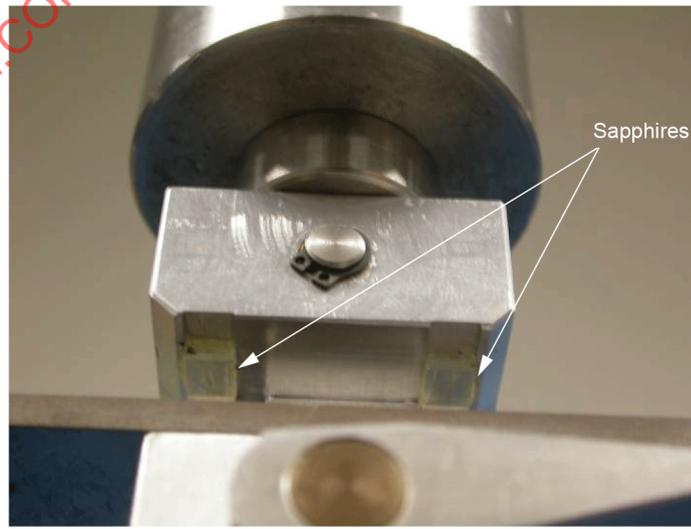
Figure B.3 – Diagram of a typical dynamic coefficient of friction tester

Dimensions in millimetres



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Figure B.4 – Material – sapphire (synthetic)



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Figure B.5 – Synthetic sapphires mounted on load block

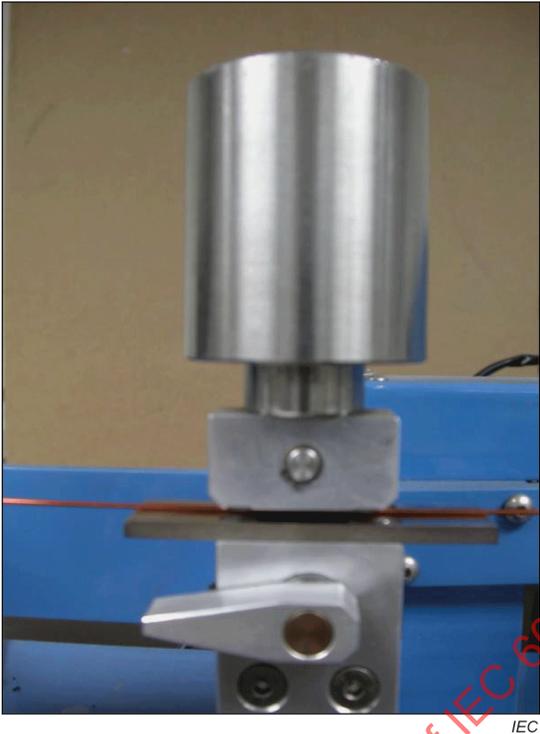


Figure B.6 – Load applied perpendicular to wire path

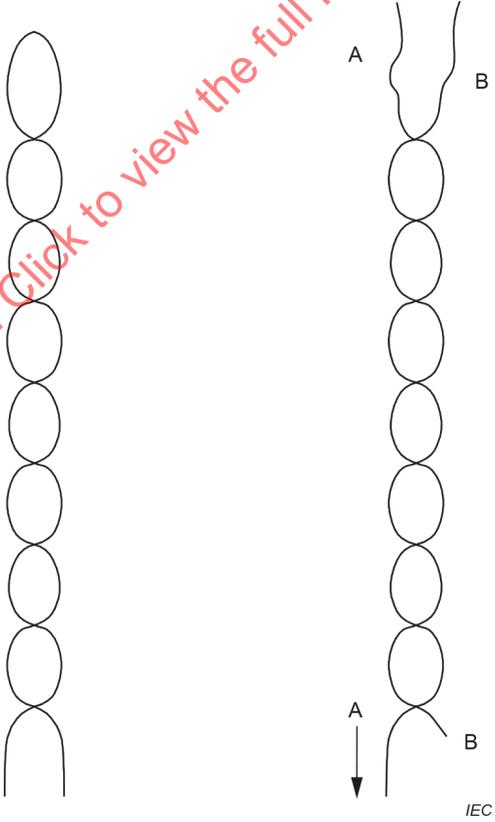


Figure B.7 – Twisted specimen

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IEC 60851-1, *Winding wires – Test methods – Part 1: General*

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IEC 60851-5:2008/AMD1:2011

IEC 60851-5:2008/AMD2:2019

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

IEC 61033:1991/AMD1:2006

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INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Winding wires – Test methods –
Part 3: Mechanical properties**

**Fils de bobinage – Méthodes d'essai –
Partie 3: Propriétés mécaniques**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WINDING WIRES – TEST METHODS –**Part 3: Mechanical properties****FOREWORD**

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IEC 60851-3 has been prepared by IEC technical committee 55: Winding wires. It is an International Standard.

This fourth edition cancels and replaces the third edition published in 2009, Amendment 1:2013 and Amendment 2:2019. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Clarification of the distance measurement for determining loss of adhesion in 6.6.3, 6.6.4 for fibre-covered wires and 6.6.5 for tape-wrapped wires.

The text of this International Standard is based on the following documents:

Draft	Report on voting
55/1938/CDV	55/1974/RVC

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 60851 series, published under the general title *Winding wires – Test methods*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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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) winding wires – Test methods (IEC 60851);
- b) specifications for particular types of winding wires (IEC 60317);
- c) packaging of winding wires (IEC 60264).

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WINDING WIRES – TEST METHODS –

Part 3: Mechanical properties

1 Scope

This part of IEC 60851 specifies the following test methods for winding wires:

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

For definitions, general notes on test methods and the complete series of test methods for winding wires, IEC 60851-1 applies. This document also provides recommended friction test methods in Annex B.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60851-2:2009, *Winding wires – Test methods – Part 2: Determination of dimensions*
IEC 60851-2:2009/AMD1:2015
IEC 60851-2:2009/AMD2:2019

ISO 178:2019, *Plastics – Determination of flexural properties*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

4 Test 6: Elongation

4.1 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 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.

4.2 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.

5 Test 7: Springiness

5.1 General

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

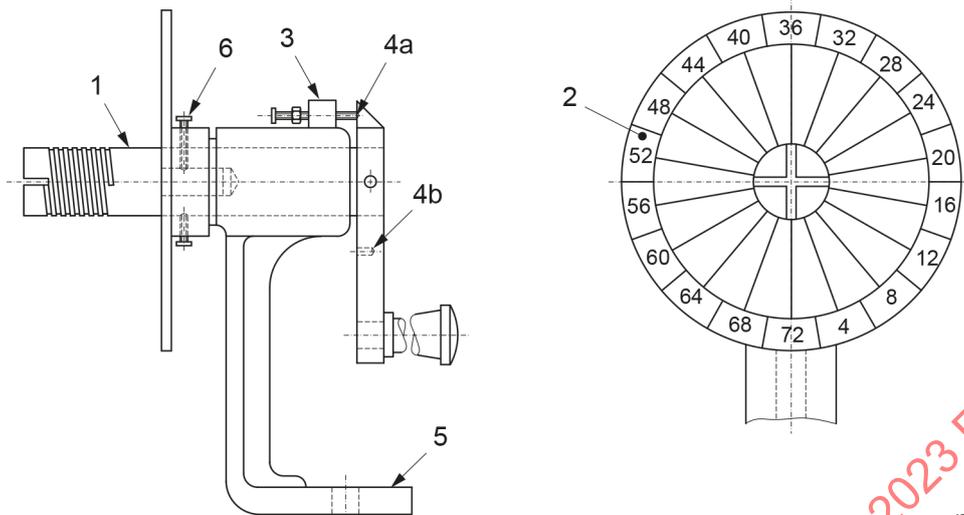
5.2 Round wire with a nominal conductor diameter from 0,080 mm up to and including 1,600 mm

5.2.1 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.

5.2.2 Equipment

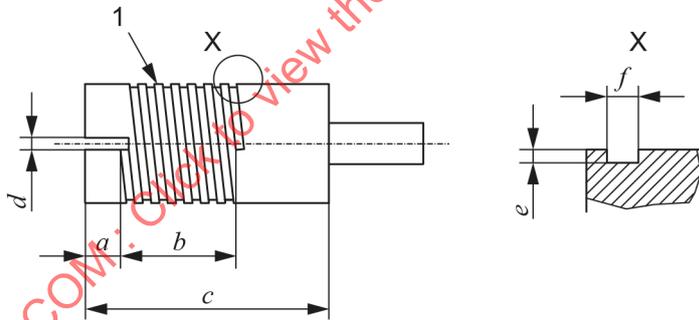
Figure 1 shows an example of the test equipment with details of the mandrel given in Figure 2 and Table 1. Figure 2 indicates a helical groove, which may be used to facilitate winding. The provision of this groove, however, is not mandatory. The dial is marked with 72 equally spaced divisions so that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



Key

- 1 mandrel
- 2 dial
- 3 locking device
- 4 locking device
- 5 base-plate
- 6 mandrel-fixing screw

Figure 1 – Test equipment to determine springiness



Key

- 1 7 threads
- 2 part X enlarged

Figure 2 – Construction and details of the mandrel (see Table 1)

Table 1 – Mandrels for springiness

Mandrel diameter ^a mm	Dimensions ^b mm					
	a	b	c	d	e	f
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

^a At the bottom of the groove, if provided.

^b See Figure 2.

5.2.3 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 counterclockwise (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, it is possible to obtain erroneous results.

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 shall 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.

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

5.3.1 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.

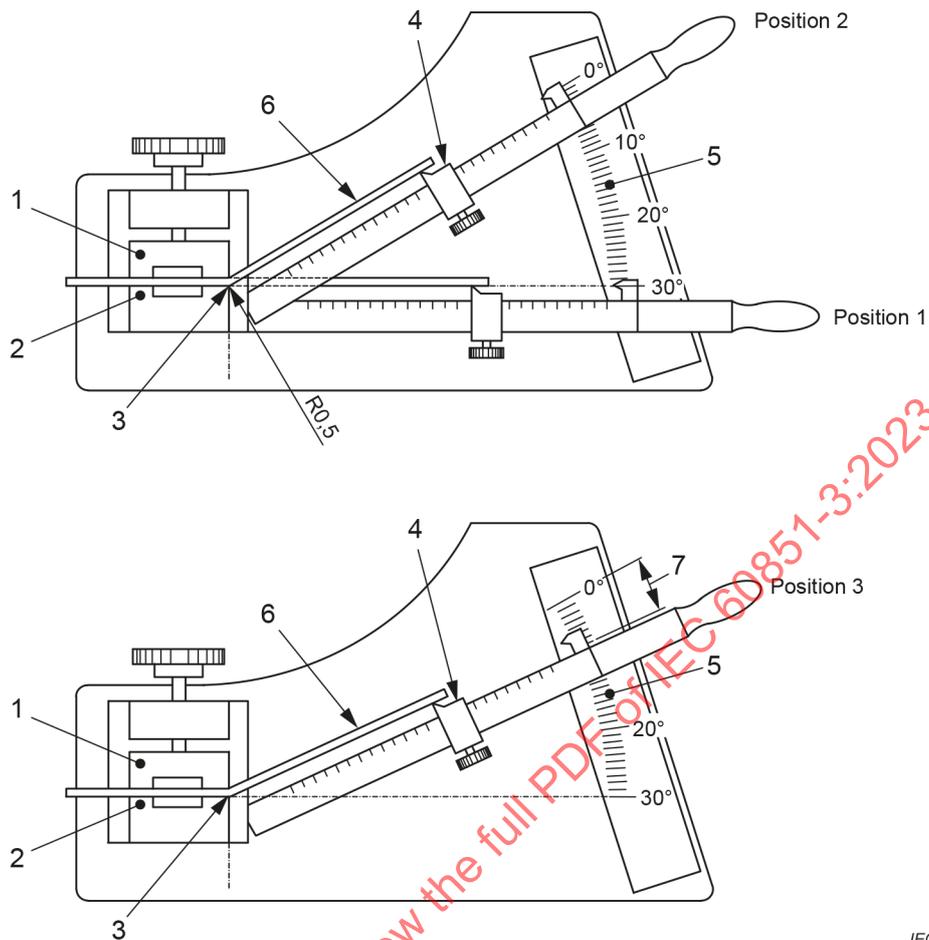
5.3.2 Equipment

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.

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Dimensions in millimetres



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Key

- 1 moveable jaw
- 2 fixed jaw
- 3 centre of graduated sector
- 4 slider
- 5 graduated sector
- 6 wire specimen
- 7 springback

Figure 3 – Test equipment to determine springiness**5.3.3 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.

5.3.4 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. All three values shall be reported. The mean value represents springiness.

6 Test 8: Flexibility and adherence

6.1 General

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.

6.2 Mandrel winding test

6.2.1 Round wire

6.2.1.1 General

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 that 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.

6.2.1.2 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 4 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 ^a
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

^a One times magnification expresses normal vision.

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

6.2.1.3 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.

6.2.1.4 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.

6.2.1.5 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.

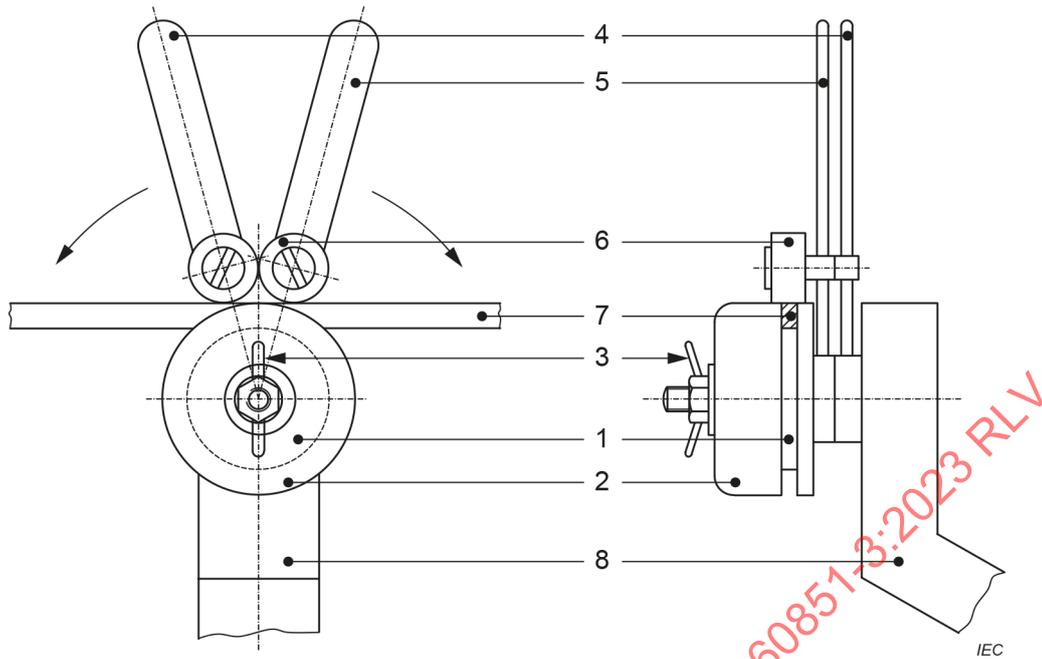
Three specimens shall be tested. Exposure of the bare conductor or any delamination shall be reported.

6.2.2 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 the case of enamelled wire, for exposure of the bare conductor or underlying coating in the case of fibre covered wire and for exposure of the bare conductor and delamination in the 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). If the wire shows cracks or delamination, exposure of the bare conductor or underlying coating, whichever is applicable, this shall be reported.



