

Electrical insulating materials — Properties of thermal endurance —

Part 1: Ageing procedures and evaluation of test results

The European Standard EN 60216-1:2001 has the status of a British Standard

ICS 29.035.01

National foreword

This British Standard is the official English language version of EN 60216-1:2001. It is identical with IEC 60126-1:2001. It supersedes BS 5691-1:1995 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee GEL/15, Insulating material, to Subcommittee GEL/15/5, Methods of test, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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

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**Electrical insulating materials -
Properties of thermal endurance
Part 1: Ageing procedures and evaluation of test results
(IEC 60216-1:2001)**

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Propriétés d'endurance thermique
Partie 1: Méthodes de vieillissement et
évaluation des résultats d'essai
(CEI 60216-1:2001)

Elektroisolierstoffe -
Eigenschaften hinsichtlich des
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Teil 1: Warmlagerungsverfahren und
Auswertung von Prüfergebnissen
(IEC 60216-1:2001)

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Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

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CENELEC

European Committee for Electrotechnical Standardization
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Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of document 15E/153/FDIS, future edition 5 of IEC 60216-1, prepared by SC 15E, Methods of test, of IEC TC 15, Insulating materials, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60216-1 on 2001-10-01.

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The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
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- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2004-10-01

Annexes designated "normative" are part of the body of the standard.

Annexes designated "informative" are given for information only.

In this standard, annex ZA is normative and annexes A, B and C are informative.

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60216-1:2001 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

The listing of the thermal capabilities of electrical insulating materials, based on service experience, was found to be impractical, owing to the rapid development of polymer and insulation technologies and the long time necessary to acquire appropriate service experience. Accelerated ageing and test procedures were therefore required to obtain the necessary information. The IEC 60216 series has been developed to formalize these procedures and the interpretation of their results.

Physico-chemical models postulated for the ageing processes led to the almost universal assumption of the Arrhenius equations to describe the rate of ageing. Out of this arose the concept of the temperature index (TI) as a single-point characteristic based upon accelerated ageing data. This is the numerical value of the temperature in °C at which the time taken for deterioration of a selected property to reach an accepted end-point is that specified (usually 20 000 h).

NOTE The term Arrhenius is widely used (and understood) to indicate a linear relationship between the logarithm of a time and the reciprocal of the thermodynamic (absolute or kelvin) temperature. The correct usage is restricted to such a relationship between a reaction rate constant and the thermodynamic temperature. The common usage is employed throughout this standard.

The large statistical scatter of test data which was found, together with the frequent occurrence of substantial deviations from the ideal behaviour, demonstrated the need for tests to assess the validity of the basic physico-chemical model. The application of conventional statistical tests, as set out in IEC 60493, fulfilled this requirement, resulting in the "confidence limit", (TC) of TI, but the simple, single-point TI was found inadequate to describe the capabilities of materials. This led to the concept of the "Thermal Endurance Profile" (TEP) given in the second edition of this part of IEC 60216, incorporating the temperature index, its variation with specified ageing time, and a confidence limit.

A complicating factor is that the properties of a material subjected to thermal ageing may not all deteriorate at the same rate, and different end-points may be relevant for different applications. Consequently, a material may be assigned more than one temperature index, derived, for example, from the measurement of different properties and the use of different end-point times.

A useful addition to the standard was the relative temperature index (RTI) obtained by simultaneous ageing of a known reference material with the test material, eliminating some of the uncertainties associated with, for example, oven temperature control.

It was subsequently found that the statistical confidence index included in the TEP was not widely understood or used. However, the statistical tests were considered essential, particularly after minor modifications to make them relate better to practical circumstances: the concept of the halving interval (HIC) was introduced to indicate the rate of change of ageing time with temperature. TEP was then abandoned, with the TI and HIC being reported in a way which indicated whether or not the statistical tests had been fully satisfied. At the same time, the calculation procedures were made more comprehensive, enabling full statistical testing of data obtained using a diagnostic property of any type, including the particular case of partially incomplete data. The calculation procedures (by now quite complex) were made more acceptable by the provision of computer programmes suitable for low-price personal computers.

At the time of preparation of the present edition, it was decided that RTI should be made the subject of a separate standard.

