BS EN 60172:2015

BSI Standards Publication

Test procedure for the determination of the temperature index of enamelled and tape wrapped winding wires

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National foreword

This British Standard is the UK implementation of EN 60172:2015. It is identical to IEC 60172:2015. It supersedes BS EN 60172:1994+A2:2010 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee L/-/99, Miscellaneous Standards - Electrical.

A list of organizations represented on this committee can be obtained on request to its secretary.

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 60172

June 2015

ICS 29.060.10

Supersedes EN 60172:1994

English Version

Test procedure for the determination of the temperature index of enamelled and tape wrapped winding wires (IEC 60172:2015)

Méthode d'essai pour la détermination de l'indice de température des fils de bobinage émaillés et enveloppés de ruban
(IEC 60172:2015)

Prüfverfahren zur Bestimmung des Temperaturindex von Lackdrähten und bandumwickelten Drähten
(IEC 60172:2015)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

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European foreword

The text of document 55/1518/FDIS, future edition 4 of IEC 60172, prepared by IEC/TC 55 "Winding wires" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60172:2015.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2016-03-16
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2018-06-16

This document supersedes EN 60172:1994.

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Endorsement notice

The text of the International Standard IEC 60172:2015 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60317 (series)	NOTE	Harmonized as EN 60317 (series).
IEC 60455-3-5	NOTE	Harmonized as EN 60455-3-5.
IEC 60464-3-2	NOTE	Harmonized as EN 60464-3-2.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60216-1	-	Electrical insulating materials - Thermal endurance properties -- Part 1: Ageing procedures and evaluation of test results	EN 60216-1	-
IEC 60216-3	-	Electrical insulating materials - Thermal endurance properties -- Part 3: Instructions for calculating thermal endurance characteristics	EN 60216-3	-

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

TEST PROCEDURE FOR THE DETERMINATION OF THE TEMPERATURE INDEX OF ENAMELLED AND TAPE WRAPPED WINDING WIRES

FOREWORD

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International Standard IEC 60172 has been prepared by IEC Technical Committee 55: Winding wires.

This fourth edition cancels and replaces the third edition published in 1987, Amendment 1:1997 and Amendment 2:2010. This edition constitutes a technical revision.

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

– Revision of Clause 1, Scope, to incorporate appropriate text from former Clause 2, Object;
– Deletion of Clause 2, Object, by placement of its text into existing clauses;
– New Clause 2, Normative references;
– Revision of 5.1.1, 5.3 and 5.4 with corrections to Amendment 2 to the third edition;
– Revision of Clause 7 as to clarify which specimens comply with Table 3 and Table 4;
– Revision of figures with high-resolution photos and graphs.

The text of this standard is based on the following documents:

FDIS	Report on voting
55/1518/FDIS	55/1524/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

TEST PROCEDURE FOR THE DETERMINATION OF THE TEMPERATURE INDEX OF ENAMELLED AND TAPE WRAPPED WINDING WIRES

1 Scope

This International Standard specifies, in accordance with the provisions of IEC 60216-1, a method for evaluating the temperature index of enamelled wire, varnished or unvarnished with an impregnating agent, and of tape wrapped round and rectangular wire, in air at atmospheric pressure by periodically monitoring changes in response to AC proof voltage tests. This procedure does not apply to fibre-insulated wire or wire covered with tapes containing inorganic fibres.

NOTE The data obtained according to this test procedure provide the designer and development engineer with information for the selection of winding wire for further evaluation of insulation systems and equipment tests.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60216-1, *Electrical insulating materials – Thermal endurance properties – Part 1: Ageing procedures and evaluation of test results*

IEC 60216-3, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
temperature index
TI
numerical value of the Celsius temperature expressed in degrees Celsius characterizing the thermal capability of an insulating material or an insulation system

Note 1 to entry: In case of insulating materials, the temperature index is derived from the thermal endurance relationship at a given time, normally 20 000 hours. It may be used as basis for determination of the material's temperature class.

Note 2 to entry: In case of insulation systems, the temperature index may be derived from known service experience or from a known comparative functional evaluation of an evaluated and established reference insulation system as basis.

[SOURCE: IEC 60050-212:2010, 212-12-11]

3.2
specimen failure time
number of hours at the exposure temperature that have elapsed at the time a specimen fails the proof test

3.3
time to failure
L
number of hours to failure calculated from the specimen failure times for a set of specimens at one exposure temperature

4 Summary of procedure

A set of specimens in accordance with Clause 5 is subjected to a testing cycle. This cycle consists of a heat-storing period at a temperature given in Clause 6, followed by a proof voltage test at room temperature in accordance with Clause 7.

This cycle is repeated until a sufficient number of specimens has failed. The time to failure is calculated in accordance with Clause 8. The test is carried out at three or more temperatures. A regression line is calculated in accordance with 8.4 and the time to failure values plotted on thermal endurance graph paper as a function of the exposure temperature.

The temperature in degrees Celsius, corresponding to the point of intersection of the regression line with the ordinate of 20 000 h endurance represents the temperature index of the winding wire under test.

5 Test specimens

5.1 Preparation

5.1.1 Enamelled round wire with a nominal conductor diameter of 0,224 mm up to and including 2,65 mm

The grade of insulation used for determining the thermal index shall be grade 2 or grade 2B for self-bonding winding wires.

Wire sizes 0,315 mm and 0,28 mm are permitted for use when the specification size range is limited to 0,50 mm and finer.

NOTE For round enamelled winding wires, in order to avoid undue fragility of the test specimen, experience has shown that nominal conductor diameters of 0,800 mm up to and including 2,65 mm are generally found convenient to handle and test.

Specimens shall be prepared as follows:

a) A wire specimen approximately 400 mm in length shall be twisted together over a distance of 125 mm with a device as shown in Figure 1. The force (weight) applied to the wire pair while being twisted and the number of twists are specified in Table 1.

