IEC 60216-5

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INTERNATIONAL STANDARD

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Electrical insulating materials – Thermal endurance properties – Part 5: Determination of relative temperature index (RTI) of an insulating material

Matériaux isolants électriques – Propriétés d'endurance thermique – Partie 5: Détermination de l'indice de température relatif (ITR) d'un matériau isolant

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

Part 5: Determination of relative temperature index (RTI) of an insulating material

FOREWORD

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IEC 60216-5 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is an International Standard.

This fourth edition cancels and replaces the third edition published in 2008. This edition constitutes a technical revision.

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

a) Annex C "Computer program" has been completely reworked;
b) in 3.1, the terms "ATE" and "RTE" were replaced by "ATI" and "RTI" to emphasize their reference to an electrical insulating material (EIM).

This standard is to be read in conjunction with IEC 60216-1:2013, IEC 60216-2:2005 and IEC 60216-3:2021.

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

Draft	Report on voting
112/582/FDIS	112/588/RVD

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/standardsdev/publications.

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

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ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

Part 5: Determination of relative temperature index (RTI) of an insulating material

1 Scope

This part of IEC 60216 specifies the experimental and calculation procedures to be used for deriving the relative temperature index of a material from experimental data obtained in accordance with the instructions of IEC 60216-1 and IEC 60216-2. The calculation procedures are supplementary to those of IEC 60216-3.

Guidance is also given for assessment of thermal ageing after a single fixed time and temperature, without extrapolation.

The experimental data can in principle be obtained using destructive, non-destructive or proof tests, although destructive tests have been much more extensively employed. Data obtained from non-destructive or proof tests can be “censored”, in that measurement of times taken to reach the endpoint have been terminated at some point after the median time but before all specimens have reached end-point (see IEC 60216-1).

Guidance is given for preliminary assignment of a thermal class for an electrical insulating material (EIM), based upon the thermal ageing performance.

While the thermal classification of an EIM is not directly related to the thermal classification of an electrical insulation system (EIS), the thermal classification of an EIS follows the same concepts as presented in this part of the 60216 series. The calculation procedures of this standard apply to the determination of the thermal class of an EIS when the thermal stress is the prevailing ageing factor.

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 60216-1:2013, *Electrical insulating materials – Thermal endurance properties – Part 1: Ageing procedures and evaluation of test results*

IEC 60216-2:2005, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

IEC 60216-3:2021, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

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

ISO and IEC maintain terminological 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

3.1.1
electrical insulating material
EIM
material of low electric conductivity, used to separate conducting parts at different electric potentials or to isolate such parts from the surroundings

3.1.2
assessed temperature index
ATI
numerical value of the temperature index in degrees Celsius of the reference EIM

Note 1 to entry: The value of the ATI can vary between applications for the same material.

3.1.3
candidate EIM
material for which an estimate of the thermal endurance is required to be determined

Note 1 to entry: The determination is made by simultaneous thermal ageing of the material and a reference EIM.

3.1.4
reference EIM
material with known thermal endurance (derived from service experience or previous RTI or TI evaluation), used as a reference for comparative tests with the candidate EIM

3.1.5
central second moment of a data group
sum of the squares of the differences between the data values and the value of the group mean divided by the number of data in the group

3.1.6
correlation time for RTI
estimated time to endpoint of the reference EIM at a temperature equal to its ATI in degrees Celsius

3.1.7
degrees of freedom
number of data values minus the number of parameter values

3.1.8
standard error
standard error of an estimate of the true value of a data group property is the value of the standard deviation of the hypothetical sampling population of which the group property can be considered to be a member

Note 1 to entry: For the group mean it is equal to the group standard deviation divided by the square root of the number of data in the group, and indicates the uncertainty in the true value of the mean.

Note 2 to entry: This standard is concerned only with means and the difference between two means (see Clause A.3).

3.1.9
standard deviation
square root of the variance of a data group or sub-group

3.1.10
relative temperature index
RTI
determined by test in relation to the thermal performance of a known reference EIM

3.1.11
variance of a data group
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 can, for example, be a mean value (1 parameter) or a line (2 parameters, in this document, the slope and the intercept with the y axis).