Simultaneously with the development of the IEC 60216 series, other standards were being developed in ISO, intended to satisfy a similar requirement for plastics and rubber materials. These are ISO 2578 and ISO 11346 respectively, which use less rigorous statistical procedures and more restricted experimental techniques. It is hoped that the wide availability of the computer facilities mentioned above and the inclusion of a section of simplified procedures will remove the need for these separate standards.

IEC 60216, which deals with the determination of thermal endurance properties of electrical insulating materials is composed of several parts:

- Part 1: Ageing procedures and evaluation of test results;
- Part 2: Choice of test criteria;
- Part 3: Instruction for calculating thermal endurance characteristics;
- Part 4-1: Ageing ovens – Section 1: Single-chamber ovens;
- Part 4-2: Ageing ovens – Precision ovens for use up to 300 °C;
- Part 4-3: Ageing ovens – Multi-chamber ovens;
- Part 5: Guidelines for the application of thermal endurance characteristics.

NOTE This series may be extended. For revisions and new parts, see the current catalogue of IEC publications for an up-to-date list.

ELECTRICAL INSULATING MATERIALS – PROPERTIES OF THERMAL ENDURANCE –

Part 1: Ageing procedures and evaluation of test results

1 Scope

This part of IEC 60216 specifies the general ageing conditions and procedures to be used for deriving thermal endurance characteristics and gives guidance in using the detailed instructions and guidelines in the other parts of the standard.

Simplified procedures are also given, with the conditions under which these procedures may be used.

Although originally developed for use with electrical insulating materials and simple combinations of such materials, the procedures are considered to be of more general applicability and are widely used in the assessment of materials not intended for use as electrical insulation.

In the application of this standard, it is assumed that a practically linear relationship exists between the logarithm of the time required to cause the predetermined property change and the reciprocal of the corresponding absolute temperature (Arrhenius relationship).

For the valid application of the standard, no transition, in particular no first-order transition, should occur in the temperature range under study.

Throughout the rest of this standard the term "insulating materials" is always taken to mean "insulating materials and simple combinations of such materials".

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60216. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 60216 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(212):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 212: Insulating solids, liquids and gases*

IEC 60212:1971, *Standard conditions for use prior to and during the testing of solid electrical insulating materials*

IEC 60216-2:1990, *Guide for the determination of thermal endurance properties of electrical insulating materials – Part 2: Choice of test criteria*

IEC 60216-3, *Guide for the determination of thermal endurance properties of electrical insulating materials – Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-4-1:1990, *Guide for the determination of thermal endurance properties of electrical insulating materials – Part 4: Ageing ovens – Section 1: Single-chamber ovens*

IEC 60493-1:1974, *Guide for the statistical analysis of ageing test data – Part 1: Methods based on mean values of normally distributed test results*

ISO 291:1997, *Plastics – Standard atmospheres for conditioning and testing*

ISO 2578:1993, *Plastics – Determination of time-temperature limits after prolonged exposure to heat*

ISO 11346:1997, *Rubber, vulcanized or thermoplastic – Estimation of life-time and maximum temperature of use from an Arrhenius plot*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this part of IEC 60216, the following definitions apply:

3.1.1

temperature index

TI

numerical value of the temperature in degrees Celsius derived from the thermal endurance relationship at a time of 20 000 h (or other specified time)

[IEV 212-02-08, modified]

3.1.2

halving interval

HIC

numerical value of the temperature interval in kelvins which expresses the halving of the time to end-point taken at the temperature equal to TI

[IEV 212-02-10, modified]

3.1.3

thermal endurance graph

graph in which the logarithm of the time to reach a specified end-point in a thermal endurance test is plotted against the reciprocal thermodynamic (absolute) test temperature

[IEV 212-02-07]

3.1.4

thermal endurance graph paper

graph paper having a logarithmic time scale as the ordinate, graduated in powers of ten (from 10 h to 100 000 h is often a convenient range). Values of the abscissa are proportional to the reciprocal of the thermodynamic (absolute) temperature. The abscissa is usually graduated in a non-linear (Celsius) temperature scale oriented with temperature increasing from left to right.