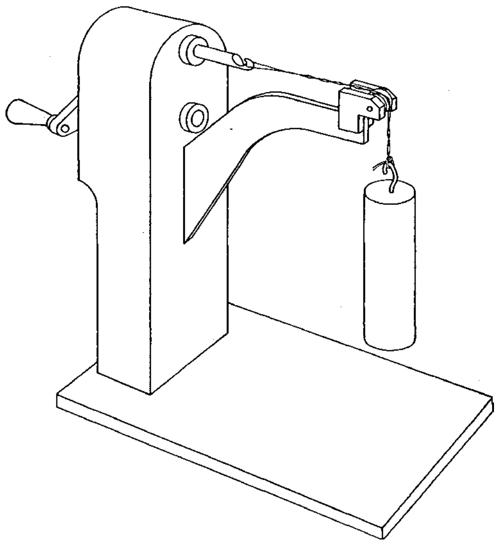
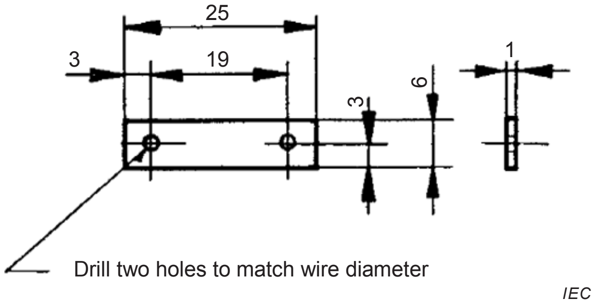


Figure 1 – Device used to form enamelled round wire test specimen

Table 1 – Force and number of twists for specimens

Nominal diameter mm		**Force applied to wire pair** N	**Number of twists per 125 mm**
Over	**Up to and including**		
0,224	0,25	0,85	33
0,25	0,35	1,7	23
0,35	0,50	3,4	16
0,50	0,75	7,0	12
0,75	1,05	13,5	8
1,05	1,50	27,0	6
1,50	2,15	54,0	4
2,15	3,50	108,0	3

b) Spacers may be prepared as shown in Figure 2. Such thermally stable insulating materials as ceramic or silicone glass fibre laminate may be used. The spacers are marked with a suitable identifying letter or number.

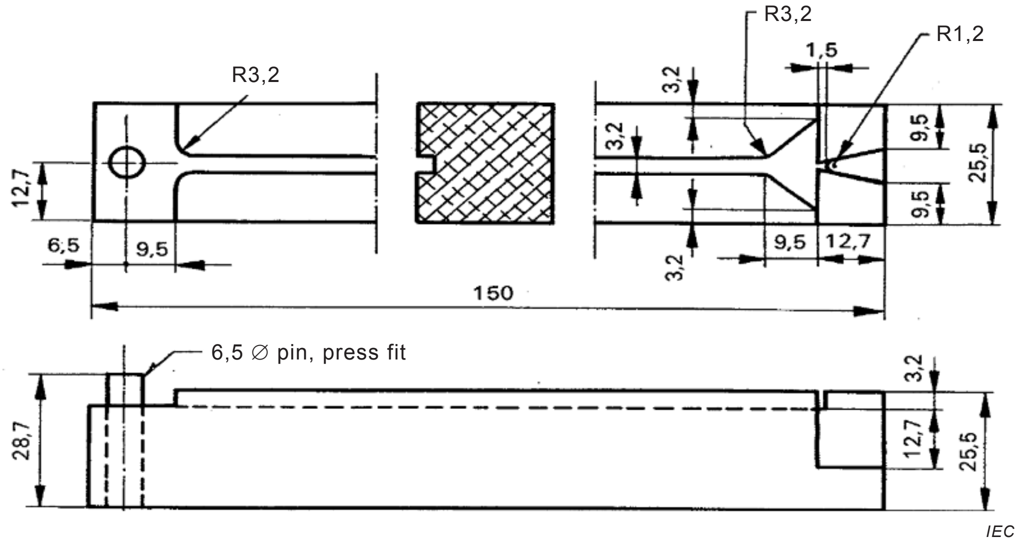


Material: Silicone glass laminate

Dimensions in millimetres

Figure 2 – Spacer

c) The test specimens may be shaped in a jig, an engineering drawing of which is shown in Figure 3. A specimen is placed in the jig and a spacer, placed on the parallel leads of the twisted pair, is brought up to the face of the jig as shown in Figure 4. The leads are then bent parallel to hold the spacer in position. The forming jig provides more uniform test specimens. If a specimen holder is used, the spacers are unnecessary.



R = Radius of bend

Dimensions in millimetres

Figure 3 – Twist forming jig

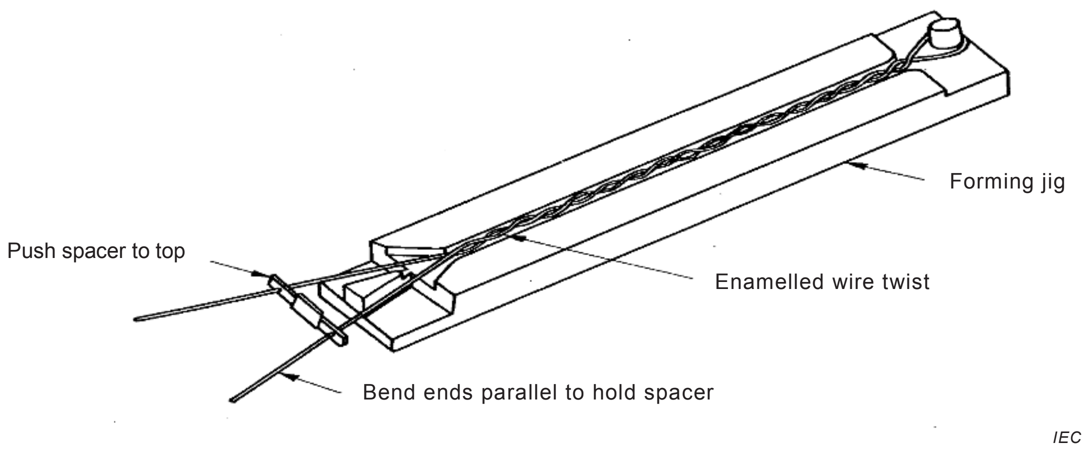


Figure 4 – Test specimen set up in forming jig

d) The loop at the end of the twisted section shall be cut at two places (not one) to provide the maximum spacing between the cut ends as shown in Figure 5. Any bending of the wires, at this end or the other untwisted end, to ensure adequate separation between the wires shall avoid sharp bends or damage to the insulation.

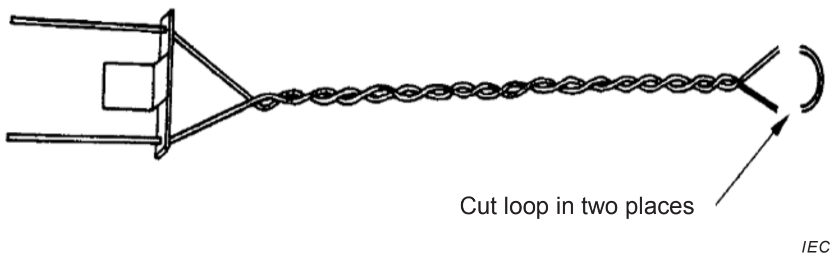


Figure 5 – Test specimen formed with loop cut

e) In order to ensure homogeneity of the batch of test specimens, it is recommended that test specimens be subjected to a test voltage three times the value given in Table 2 for 1 s.