Key

- 1 mandrel
- 2 mandrel clamping collar
- 3 winding nut
- 4 lever
- 5 lever
- 6 ball bearing
- 7 specimen
- 8 support

Figure 4 – Test equipment for mandrel winding test

6.2.3 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 IEC 60851-2:2009, 3.2.5.3. 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. If the wire does not show the required degree of closeness of the covering, this shall be reported.

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

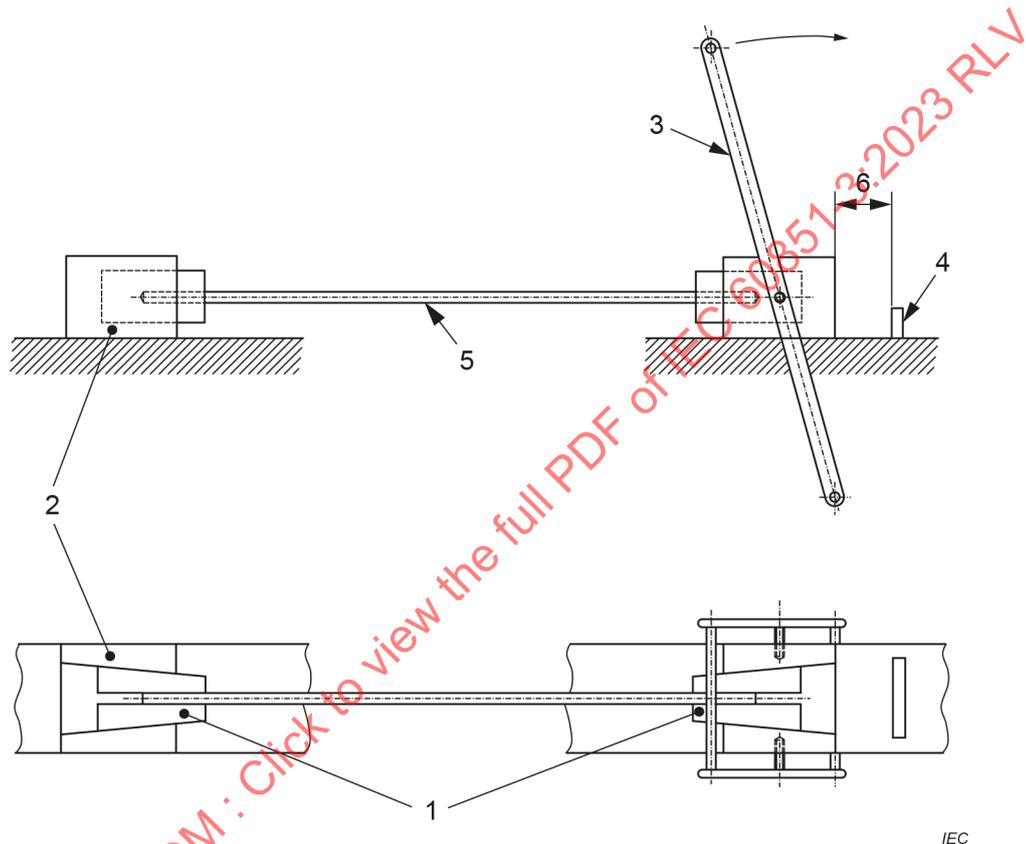
A straight piece of wire shall be elongated according to Clause 4 to the percentage specified in the relevant standard. After elongation, the specimen shall be examined for cracks or loss of adhesion with normal vision or with a magnification of up to six times.

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

6.4 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 with test equipment as shown in Figure 5. A free measuring length of between 200 mm and 250 mm shall be provided. After stretching, 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. If the wire shows cracks and/or loss of adhesion, this shall be reported.



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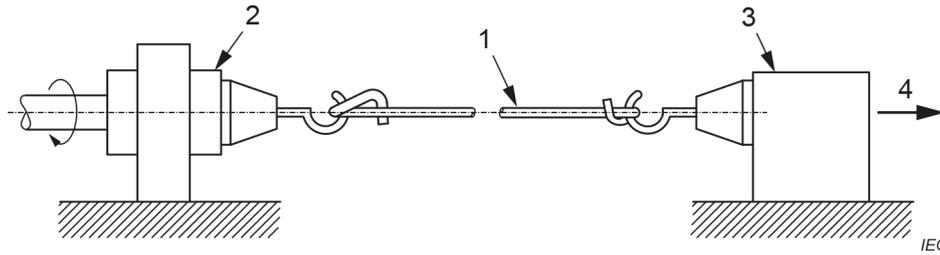
Key

- 1 wedge grips (clamps)
- 2 fixed jaw set
- 3 lever arm
- 4 adjustable stop
- 5 specimen
- 6 specified elongation

Figure 5 – Test equipment for jerk test

6.5 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.



Key

- 1 specimen
- 2 rotary clamp
- 3 fixed clamp
- 4 load

Figure 6 – Test equipment for peel test

Table 3 – Load for peel test

Nominal conductor diameter mm		Load N
Over	Up to and including	
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. If loss of adhesion is observed, this shall be reported.

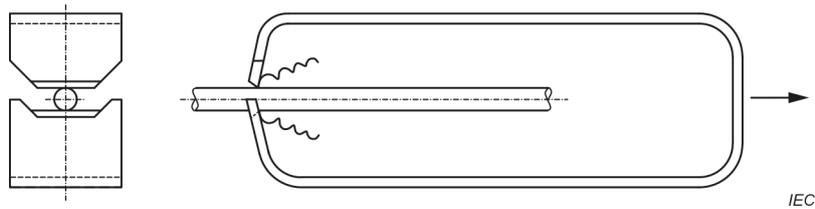


Figure 7 – Scraper

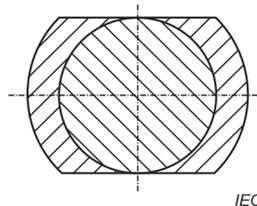


Figure 8 – Cross-section of the wire after removal of the coating

6.6 Adherence test

6.6.1 General

A straight piece of wire of about 300 mm length shall be elongated in accordance with Clause 4 to the percentage specified in the relevant standard.

6.6.2 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. If loss of adhesion is observed, as determined by longitudinal measurement from the cut, it shall be reported. 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, under a magnification of six to ten times.

6.6.3 Impregnated fibre covered round and rectangular wire

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

One specimen shall be tested. If loss of adhesion is observed according to the relevant specification, as determined by longitudinal measurement in one direction from the cut, it shall be reported. The maximum value observed shall be reported after examining all sides of the specimen, under a magnification of six to ten times.

6.6.4 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 specimen through to the conductor. After elongation, the specimen shall be examined for loss of adhesion under a magnification of six to ten times.

One specimen shall be tested. If loss of adhesion is observed according to the relevant specification, as determined by longitudinal measurement in one direction from the cut, it shall be reported. The maximum value observed shall be reported after examining all sides of the specimen, under a magnification of six to ten times.

6.6.5 Tape-wrapped round and rectangular wire (for adhesive tape only)

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 under a magnification of six to ten times. One specimen shall be tested. The maximum value observed shall be reported after examining all sides of the specimen, under a magnification of six to ten times. If loss of adhesion is observed according to the relevant specification, as determined by longitudinal measurement in one direction from the cut, it shall be reported.

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

7.1 General

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.

7.2 Principle

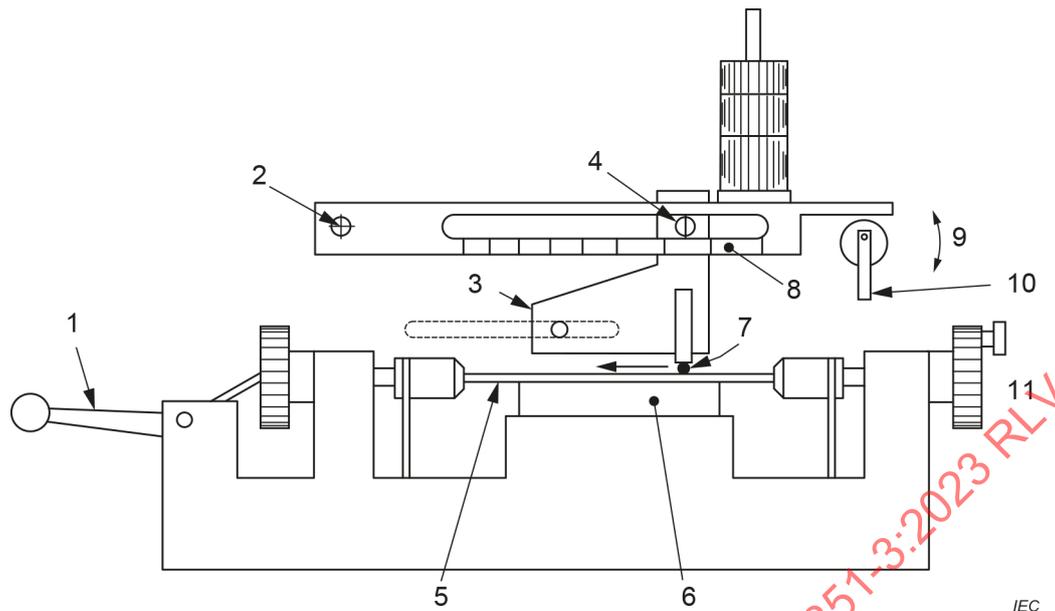
A straight piece of wire is subjected to a unidirectional scrape test, by a needle to which a progressively increasing load is applied and which scrapes along the wire surface. The load that causes an electrical contact of the needle with the conductor is called the load-to-failure.

7.3 Equipment

Test equipment as shown in Figure 9 shall be used. It shall be provided with a mechanism to produce a 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 DC 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.



Weighted scraping device moves from right to left with increasing load on wire

Key

- 1 capstan for straightening specimen
- 2 fixed pivot point
- 3 weighted scraping device
- 4 indexer
- 5 specimen
- 6 anvil with adjustable height for wires with different diameters
- 7 piano wire
- 8 scale, indicating multiplying factor
- 9 reset/operate
- 10 reset lever
- 11 chucks index at 120° increments

Figure 9 – Test equipment for unidirectional scrape test

7.4 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.

8 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 and to enamelled rectangular wire)

8.1 General

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

8.2 Vertical bond retention of a helical coil

8.2.1 General

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.

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

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

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

8.2.3.1 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.

8.2.3.2 Specimen

A straight piece of wire shall be wound on a polished mandrel 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. A steel mandrel has been found to be satisfactory for larger diameter wires. For smaller wires, copper mandrels have been found to aid in the removal of the coil from the mandrel by stretching the mandrel to reduce its diameter.

The coil on the mandrel shall be positioned vertically as shown in Figure 10 a) 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.

8.2.3.3 Procedure at room temperature

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

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

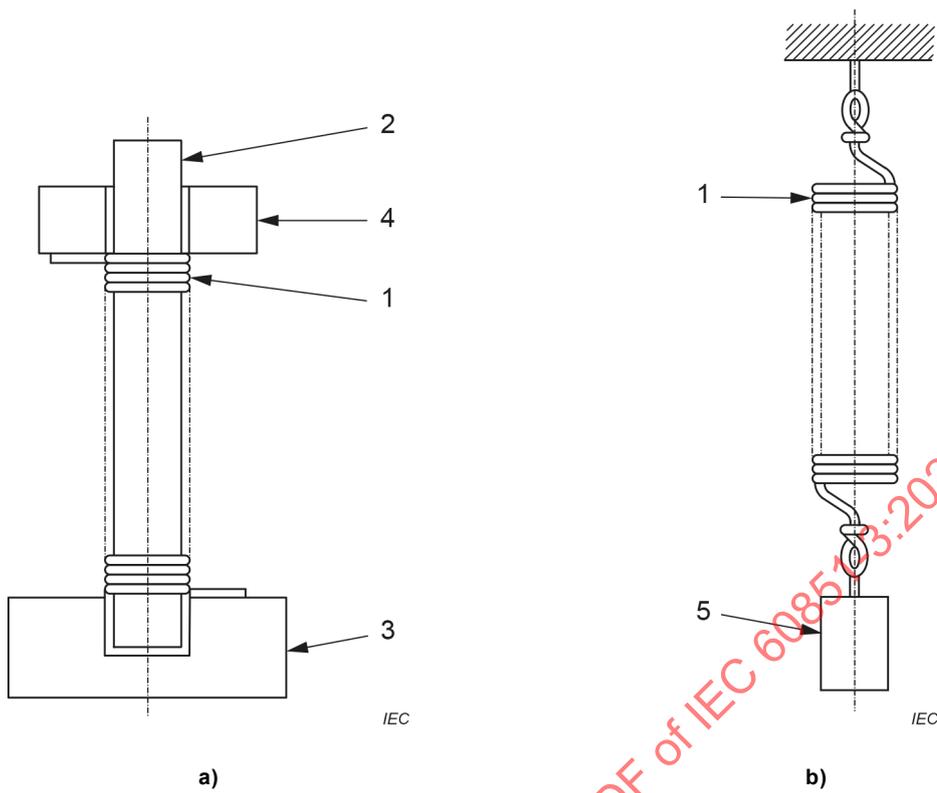
8.2.3.4 Procedure at elevated temperature

A specimen shall be suspended by one of its ends (see Figure 10 b)) and loaded as specified in Table 5. The load shall be applied in a way that 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. If turns other than the first and the last are separated, this shall be reported. The temperature for bonding the specimen shall be reported.

Table 4 – Preparation of helical coils

Nominal conductor diameter mm		Diameter of the mandrel mm	Maximum winding force N	Load on the coil during bonding N
Over	Up to and including			
0,050	0,071	1	0,05	0,05
0,071	0,100	1	0,05	0,05
0,100	0,160	1	0,12	0,15
0,160	0,200	1	0,30	0,25
0,200	0,315	2	0,80	0,35
0,315	0,400	3	0,80	0,50
0,400	0,500	4	2,00	0,75
0,500	0,630	5	2,00	1,25
0,630	0,710	6	5,00	1,75
0,710	0,800	7	5,00	2,00
0,800	0,900	8	5,00	2,50
0,900	1,000	9	5,00	3,25
1,000	1,120	10	12,00	4,00
1,120	1,250	11	12,00	4,50
1,250	1,400	12	12,00	5,50
1,400	1,600	14	12,00	6,50
1,600	1,800	16	30,00	8,00
1,800	2,000	18	30,00	10,00



Key

- 1 coil
- 2 mandrel
- 3 mandrel-holder
- 4 weight
- 5 separating load

Figure 10 – Test equipment for bond retention of a helical coil

Table 5 – Bond retention at elevated temperature

Nominal conductor diameter mm		Load N	Nominal conductor diameter mm		Load N
Over	Up to and including		Over	Up to and including	
0,050	0,071	0,04	0,800	0,900	2,60
0,071	0,100	0,06	0,900	1,000	3,20
0,100	0,160	0,09	1,000	1,120	3,80
0,160	0,200	0,19	1,120	1,250	4,40
0,200	0,315	0,25	1,250	1,400	4,90
0,315	0,400	0,55	1,400	1,600	6,40
0,400	0,500	0,80	1,600	1,800	7,90
0,500	0,630	1,20	1,800	2,000	7,90
0,630	0,710	1,70			
0,710	0,800	2,10			

8.3 Bond strength of a twisted coil

8.3.1 General

Bond strength is the maximum force required to break the twisted coil.

8.3.2 Principle

A random wound coil prepared from the wire is formed to an oval shape, twisted and then bonded by applying a DC current. This specimen produces a rod, which is tested in tensile testing equipment in a horizontal position to obtain the maximum deflection force to break this rod. The test shall be repeated at elevated temperature.