3.1.5

ordered data

set of data arranged in sequence so that, in the appropriate direction through the sequence, each member is greater than, or equal to, its predecessor.

NOTE Ascending order in this standard implies that the data is ordered in this way, the first order-statistic being the smallest.

3.1.6

order-statistics

each individual value in a set of ordered data is referred to as an order-statistics identified by its numerical position in the sequence

3.1.7

incomplete data

ordered data, where the values above and/or below defined points are not known

3.1.8

censored data

incomplete data, where the number of unknown values is known.

NOTE If the censoring is begun above/below a specified numerical value, the censoring is of type 1. If above/below a specified order-statistic, it is of type 2. This standard is concerned only with type 2.

3.1.9

degrees of freedom

number of data values minus the number of parameter values

3.1.10

variance of a data set

sum of the squares of the deviations of the data from a reference level defined by one or more parameters, divided by the number of degrees of freedom

NOTE The reference level may for example, be a mean value (one parameter) or a line (two parameters, slope and intercept).

3.1.11

covariance of data sets

for two sets of data with equal numbers of elements where each element in one set corresponds to one in the other, the sum of the products of the deviations of the corresponding members from their set means, divided by the number of degrees of freedom

3.1.12

regression analysis

process of deducing the best-fit line expressing the relation of corresponding members of two data groups by minimizing the sum of squares of deviations of members of one of the groups from the line.

NOTE The parameters are referred to as the regression coefficients.

3.1.13

correlation coefficient

number expressing the completeness of the relation between members of two data sets, equal to the covariance divided by the square root of the product of the variances of the sets

NOTE The value of its square is between 0 (no correlation) and 1 (complete correlation).

3.1.14

confidence limit

TC

statistical parameter, calculated from the test data, which with 95 % confidence constitutes a lower limit for the true value of the temperature index estimated by TI

NOTE 1 95 % confidence implies that there is only 5 % probability that the true value of the temperature index is actually smaller than TC.

NOTE 2 In other connections, confidence values other than 95 % may sometimes be used; for example, in the linearity test for destructive test data.

3.1.15

destructive test

diagnostic property test, where the test specimen is irreversibly changed by the property measurement, in a way which precludes a repeated measurement on the same specimen

3.1.16

non-destructive test

diagnostic property test, where the properties of the test specimen are not permanently changed by the measurement, so that a further measurement on the same specimen may be made after appropriate treatment

3.1.17

proof test

diagnostic property test, where each test specimen is, at the end of each ageing cycle, subjected to a specified stress, further ageing cycles being conducted until the specimen fails on testing

3.1.18

temperature group (of specimens)

number of specimens being exposed together to the same temperature ageing in the same oven

NOTE Where there is no risk of ambiguity, either temperature groups or test groups may be referred to simply as groups.

3.1.19

test group (of specimens)

number of specimens removed together from a temperature group (as above) for destructive testing

3.2 Symbols and abbreviated terms

		Clause
a, b	Regression coefficients	
a, b, c, d	Numbers of specimens for destructive tests	5.3.2.3, 7.2.3
n	Number of y -values	6.4.1
N	Total number of test specimens	5.3.2.3, 7.2.3
m_i	Number of specimens in temperature group i (censored data)	6.3.2
r	Correlation coefficient	7.6.3
F	Fisher distributed stochastic variable	6.6.1
s_y	Square root of mean square deviation of points from regression line	
x	Reciprocal thermodynamic temperature ($1/\theta$)	
y	Logarithm of time to end-point	
ϑ	Temperature, °C	
Θ	Temperature, thermodynamic (kelvins)	
Θ_0	Value in kelvins of 0 °C (273,15 K)	
τ	Time (to end-point)	
χ^2	χ^2 -distributed stochastic variable	
μ_2	Central second moment of group of values	
TI	Temperature Index	
TC	Lower 95 % confidence limit of TI	
HIC	Halving interval at temperature equal to TI	
TEP	Thermal endurance profile	
RTI	Relative temperature index	

4 Synopsis of procedures

4.1 Full procedures

The standardized procedure for the evaluation of the thermal properties of a material consists of a sequence of steps, as follows.