Table 2 – Proof voltage for round enamelled wire

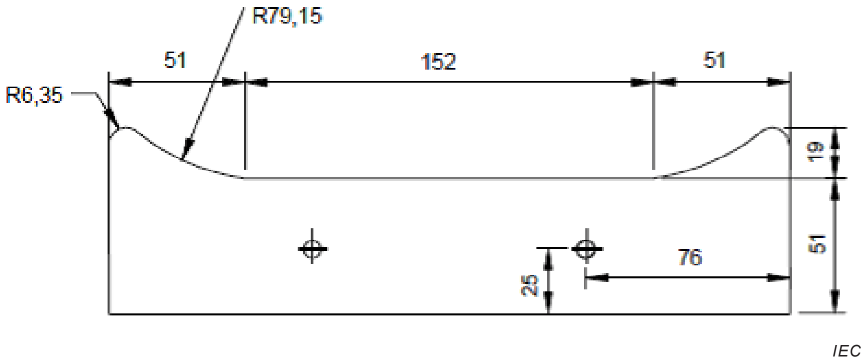
Increase in diameter due to the insulation (mm)		Voltage (rms)
Over	**Up to and including**	
–	0,015	300
0,015	0,024	300
0,024	0,035	400
0,035	0,050	500
0,050	0,070	700
0,070	0,090	1 000
0,090	0,130	1 200

5.1.2 Tape wrapped round wire and enamelled or tape wrapped rectangular wire

NOTE This procedure applies to any convenient dimension of round or rectangular wire. However, selecting wires having dimensions that minimize the bending force needed to shape the test specimen will make the procedure easier to perform. Wire with high stiffness will yield specimens with poor wire-to-wire contact areas.

Specimens shall be prepared as follows:

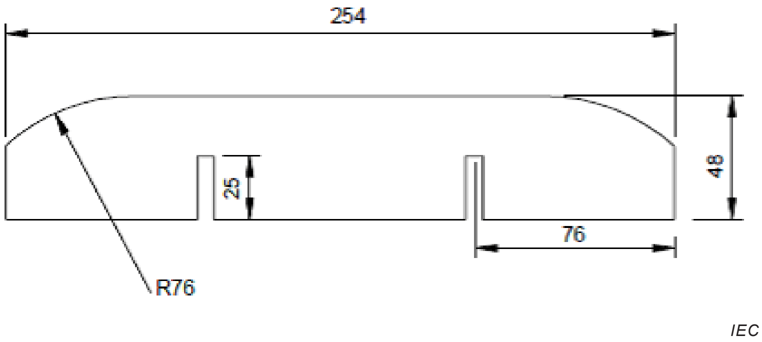
a) Two straight specimens of wire each of 250 mm length shall be cut from the supply spool.
b) 10 mm to 15 mm of the insulation shall be removed from one end of each piece of wire to provide for electrical connection.
c) Each specimen shall be formed in a jig, as shown in Figure 6. This produces a straight centre section of about 150 mm with bent ends, which provide the necessary flare at both ends of the final specimen.



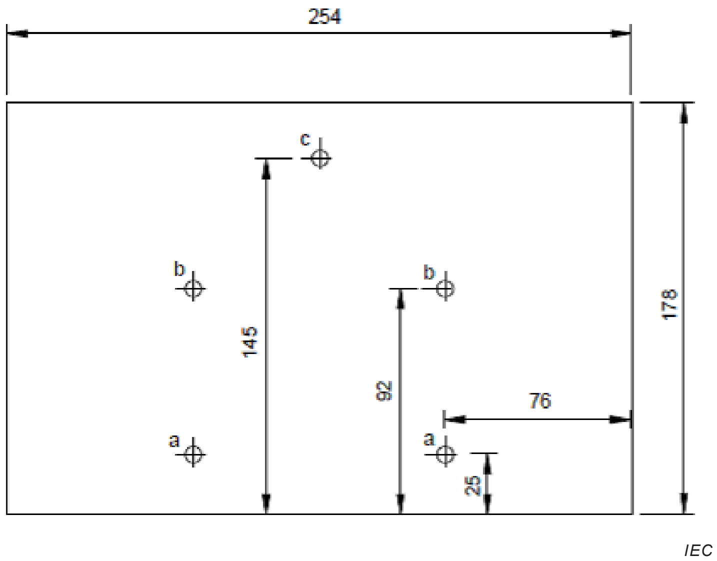
a) Fixed template

All parts 12,5 mm thick compound plate stock

Phenolic impregnated fabric



b) Movable template (same dimensions as a))

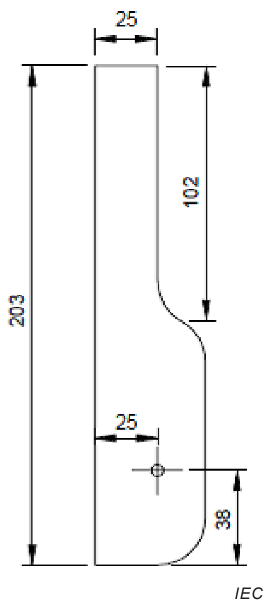


a mounting screws for fixed template

b mounting screws for movable template (template shall be free to slide)

c mounting screw for clamping lever (lever shall be free to rotate)

c) Platine



d) Clamping lever

Dimensions in millimetres

Figure 6 – Jig for bending large magnet wire, dielectric test specimen

d) The two formed specimens shall be placed together back-to-back and tightly wrapped with glass yarn over the straight centre section of the specimen, as shown in Figure 7.