NOTE This test is similar to method A, twisted coil test, given in IEC 61033:1991, 2.1 and IEC 61033:1991/AMD1:2006, 2.1, and is based on the same principle. It differs from method A of IEC 61033 with respect to twisting and bonding the specimen and with respect to wire sizes. It facilitates the testing of different wire sizes, whereas method A of IEC 61033 specifies that a wire of a nominal conductor diameter of 0,315 mm shall be used.

8.3.3 Equipment

The following equipment shall be used:

- coil winder in accordance with Figure 11 a) and Figure 11 b);
- coil twister in accordance with Figure 13;
- tensile test equipment in accordance with ISO 178 with a support complying with Figure 13;
- DC supply unit providing a constant current output with a capacity of minimum 50 V and 15 A;
- attached to the tensile test equipment, an oven with forced air circulation, which shall maintain the test temperature within a tolerance of ± 2 °C and which shall allow heating at least five specimens simultaneously within 5 min to 10 min to the test temperature.

8.3.4 Specimen

A random wound coil shall be prepared from the wire using winding equipment according to Figure 11 a) and Figure 11 b). The number of windings shall be calculated as

$$N = \frac{100 \times 0,315^2}{d^2}$$

where d is the nominal conductor diameter of the wire under test.

NOTE 1 For a nominal conductor diameter of $d = 0,315$ mm, N represents 100 turns. For other values of d , the above equation will lead to a number N , which gives the same total conductor cross-section as $N = 100$ and $d = 0,315$ mm.

To prevent opening of the coil after removal from the winding equipment, each end of the wire (or short pieces of enamelled wire) shall be wrapped around the coil two or three times at opposite positions. For this purpose, the winding equipment is provided with appropriate notches (see Figure 11 b)).

For winding the coil, the following dimensions shall apply:

- winding diameter: $(57 \pm 0,1)$ mm;
- width of slot: $(5 \pm 0,5)$ mm.

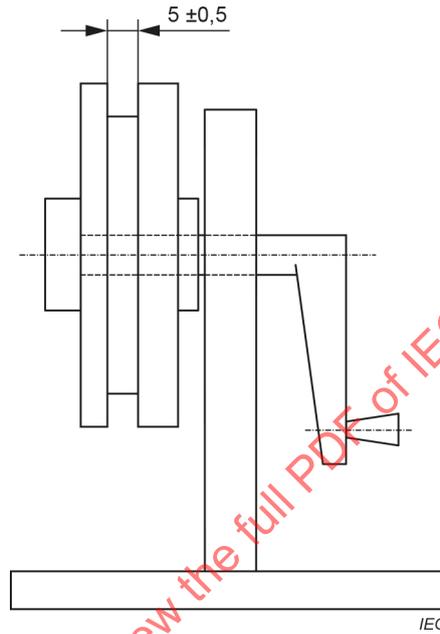
After removal from the winding equipment, the coil shall be formed to an oval shape (see Figure 12) and then twisted in a twisting device around its longitudinal axis according to Figure 13. This device allows application of a mechanical load to be applied to the coil while it

is twisted and subsequently bonded. This load shall be 100 N. The coil shall be twisted for two and a half turns and then half a turn in the reverse direction. While held under a mechanical load in the twisting device, the specimen shall be bonded by applying a constant DC current to the wire. A current shall be chosen that bonds the specimen within a period of 30 s to 60 s.

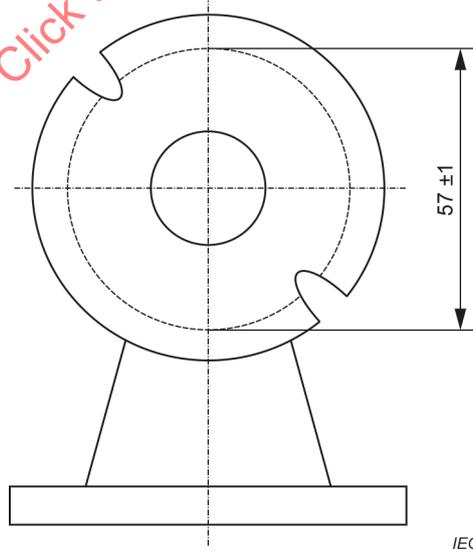
NOTE 2 Since DC current is used, it allows an easy approach to determine the average temperature of the specimen at the end of the heating period (see Annex A).

The specimen is a rod of about 7 mm in diameter and 85 mm to 90 mm in length.

Dimensions in millimetres



a) Coil winder

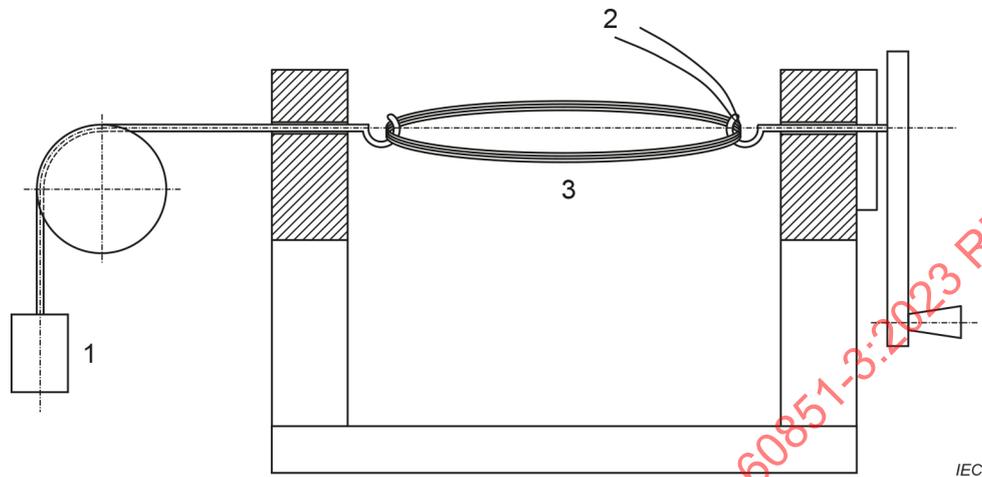


b) Coil winder, front view

Figure 11 – Coil winder



Figure 12 – Oval shape coil



Key

- 1 load 100 N
- 2 DC current
- 3 twisted coil

Figure 13 – Twisting device with a load applied to the twisted coil specimen

8.3.5 Procedure

With the specimen properly positioned on a support according to Figure 14, the bond strength of the specimen shall be determined by adjusting the crosshead speed so that the maximum deflection force is reached in about 1 min.

For tests at elevated temperature, the specimen shall be placed in the oven preheated to the specified temperature. The specimen shall be tested after it has reached the oven temperature but not later than 15 min after being placed in the oven.

8.3.6 Result

For each temperature, five specimens shall be tested. The five single values shall be reported for each test temperature. The mean value represents the bond strength. The nominal conductor diameter, the number of turns of the coil and the bonding conditions of specimens shall also be reported.

Dimensions in millimetres

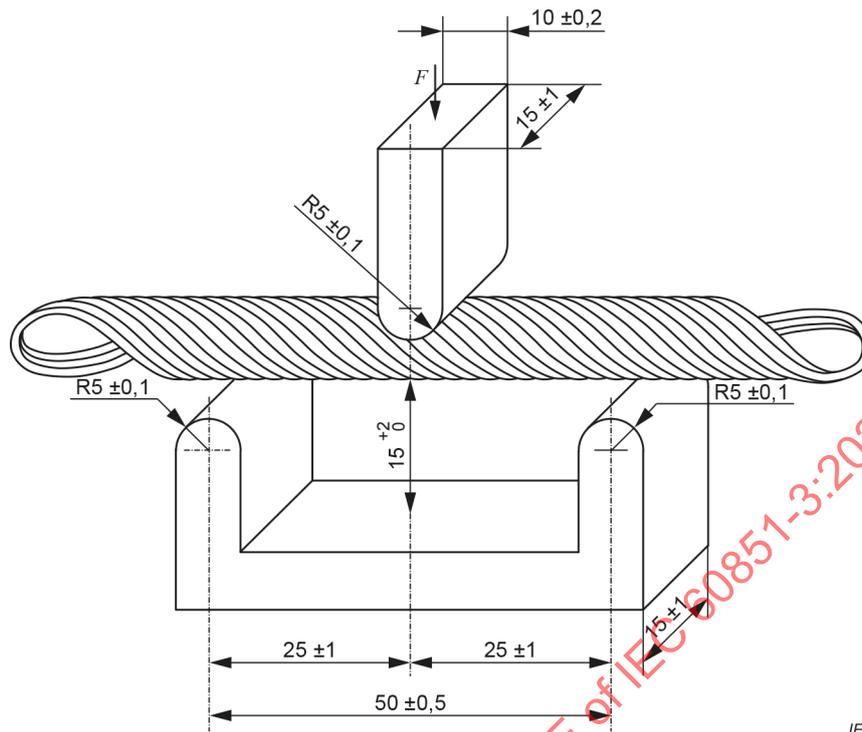


Figure 14 – Arrangement of supports

8.4 Enamelled rectangular wire heat bonding

Five specimens, each composed of two straight pieces of wire of about 100 mm length, are prepared according to Figure 15 and placed in a clamping device with an overlap length (L) (25 ± 5) mm under a pressure of 1,00 MPa. Other overlap lengths and clamping pressures may be agreed upon between user and supplier.

The total length of each specimen between jaws shall be about 125 mm.

The required load (P) for this pressure is calculated as:

$$P = 1,00 \times 25 \times (h - 2R)$$

where

R is the corner radius of the wire (mm);

h is the width of the wire.

The specimens shall be cured in an oven at $(120 \pm 2) ^\circ\text{C}$ for (24 to 24,5) h or as agreed upon between user and supplier.

After being cooled to ambient temperature, the specimens shall be subjected to a lap shear test by applying a gradually increasing load until detachment. The load shall be applied in a way that avoids any additional shock.

Shearing stress (MPa), which shall be as agreed upon between user and supplier, is calculated as:

$$T = \frac{F}{(h - 2 \times R) \times L}$$

where

F is the maximum measured force in N;

H is the width of the wire;

L is the overlap contact length between the wires;

R is the corner radius of the wire (mm);

T is the shearing stress.

The overlap length and the temperature for bonding the specimen shall be reported.

Dimensions in millimetres

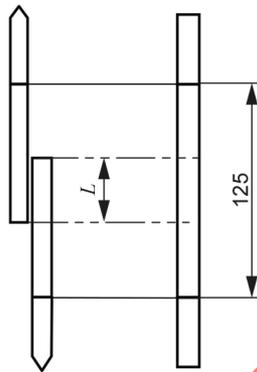


Figure 15 – Samples for heat bonding

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Annex A (informative)

Bond strength of heat bonding wires

A.1 Calculation of the temperature of the twisted coil specimen

A.1.1 Method

While heating the twisted coil by means of DC current, the average temperature of the specimen may be derived from its DC resistance, which is the ratio of the voltage and the constant current applied. Such ratios can be determined at the beginning and at the end of any heating period and allow the calculation of the temperature at the end of the heating period.

A.1.2 Temperature coefficient

For the following calculations, a temperature coefficient of copper of $\alpha = 0,004 \text{ K}^{-1}$ is used.

A.1.3 Calculation

With this temperature coefficient, the resistance of the test specimen at the end of a heating period is calculated from the equation

$$R_{T_t} = R_{T_o} + \alpha R_{T_o} \times (T_t - T_o)$$

where

R_{T_o} is the resistance in the beginning (at room temperature);

T_t is the temperature at the end of the heating period;

T_o is the temperature at the beginning of the heating period (T_o is normally identical to room temperature, i.e., 23 °C).

Subscript t stands for the end of the heating period.

If the current is constant, the following equation applies:

$$\frac{R_{T_t}}{R_{T_o}} = \frac{U_t}{U_o}$$

where

U_t is the voltage at the end of the heating period;

U_o is the voltage at the beginning of the heating period.

This results in the temperature at the end of the heating period:

$$T_t = T_o + \left[250 \times \left(\frac{U_t}{U_o} - 1 \right) \right] \text{ in } ^\circ\text{C}$$

A.2 Determination of the heating period

A.2.1 Voltage-time graphs

While heating the twisted coil with a constant current, the electrical resistance increases with the temperature. To maintain the current, the voltage output of the constant current transformer increases accordingly. This allows plotting of DC voltage output against time. This provides information about the time t of the heating period. Different graphs may be taken for different currents all plotted on one and the same diagram.

A.2.2 Voltage at maximum temperature

In a specific case one might wish to bond the specimen up to a certain temperature, but not to exceed this temperature. If this maximum temperature is defined, the last equation as shown in A.1.3 allows the calculation of the voltage required to reach that temperature with a particular heating current:

$$U_t = U_o + 0,004 \times (T_t - T_o) U_o$$

The point of intersection of the voltage-time graph with the Y-axis corresponds to the value of U_o . With this reading, this equation allows the calculation of the voltage to arrive at the temperature of the specimen at the end of the heating period. The corresponding value of the X-axis gives the time length of the heating period required to reach the temperature T_t .

If the same calculation is done with all voltage-time graphs for one and the same temperature T_t , the corresponding entries may be used to produce an isothermic graph that intersects the voltage-time graphs. If this is repeated with different temperatures, it results in a final diagram, which is very helpful in selecting a suitable pair of values for the heating current in amperes and the time in seconds of the heating period to heat the test specimen up to the chosen temperature T_t .

Figure A.1 to Figure A.4 show examples of such complete diagrams for easy reference, based on wire sizes 0,300 mm, 0,315 mm, 0,355 mm and 0,500 mm respectively.