NOTE It is strongly recommended that the full evaluation procedure, as described below and in 5.1 to 5.8, be used. Because the calculations as specified in IEC 60216-3 are complex and tedious if carried out using a hand calculator, IEC 60216-3 also contains a computer programme which greatly simplifies the task, and, in addition, displays the thermal endurance graph on the computer screen.

- a) Preparing suitable specimens appropriate for the intended property measurements (see 5.3).
- b) Subjecting groups of specimens to ageing at several fixed levels of elevated temperature, either continuously, or cyclically for a number of periods between which the specimens are normally returned to room temperature or another standard temperature (see 5.5).
- c) Subjecting specimens to a diagnostic procedure in order to reveal the degree of ageing. Diagnostic procedures may be non-destructive or destructive determinations of a property or potentially destructive proof tests (see 5.1 and 5.2).
- d) Extending the continuous heat exposure or the thermal cycling until the specified end-point, i.e. failure of specimens or a specified degree of change in the measured property, is reached (see 5.1, 5.2 and 5.5).
- e) Reporting the test results in a way depending on the kind of ageing procedure (continuous or cyclic) and diagnostic procedure (see under item c)): ageing curves, or time or number of cycles to reach the end-point, for each specimen.
- f) Evaluating these data numerically and presenting them graphically, as explained in 6.1 and 6.8.
- g) Expressing the complete information in abbreviated numerical form, as described in 6.2 by means of the temperature index and halving interval.

The full experimental and evaluation procedures are given in clause 5 to subclause 6.8.

4.2 Simplified numerical and graphical evaluation procedures

Simplified procedures, which do not test the data dispersion but only deviations from linear behaviour, are also available. These are described in 7.1 to 7.6.

It is also possible, with some limitations, to evaluate the thermal endurance data graphically. In this case, statistical assessment of data dispersion is not possible, but it is considered important to evaluate any deviation of the data from the linear relationship. Instructions for the graphical procedures are also given in 7.1 to 7.6.

5 Detailed experimental procedures

5.1 Selection of test procedures

5.1.1 General considerations

Each test procedure should specify the shape, dimensions and number of the test specimens, the temperatures and times of exposure, the property to which TI is related, the methods of its determination, the end-point, and the derivation of the thermal endurance characteristics from the experimental data.

The chosen property should reflect, in a significant fashion if possible, a function of the material in practical use. A choice of properties is given in IEC 60216-2.

To provide uniform conditions, the conditioning of specimens after removal from the oven and before measurement may need to be specified.

5.1.2 Specific instructions for determination of TI

If IEC material specifications are available, property requirements in terms of acceptable lower limits of TI values are usually given. If such material specifications are not available, a selection of properties and methods for the evaluation of thermal endurance is given in IEC 60216-2. (If such a method cannot be found, an international, national or institution standard or a specially devised method should be used, and in that order of preference.)

5.1.3 Determination of TI for times other than 20 000 h.

In the majority of cases, the required thermal endurance characteristics are for a projected duration of 20 000 h. However, there is often a need for such information related to other longer or shorter times. In cases of longer times, the times given as requirements or recommendations in the text of this standard (for example, 5 000 h for the minimum value of the longest time to end-point) shall be increased in the ratio of the actual specification time to 20 000 h. In the same way, the ageing cycle durations should be changed in approximately the same ratio. The temperature extrapolation again shall not exceed 25 K. In cases of shorter specification times, the related times may be decreased in the same ratio if necessary.

Particular care will be needed for very short specification times, since the higher ageing temperatures may lead into temperature regions which include transition points, for example, glass transition temperature or partial melting, with consequent non-linearity. Very long specification times may also lead to non-linearity (see also annex A).

5.2 Selection of end-points

The thermal endurance of materials may need to be characterized by different endurance data (derived using different properties and/or end-points), in order to facilitate the adequate selection of the material in respect of its particular application in an insulation system. See IEC 60216-2.

There are two alternative ways in which the end-point may be defined.

- a) As a percentage increase or decrease in the measured value of the property from the original level. This approach will provide comparisons among materials but bears a poorer relationship than item b) to the property values required in normal service. For the determination of the initial value, see 5.4.