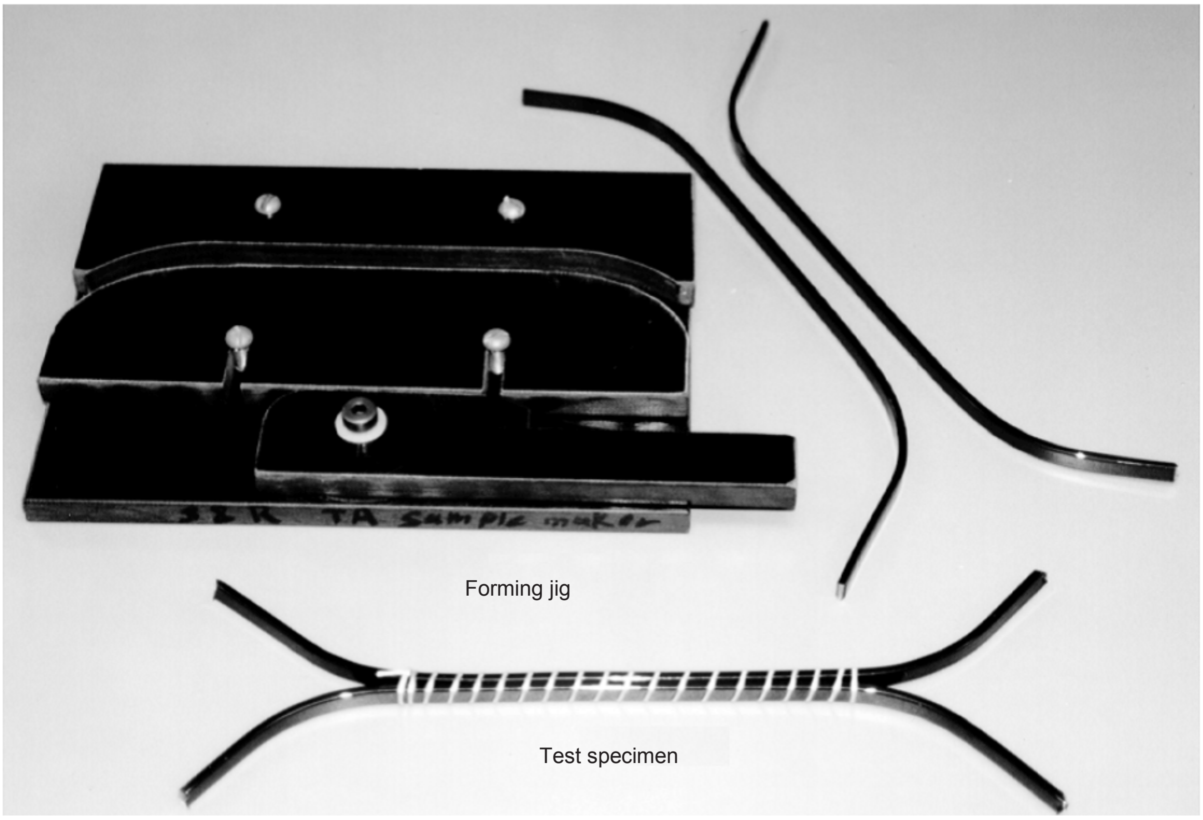


Figure 7 – Forming jig and test specimen

Care shall be taken that the centre section shows a close contact between the two pieces.

After tying, further bending of the ends shall be avoided. Pre-annealing of the specimen prior to testing or impregnating will remove stress and craze marks and therefore may be desirable with certain material.

e) Prior to testing the specimen shall be proof-tested at 1 000 V a.c.

5.2 Varnish impregnation

Experience has shown that insulated wire according to IEC 60317 and impregnating agents according to IEC 60455-3-5 or IEC 60464-3-2 can affect one another during the thermal ageing process.

NOTE 1 Testing varnished specimens will allow for evaluation of the compatibility of the wire insulation with an impregnating agent. Thus the temperature indices of different combinations can be compared.

Interaction between wire insulation and such agent may increase or decrease the relative thermal life of this combination compared with the life of the wire tested without impregnation. Therefore, with impregnated specimens, this test procedure may give an indication of the thermal endurance of a combination of wire insulation and impregnating agent.

If such impregnation is required, the following procedure shall be applied:

With the specimen in the vertical position, it shall be immersed in the impregnating agent for (60 ± 10) s (see note). It shall be removed slowly and uniformly at a rate of about 1 mm/s. It shall be drained horizontally for 10 min to 15 min and cured horizontally according to the manufacturer's recommendation or to an agreed schedule. If more than one treatment is to be given, immerse, drain and cure the specimen vertically reversing the specimen for each subsequent treatment.

NOTE 2 Some impregnating agents, such as high viscosity or thixotropic products require alternative processing methods.

5.3 Notes on number of test specimens

The accuracy of the test results depends largely upon the number of test specimens aged at each temperature. A greater number of test specimens is required to achieve an acceptable degree of accuracy if there is a wide spread in results among the specimens exposed at each temperature.

Experience has shown that twenty specimens without impregnation and ten specimens with impregnation give results with an acceptable tolerance. A minimum of ten specimens shall be used.

5.4 Specimen holder

5.4.1 For specimens according to 5.1.1

Since individual handling of the twisted specimens may result in premature failures, it is recommended that the specimens be placed in a suitable holder, as shown in Figure 8. The holder should be designed in a manner that will protect the twisted specimens from external mechanical damage and warping. The holder will be so constructed as to allow the ends of the twist to protrude from the holder to make electrical connection for the proof testing as shown in Figure 9. The holder shall be designed for at least ten specimens to decrease handling time.