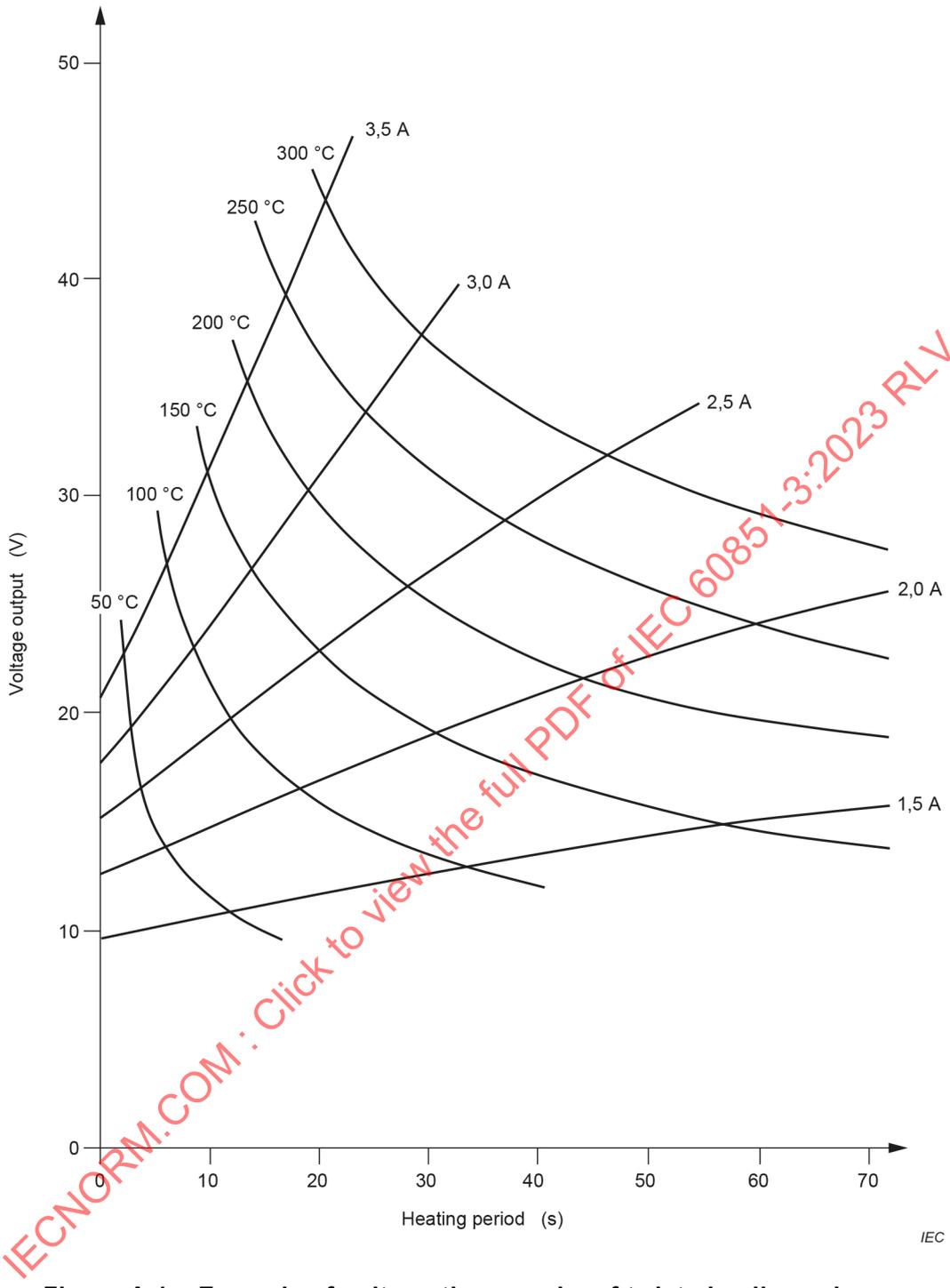


Figure A.1 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,300 mm with isothermic graphs

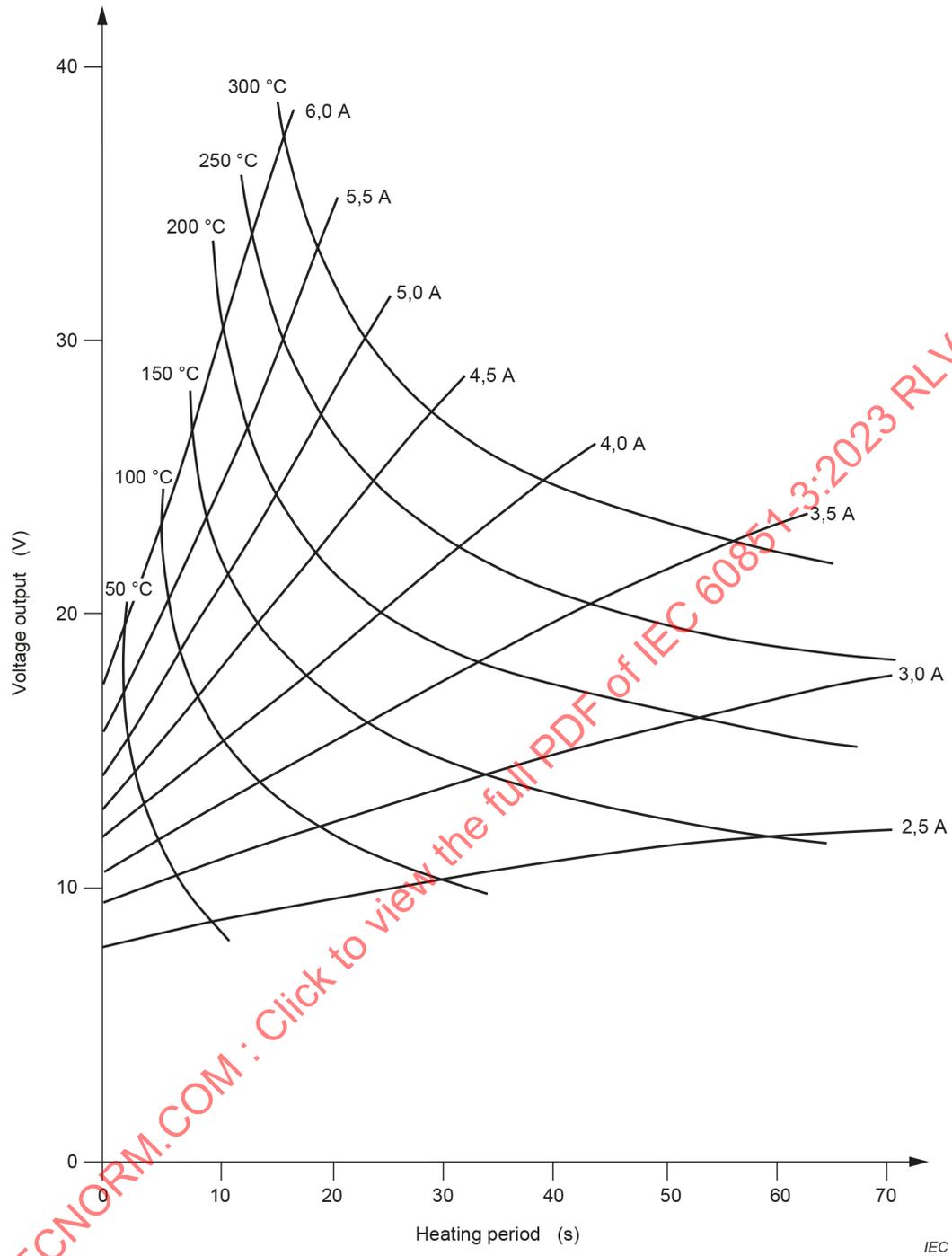


Figure A.2 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,315 mm with isothermic graphs

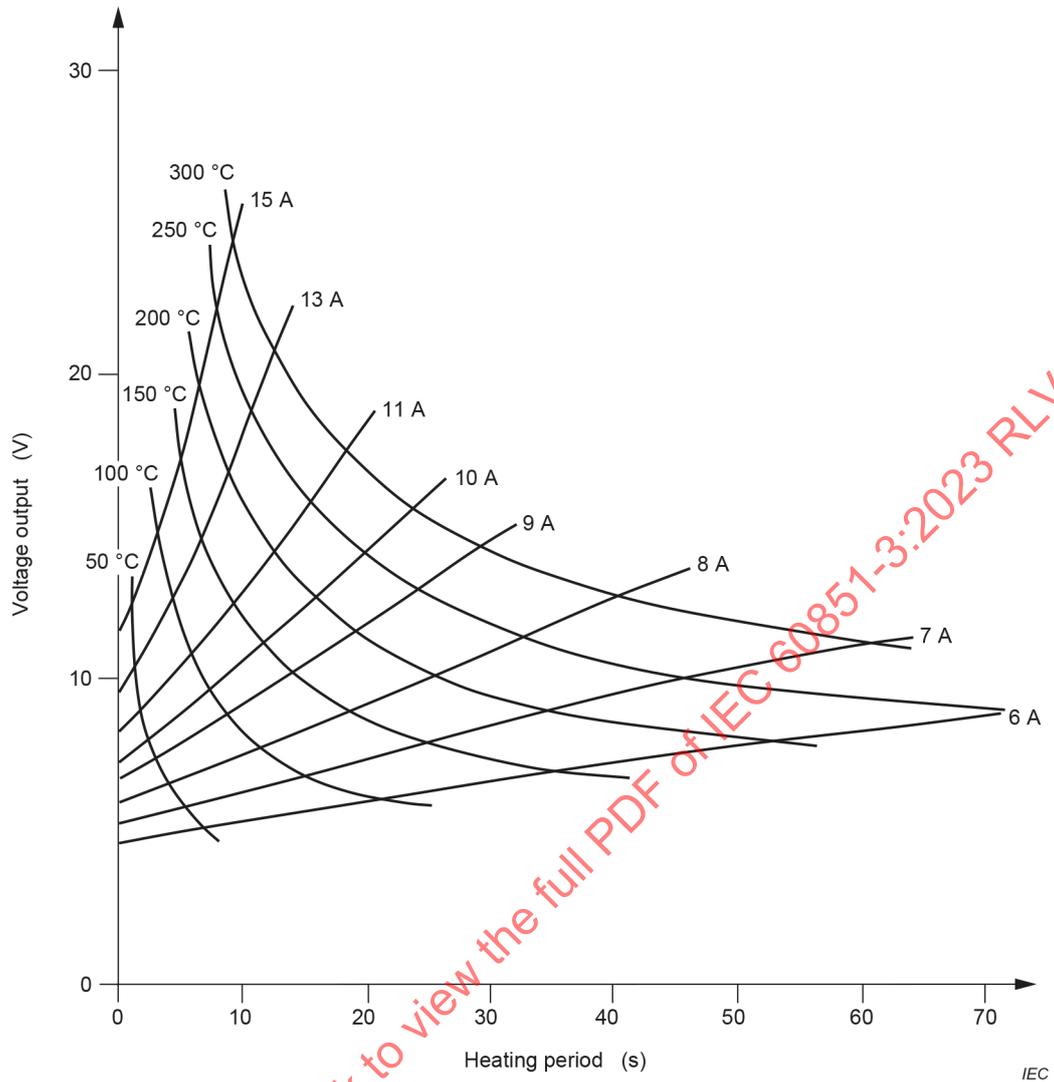


Figure A.3 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,355 mm with isothermic graphs

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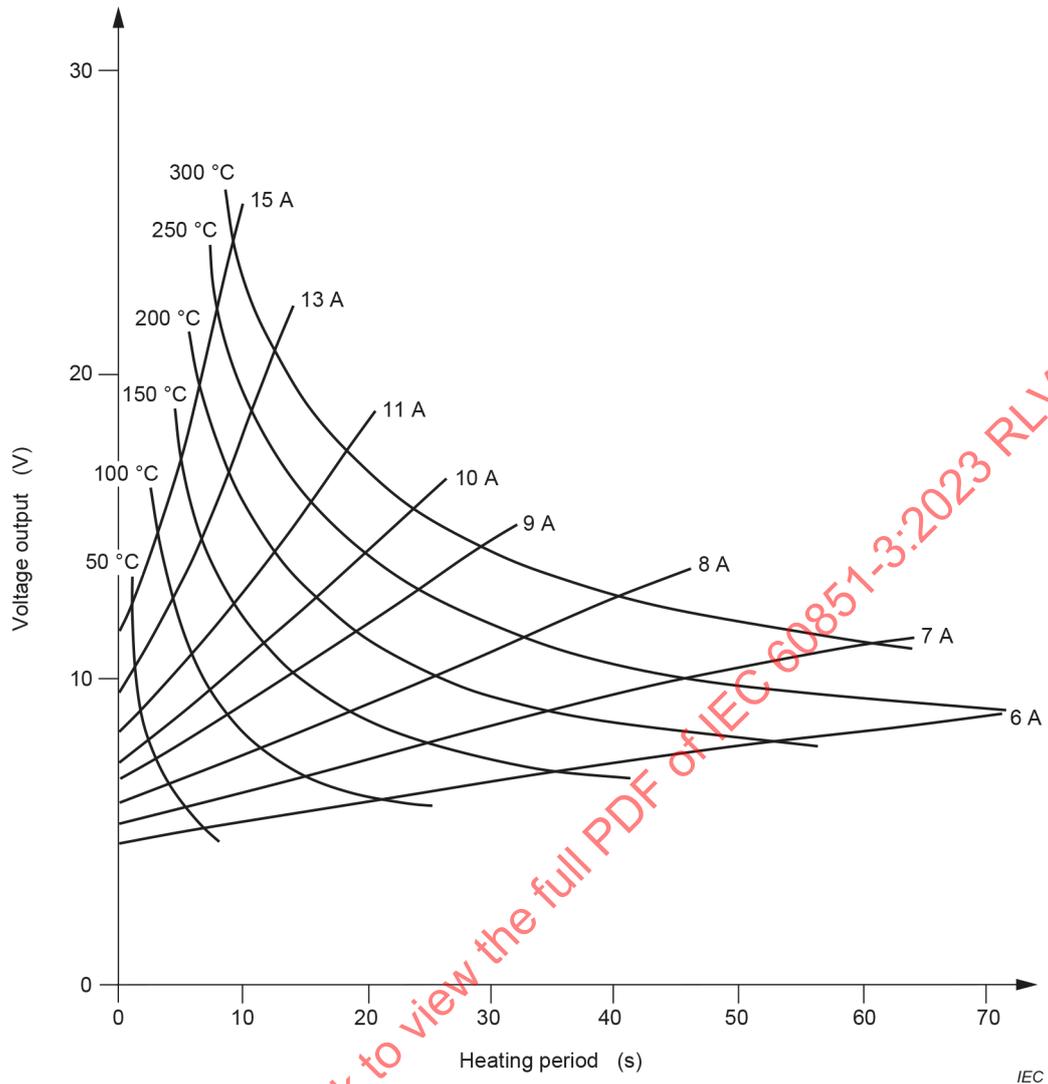


Figure A.4 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,500 mm with isothermic graphs

Annex B (informative)

Friction test methods

B.1 General

This annex provides recommendations to the purchaser and supplier of winding wires with respect to friction test methods to be used for winding wires. The use of additional methods can be agreed upon between purchaser and supplier.

B.2 Test A: Static coefficient of friction test method

B.2.1 Test method (applicable to enamelled round wires with a nominal conductor diameter from 0,050 mm up to and including 1,600 mm)

The static coefficient of friction (μ_s) is determined by measuring the inclining angle (α) of a plane at the moment when a block begins to slip on the track made from the wire specimen. The wire test specimen shall be removed from the delivery spools by de-reeling over the end flange. The top layers of the spool shall be removed before testing when the wire surface is contaminated by dirt or dust. One part of the wire specimen is straightened and then fixed on the inclining plane by means of the two posts and the two clamps constituting the sliding track. The other part of the wire specimen is mounted in a similar way on the sliding block.

The sliding block with the wire specimen is then placed on the track of the plane to be inclined in such a way that the wire on the block and the wire on the plane are crossed at right angles at the point of contact.

The plane is then slowly inclined (approximately 1°/s) until the block starts to slide down the track. At that moment, the angle of inclination (α) is read from the scale.

The static coefficient of friction is calculated as follows:

$$\mu_s = \tan \alpha$$

B.2.2 Test apparatus

The general arrangement of the test apparatus is shown in Figure B.1.

The apparatus consists of a plane (1), which can be inclined to an angle (α) by turning the plane around the axis (8). The support (9) carries a scale (7) marked with the inclination angle (α) or the coefficient of friction ($\tan \alpha$).

The plane has means for fixing the wire specimen (3), for example the two posts (5) and the two clamps (6). The parallel parts of the wire shall be 110 mm apart. The parallel parts form a sliding track running from the scale end to the axis on the plane.

On the block (2) clamps and posts are provided to fix the second wire specimen (4). The parallel parts of the specimen shall be 60 mm apart. It is critical that the size of the block allows the clamps and posts to stay clear of the plane (1) to avoid additional friction forces. The block shall have:

- a mass of about 50 g for a wire with a nominal conductor diameter up to and including 0,150 mm;
- a mass of about 500 g for a wire with a nominal conductor diameter over 0,150 mm.

The mass is not critical as it is nonetheless changed by the mass of the second wire specimen.

The angle of inclination shall be changed slowly by means of a motor-operated block and tackle.

B.3 Test B: First dynamic coefficient of friction test method

B.3.1 Principle

The coefficient of friction, μ_d , is determined by measuring the frictional force, C , applied on the wire when moving under the pressure of a known mass, E :

$$\mu_d = \frac{C}{9,81 \times E}$$

B.3.2 Method of test

The general arrangement of the test apparatus is shown in Figure B.2.

