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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Electrical insulating materials – Thermal endurance properties – Part 1: Ageing procedures and evaluation of test results

Matériaux isolants électriques – Propriétés d'endurance thermique – Partie 1: Méthodes de vieillissement et évaluation des résultats d'essai

IEC 60216-1:2013

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

Part 1: Ageing procedures and evaluation of test results

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60216-1 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems.

This sixth edition cancels and replaces the fifth edition, published in 2001. It constitutes an editorial revision where the simplified method has been removed and now forms Part 8 of the IEC 60216 series: *Instructions for calculating thermal endurance characteristics using simplified procedures*.

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

FDIS	Report on voting
112/235/FDIS	112/243/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.

A list of all parts in the IEC 60216 series, published under the general title *Electrical insulating materials – Thermal endurance properties*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site 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.

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 behavior, 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 60493-1, 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), 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.

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. 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. A simplified calculation procedure is described in IEC 60216-8.

ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

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.

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

IEC 60216-2, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

IEC 60216-3:2006, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-4 (all Parts 4), *Electrical insulating materials – Thermal endurance properties – Part 4: Ageing ovens*

IEC 60216-4-1, *Electrical insulating materials – Thermal endurance properties – Part 4-1: Ageing ovens – Single-chamber ovens*

IEC 60216-8, *Electrical insulating materials – Thermal endurance properties – Part 8: Instructions for calculating thermal endurance characteristics using simplified procedures*[1]

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1 To be published.

IEC 60493-1:2011, *Guide for the statistical analysis of ageing test data – Part 1: Methods based on mean values of normally distributed test results*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and 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)

3.1.2
halving interval
HIC
numerical value of the temperature interval in Kelvin which expresses the halving of the time to end-point taken at the temperature equal to TI

[SOURCE: IEC 60050-212:2010, definition 212-12-13, modified – "equal to TI" replaces "corresponding to the temperature index or the relative temperature index"]

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

[SOURCE: IEC 60050-212:2010, definition 212-12-10, modified – "insertion of word "(absolute)"]

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)

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

Note 2 to entry: 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
test group of specimens
number of specimens being exposed together to the same temperature ageing in the same oven

Note 1 to entry: 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
test group of specimens
number of specimens removed together from a temperature group (as above) for destructive testing

3.1.20
end point
property level that is effected by practical application to the equipment in the thermal endurance test

3.2 Symbols and abbreviations

Symbol	Meaning
a,b	Regression coefficients
$n_{\mathrm{a,b,c,d}}$	Numbers of specimens for destructive tests
n	Number of y-values
N	Total number of test specimens
m_i	Number of specimens in temperature group i (censored data)
r	Correlation coefficient
F	Fisher distributed stochastic variable
x	Reciprocal thermodynamic temperature ($1/\Theta$)
y	Logarithm of time to end-point
ϑ	Temperature, °C
Θ	Temperature, thermodynamic (Kelvin)
Θ_0	Value in Kelvin (0 °C = 273,15 K)
τ	Time (to end-point)
χ^2	χ^2-distributed stochastic variable
TI	Temperature index
TC	Lower 95 % confidence limit of TI
HIC	Halving interval at temperature equal to TI
RTI	Relative temperature index

4 Synopsis of procedures – Full procedures

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

It is strongly recommended that the full evaluation procedure, as described below and in 5.1 to 5.8, be used.

a) Prepare suitable specimens appropriate for the intended property measurements (see 5.3).
b) Subject 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) Subject 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) Extend 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) Report the test results, showing the kind of ageing procedure (continuous or cyclic) and diagnostic procedure (see under item c) above); the ageing curves, or time or number of cycles to reach the end-point, for each specimen.
f) Evaluate these data numerically and present them graphically, as explained in 6.1 and 6.8.
g) Express 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 and as far as 6.8.

A simplified procedure is given in IEC 60216-8.

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 Selection of test properties for 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, for example, 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.

b) As a fixed value of the property. This value might be selected with respect to usual service requirements. End-points of proof tests are predominantly given in the form of fixed values of the property.

The end-point should be selected to indicate a degree of deterioration of the insulating material which has reduced its ability to withstand a stress encountered in actual service in an insulation system. The degree of degradation indicated as the end-point of the test should be related to the allowable safe value for the material property which is desired in practice.

5.3 Preparation and number of test specimens

5.3.1 Preparation

The specimens used for the ageing test should constitute a random sample from the population investigated and are to be treated uniformly.

The material specifications or the test standards will contain all necessary instructions for the preparation of specimens.

The thickness of specimens is in some cases specified in the list of property measurements for the determination of thermal endurance. See IEC 60216-2. If not, the thickness shall be reported. Some physical properties are sensitive even to minor variations of specimen thickness. In such cases, the thickness after each ageing period may need to be determined and reported if required in the relevant specification.

The thickness is also important because the rate of ageing may vary with thickness. Ageing data of materials with different thicknesses are not always comparable. Consequently, a material may be assigned more than one thermal endurance characteristic derived from the measurement of properties at different thicknesses.

The tolerances of specimen dimensions should be the same as those normally used for general testing; where specimen dimensions need smaller tolerances than those normally used, these special tolerances should be given. Screening measurements ensure that specimens are of uniform quality and typical of the material to be tested.

Since processing conditions may significantly affect the ageing characteristics of some materials, it shall be ensured that, for example, sampling, cutting sheet from the supply roll, cutting of anisotropic material in a given direction, molding, curing, pre-conditioning, are performed in the same manner for all specimens.

5.3.2 Number of specimens

5.3.2.1 General

The accuracy of endurance test results depends largely on the number of specimens aged at each temperature. Instructions for an adequate number of specimens are given in IEC 60216-3. Generally, the following instructions (5.3.2.1 to 5.3.2.3), which influence the testing procedure given in 5.8, shall apply.

It is good practice to prepare additional specimens, or at least to provide a reserve of the original material batch from which such specimens may subsequently be prepared. In this way, any required ageing of additional specimens in case of unforeseen complications will introduce a minimum risk of producing systematic differences between groups of specimens. Such complications may arise, for example, if the thermal endurance relationship turns out to be non-linear, or if specimens are lost due to thermal runaway of an oven.

Where the test criterion for non-destructive or proof tests is based upon the initial value of the property, this should be determined from a group of specimens of at least twice the number of specimens in each temperature group. For destructive tests, see 5.3.2.4.

5.3.2.2 Number of specimens for non-destructive tests

For each exposure temperature, in most cases a group of five specimens will be adequate. However, further guidance will be found in IEC 60216-3.

5.3.2.3 Number of specimens for proof tests

In most cases a group of at least 11 specimens for each exposure temperature will be required. For graphical derivation and in some other cases the treatment of data may be simpler if the number of specimens in each group is odd. Further guidance will be found in IEC 60216-3.

5.3.2.4 Number of specimens for destructive tests

This number (N) is derived as follows: $N = n_a \times n_b \times n_c + n_d$

where

n_a is the number of specimens in a test group undergoing identical treatment at one temperature and discarded after determination of the property (usually five);

n_b is the number of treatments, i.e. total number of exposure times, at one temperature;

n_c is the number of ageing temperature levels;

n_d is the number of specimens in the group used to establish the initial value of the property. Normal practice is to select $n_d = 2n_a$ when the diagnostic criterion is a percentage change of the property from its initial level. When the criterion is an absolute property level, n_d is usually given the value of zero, unless reporting of the initial value is required.