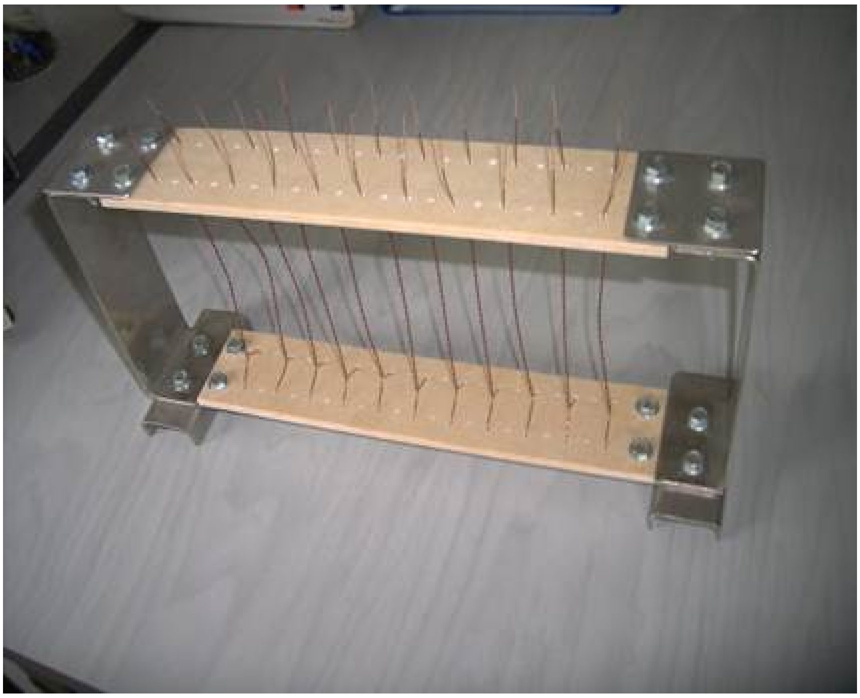


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Figure 8 – Specimen holder

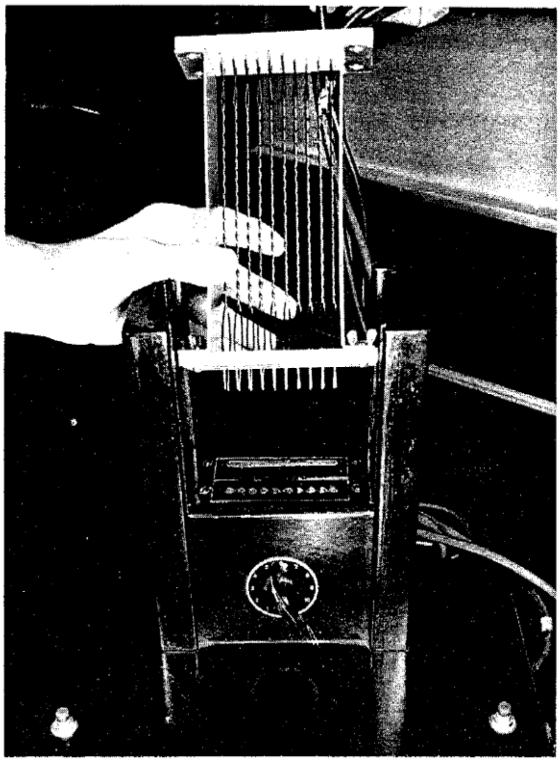

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Figure 9 – Specimen holder and electrical connection fixture

5.4.2 For specimens according to 5.1.2

The specimen shall be hung in the oven. No special holder is required.

6 Temperature exposure

Recommended temperatures to which the test specimens are subjected are given in this Clause 6.

In Table 3, the recommended temperature and time of exposure in each cycle are given. A test cycle is defined as one exposure to a high temperature followed by one proof-voltage test at room temperature (20°C – 30°C). The test specimens shall be placed directly into and removed from the ageing ovens without controlling the heating or cooling rate.

The ovens should be heated to the proper temperature before the specimens are subjected to the exposure temperature.

The specimens should be aged in a forced air circulation oven which is capable of maintaining the temperature of the specimens under test within 2°C of the selected exposure temperature.

The exposure times are selected to subject the test specimens to approximately 10 cycles at each temperature before the time to failure is reached.

Table 3 – Recommended exposure times in days per cycle

Exposure or ageing temperature (°C)	Estimated temperature index						
	105-109	**120-130**	**150-159**	**180-189**	**200-209**	**220-239**	**240-249**
320	–	–	–	–	–	–	1
310	–	–	–	–	–	–	2
300	–	–	–	–	–	1	4
290	–	–	–	–	–	2	7
280	–	–	–	–	1	4	14
270	–	–	–	–	2	7	28
260	–	–	–	1	4	14	49
250	–	–	–	2	7	28	–
240	–	–	–	4	14	49	–
230	–	–	–	7	28	–	–
220	–	–	1	14	49	–	–
210	–	1	2	28	–	–	–
200	–	2	4	49	–	–	–
190	1	4	7	–	–	–	–
180	2	7	14	–	–	–	–
170	4	14	28	–	–	–	–
160	7	28	49	–	–	–	–
150	14	49	–	–	–	–	–
140	28	–	–	–	–	–	–
130	49	–	–	–	–	–	–
120	–	–	–	–	–	–	–

NOTE The recommendations in Table 3 differ from those in IEC 60216-3 but have been found to be more suitable for enamelled wires.

Thermal endurance values obtained from test specimens subjected to an average of less than eight or more than twenty cycles at the exposed temperature may not be reliable and should not be used to predict the temperature rating of the enamelled wire. Therefore, a shorter or longer cycle time than those given in Table 3 may be chosen for certain exposure temperatures, to ensure that the average number of cycles to failure falls within this range.

After the specimens have been subjected to a particular cycle, the time may be appropriately increased or decreased to control the number of cycles required to reach the time to failure.

Test specimens should be exposed to a minimum of three and preferably four exposure temperatures. The lowest temperature, recommended at 20 °C above the desired thermal class, should be one which results in a time frame to failure of more than 5 000 h. The highest exposure temperature shall have a value of at least 100 h to be considered a valid data point. Exposure temperatures should not be more than 20 °C apart. The accuracy of the temperature index predicted from the results will improve as the exposure temperature approaches the temperature to which the insulation is exposed in service.

7 Test voltage and its application

The voltage to be applied shall be an a.c. voltage and shall have a nominal frequency of 50 Hz or 60 Hz of an approximately sine-wave form, the peak factor being within the limits of $\sqrt{2} \pm 5\%$ (1,34 to 1,48). The test transformer shall have a rated power of at least 500 VA and shall provide a current of essentially undistorted waveform under test conditions.

To detect failure, the overcurrent indication device shall operate when a current of 5 mA or more flows through the high-voltage circuit. The test voltage source shall have a capacity to supply the detection current (5 mA or more) with a maximum voltage drop of 10 %.

The test specimens are removed from the ovens and cooled to room temperature. Each specimen shall be subjected to a proof voltage according to the increase in diameter due to insulation as specified in Table 3 for specimens according to 5.1.1 and in Table 4 for specimens according to 5.1.2. In the case of self-bonding wires, the self-bonding layer is included in the increase in diameter due to the insulation.

Table 4 – Proof voltage for tape-wrapped round and for enamelled or tape-wrapped rectangular wire

Increase in dimension due to the insulation (mm)		Voltage (rms)
Over	**Up to and including**	
0,035	0,050	300
0,050	0,065	375
0,065	0,080	450
0,080	0,090	550
0,090	0,100	650
0,100	0,115	700
0,115	0,130	750
0,130	0,140	800
0,140	0,150	850

The proof voltage shall be applied to the test specimens for approximately 1 s.

NOTE A relatively short time of application of the test voltage is desirable to minimize the effects of corona and dielectric fatigue.

Care shall be taken in all cases to avoid mechanical damage to the test specimens. The specimens that fail the proof test shall be discarded and the remaining specimens returned to the oven for another temperature exposure.

8 Calculations

8.1 Specimen failure time

The failure time of an individual specimen at one exposure temperature is determined by calculating the mid-point between the total hours of exposure temperature at which the specimen failed the proof voltage and the total hours of exposure of the previous cycles. This assumes that the specimen would probably have failed the proof voltage at some point in the middle of the last temperature exposure cycle. Thus, the specimen failure time is the sum of the total hours at the time to failure, minus half the hours of the last exposure cycle.