The enamelled wire runs via a guide wheel and a brake (4) over a metal plate (2). Via another guide wheel, the wire is lead below this plate (2) and runs back, parallel with the first passage, over this plate again (see Figure B.2). By means of a capstan (1), the wire is drawn with a speed of 0,25 m/s. A mass (5) is placed on the running wire over the plate (2), which is coupled to a force indication meter (3).

The force indication meter can be coupled to a linear recorder (measuring range 1 mV to 250 mV). This linear recorder shows the spread of the smoothness and the level of the wire smoothness over a long distance.

B.4 Test C: Second dynamic coefficient of friction test method (applicable to enamelled round wires with a nominal conductor diameter from 0,050 mm up to and including 1,600 mm)

B.4.1 Test equipment

The design of typical test equipment is illustrated in Figure B.3. Figure B.4 contains detailed drawings of synthetic sapphires and Figure B.5 is a photograph of the load block. The tester is supplied with a wire guiding system and a take-up which pulls the wire over the test bed at 15 m/min as shown in Figure B.6. The test block is aligned parallel with the test bed and the test weights are perpendicular to the wire specimen.

As the wire is pulled under the test block (synthetic sapphires), the friction between the wire surface and the sapphire surface develops a longitudinal force, which is transferred to the measuring system by a shaft supported by two sets of linear ball bearings in contact with the measuring system. The force indicated by the measuring system is divided by the load on the test surface to obtain the dynamic coefficient of friction.

The measuring system in Figure B.3 shows the dynamic coefficient of friction tester with a load cell in place to measure the force. A linear variable differential transformer (LVDT) may also be used to measure the force instead of a load cell. The electrical output from the force measurement device is fed into a computer or into a microprocessor that collects data measurements, usually 1 000 points. Statistics are performed on this data set so that proper interpretation of the results can be made.

NOTE 1 Values for the dynamic coefficient of friction are characteristic of the type of lubrication and the magnet wire specimen surface. The dynamic coefficient of friction values are generally not dependent on wire size.

NOTE 2 Wire lubricated with a mineral oil typically will have a mean dynamic coefficient of friction in the range of 0,9 to 0,16. Wire lubricated with a paraffin wax will typically have a mean dynamic coefficient of friction ranging from 0,03 to 0,06 and will be more consistent in value as evidenced by a lower standard deviation. The mean value, maximum value and standard deviation value can be used to evaluate the application of the lubricant to the wire and smoothness of the wire surface.

The test procedure is designed to provide a measure of the lubrication and the film surface smoothness as a combined value. It is assumed that the wire will be de-reeled from its packaging with minimal contact with surfaces other than those associated with the tester and packaging.

If it is suspected that the presence of dust or dirt may have an effect on the coefficient of friction, one or two outer layers of wire should be removed from the package and the sample retested.

Test surfaces in contact with the wire shall be clean and dry at the start of each separate test. The solvent used to clean the test load surface should remove the various types of lubricants used and should dry without leaving a film residue.

B.4.2 Test specimen

The surface of the wire should be examined for damage, tangles, or excessive dust or dirt. If any of these conditions are present, the top wire specimen layer of the spool should be surfaced off before testing. The wire test specimen should be removed from the shipping package by de-reeling over the end flange or pulling the wire from a pail or drum.

B.4.3 Specimen preparation

The wire specimen is pulled over a test bed surface under a test load (L). A frictional force (F_d) is developed between the wire surfaces and transferred to an appropriate measuring device. The reading (F_d) in grams-force is divided by the test load (L) in grams-force to obtain the dynamic coefficient of friction μ_d .

$$\mu_d = \frac{F_d}{L}$$

A motor should pull the wire specimen at 15 m/min \pm 1,5 m/min across a smooth surface using a motor driven take-up.

Various load weights should be available that will provide 100 grams-force to 1 000 grams-force.

The test block should be comprised of two mounted synthetic sapphires that have a surface roughness of not more than 2,4 μm . The sapphires are described in Figure B.4 and are mounted in accordance with Figure B.5.

There should be a means to guide the wire and a means to maintain a slight tension if needed.

An electrical force measuring device or transducer measures the force due to friction. A force transducer with a range of 0 grams-force to 500 grams-force, a data storage device, and a microprocessor or computer to statistically analyse the data sets should be installed.

A mechanical dampening system consisting of a paddle and a container filled with oil may be used. The electrical signals from the load cell or LVDT can also be dampened electronically.

A cleaning solvent appropriate for dissolving the lubricant being tested should be used for cleaning the sapphires and metal surfaces between tests.

B.4.4 Procedure

The coefficient of friction tester should be level so that the only force being measured by the pressure transducer is that which is perpendicular to the load being applied and so that gravity is not a factor.

Calibrate the pressure transducer by setting the zero without any load and setting the span by hanging a weight of 100 g or a weight of 200 g. Remove the weight and the display should again read zero.

Enter the parameters of the test into the microprocessor or personal computer.

De-reel the wire from its packaging by pulling the wire over the flange, through the tensioning device, through the guides, and onto the take-up spindle.

Adjust the guide pulleys so that the wire is parallel with the test bed. Clean the test bed, any guide pulleys, and the sapphire surfaces with a suitable solvent.

Place the appropriate weight from Table B.1 onto the load block:

Table B.1 – Load block weights for dynamic coefficient of friction testing

Conductor diameter mm	Weight g
0,050 to 0,071	100
0,071 to 0,125	200
0,125 to 0,450	600
0,450 to 1,600	1 000

Adjust the test bed to make the test load parallel with the test surface. Turn the wire take up on and start collecting data after the setup is stable and aligned and continue until the desired number of data points has been stored.

Analyse the data for minimum reading, maximum reading, mean value, and standard deviation.

The dynamic coefficient of friction μ_d should be calculated as follows:

$$\mu_d = \frac{F_d}{L}$$

where

F_d is the force reading in grams force;

L is the test load in grams force.

B.5 Test D: Force of friction by the twisted pair method

B.5.1 Enamelled round wires with a nominal conductor diameter from 0,1 mm up to and including 1,500 mm

From an enamelled wire specimen, a twist is made similar to the one used for test 13 (breakdown voltage) in IEC 60851-5:2008, 4.3 and IEC 60851-1:2008/AMD1:2011, 4.3. The end of the first twist strand is attached to a fixed jaw and a force is applied to the opposite end of the second strand that has been kept free to slide by traction and without rotating, using for example a dynamometer. The force to separate the two strands is the sliding force.

B.5.2 Test method

A specimen of approximately 400 mm in length shall be twisted back on itself for a distance of 125 mm on an apparatus as shown in Figure B.7. The force (weight) applied to the wire pair while the wire pair is being twisted and the number of twists are given in Table B.2.

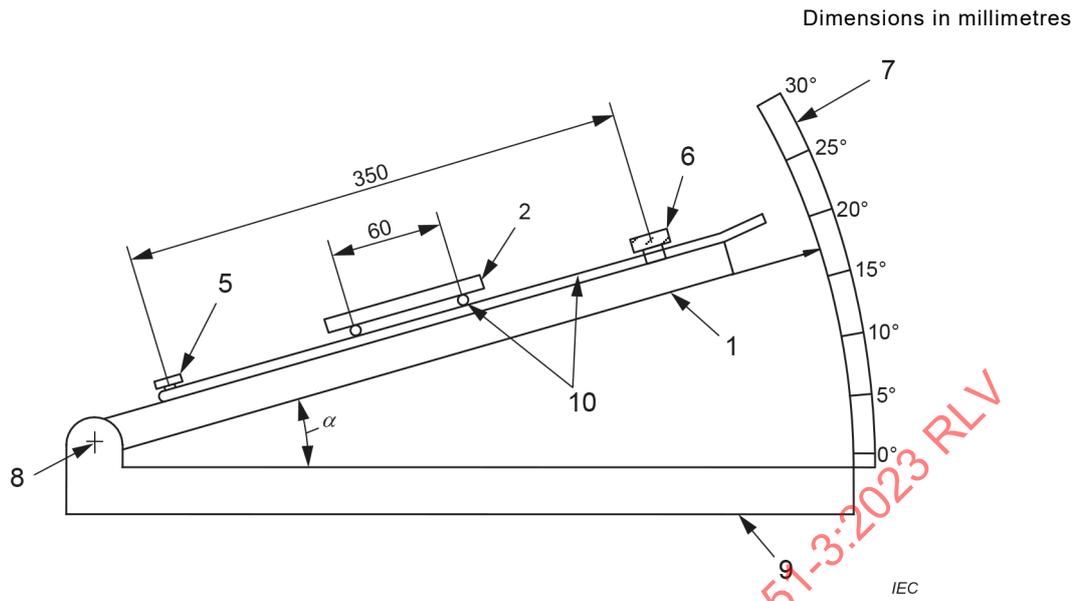
At the twisted end, the loop is cut in two separate places to obtain a maximum separation between these cut ends.

Any bending of the wires, at the cut end or at the other untwisted end, to ensure adequate separation between the wires, shall avoid sharp bends or damage to the insulation.

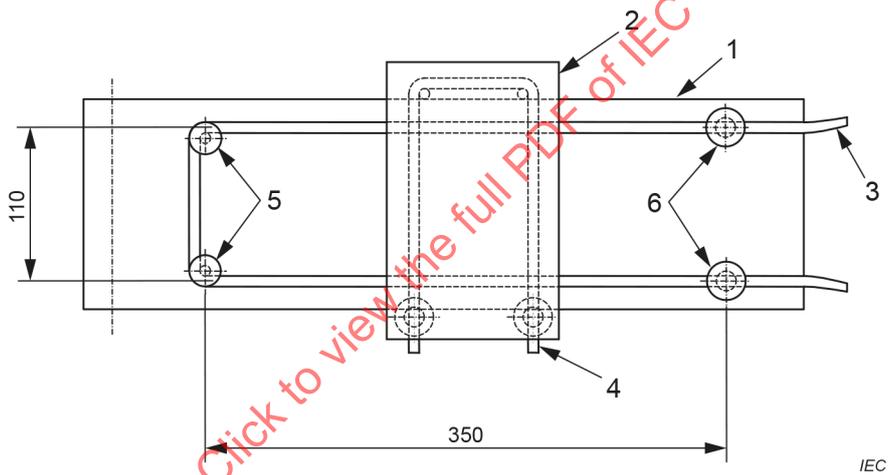
One end of one wire shall be attached firmly to a jaw, while at the opposite end of the other wire a force (weight) is applied to let that wire slide without any rotation. Three specimens shall be tested.

Table B.2 – Twisted pair method

Nominal conductor diameter mm		Force applied to wire pairs N	Number of twists per 125 mm
Over	Up to and including		
0,10	0,25	0,85	17
0,25	0,315	1,40	15
0,315	0,40	2,40	13
0,40	0,50	3,40	12
0,50	0,71	6,00	11
0,71	0,80	8,50	10
0,80	0,90	10,00	9
0,90	1,00	12,50	8
1,00	1,12	15,00	7
1,12	1,25	20,00	6
1,25	1,50	27,00	5



a) Side view

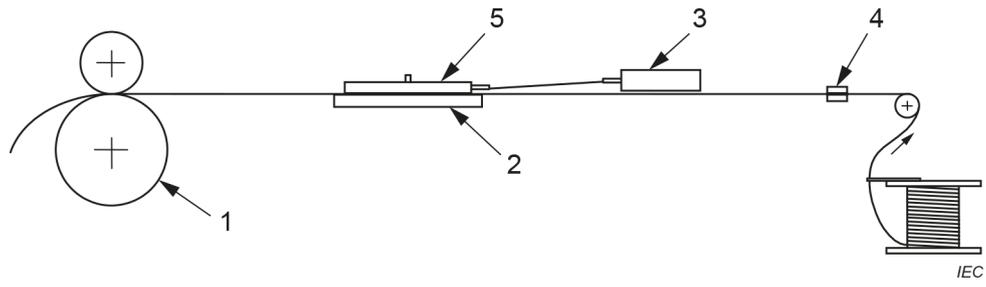


b) Top view

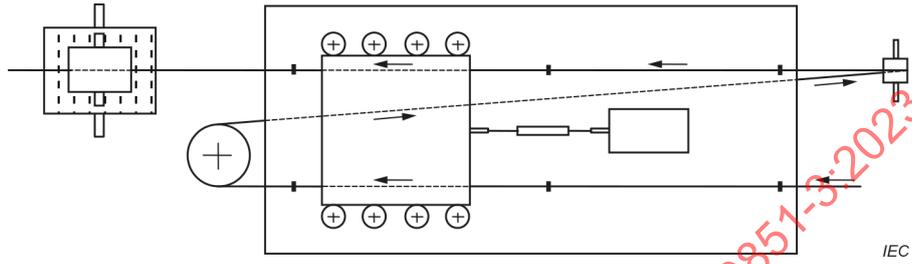
Key

- 1 plane
- 2 block
- 3 wire specimen
- 4 wire
- 5 posts
- 6 clamps
- 7 scale
- 8 axis
- 9 support
- 10 winding wire specimen

Figure B.1 – Static coefficient of friction test apparatus



a) Side view



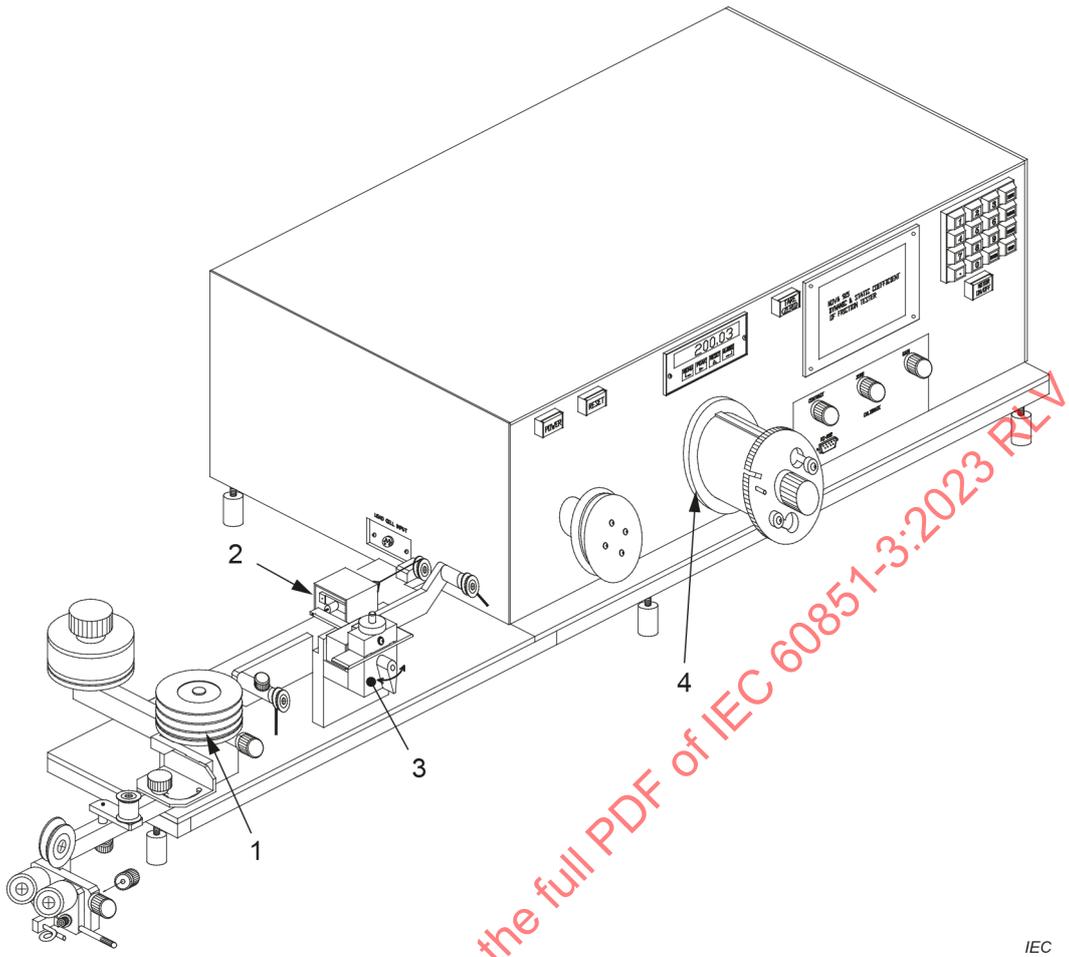
b) Top view

Components

- 1 capstan
- 2 plate
- 3 force indication meter
- 4 brake
- 5 mass

Figure B.2 – Dynamic coefficient of friction test apparatus

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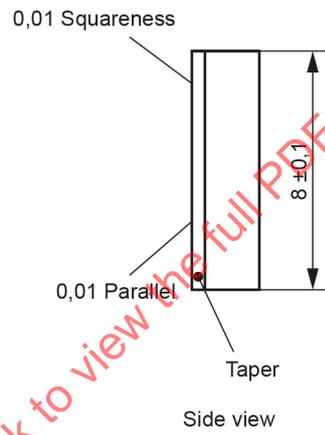
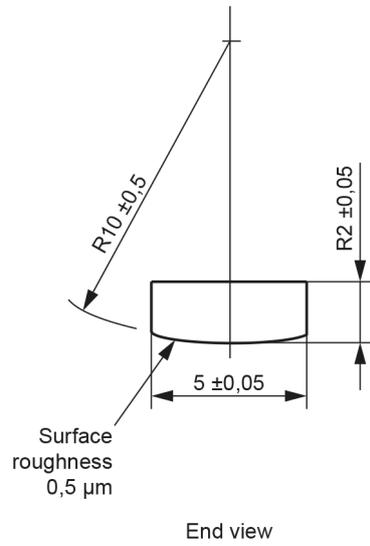
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Key