3.2 Symbols and units

a_A	Regression coefficient (y-intercept) of thermal endurance equation for reference EIM
a_B	Regression coefficient (y-intercept) of thermal endurance equation for candidate EIM
b_A	Regression coefficient (slope) of thermal endurance equation for reference EIM
b_B	Regression coefficient (slope) of thermal endurance equation for candidate EIM
X	Variable for statistical analysis equal to $1/(\vartheta + \Theta_0)$
Y	Variable for statistical analysis equal to ln (τ)
ϑ	Ageing temperature in determination of RTI
Θ_0	Temperature on Kelvin scale equal to 0 °C
τ	Time to endpoint
τ_c	Estimated time to endpoint of reference EIM at a temperature equal to ATI ("correlation time")
$\mu_{2(A)}$	Central second moment of x values for reference EIM
$\mu_{2(B)}$	Central second moment of x values for candidate EIM
n_A	Number of y values for reference EIM data
n_B	Number of y values for candidate EIM data
T	Student's t distributed stochastic variable

S	Standard error of the difference of two means
s_A^2	Variance of y values for reference EIM data
s_B^2	Variance of y values for candidate EIM data
$\bar{x}_A$	General mean of x-values for reference EIM data
$\bar{x}_B$	General mean of x-values for candidate EIM data
$\bar{y}_A$	General mean of y-values for reference EIM data
$\bar{y}_B$	General mean of y-values for candidate EIM data
θ_A	Temperature in degrees Celsius equal to ATI
θ_B	Temperature in degrees Celsius equal to RTI
$\hat{X}_B$	x value corresponding to θ_B
$\hat{X}_A$	x value corresponding to θ_A
$\theta_{c(B)}$	Lower confidence limit of θ_B
$\theta_{c(A)}$	Lower confidence limit of θ_A
$X_{L(B)}$	x value corresponding to lower confidence limit of θ_B
$X_{L(A)}$	x value corresponding to lower confidence limit of θ_A
Δ_B	Lower confidence interval of θ_B
Δ_A	Lower confidence interval of θ_A
$HIC_{B(c)}$	Halving interval of candidate EIM at a time equal to τ_c
s_D^2	Variance associated with the difference between the mean y-values for the two materials
n_D	Degrees of freedom of s_D^2
υ_A, υ_B	Logarithms of the longest mean times to endpoint for materials A and B
b_r	Intermediate variable: adjusted value of b for calculation of temperature confidence interval
s_r	Intermediate variable: adjusted value of s for calculation of temperature confidence interval

4 Objectives of RTI determination

The objectives of the determination are as follows.

a) To exploit an assumed relationship between thermal endurance (with an appropriate test criterion for ageing) and service performance, and to use this to predict a value for a preliminary assessment of service temperature of a material for which there is relatively little service experience (by comparison with a known reference EIM, see Clauses 5 and 6).

   In the majority of cases, this will involve extrapolation to a longer time and/or lower temperature than in the experimental data. This extrapolation should be kept to a minimum by appropriate choice of ageing temperatures and times since the uncertainty in the result increases rapidly as the extrapolation is increased. However, even when there is no extrapolation, the uncertainty is still finite, on account of the variances of the experimental data and experimental errors.

b) To improve the precision of a thermal endurance determination by reduction of systematic errors in the ageing process. If, after ageing, the results for the reference EIM are found to be significantly different from earlier experience, this may indicate changes in material or equipment. This may be investigated and possibly corrected. In any case, the simultaneous ageing of reference and candidate will at least partially compensate for the systematic changes. Statistical procedures for use in assessing the significance of changes are given in Annex A.

c) To provide instructions for assigning a thermal class to an EIM.

5 Experimental procedures

5.1 Selection of reference EIM

The primary requirement for the reference EIM is that it has a known temperature index (ATI) for the application under consideration. The temperature index, if determined by an RTI procedure, is preferably supported by actual service experience (see Annex D).

The expected ageing mechanisms and rates of both materials shall be similar, and relevant to the application.