8.2 Time to failure

The time to failure of a set of specimens at one exposure temperature shall be calculated by using either the median value or the logarithmic mean value. For many materials, the median value is statistically valid. In most cases, use of the median will significantly reduce testing time, since the test ceases once the median value has been obtained.

When using the median value, the time to failure is calculated as follows:

Where there are a total number of n specimens in a set of specimens, the time to failure of the set equals:

a) the specimen failure time of specimen number $(n + 1)/2$; if n is odd (see 8.1);

b) the logarithmic mean value of the specimen failure times of specimens number $n/2$ and $(n + 2)/2$; if n is even (see 8.1).

For instance, if n is 12, the time to failure of the set would be the mean value of the specimen failure times of the sixth and the seventh specimen. For convenience, it is suggested that when the median value is used for calculating the time to failure of the set, the total number of specimens of a set be odd, thus simplifying calculation.

When using the logarithmic mean value, the time to failure is calculated by dividing the sum of the logarithms of the specimen failure times of the set (see 8.1) by the total number n of specimens in the set. The antilogarithm of this mean value is the time to failure of the set.

8.3 Linearity of data

To avoid misleading extrapolations (see 8.4), the correlation coefficient should be calculated as shown in Annex B, to provide a measure of linearity.

If the correlation coefficient r is equal to or greater than 0,95, the data are said to be linear and the data points will be reasonably close to a straight line. In the event that the correlation coefficient is less than 0,95, the data are said to be non-linear and an additional test should be performed at a temperature below the lowest previous temperature.

The new temperature point may be 10 ºC below the previous lowest temperature point. When re-calculating the temperature index and correlation coefficient, one temperature point may be deleted, starting with the highest temperature, for each new temperature point obtained.

The data will be linear if the thermal deterioration of the enamelled wire or the varnished enamelled wire appears as one chemical reaction. Non-linearity may indicate that:

a) two or more reactions which have different activation energies (slopes) are predominant at different temperatures within the testing range; or

b) errors have been introduced through the sampling technique and/or the testing procedure.

Non-linear data should not be used for extrapolation.

8.4 Calculating and plotting thermal endurance and temperature index

Thermal endurance is graphically presented by plotting the time to failure (see 8.2) versus its respective exposure temperature on graph paper having a logarithmic time scale as the ordinate and the reciprocal of absolute temperature as the abscissa. The exposure temperatures at 2 000 h and 20 000 h are estimated based on the first order regression calculation presented in Annex A. A regression line is drawn through these two points on the graph, which represents the thermal endurance of the enamelled winding wire (see Figure 10).

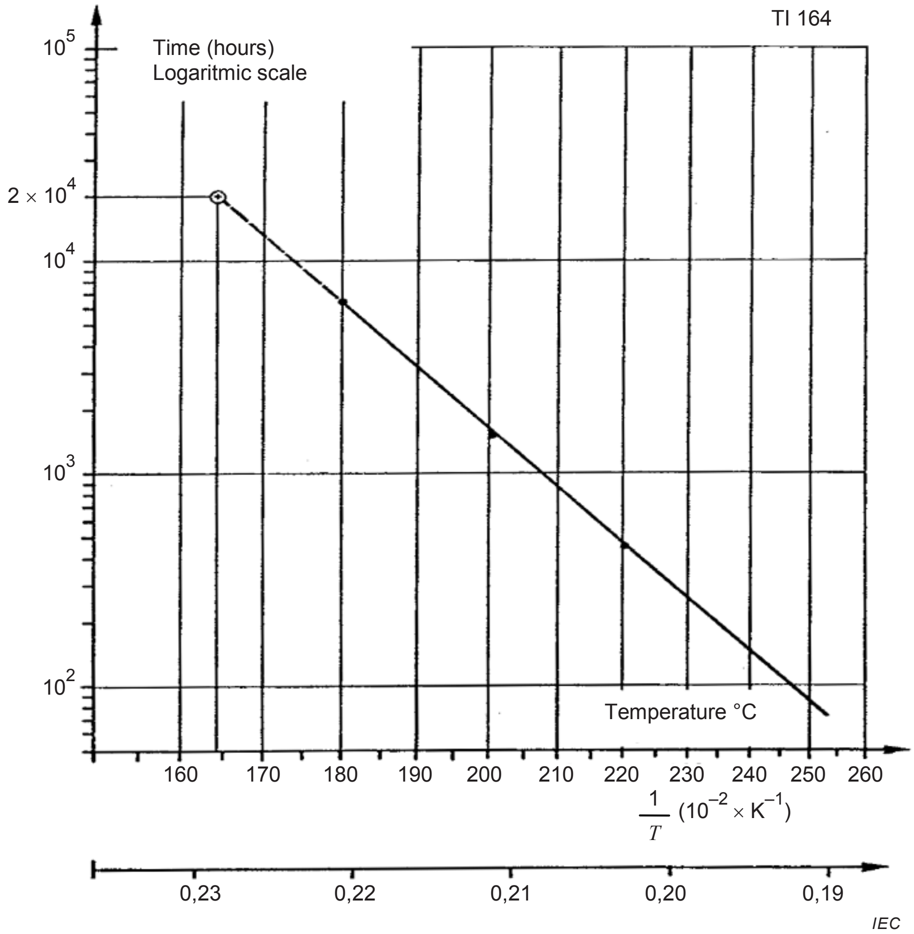

Figure 10 – Thermal endurance graph – Temperature index

The Temperature Index of the enamelled wire is the number corresponding to the temperature in degrees Celsius at which the regression line intersects the 20 000 h line. It is listed without reference to degrees Celsius.

If further statistical analysis of the data is necessary, reference may be made to IEC 60216-3.

9 Report

The report of the results shall contain the following information as a minimum:

a) identification or description of the wire enamel, grade and the type of conductor (e.g. copper, aluminium, etc.);

b) identification or description of the impregnating varnish and varnishing process;

c) time to failure of each set of specimens at each exposure temperature;

d) a graph of the first order regression line through the time to failure values;

e) the temperature index (TI)

Annex A
(normative)

Method for calculation of the regression line

This Annex A presents a method for quickly plotting the regression line for thermal endurance data. This method may be used for any number of measurements at various test temperatures. If information concerning the confidence limits is required, a more detailed analysis shall be made in accordance with IEC 60216-3.

It has been established that many insulations deteriorate in such a manner that the following equation applies:

$$L = Ae^{B/T} \tag{1}$$

where:

L	=	insulation endurance in hours;
T	=	absolute temperature in kelvins;
A, B	=	constants for each insulation, and
e	=	base of natural logarithms.