- 1 wire tensioner
- 2 load cell assembly
- 3 sapphire test head and support block assembly
- 4 wire take-up mandrel

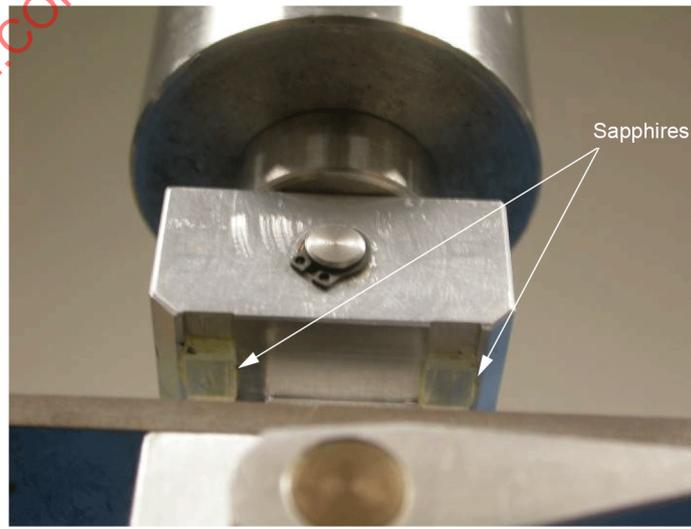
Figure B.3 – Diagram of a typical dynamic coefficient of friction tester

Dimensions in millimetres



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Figure B.4 – Material – sapphire (synthetic)



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Figure B.5 – Synthetic sapphires mounted on load block

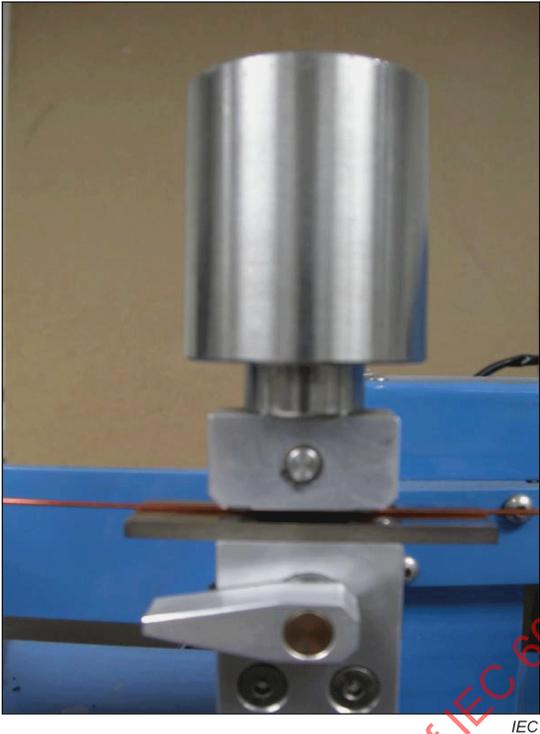


Figure B.6 – Load applied perpendicular to wire path

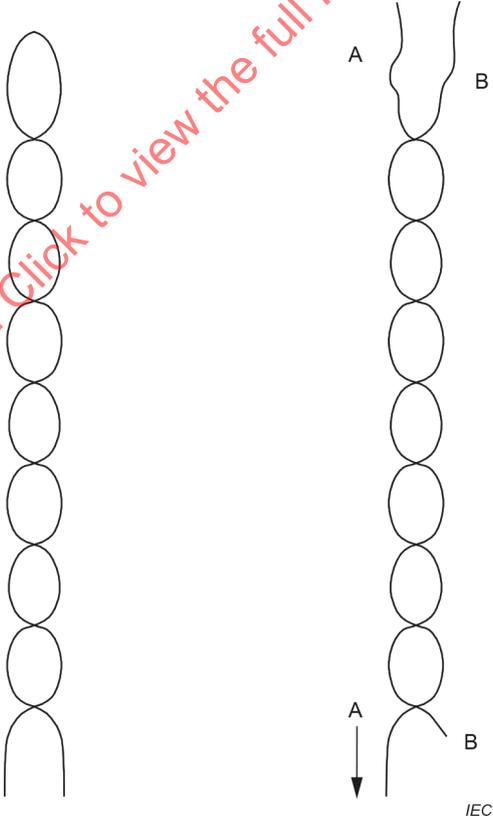


Figure B.7 – Twisted specimen

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

FILS DE BOBINAGE – MÉTHODES D'ESSAI –

Partie 3: Propriétés mécaniques

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L'IEC 60851-3 a été établie par le comité d'études 55 de l'IEC: Fils de bobinage. Il s'agit d'une Norme internationale.

Cette quatrième édition annule et remplace la troisième édition parue en 2009, l'Amendement 1 paru en 2013 et l'Amendement 2 paru en 2019. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

- a) clarification de la mesure de distance visant à déterminer la perte d'adhérence en 6.6.3, en 6.6.4 pour les fils recouverts d'une enveloppe fibreuse et en 6.6.5 pour les fils rubanés.

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
55/1938/CDV	55/1974/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous https://www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous <https://www.iec.ch/publications>.

Une liste de toutes les parties de la série IEC 60851, publiées sous le titre général *Fils de bobinage – Méthodes d'essai*, peut être consultée sur le site web de l'IEC.

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INTRODUCTION

La présente partie de l'IEC 60851 appartient à une série de normes qui traite des fils isolés utilisés dans les enroulements des appareils électriques. Cette série comporte trois groupes qui définissent respectivement:

- a) les méthodes d'essai des fils de bobinage (IEC 60851);
- b) les spécifications concernant les types particuliers de fils de bobinage (IEC 60317);
- c) le conditionnement des fils de bobinage (IEC 60264).

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FILS DE BOBINAGE – MÉTHODES D'ESSAI –

Partie 3: Propriétés mécaniques

1 Domaine d'application

La présente partie de l'IEC 60851 spécifie les méthodes d'essai suivantes pour les fils de bobinage:

- Essai 6: Allongement;
- Essai 7: Effet de ressort;
- Essai 8: Souplesse et adhérence;
- Essai 11: Résistance à l'abrasion;
- Essai 18: Thermodhérence.

Pour les définitions, les généralités concernant les méthodes d'essai et les séries complètes des méthodes d'essai des fils de bobinage, c'est l'IEC 60851-1 qui s'applique. Le présent document donne aussi les méthodes d'essai de frottement recommandées dans l'Annexe B.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60851-2:2009, *Fils de bobinage – Méthodes d'essai – Partie 2: Détermination des dimensions*

IEC 60851-2:2009/AMD1:2015

IEC 60851-2:2009/AMD2:2019

ISO 178:2019, *Plastiques – Détermination des propriétés en flexion*

3 Termes et définitions

Aucun terme n'est défini dans le présent document.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse <https://www.electropedia.org/>
- ISO Online browsing platform: disponible à l'adresse <https://www.iso.org/obp>

4 Essai 6: Allongement

4.1 Allongement à la rupture

L'allongement est l'augmentation de longueur exprimée en pourcentage de la longueur initiale.

Une longueur de fil droit doit être allongée jusqu'à la rupture du conducteur à la vitesse de (5 ± 1) mm/s au moyen d'une machine d'essai d'allongement ou d'une machine d'essai de traction qui réalise la mesure sur une longueur libre comprise entre 200 mm et 250 mm. L'augmentation linéaire à la rupture doit être calculée en pourcentage de la longueur libre mesurée.

Trois éprouvettes doivent être soumises à essai. Les trois valeurs individuelles doivent être consignées. La valeur moyenne représente l'allongement à la rupture.

4.2 Résistance à la traction

La résistance à la traction est le rapport entre la force appliquée au moment de la rupture et la section initiale.

Une longueur de fil droit doit être allongée jusqu'à la rupture du conducteur à la vitesse de (5 ± 1) mm/s au moyen d'une machine d'essai de traction qui réalise la mesure sur une longueur libre comprise entre 200 mm et 250 mm, et qui enregistre la force au moment de la rupture.

Trois éprouvettes doivent être soumises à essai. La section initiale et les trois valeurs individuelles de force à la rupture doivent être consignées. La valeur moyenne des rapports entre la force au moment de la rupture et la section initiale représente la résistance à la traction.

5 Essai 7: Effet de ressort

5.1 Généralités

L'effet de ressort est le retour en arrière mesuré en degrés après que le fil a été soit bobiné en forme d'hélice, soit courbé selon un angle.

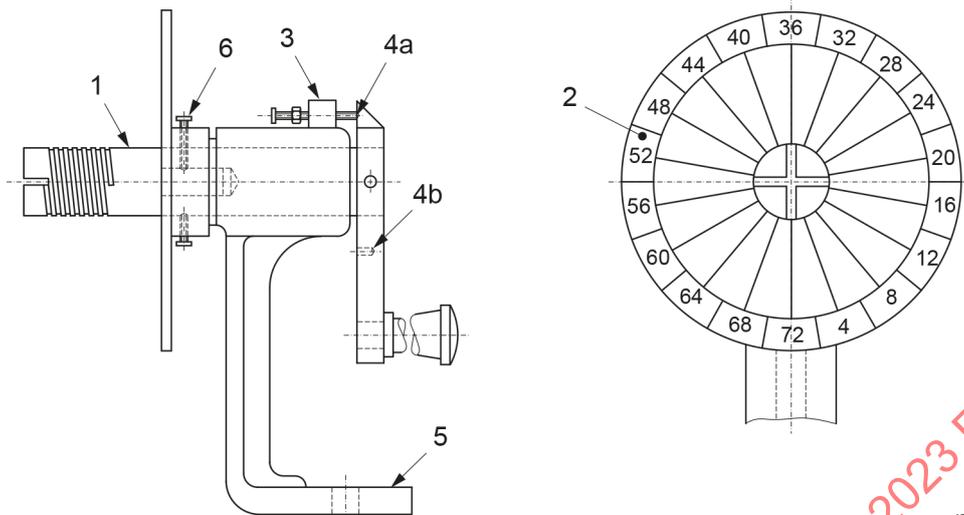
5.2 Fil de section circulaire de diamètre nominal de conducteur compris entre 0,080 mm et 1,600 mm (inclus)

5.2.1 Principe

Une longueur de fil droit est enroulée sur un mandrin de façon à former cinq spires. La norme pertinente spécifie le diamètre du mandrin et la traction à appliquer. La mesure de l'effet de ressort est indiquée par l'angle de retour en arrière de l'extrémité des cinq spires.

5.2.2 Appareil

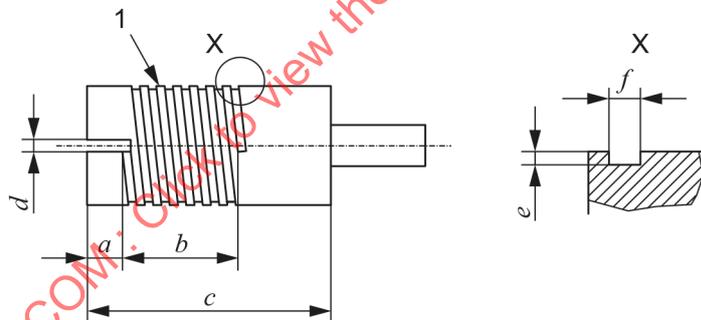
La Figure 1 décrit un exemple d'appareil d'essai. Les détails du mandrin sont donnés à la Figure 2 et dans le Tableau 1. La Figure 2 mentionne une gorge en hélice qui peut être utilisée pour faciliter le bobinage. Toutefois, cette gorge n'est pas obligatoire. Le cadran porte 72 divisions équidistantes, de sorte qu'avec cinq spires, la valeur lue correspond au retour en arrière pour une seule spire, exprimée en degrés.



Légende

- 1 mandrin
- 2 cadran
- 3 dispositif de verrouillage
- 4 dispositif de verrouillage
- 5 base
- 6 vis de fixation du mandrin

Figure 1 – Appareil pour la mesure de l'effet de ressort



Légende

- 1 7 filets
- 2 agrandissement de la partie X

Figure 2 – Construction et détails du mandrin (voir le Tableau 1)

Tableau 1 – Mandrins pour l'effet de ressort

Diamètre du mandrin ^a mm	Dimensions ^b mm					
	a	b	c	d	e	f
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

^a Au fond de la gorge, le cas échéant.

^b Voir Figure 2.

5.2.3 Procédure

Le mandrin spécifié doit être monté et verrouillé à axe horizontal de façon que la rainure ou le trou d'attache du fil corresponde au repère zéro du cadran. Le mandrin doit être talqué pour empêcher le fil de coller à la surface du mandrin.

Une tension doit être appliquée à une longueur de fil droit d'environ 1 m en attachant la charge spécifiée à l'une des extrémités du fil. La manivelle pour faire tourner le mandrin doit être déverrouillée. L'autre extrémité du fil doit être engagée dans la rainure ou le trou de façon que le fil traverse suffisamment le mandrin pour être fixé et maintenu sur le mandrin. La charge doit être abaissée doucement pour appliquer la traction au fil qui est suspendu verticalement au-dessous du mandrin, le repère zéro du cadran et la rainure ou le trou pointant vers le bas.

L'extrémité libre du fil ayant été attachée solidement, le mandrin doit être entraîné dans le sens inverse des aiguilles d'une montre (le cadran étant vu de face) de façon à former cinq spires complètes, et jusqu'à ce que le zéro du cadran soit tourné verticalement vers le haut. La manivelle doit alors être verrouillée dans cette position. La charge doit être retirée pendant que le fil est maintenu en position; le fil doit ensuite être coupé à environ 25 mm après l'extrémité de la cinquième spire. Cette extrémité du fil doit être courbée dans une position verticale alignée sur le zéro du cadran, afin de jouer le rôle d'aiguille.

Un crayon ou un outil similaire doit être placé à la gauche de cette extrémité de fil pour empêcher tout retour en arrière soudain. Le bobinage doit ensuite pouvoir se dérouler librement et lentement, sans à-coups.

NOTE Si le fil se détend brusquement, des résultats erronés peuvent être obtenus.

Le mandrin et le cadran doivent alors être libérés et entraînés dans le sens des aiguilles d'une montre pour amener de nouveau l'aiguille en arrière en position verticale. L'angle de retour en arrière est égal à la lecture sur le cadran correspondant à l'aiguille. Dans le cas d'un fil très nerveux, l'aiguille peut faire plus d'un tour. La valeur 72 doit alors être ajoutée à la lecture du cadran pour chaque révolution complète lors du retour en arrière.

Trois éprouvettes doivent être soumises à essai. Les trois valeurs individuelles doivent être consignées. La valeur moyenne représente l'effet de ressort.

5.3 Fil de section circulaire de diamètre nominal de conducteur supérieur à 1,600 mm et fil de section rectangulaire

5.3.1 Principe

Une longueur de fil droit doit être courbée selon un angle de 30°. Après avoir supprimé la contrainte, la mesure de l'effet de ressort est indiquée par l'angle de retour en arrière.

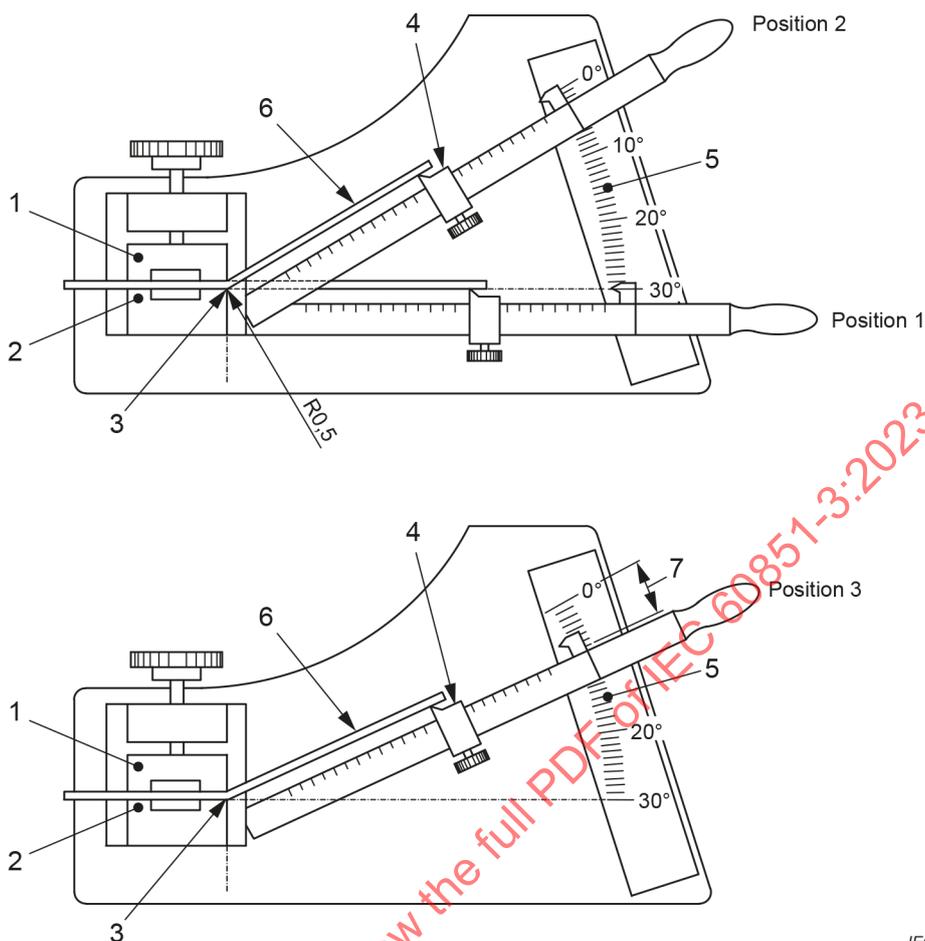
5.3.2 Appareil

La Figure 3 représente un exemple d'appareil d'essai. Il consiste fondamentalement en deux mâchoires, dont l'une est fixe (2) et l'autre mobile (1), et un secteur gradué en degrés (5) dont l'échelle de 0° à 10° est graduée par paliers de 0,5°. Le secteur gradué est un arc placé dans un plan à 90° des faces de serrage. Son centre est situé sur l'arête extérieure de la mâchoire fixe (3). Le levier avec son point d'appui placé au centre de l'arc peut se déplacer sur le secteur gradué dans le plan vertical.

Le levier doit être équipé d'une aiguille ou d'un repère pour une lecture convenable de l'angle de retour en arrière. Le levier d'une longueur approximative de 305 mm est équipé d'une échelle en millimètres dont l'origine est le centre de l'arc et d'un curseur (4) mobile à arête vive.

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Dimensions en millimètres



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Légende

- 1 mâchoire mobile
- 2 mâchoire fixe
- 3 centre du secteur gradué
- 4 curseur
- 5 secteur gradué
- 6 éprouvette
- 7 retour en arrière

Figure 3 – Appareil d'essai pour la mesure de l'effet de ressort**5.3.3 Éprouvette**

Un échantillon de fil d'au moins 1 200 mm de longueur doit être prélevé de la bobine avec une courbure aussi réduite que possible. Le fil doit être redressé à la main et coupé en trois portions de 400 mm chacune. Il ne doit pas être fait usage d'outils pour l'allongement. Une courbure inutile doit être évitée afin de réduire le plus possible l'érouissage.

5.3.4 Procédure

La position du curseur sur le levier est déterminée en multipliant le diamètre du conducteur ou son épaisseur par 40. L'éprouvette doit être serrée entre les mâchoires avec une force juste suffisante pour éviter le glissement. L'éprouvette doit être serrée dans une position qui permet la courbure du fil dans la direction qu'il avait sur la bobine. L'extrémité libre de l'éprouvette doit dépasser l'arête vive du curseur de (12 ± 2) mm.

À l'aide du levier, et en partant de la position initiale (le repère 30° en position 1), le fil doit être courbé de 30° (le repère 0° en position 2). Le temps de courbure total doit être compris entre 2 s et 5 s. L'éprouvette doit être maintenue dans cette position pendant un maximum de 2 s, puis déplacée dans l'autre sens à la même vitesse angulaire que lors de la courbure, jusqu'à ce que l'arête vive du curseur ne soit plus au contact de l'éprouvette. Le levier doit être à nouveau déplacé jusqu'à ce que l'arête vive du curseur vienne au contact de l'éprouvette, sans la courber. Dans cette position, l'angle de retour en arrière est égal à celui lu sur l'échelle du secteur gradué avec l'aiguille du levier (position 3).

Trois éprouvettes doivent être soumises à essai. Les trois valeurs individuelles doivent être consignées. La valeur moyenne représente l'effet de ressort.

6 Essai 8: Souplesse et adhérence

6.1 Généralités

La souplesse et l'adhérence reflètent la capacité du fil à supporter des étirements, bobinages, courbures ou torsions sans montrer de craquelures ou de perte d'adhérence de l'isolant.

6.2 Essai d'enroulement sur mandrin

6.2.1 Fil de section circulaire

6.2.1.1 Généralités

Une longueur de fil droit doit être enroulée de façon à former 10 spires jointives sur un mandrin bien poli, dont le diamètre est donné dans la norme pertinente. La vitesse d'enroulement du mandrin doit être de 1 tr/s à 3 tr/s, la traction exercée sur le fil étant telle que celui-ci soit maintenu en contact avec le mandrin. L'enroulement doit être effectué sans allongement ni torsion. Des appareils appropriés doivent être utilisés.

6.2.1.2 Fil de section circulaire émaillé de diamètre nominal de conducteur jusqu'à et y compris 1,600 mm

Si la norme pertinente demande un préallongement avant de réaliser l'enroulement, le fil doit être allongé selon le pourcentage spécifié à l'Article 4. Après enroulement, l'éprouvette doit être examinée en vue de déceler les craquelures éventuelles, en respectant le grossissement donné dans le Tableau 2.

Tableau 2 – Grossissement pour détecter les craquelures

Diamètre nominal de conducteur mm		Grossissement ^a
À partir de	Jusqu'à et y compris	
–	0,040	10 à 15 fois
0,040	0,500	6 à 10 fois
0,500	1,600	1 à 6 fois

^a Une fois correspond à la vision normale.

Trois éprouvettes doivent être soumises à essai. Les craquelures détectées doivent être consignées.

6.2.1.3 Fil de section circulaire recouvert d'une enveloppe fibreuse

Après enroulement, l'éprouvette doit être examinée en vue de déceler l'apparition du conducteur nu, à l'œil nu ou avec un grossissement maximal de six fois.

Trois éprouvettes doivent être soumises à essai. L'apparition du conducteur nu doit être consignée.

6.2.1.4 Fil de section circulaire émaillé recouvert d'une enveloppe fibreuse

Après enroulement, l'éprouvette doit être examinée en vue de déceler l'apparition du conducteur nu ou de l'émail sous-jacent, à l'œil nu ou avec un grossissement maximal de six fois.

Trois éprouvettes doivent être soumises à essai. L'apparition du conducteur nu ou de l'émail sous-jacent doit être consignée.

6.2.1.5 Fil de section circulaire rubané

Après enroulement, l'éprouvette doit être examinée en vue de déceler l'apparition du conducteur nu ou le pelage, à l'œil nu ou avec un grossissement maximal de six fois.

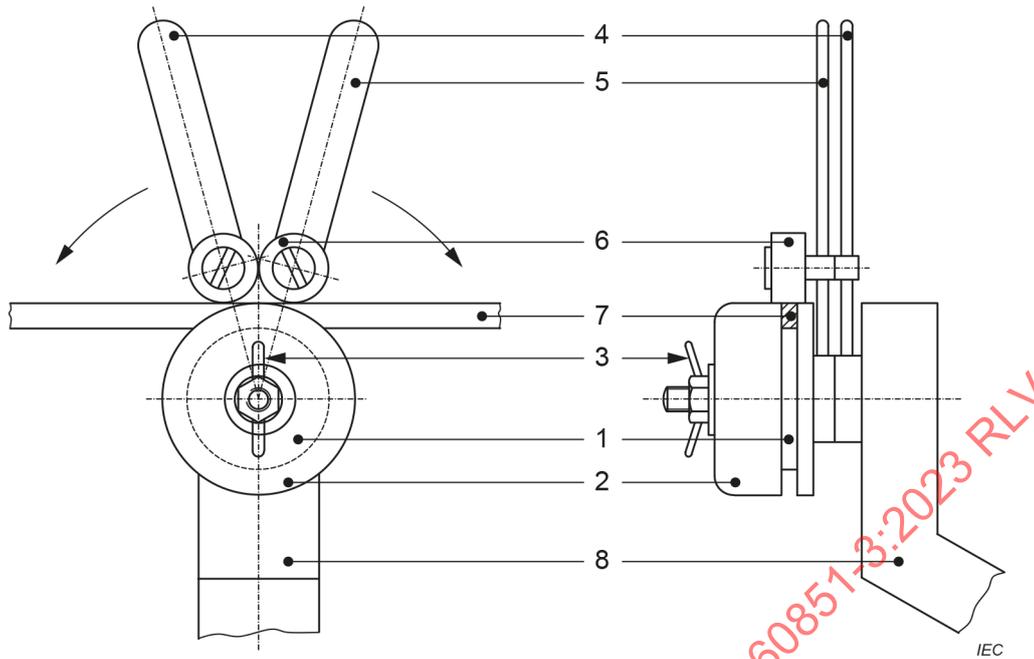
Trois éprouvettes doivent être soumises à essai. L'apparition du conducteur nu ou le pelage doivent être consignés.

6.2.2 Fil de section rectangulaire

Une longueur de fil droit de 400 mm environ doit être courbée à 180° sur un mandrin poli dont le diamètre est donné dans la norme pertinente, dans deux directions et en formant un S allongé. La partie droite entre les courbures en U doit être d'au moins 150 mm. Il convient de veiller à ce que l'éprouvette ne se voile pas ou qu'elle ne prenne pas une forme irrégulière. Un appareillage approprié est représenté à la Figure 4.

Après courbure, l'isolant doit être examiné avec un grossissement de six à dix fois en vue de déceler ce qui suit: les craquelures éventuelles dans le cas d'un fil émaillé, l'apparition du conducteur nu ou de l'émail sous-jacent dans le cas d'un fil à enveloppe fibreuse, l'apparition du conducteur nu et le pelage dans le cas d'un fil rubané.

Six éprouvettes doivent être courbées, trois sur plat (sur l'épaisseur), trois sur chant (sur la largeur). Si le fil présente des craquelures ou un pelage, l'apparition du conducteur nu ou de l'émail sous-jacent, selon le critère qui s'applique, cela doit être consigné.



Légende

- 1 mandrin
- 2 collier de serrage du mandrin
- 3 écrou
- 4 levier
- 5 levier
- 6 roulement à billes
- 7 éprouvette
- 8 support

Figure 4 – Appareil d’essai d’enroulement sur mandrin

6.2.3 Fil toronné avec enveloppe

Une longueur de fil droit doit être enroulée de façon à former 10 spires continues sur un mandrin poli ayant le diamètre indiqué dans la norme pertinente, avec la traction donnée en 3.2.5.3 de l’IEC 60851-2:2009. En l’enroulant autour du mandrin, il convient de s’assurer que l’éprouvette n’est pas tordue à chaque tour.

Après l’enroulement, l’éprouvette doit être examinée à l’œil nu en vue de déceler des ouvertures dans l’enveloppe.

Une éprouvette doit être soumise à essai. Si le fil ne présente pas le degré exigé de placage de l’enveloppe, cela doit être consigné.

6.3 Essai d’étirement (applicable au fil de section circulaire émaillé de diamètre nominal de conducteur supérieur à 1,600 mm)

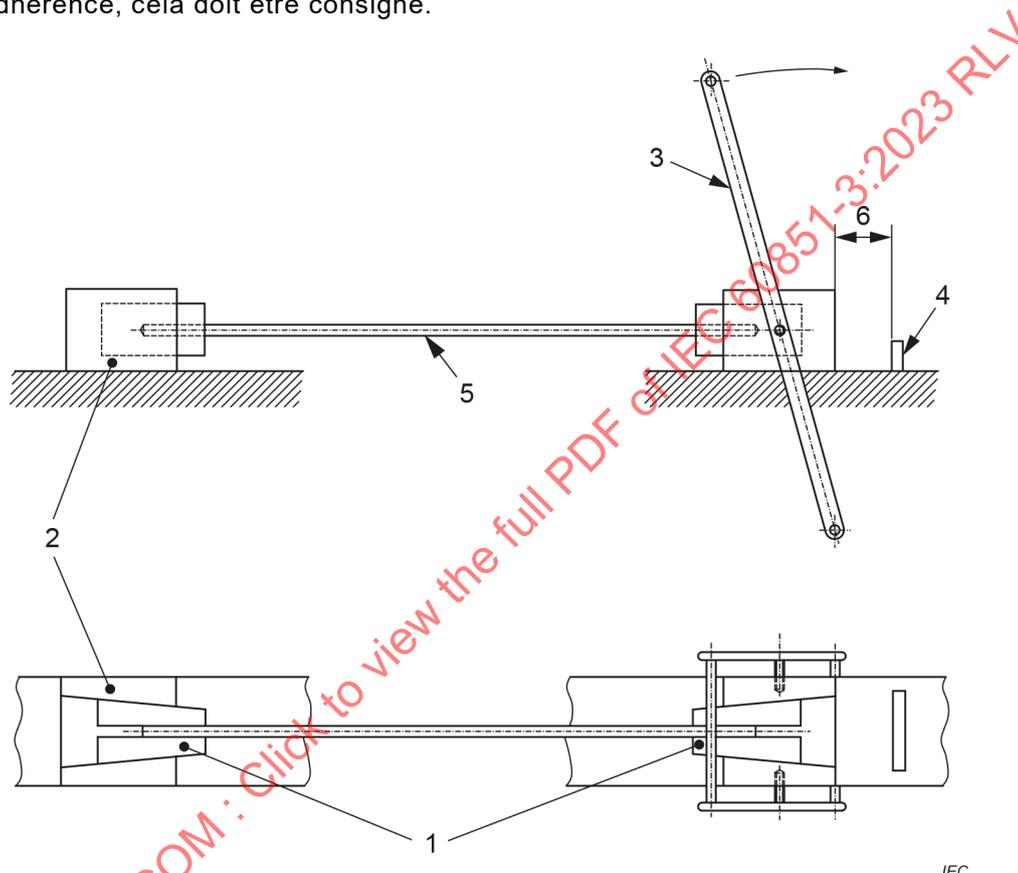
Une longueur de fil droit doit être allongée conformément à l’Article 4, au pourcentage spécifié dans la norme pertinente. Après allongement, l’éprouvette doit être examinée en vue de déceler les craquelures éventuelles ou les pertes d’adhérence, à l’œil nu ou avec un grossissement maximal de six fois.

Trois éprouvettes doivent être soumises à essai. Si des craquelures et/ou de la perte d’adhérence sont détectées, cela doit être consigné.

6.4 Essai de traction brusque (applicable au fil de section circulaire émaillé de diamètre nominal de conducteur jusqu'à et y compris 1,000 mm)

Une longueur de fil droit doit être étirée brusquement à la rupture à l'aide de l'appareil d'essai représenté à la Figure 5. Une longueur de mesure libre comprise entre 200 mm et 250 mm doit être fournie. Après étirement, l'éprouvette doit être examinée en vue de déceler les craquelures éventuelles ou les pertes d'adhérence, en respectant le grossissement donné dans le Tableau 2. Il ne doit pas être tenu compte des parties situées à moins de 2 mm du point de rupture.

Trois éprouvettes doivent être soumises à essai. Si le fil présente des craquelures et/ou de la perte d'adhérence, cela doit être consigné.



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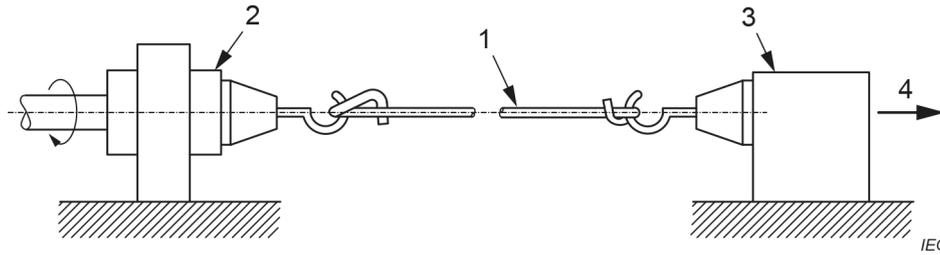
Légende

- 1 coins de serrage (mordaches)
- 2 partie fixe des mâchoires
- 3 bras de levier
- 4 arrêtoir réglable
- 5 éprouvette
- 6 allongement spécifié

Figure 5 – Appareil pour l'essai de traction brusque

6.5 Essai de pelage (applicable au fil de section circulaire émaillé de diamètre nominal de conducteur supérieur à 1,000 mm)

Une longueur de fil droit doit être placée dans l'appareil d'essai représenté à la Figure 6, consistant en deux dispositifs de fixation distants de 500 mm sur le même axe. L'un des dispositifs peut tourner. L'autre ne peut pas tourner mais peut se déplacer suivant l'axe; ce deuxième dispositif est chargé selon le Tableau 3 pour appliquer une traction au fil lorsque ce dernier tourne.



Légende

- 1 éprouvette
- 2 mordache tournante
- 3 mordache fixe
- 4 charge

Figure 6 – Appareil pour l’essai de pelage

Tableau 3 – Charge pour l’essai de pelage

Diamètre nominal de conducteur mm		Charge N
À partir de	Jusqu’à et y compris	
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

Au moyen d’un racloir comme celui représenté à la Figure 7, le revêtement doit être éliminé sur deux génératrices opposées du fil jusqu’au conducteur nu, comme indiqué à la Figure 8. La pression du racloir doit être suffisante pour enlever le revêtement et donner une surface propre et lisse à la limite revêtement/conducteur, sans éliminer une quantité non négligeable de matériau conducteur. L’élimination du revêtement doit commencer à environ 10 mm de chacun des dispositifs de fixation. Le dispositif de fixation tournant doit être actionné à une vitesse comprise entre 60 tr/min et 100 tr/min jusqu’à ce que le nombre de tours R atteigne la valeur spécifiée dans la norme pertinente.

Après pelage et rotation, l’éprouvette doit être examinée en vue de déceler une perte d’adhérence. Le revêtement qui peut être enlevé du fil sans difficulté (par exemple avec l’ongle du pouce) doit être considéré comme ayant perdu son adhérence même s’il ne s’est pas complètement détaché du fil.

Une éprouvette doit être soumise à essai. Si une perte d’adhérence est observée, cela doit être consigné.

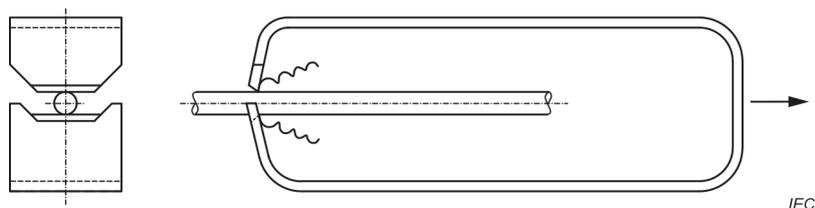


Figure 7 – Racloir

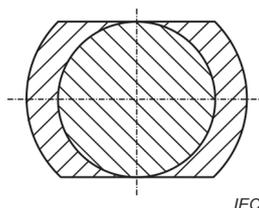


Figure 8 – Section droite du fil dont on a retiré l'émail

6.6 Essai d'adhérence

6.6.1 Généralités

Une longueur de fil droit de 300 mm environ doit être allongée conformément à l'Article 4, selon le pourcentage spécifié dans la norme pertinente.

6.6.2 Fil de section rectangulaire émaillé

Le revêtement doit être coupé selon le périmètre d'une section droite, sensiblement au milieu de la longueur mesurée qui sera soumise à l'allongement. Après allongement, l'éprouvette doit être examinée quant à la perte d'adhérence sur le conducteur.

Une éprouvette doit être soumise à essai. Si une perte d'adhérence, mesurée longitudinalement à partir de l'incision, est observée, elle doit être consignée. La longueur de la perte d'adhérence doit être mesurée dans une seule direction à partir de l'incision. La valeur maximale relevée doit être consignée après l'examen de tous les côtés de l'éprouvette, avec un grossissement de six à dix fois.

6.6.3 Fil de section circulaire ou rectangulaire recouvert d'une enveloppe fibreuse imprégnée

Le revêtement doit être coupé selon le périmètre d'une section droite en deux points espacés de 100 mm dans la partie centrale du conducteur qui sera soumise à l'allongement. Après allongement, l'éprouvette doit être examinée quant à la perte d'adhérence sur le conducteur, avec un grossissement de six à dix fois.

Une éprouvette doit être soumise à essai. Si une perte d'adhérence, mesurée longitudinalement à partir de l'incision, est observée conformément à la spécification applicable, elle doit être consignée. La valeur maximale relevée doit être consignée après l'examen de tous les côtés de l'éprouvette, avec un grossissement de six à dix fois.

6.6.4 Fil de section circulaire ou rectangulaire émaillé recouvert d'une enveloppe fibreuse

Le revêtement doit être coupé selon le périmètre d'une section droite en deux points espacés de 100 mm dans la partie centrale du conducteur qui sera soumise à l'allongement. Après allongement, l'éprouvette doit être examinée quant à la perte d'adhérence sur le conducteur, avec un grossissement de six à dix fois.

Une éprouvette doit être soumise à essai. Si une perte d'adhérence, mesurée longitudinalement à partir de l'incision, est observée conformément à la spécification applicable, elle doit être consignée. La valeur maximale relevée doit être consignée après l'examen de tous les côtés de l'éprouvette, avec un grossissement de six à dix fois

6.6.5 Fil de section circulaire ou rectangulaire rubané (uniquement pour du ruban adhésif)

Le revêtement doit être coupé selon le périmètre d'une section droite, sensiblement au milieu de la longueur mesurée qui sera soumise à l'allongement. Après allongement, l'éprouvette doit être examinée quant à la perte d'adhérence sur le conducteur, avec un grossissement de six à dix fois. Une éprouvette doit être soumise à essai. La valeur maximale relevée doit être consignée après l'examen de tous les côtés de l'éprouvette, avec un grossissement de six à dix fois. Si une perte d'adhérence, mesurée longitudinalement à partir de l'incision, est observée conformément à la spécification applicable, elle doit être consignée.

7 Essai 11: Résistance à l'abrasion (applicable au fil de section circulaire émaillé)

7.1 Généralités

La résistance à l'abrasion est la force maximale que peut supporter un revêtement quand une aiguille racle le fil avec une force progressivement croissante.

7.2 Principe

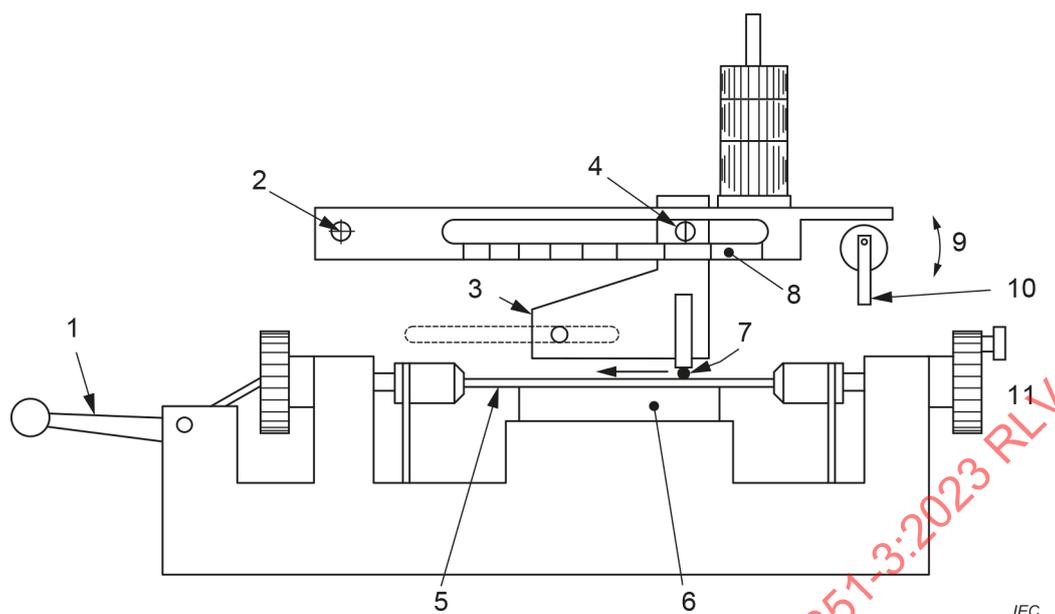
Une longueur de fil droit est soumise à un essai d'abrasion unidirectionnelle au moyen d'une aiguille sur laquelle on applique une charge progressivement croissante et qui racle la surface du fil. La charge qui provoque un court-circuit électrique entre l'aiguille et le conducteur est appelée "charge de rupture".

7.3 Appareil

Un appareil d'essai tel qu'il est représenté à la Figure 9 doit être utilisé. Cet appareil doit être équipé d'un mécanisme ayant une action abrasive dans une seule direction à raison de (400 ± 40) mm/min. Le dispositif d'abrasion doit être constitué d'une corde à piano polie ou d'une aiguille de $(0,23 \pm 0,01)$ mm de diamètre placée entre deux mors qui maintiennent la corde à piano ou l'aiguille de façon rigide, sans déformation ou courbure et à angle droit de la direction du mouvement. L'abrasion doit se faire dans la direction de l'axe du fil à soumettre à essai. Pour placer l'éprouvette, l'appareil doit comprendre deux mors sur l'enclume-support, laquelle peut être abaissée quand un fil est mis en place dans les mors, puis redressée.

L'appareil d'essai doit comprendre une alimentation en courant continu de $(6,5 \pm 0,5)$ V à appliquer entre le conducteur et la corde à piano ou l'aiguille. Le courant de court-circuit doit être limité à 20 mA, par exemple au moyen d'une résistance en série ou d'un relais. Le circuit doit être conçu de façon à détecter le court-circuit et à arrêter l'appareil quand la corde à piano ou l'aiguille est en contact avec le conducteur du fil sur environ 3 mm.

L'appareil doit comporter sur la partie inférieure du fléau une échelle graduée qui indique le facteur par lequel la charge initiale appliquée à la corde à piano ou à l'aiguille doit être multipliée pour donner la charge de rupture.



Le dispositif d'abrasion chargé augmente la charge sur le fil en se déplaçant de droite à gauche

Légende

- 1 manchon pour redresser l'éprouvette
- 2 point fixe du pivot
- 3 dispositif d'abrasion chargé
- 4 index
- 5 éprouvette
- 6 enclume à hauteur réglable pour des fils de diamètres différents
- 7 corde à piano
- 8 échelle indiquant le facteur de multiplication
- 9 arrêt/mise en marche
- 10 levier de mise en marche
- 11 bague indexée par palier de 120°

Figure 9 – Appareil pour l'essai d'abrasion unidirectionnelle

7.4 Procédure

Une longueur de fil droit doit être essuyée, placée dans l'appareil et redressée par un allongement maximal de 1 %. L'éprouvette doit alors être fixée par les mors, et l'enclume-support est amenée au contact de l'éprouvette. La charge initiale appliquée au dispositif d'abrasion doit être inférieure à 90 % de la charge minimale de rupture spécifiée dans la norme pertinente. La charge appliquée doit être telle qu'elle provoque un court-circuit entre la corde à piano/l'aiguille et le conducteur, par mise à nu du conducteur à une distance comprise entre 150 mm et 200 mm du point fixe du pivot. Le dispositif d'abrasion chargé doit être appliqué lentement sur la surface du fil puis l'action d'abrasion commence.

La valeur à laquelle l'appareil s'arrête doit être lue sur l'échelle graduée située en partie inférieure du fléau. Le produit de cette valeur par la charge initiale appliquée doit être consigné.

L'essai doit être répété deux fois sur la même éprouvette en faisant tourner le fil autour de son axe de 120° et 240° par rapport à la position initiale; les mêmes informations doivent être consignées.

Une éprouvette doit être soumise à essai. Les trois valeurs individuelles doivent être consignées. La valeur moyenne représente la charge de rupture moyenne.