5.2 Selection of diagnostic test for extent of ageing

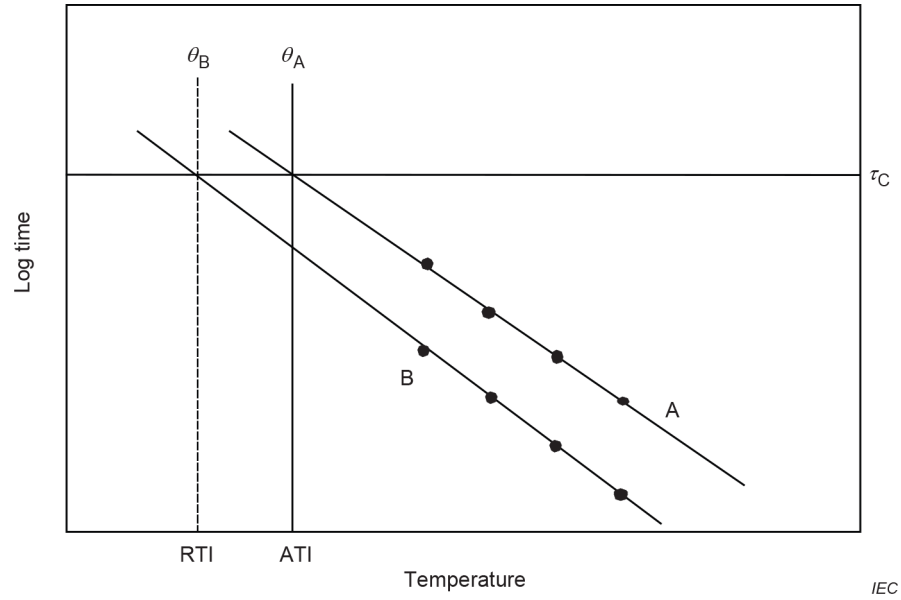
The diagnostic test shall be one considered relevant to the application for which the RTI is required. The same test shall be applied to both reference and candidate EIM.

5.3 Ageing procedures

The number and type of test specimens of each material and the ageing temperatures and times shall be in accordance with the requirements of IEC 60216-1:2013, 5.3.2, 5.4 and the first paragraph of 5.5. At each common ageing temperature, the oven load shall comprise appropriate numbers of test specimens of both materials in the same oven. The specimens shall be evenly distributed in the oven so that there is likely to be no systematic difference between the ageing conditions applied to the specimens of the two materials. It is important that test specimens of both materials are aged simultaneously at a minimum of three temperatures to be included in the calculations.

NOTE As an example, while the data represented in Figure 1 would be acceptable for analysis of the data represented by Figure 2, the lowest temperature group of the candidate EIM and the highest temperature group of the reference cannot be included, since in each case, the specimen group is made up of only one material or one of the two materials did not reach the chosen end point within the test time.

If, when ageing at the selected temperatures is completed, the results from either material do not meet the requirements of criteria b) in 7.1 of this document, a further specimen group shall be aged, within the same oven, at an appropriate temperature. This group shall again be composed of the required number and type of specimens of each material.

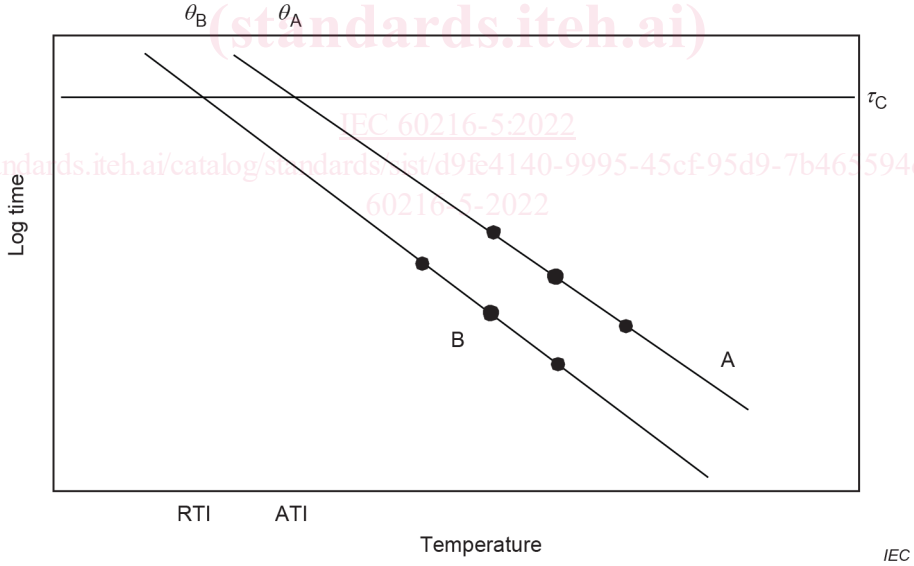


Key

A = reference EIM

B = candidate EIM

Figure 1 – Thermal endurance graphs



Key

A = reference EIM

B = candidate EIM

NOTE The test specimens of both materials are not aged simultaneously at a minimum of three temperatures.