Equation (1) may be expressed as a linear function by taking logarithms:

$$\log_{10} L = \log_{10} A + (\log_{10} e) \cdot \frac{B}{T} \tag{2}$$

Let:

Y	=	$\log_{10} L$
a	=	$\log_{10} A$
X	=	$1/T$
b	=	$(\log_{10} e)\, B$

Then:

$$Y = a + bX \tag{3}$$

Thus, data from testing at higher temperatures may be plotted on $\log_{10} L$ versus $1/T$ graph paper and a straight line extrapolated to lower temperatures. However, since the nature of logarithmic plots does not allow accurate extrapolation by the method of drawing the best apparent straight line through the data points, a more rigorous method shall be used for greater accuracy and uniformity. By using the method of least squares, the constants a

and b may be derived in terms of the experimental data obtained. These equations are as follows:

$$a = \frac{\sum Y - b \sum X}{N} \tag{4}$$

$$b = \frac{N \sum XY - \sum X \sum Y}{N \sum X^2 - (\sum X)^2} \tag{5}$$

where:

X	=	$1/T$ = reciprocal of the test temperature in kelvins (θ°C + 273°C);
N	=	number of test temperatures used;
Y	=	$\log_{10} L$ = logarithm of time to failure;
Σ	=	summation of N values.

Knowing the constant a, and the slope b of the regression line, the temperature at any required life value may be calculated as follows:

$$Y = a + bX$$

$$T = \frac{1}{X} = \frac{b}{Y - a} \tag{6}$$

$$\text{Temperature at 20 000 h in degrees Celsius} = \frac{b}{4{,}3010 - a} - 273 \tag{7}$$

(temperature index)

$$\text{Temperature at 2 000 h in degrees Celsius} = \frac{b}{3{,}3010 - a} - 273 \tag{8}$$

To simplify the handling of the test data used in Equations (4) to (8), it is suggested that the steps for a sample calculation be followed as outlined below (see Table A.1 and Table A.2):

a) In column 1, list the temperatures in ºC, as illustrated in Table A.2, at which a set of specimens was tested.

b) In columns 2 and 3, list the reciprocals ($X = 1/T$) and the reciprocals squared (X^2 $1/T^2$) of the above test temperatures converted to kelvins (see also Table A.1).

c) In column 4, list the time to failure L, in hours, of each set of specimens, and in the column 5, list the $\log_{10}$ of the values in the fourth column ($Y = \log_{10} L$).

d) In column 6, list the products of X and Y.

e) Provide summation for columns 2, 3, 5 and 6 and enter the summation (indicated by Σ) at the bottom of the respective column.

f) Indicate the number N of times to failure on the worksheet.

g) Using the values obtained in steps e) and f), compute b (Equation 5) and a (Equation 4) in that order. The constant a will always be negative.

h) Using constants a and b, calculate the temperature in degrees Celsius at 20 000 h (Equation 7) and at 2 000 h (Equation 8).

i) Plot the above two temperature points from step h) on $\log_{10}L$ versus $1/T$ graph paper and draw the regression line through them (see Figure A.1).

j) Plot the times to failure L at their respective temperatures on the same graph.

Table A.1 – Commonly used test temperatures in degrees Celsius and the corresponding kelvins with its reciprocal and reciprocal squared values

θ (°C)	T (K)	$X = 1/T$ (K^{-1})	$X^2 = 1/T^2$ (K^{-2})
105	378	$2{,}646 \times 10^{-3}$	$6{,}999 \times 10^{-6}$
120	393	2,545 x 10^{-3}	6,475 x 10^{-6}
125	398	$2{,}513 \times 10^{-3}$	$6{,}313 \times 10^{-6}$
130	403	$2{,}481 \times 10^{-3}$	$6{,}157 \times 10^{-6}$
140	413	$2{,}421 \times 10^{-3}$	$5{,}863 \times 10^{-6}$
150	423	$2{,}364 \times 10^{-3}$	$5{,}589 \times 10^{-6}$
155	428	2,336 x 10^{-3}	5,459 x 10^{-6}
165	438	$2{,}283 \times 10^{-3}$	$5{,}212 \times 10^{-6}$
175	448	$2{,}232 \times 10^{-3}$	$4{,}982 \times 10^{-6}$
180	453	$2{,}208 \times 10^{-3}$	$4{,}873 \times 10^{-6}$
185	458	$2{,}183 \times 10^{-3}$	$4{,}767 \times 10^{-6}$
190	463	$2{,}160 \times 10^{-3}$	$4{,}665 \times 10^{-6}$
200	473	$2{,}114 \times 10^{-3}$	$4{,}470 \times 10^{-6}$
210	483	$2{,}070 \times 10^{-3}$	$4{,}287 \times 10^{-6}$
220	493	$2{,}028 \times 10^{-3}$	$4{,}114 \times 10^{-6}$
225	498	$2{,}008 \times 10^{-3}$	$4{,}032 \times 10^{-6}$
230	503	$1{,}988 \times 10^{-3}$	$3{,}952 \times 10^{-6}$
240	513	$1{,}949 \times 10^{-3}$	$3{,}800 \times 10^{-6}$
250	523	$1{,}912 \times 10^{-3}$	$3{,}656 \times 10^{-6}$
260	533	$1{,}876 \times 10^{-3}$	$3{,}520 \times 10^{-6}$
270	543	$1{,}842 \times 10^{-3}$	$3{,}392 \times 10^{-6}$
280	553	$1{,}808 \times 10^{-3}$	$3{,}270 \times 10^{-6}$
300	573	$1{,}745 \times 10^{-3}$	$3{,}048 \times 10^{-6}$
320	593	1,686 x 10^{-3}	2,844 x 10^{-6}

NOTE Calculations for X^2 are based on non-rounded values.

Table A.2 – Sample calculation

Column 1 Temperature (°C)	Column 2 $X = 1/T$	Column 3 $X^2 = 1/T^2$	Column 4 L (h)	Column 5 $Y = \log_{10}L$	Column 6 $XY = (\log_{10}L)/T$
170	$2,257\ 73 \times 10^{-3}$	$5,095\ 57 \times 10^{-6}$	5 600	3,748 19	$8,460\ 92 \times 10^{-3}$
185	$2,183\ 41 \times 10^{-3}$	$4,767\ 26 \times 10^{-6}$	2 600	3,414 97	$7,456\ 27 \times 10^{-3}$
200	$2,114\ 16 \times 10^{-3}$	$4,469\ 69 \times 10^{-6}$	1 500	3,176 09	$6,714\ 78 \times 10^{-3}$
215	$2,049\ 18 \times 10^{-3}$	$4,199\ 14 \times 10^{-6}$	640	2,806 18	$5,750\ 37 \times 10^{-3}$
Σ	$8,604\ 09 \times 10^{-3}$	$18,531\ 66 \times 10^{-6}$		13,145 43	$28,382\ 34 \times 10^{-3}$

$N = 4$

$$b = \frac{N\sum XY - \sum X \sum Y}{N\sum X^2 - (\sum X)^2} = \frac{4 \, x \, 28{,}382\,34 \, x \, 10^{-3} - 8{,}604\,09 \, x \, 10^{-3} \, x \, 13{,}145\,43}{4 \, x \, 18{,}531\,66 \, x \, 10^{-6} - 8{,}604\,09 \, x \, 10^{-3} \, x \, 8{,}604\,09 \, x \, 10^{-3}} = 4\,413$$

$$a = \frac{\sum Y - b\sum X}{N} = \frac{13{,}145\,43 - 4\,413 \, x \, 8{,}604\,09 \, x \, 10^{-3}}{4} = -\,6{,}206\,10$$

Temperature at 20 000 h in degrees Celsius = $\dfrac{b}{Y - a} - 273$

$$\frac{4413}{4{,}301\,0 + 6{,}206\,10} - 273 = 147\ °\text{C}$$

Temperature at 2 000 h in degrees Celsius = $\dfrac{b}{Y - a} - 273$

$$\frac{4413}{3{,}301\,0 + 6{,}206\,10} - 273 = 191\ °\text{C}$$

This graph should contain all appropriate information regarding insulating materials and systems

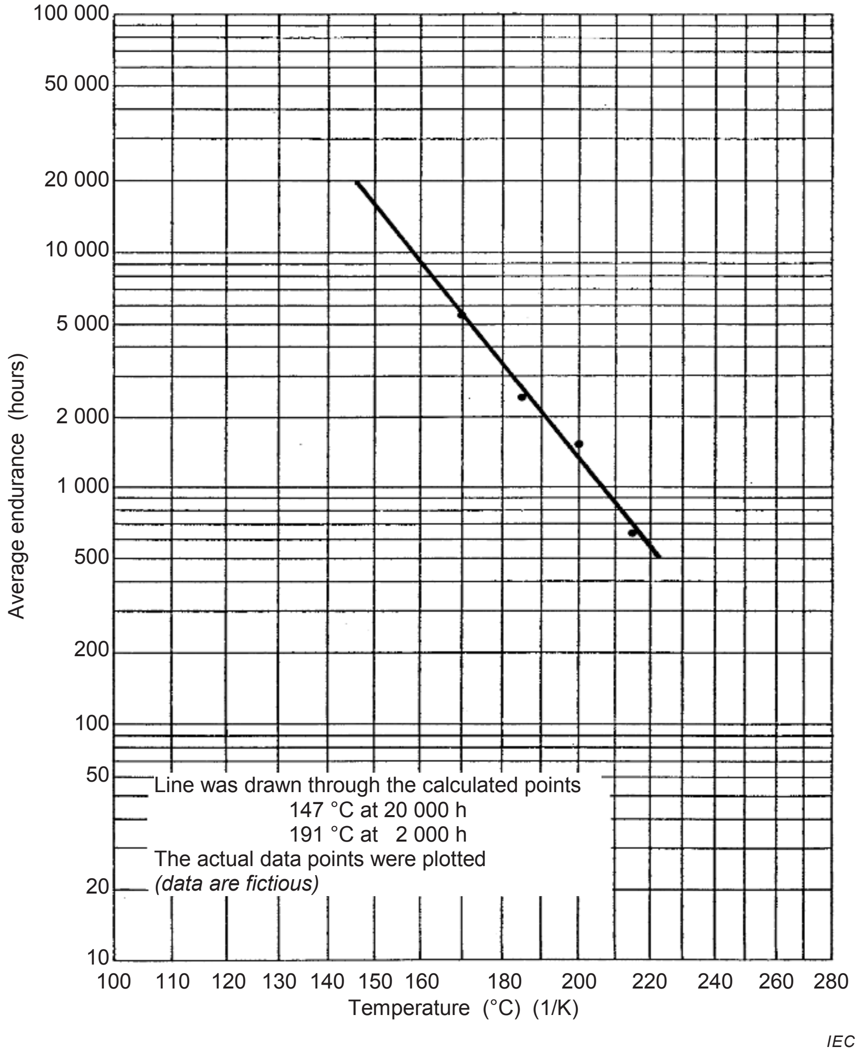

Figure A.1 – Plot of regression line based on sample calculation (Table A.2)

Annex B
(normative)

Correlation coefficient

The correlation coefficient r is a measure of the amount of relationship between variables.

When r = 1,0, a perfect association between the variable exists, and when r = 0, a completely random relation exists.

$$r=\sqrt{\frac{aY+bXY-N(Avg\,Y)^2}{Y^2-N(Avg\,Y)^2}}$$

where:

a	=	Y intercept of the regression line;
b	=	slope of the regression line;
X	=	$1/T$ = reciprocal of the test temperature in kelvins (8 ºC + 273 ºC);
N	=	number of test temperatures used;
X, Y	=	the variables.

Using the example data in Table A.2 in Annex A, the correlation coefficient is calculated according to the following equation:

$$\sqrt{\frac{a\Sigma Y+b\Sigma XY-N(Avg\,Y)^2}{\Sigma Y^2-N(Avg\,Y)^2}}=0{,}996$$

If the correlation coefficient r is equal to or greater than 0,95, the data is said to be linear and the data points will be reasonably close to a straight line.

In the event that the correlation coefficient is less than 0,95, the data is said to be nonlinear and additional tests at other test temperatures are required. It is recommended that the new temperature point be 10 °C below the previous lowest temperature point.

When recalculating the temperature index and correlation coefficient, it is permissible for one temperature point to be deleted, starting with the highest temperature, provided that there are still three valid data points.

The data will be linear if the thermal deterioration of the film insulated wire or the varnished film insulated wire appears as one chemical reaction. Nonlinearity possibly indicates the following:

a) Two or more reactions that have different activation energies (slopes) are predominant at different temperatures within the testing range; or
b) Errors have been introduced through the sampling technique or the testing procedure, or both.

It shall be noted that nonlinear results provide useful engineering data when plotted on the thermal endurance graph even when the data cannot be extrapolated appropriately to give a temperature index (TI).

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