Figure 2 – Unacceptable thermal endurance graphs

6 Calculation procedures

6.1 Thermal endurance data – Calculation of intermediate parameters

Calculation of the thermal endurance equations shall be made in accordance with the instructions of IEC 60216-3.

The following input parameters as set out in Table 1 are needed for the calculations relevant to RTI and should be recorded (each of the symbols may have either subscript A for reference EIM or B for candidate EIM).

Table 1 – Input parameters for the calculations concerning RTI

Parameter	Symbol in IEC 60216-3	Equation in IEC 60216-3	Symbol in IEC 60216-5	
Slope of regression line	b	(33)	b_A	b_B
Intercept of regression line	a	(34)	a_A	a_B
Weighted mean of x values	$\overline{x}$	(26)	$\overline{x}_A$	$\overline{x}_B$
Central 2nd moment of x values	$\mu_2(x)$	(31)	$\mu_{2(A)}$	$\mu_{2(B)}$
Weighted mean of y values	$\overline{y}$	(27)	$\overline{y}_A$	$\overline{y}_B$
Variance of y values	s^2	(41)	s_A^2	s_B^2
Number of y values	N	(25)	n_A	n_B
Halving interval	HIC	(53)	–	$HIC_{B(c)}$
Largest mean log time to endpoint	$\overline{y}_k$	–	υ_A	υ_B
Lower confidence limit of θ	$\hat{\vartheta}_c$	(50)	$\theta_{c(A)}$	$\theta_{c(B)}$
NOTE If the calculations of IEC 60216-3 are performed by the recommended computer programme of Annex C, the values of $\theta_{c(A)}$ and $\theta_{c(B)}$ may be calculated directly in that program.				

The result of the linearity test (IEC 60216-3:2021, 6.3.2) is also necessary.

6.2 Calculation of RTI

Calculation of the coefficients of the thermal endurance equations shall be made for both reference and candidate EIMs in accordance with the instructions of 6.1 and 6.2 of IEC 60216-3:2021 (see 6.1 of this document). From these coefficients, the values of τ_c and θ_B shall be calculated as below (see also Figure 1).

a) From the regression coefficients of the reference EIM, calculate the time τ_c corresponding to its ATI:

$$\ln \tau_c = a_A + \frac{b_A}{(\theta_A + \Theta_0)} \quad (1)$$

b) From the regression coefficients of the candidate EIM, calculate the temperature corresponding to the time τ_c:

$$\theta_B = \frac{b_B}{[\ln(\tau_c) - a_B]} - \Theta_0 \quad (2)$$

The required RTI is equal to the value of θ_B in degrees Celsius.

6.3 Statistical and numerical tests

6.3.1 Tests of IEC 60216-3

The statistical and numerical tests of IEC 60216-3 shall be carried out before the calculations of this standard, and their results employed in compiling the report of 7.3.

6.3.2 Precision of correlation time

Where a reference EIM has been tested on a previous occasion, with the same diagnostic test and ATI, the values of τ_c should be compared using the Student's t-test for the difference of two means. A significant difference may imply a change in the reference EIM itself, a change in the oven equipment or a change in the test apparatus. The cause should be investigated and reported.

Statistical procedures for assessing the significance of differences between values are given in Annex A.

6.3.3 Lower confidence interval of RTI

The lower confidence limit of RTI is calculated from the lower confidence limits of temperature estimates equal to θ_A and θ_B (IEC 60216-3:2021, 6.3.3 b), Equations (46) to (50)).

The lower confidence limit of θ_B, $\theta_{c(B)}$, is calculated as in IEC 60216-3:2021, 6.3.3 b) for a time equal to τ_c and subtracted from θ_B to give the confidence interval Δ_B.

$$X_{L(B)} = \bar{x}_B + \frac{(Y - \bar{y}_B)}{b_r} + \frac{t\, s_r}{b_r} \tag{3}$$

$$Y = \ln \tau_c \quad ; \quad \hat{X}_B = (Y - a_B) / b_B \tag{4}$$

$$\text{where } b_r = b_B - \frac{t^2 s_B^2}{b_B\, \mu_{2(B)}} \tag{5}$$

$$s_r^2 = s_B^2 \left(\frac{b_r}{b_B} + \frac{\left(\hat{X} - \bar{x}_B\right)^2}{\mu_{2(B)}} \right) \tag{6}$$

Where

t is the value of Student's t for n_B degrees of freedom and a significance level of 0,05 (see Table B.3);

$\mu_{2(B)}$ is the central second moment of the x values: