IEC 60216-5

Edition 4.0 2022-11
COMMENTED VERSION

INTERNATIONAL STANDARD

colour inside

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

IEC 60216-5:2022-11 CMV(en)

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

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

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INTERNATIONAL
ELECTROTECHNICAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

Part 5: Determination of ~~relative thermal endurance index (RTE)~~ relative temperature index (RTI) 1 of an insulating material

FOREWORD

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This commented version (CMV) of the official standard IEC 60216-5:2022 edition 4.0 allows the user to identify the changes made to the previous IEC 60216-5:2008 edition 3.0. Furthermore, comments from IEC TC 112 experts are provided to explain the reasons of the most relevant changes, or to clarify any part of the content.

A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text. Experts' comments are identified by a blue-background number. Mouse over a number to display a pop-up note with the comment.

This publication contains the CMV and the official standard. The full list of comments is available at the end of the CMV.

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 thermal endurance index (RTE)~~ 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 ~~thermal endurance~~ 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 ~~may~~ can **2** 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 ~~may~~ can **3** be "censored", in that measurement of times taken to reach the endpoint ~~may~~ **4** 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) **5**, 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. **6** 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:~~2001~~2013 **7**, *Electrical insulating materials – Thermal endurance properties – Part 1: Ageing procedures and evaluation of test results*

IEC 60216-2:2005 **8**, *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~~2021 **9**, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

3 Terms, definitions, symbols and units ~~and abbreviations~~ 10

3.1 Terms~~, abbreviations,~~ and definitions

For the purposes of this document, the following terms and definitions~~, symbols, units and abbreviated terms~~ 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 11

3.1.1
electrical insulating material
EIM
~~solid or fluid with negligibly low electric conductivity, or a simple combination of such materials, used to separate conducting parts at different electrical potential in electrotechnical devices~~

material of low electric conductivity, used to separate conducting parts at different electric potentials or to isolate such parts from the surroundings 12

~~**3.1.2**~~
~~**assessed thermal endurance index**~~
~~**ATE**~~
~~numerical value of the temperature in degrees Celsius, up to which the reference EIM possesses known, satisfactory service performance in the specified application~~

~~NOTE 1 The value of the ATE may vary between applications for the same material.~~

~~NOTE 2 Sometimes referred to as "absolute" thermal endurance index.~~

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. 13

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~~, preferably~~ (derived from service experience or previous RTI or TI evaluation) 14, 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 15
estimated time to endpoint of the reference EIM at a temperature equal to its ~~assessed thermal endurance (ATE)~~ 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 ~~may~~ can **16** 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 thermal endurance index**~~
~~**RTE**~~
~~numerical value of the temperature in degrees Celsius at which the estimated time to endpoint of the candidate EIM is the same as the estimated time to endpoint of the reference EIM at a temperature equal to its assessed thermal endurance (ATE)~~

3.1.10
relative temperature index
RTI
determined by test in relation to the thermal performance of a known reference EIM **17**

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 ~~may~~ can **18**, 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 ~~RTE~~ 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 ~~ATE~~ 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 ~~ATE~~ ATI
θ_{B}	Temperature in degrees Celsius equal to ~~RTE~~ 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}
$\mathrm{HIC}_{B(c)}$	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 RTE 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).

NOTE 19 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 thermal endurance index (ATE) temperature index (ATI) for the application under consideration. The thermal endurance temperature index, if determined by an RTE 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

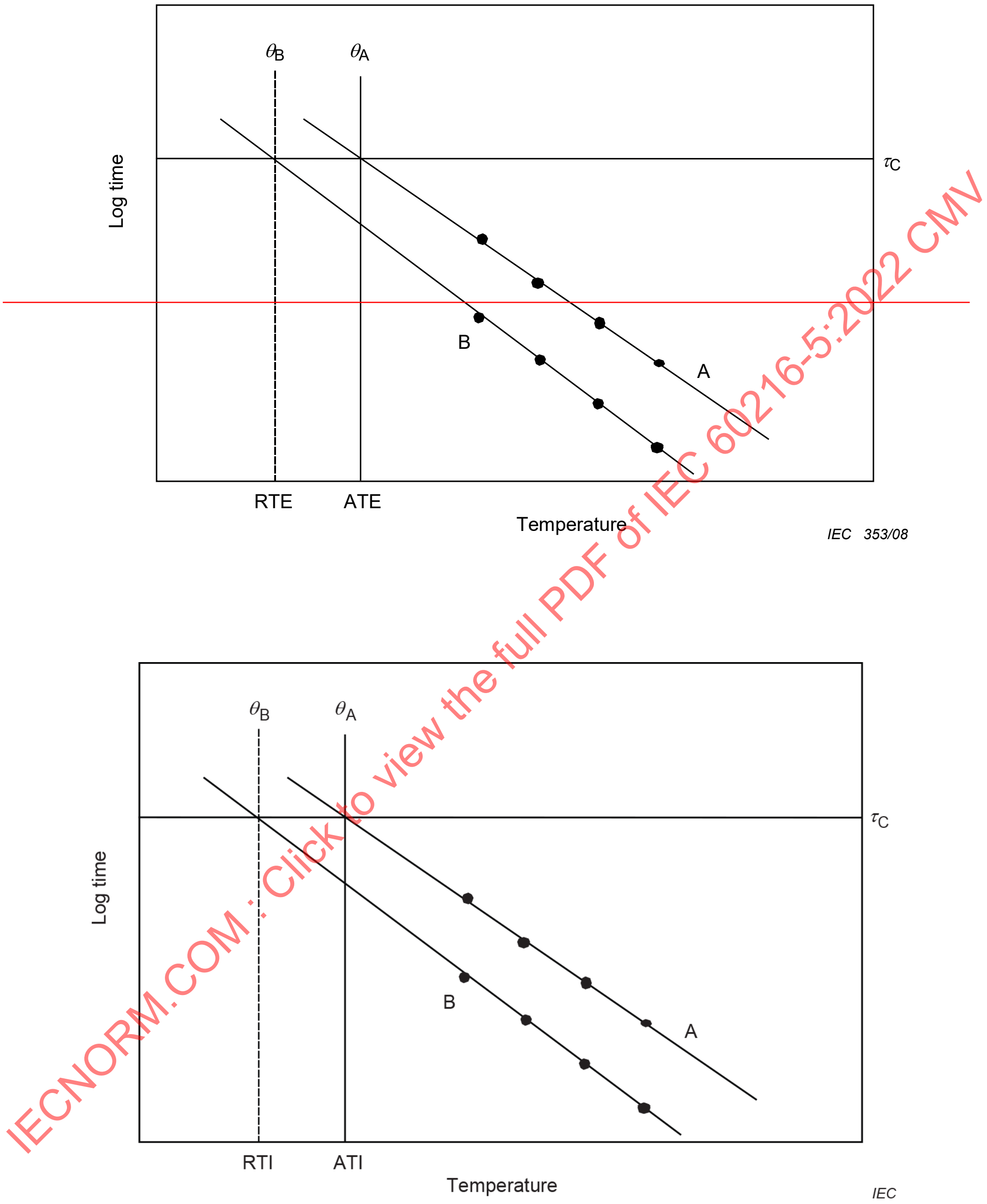
The diagnostic test shall be one considered relevant to the application for which the RTE RTI is required. The same test shall be applied to both reference and candidate EIM.

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 20 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.

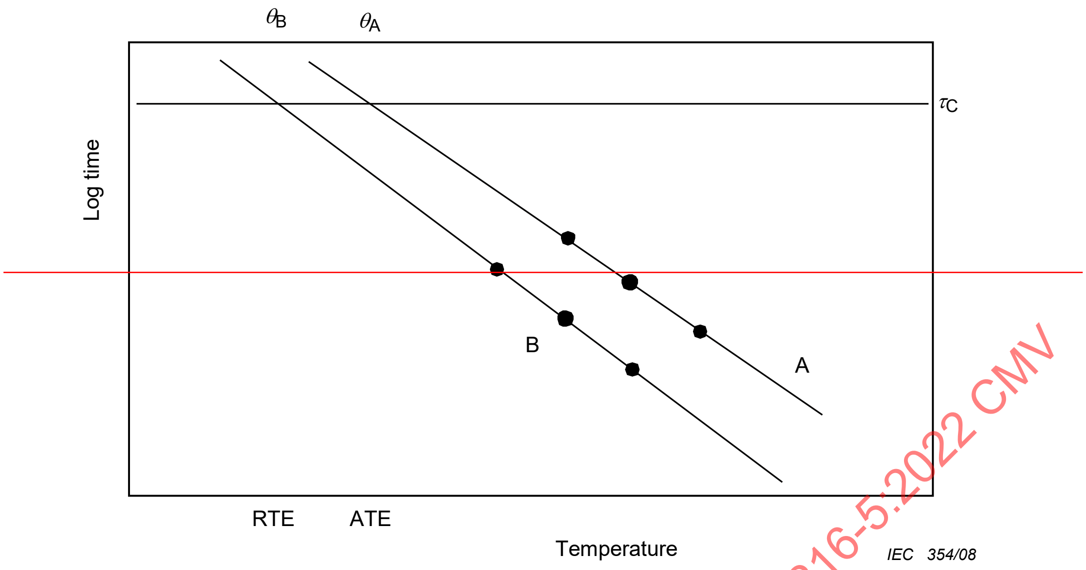


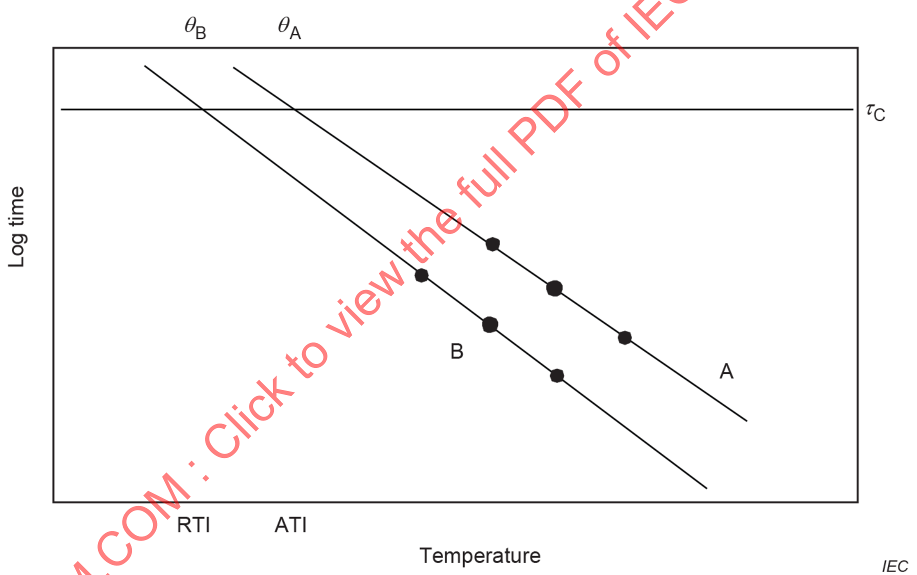
Key

A = reference EIM

B = candidate EIM

Figure 1 – Thermal endurance graphs 21





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 22

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 ~~RTE~~ 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 ~~RTE~~ 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	$\bar{x}$	(26)	$\bar{x}_A$	$\bar{x}_B$
Central 2nd moment of x values	$\mu_2(x)$	(31)	$\mu_{2(A)}$	$\mu_{2(B)}$
Weighted mean of y values	$\bar{y}$	(27)	$\bar{y}_A$	$\bar{y}_B$
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	$\bar{y}_k$	–	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 **23**, ~~subroutines should be included to record the parameters in a data file which can be recalled for the purposes of the present calculations. Alternatively,~~ 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 ~~needed~~ necessary **24**.

6.2 Calculation of ~~RTE~~ 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 ~~ATE~~ ATI:

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

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

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

The required ~~RTE~~ 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 ~~ATE~~ 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 ~~RTE~~ RTI

The lower confidence limit of ~~RTE~~ 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.

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

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

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

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

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:

$$\mu_{2(B)} = \frac{1}{n_B} \sum_{i=1}^{k} n_{i(B)} \left(x_{i(B)} - \bar{x}_{(B)} \right)^2 \tag{7}$$

(see IEC 60216-3:2021, 6.2.2 for details).

The lower confidence limit of θ_A , $\theta_{c(A)}$ is calculated as above for a time equal to τ_c and subtracted from θ_A to give the confidence interval Δ_A.

The lower confidence interval of ~~RTE~~ RTI, Δ_R, is then equal to the “Pythagorean” (orthogonal) vector sum of the above two intervals:

$$\Delta_R = \sqrt{\left(\Delta_A^2 + \Delta_B^2\right)} \tag{8}$$

6.3.4 Extrapolation

The extrapolation required to estimate the correlation time is calculated for both reference and candidate EIMs as the difference between the logarithm of the correlation time and the greatest value of the mean of the logarithms of the ageing times to endpoint (υ_A or υ_B). The extrapolation required is the greater of these two values.

7 Results and report 25

7.1 Results of statistical and numerical tests

The following criteria apply:

a) linearity of thermal endurance relationships and confidence intervals of TI results of both reference and candidate EIMs (see IEC 60216-3:2021, 6.3.2 and 6.3.3) which shall satisfy the requirements of IEC 60216-3, 7.3.1 and 7.3.2;

b) extrapolation to the correlation time (see 6.3.4 above): the extrapolation, expressed as the ratio of correlation time to greatest geometric mean ageing time shall be less than 4;

c) lower confidence interval of ~~RTE~~ RTI (see 6.3.3 above): The value of Δ_R shall be less than the halving interval ($HIC_{B(c)}$) of the candidate EIM at a time equal to the correlation time (see IEC 60216-3:2021, 7.1).

$$HIC_{B(c)} = b_B \left[\frac{1}{\left(\left(\ln \tau_c / 2\right) - a_B\right)} - \frac{1}{\left(\ln \tau_c - a_B\right)} \right] \tag{9}$$

7.2 Results

The results shall be determined from the calculations of 6.2 and 6.3.3 as follows.

a) If all three test criteria (see 7.1) are met, the result shall be the value of ~~RTE~~ RTI. The result shall be reported in the format: "~~RTE~~ RTI according to IEC 60216-5 = xxx" rounded to one full degree Celsius 26.

b) If one of the test criteria is not met, the result shall be the lower 95 % confidence limit of ~~RTE~~ RTI. The result shall be reported in the format: "~~RTE~~ RTI lower 95 % confidence limit = xxx" rounded to one full degree Celsius 27.

c) If two or more of the criteria are not met, a result in accordance with the requirements of IEC 60216-5 cannot be reported. The result may be reported in the format: "~~RTE~~ RTI = xxx. (Result not validated by the statistical analysis)".

7.3 Report

The report shall comprise the following:

a) the result;

b) the identification of the reference EIM and its ~~ATE~~ ATI (see Annex D);

c) the diagnostic test employed and the endpoint;

d) the thermal endurance reports according to IEC 60216-1 for the reference and candidate EIMs;

e) the details of the failure of statistical validation for a result in category 7.2 c).

8 Material testing by short-term thermal ageing

There is often a need for short-term thermal ageing tests on materials, e.g. to compare thermal performances of materials having slight chemical modifications with respect to a known reference EIM, or in quality reference testing of insulation containing anti-oxidant constituents, where ageing at the rated temperature of the material for a period of a few thousand hours could be employed.

The interpretation of such tests can be quite difficult, particularly if the ageing is at a single temperature, with property measurement after a single fixed time. The absence of testing for compliance with a chemical kinetic model leads to a liability to systematic errors caused by equipment or material changes.

It is recommended that in such cases, a reference EIM of similar type and rating as the test material should be aged simultaneously and tested after the same time. A similar analysis to that of Annex A can then be applied to the two sets of property values to establish whether there are significant differences between

a) the candidate EIM and the reference EIM, or

b) the current test values of the reference EIM and the historical values obtained on the same material.

In this analysis, s_1^2 and s_2^2 are the variances of the groups of property values after ageing at the test temperature; $\bar{y}_1$ and $\bar{y}_2$ are the means of these groups (see Equations (A.1) to (A.4)).

Unless otherwise specified, the test for significant difference shall be made at a level of 0,05 (see ~~Table B.1~~ Table B.2).

If significant differences are not found, it ~~may~~ can **28** be assumed that the thermal endurance performances of the two materials being compared are the same. If significant differences are found in case a) above, it is likely that the performance of the candidate EIM will not be the same as that of the reference. If significant differences are found in case b) above, then it is likely that the ageing conditions differ in some way from those originally employed: they should be investigated, and the cause established.

9 Insulation classification

When required, the candidate EIM may be assigned to an insulation thermal class in accordance with Annex B, Table B.1.

Annex A
(informative)

Repeatability of correlation time

A.1 Overview

Where a reference EIM has been tested on a previous occasion, the values of τ_c should be compared. A significant difference ~~may~~ can 29 imply a change in the reference EIM itself, or possibly a change in the oven equipment or a change in the test apparatus. The cause should be investigated and reported.

The comparison is made using the Student's t-test for the difference of two means, by the procedures below. The suffixes 1 and 2 refer to the two sets of data. In the equations, the values $\bar{y}_1$ and $\bar{y}_2$ are the logarithms of the two values of correlation time.

A.2 F-test for ~~equality of variances~~ linearity 30

The variances of the y-values for the reference EIMs in the present and previous determinations (s_1^2 and s_2^2) shall be calculated in accordance with the instructions of IEC 60216-3:2021 [6.3.2, Equation (41) or (42)]. Their ratio is then tested for linearity i.e. equality of the variances by the F-test on a significance level of 0,05 with degrees of freedom n_1-2 and n_2-2 (see ~~Table B.1~~ Table B.2).

NOTE The symbols s_1^2 and s_2^2 here refer to the estimates of variance for the material on occasions 1 and 2, and not to the within and between classes as given in IEC 60216-3:2021, Equations (41) and (42).

A.3 Standard error of the difference of two means

The values of variance are combined using Equations (A.1) and (A.2) if the values are not significantly different:

$$s_D^2 = \frac{s_1^2\left(n_1 - 1\right) + s_2^2\left(n_2 - 1\right)}{\left(n_1 + n_2 - 2\right)}\left(\frac{1}{n_1} + \frac{1}{n_2}\right) \quad \text{(A.1)}$$

$$n_D = \left(n_1 + n_2 - 2\right) \quad \text{(A.2)}$$

If the values of variance are significantly different, then Equations (A.3) and (A.4) shall be used. In this case the value n_D may not be an integer. The nearest integer (rounded up or down as appropriate) shall then be employed in subsequent calculations.

$$s_D^2 = \frac{s_1^2}{n_1} + \frac{s_2^2}{n_2} \quad \text{(A.3)}$$

$$n_{\mathrm{D}}=\frac{\left(s_{\mathrm{D}}^{2}\right)^{2}}{\frac{\left(\frac{s_{1}^{2}}{n_{1}}\right)^{2}}{n_{1}-1}+\frac{\left(\frac{s_{2}^{2}}{n_{2}}\right)^{2}}{n_{2}-1}} \tag{A.4}$$

The square root of the value of s_{D}^{2} is the standard error, s, of the difference of the general means of the y-values.

NOTE When the values of n_1 and n_2 are equal, Equations (A.1) and (A.3) become identical.

A.4 Student's t-test for difference of two means

When two estimates of a mean value (which in this case includes estimates by linear regression) are obtained from separate sets of data and the true values are expected to be the same, their equality may be tested by the Student's t-test. The principle of this test is to calculate the ratio of the difference of the mean estimates to the standard error of this difference. The variances of the two data sets are combined in the same way as the variances in Clause A.3 and the standard error calculated.

The value of t is the ratio of the difference of the means to the standard error:

$$t=\frac{\left(\bar{y}_{1}-\bar{y}_{2}\right)}{\sqrt{s_{\mathrm{D}}^{2}}} \tag{A.5}$$

The associated number of degrees of freedom is n_{D} or the nearest integer. If the value of t is greater than the value for a significance level of 0,05 given in ~~Table B.2~~ Table B.3, the difference is considered to be significant and its cause should be investigated.

For the purposes of 6.3.2, in the calculations of Equations (A.1) to (A.5), the values of s_1^2 and s_2^2 are obtained using Equation (45) of IEC 60216-3:2021, 6.3.3, which is:

$$s_{Y}^{2}=\frac{s^{2}}{N}\left[1+\frac{(X-\bar{x})^{2}}{\mu_{2}(x)}\right]$$

$$s_{1}^{2}=\left|N\,s_{Y}^{2}\right|_{1} \quad \text{and} \quad s_{2}^{2}=\left|N\,s_{Y}^{2}\right|_{2} \tag{A.6}$$

The values of $\bar{y}_1$ and $\bar{y}_2$ are the logarithms of the two values of τ_{c}.

A.5 Combination of data

If the two results for correlation time and the two values of variance are not significantly different, a more precise estimate of the logarithm of correlation time may be obtained by merging the two sets of data:

$$\bar{y} = \frac{(n_1\bar{y}_1 + n_2\bar{y}_2)}{(n_1 + n_2)} \tag{A.7}$$

$$s^2 = \frac{s_1^2(n_1 - 1) + s_2^2(n_2 - 1)}{(n_1 + n_2 - 2)} \tag{A.8}$$

Annex B
(informative)

Thermal class assignment

Table B.1 relates the thermal class assignment, when required, to the value of ~~ATE/RTE~~ ATI/RTI, in accordance with IEC 60085.

Table B.1 – Thermal class equivalents for insulating material

~~ATE/RTE~~ ATI/RTI °C		Thermal class °C	Letter designation
≥90	<105	90	Y
≥105	<120	105	A
≥120	<130	120	E
≥130	<155	130	B
≥155	<180	155	F
≥180	<200	180	H
≥200	<220	200	N
≥220	<250	220	R
≥250	<275	250	

[a] If desired, the letter designation may be added in parentheses, e.g. Class 180 (H). Where space is a factor, such as on a nameplate, the product TC may elect to use only the letter designation.

[b] Designations of thermal classes over 250 shall increase by increments of 25 and be designated accordingly.

Table B.2 and Table B.3 give the values of F and of Student's t for significance levels of 0,05 and 0,005.

NOTE 1 The significance, p, is equal to 1-P, where P is the probability of the stochastic variable (F or t) being less than the tabulated value.

The columns of the F table (Table B.2) represent the number of degrees of freedom of the numerator and the rows the number of degrees of freedom of the denominator.

The columns of the t table (Table B.3) represent the number of degrees of freedom and the rows the significance level (p).

NOTE 2 The tables include significance levels of 0,05 and 0,005 in case they ~~should~~ are needed at any time ~~be needed~~. For present purposes, the 0,005 values ~~may~~ can be deleted, but they are on record for future use.

Table B.2 – F– function; p = 0,05

	10	11	12	13	14	15	16	17	18	19	20	25	30	40	50	100	500
10	2,978	2,943	2,913	2,887	2,865	2,845	2,828	2,812	2,798	2,785	2,774	2,730	2,700	2,661	2,637	2,588	2,548
11	2,854	2,818	2,788	2,761	2,739	2,719	2,701	2,685	2,671	2,658	2,646	2,601	2,570	2,531	2,507	2,457	2,415
12	2,753	2,717	2,687	2,660	2,637	2,617	2,599	2,583	2,568	2,555	2,544	2,498	2,466	2,426	2,401	2,350	2,307
13	2,671	2,635	2,604	2,577	2,554	2,533	2,515	2,499	2,484	2,471	2,459	2,412	2,380	2,339	2,314	2,261	2,218
14	2,602	2,565	2,534	2,507	2,484	2,463	2,445	2,428	2,413	2,400	2,388	2,341	2,308	2,266	2,241	2,187	2,142
15	2,544	2,507	2,475	2,448	2,424	2,403	2,385	2,368	2,353	2,340	2,328	2,280	2,247	2,204	2,178	2,123	2,078
16	2,494	2,456	2,425	2,397	2,373	2,352	2,333	2,317	2,302	2,288	2,276	2,227	2,194	2,151	2,124	2,068	2,022
17	2,450	2,413	2,381	2,353	2,329	2,308	2,289	2,272	2,257	2,243	2,230	2,181	2,148	2,104	2,077	2,020	1,973
18	2,412	2,374	2,342	2,314	2,290	2,269	2,250	2,233	2,217	2,203	2,191	2,141	2,107	2,063	2,035	1,978	1,929
19	2,378	2,340	2,308	2,280	2,256	2,234	2,215	2,198	2,182	2,168	2,155	2,106	2,071	2,026	1,999	1,940	1,891
20	2,348	2,310	2,278	2,250	2,225	2,203	2,184	2,167	2,151	2,137	2,124	2,074	2,039	1,994	1,966	1,907	1,856
25	2,236	2,198	2,165	2,136	2,111	2,089	2,069	2,051	2,035	2,021	2,007	1,955	1,919	1,872	1,842	1,779	1,725
30	2,165	2,126	2,092	2,063	2,037	2,015	1,995	1,976	1,960	1,945	1,932	1,878	1,841	1,792	1,761	1,695	1,637
40	2,077	2,038	2,003	1,974	1,948	1,924	1,904	1,885	1,868	1,853	1,839	1,783	1,744	1,693	1,660	1,589	1,526
50	2,026	1,986	1,952	1,921	1,895	1,871	1,850	1,831	1,814	1,798	1,784	1,727	1,687	1,634	1,599	1,525	1,457
100	1,927	1,886	1,850	1,819	1,792	1,768	1,746	1,726	1,708	1,691	1,676	1,616	1,573	1,515	1,477	1,392	1,308
500	1,850	1,808	1,772	1,740	1,712	1,686	1,664	1,643	1,625	1,607	1,592	1,528	1,482	1,419	1,376	1,275	1,159

F– function; p = 0,005

	10	11	12	13	14	15	16	17	18	19	20	25	30	40	50	100	500
10	5,847	5,746	5,661	5,589	5,526	5,471	5,422	5,379	5,340	5,305	5,274	5,153	5,071	4,966	4,902	4,772	4,666
11	5,418	5,320	5,236	5,165	5,103	5,049	5,001	4,959	4,921	4,886	4,855	4,736	4,654	4,551	4,488	4,359	4,252
12	5,085	4,988	4,906	4,836	4,775	4,721	4,674	4,632	4,595	4,561	4,530	4,412	4,331	4,228	4,165	4,037	3,931
13	4,820	4,724	4,643	4,573	4,513	4,460	4,413	4,372	4,334	4,301	4,270	4,153	4,073	3,970	3,908	3,780	3,674
14	4,603	4,508	4,428	4,359	4,299	4,247	4,200	4,159	4,122	4,089	4,059	3,942	3,862	3,760	3,698	3,569	3,463
15	4,424	4,329	4,250	4,181	4,122	4,070	4,024	3,983	3,946	3,913	3,883	3,766	3,687	3,585	3,523	3,394	3,287
16	4,272	4,179	4,099	4,031	3,972	3,920	3,875	3,834	3,797	3,764	3,734	3,618	3,539	3,437	3,375	3,246	3,139
17	4,142	4,050	3,971	3,903	3,844	3,793	3,747	3,707	3,670	3,637	3,607	3,492	3,412	3,311	3,248	3,119	3,012
18	4,030	3,938	3,860	3,793	3,734	3,683	3,637	3,597	3,560	3,527	3,498	3,382	3,303	3,201	3,139	3,009	2,901
19	3,933	3,841	3,763	3,696	3,638	3,587	3,541	3,501	3,465	3,432	3,402	3,287	3,208	3,106	3,043	2,913	2,804
20	3,847	3,756	3,678	3,611	3,553	3,502	3,457	3,416	3,380	3,347	3,318	3,203	3,123	3,022	2,959	2,828	2,719
25	3,537	3,447	3,370	3,304	3,247	3,196	3,151	3,111	3,075	3,043	3,013	2,898	2,819	2,716	2,652	2,519	2,406
30	3,344	3,255	3,179	3,113	3,056	3,006	2,961	2,921	2,885	2,853	2,823	2,708	2,628	2,524	2,459	2,323	2,207
40	3,117	3,028	2,953	2,888	2,831	2,781	2,737	2,697	2,661	2,628	2,598	2,482	2,401	2,296	2,230	2,088	1,965
50	2,988	2,900	2,825	2,760	2,703	2,653	2,609	2,569	2,533	2,500	2,470	2,353	2,272	2,164	2,097	1,951	1,821
100	2,744	2,657	2,583	2,518	2,461	2,411	2,367	2,326	2,290	2,257	2,227	2,108	2,024	1,912	1,840	1,681	1,529
500	2,562	2,476	2,402	2,337	2,281	2,230	2,185	2,145	2,108	2,075	2,044	1,922	1,835	1,717	1,640	1,460	1,260

Table B.3 – *t*–function

	10	11	12	13	14	15	16	17	18	19	20	25	30	40	50	100	500
p = 0,05	1,812	1,796	1,782	1,771	1,761	1,753	1,746	1,740	1,734	1,729	1,725	1,708	1,697	1,684	1,676	1,660	1,648
p = 0,005	3,169	3,106	3,055	3,012	2,977	2,947	2,921	2,898	2,878	2,861	2,845	2,787	2,750	2,704	2,678	2,626	2,586

Annex C
(informative)

Computer program

C.1 Computer programs for IEC 60216-5:2008 (RTE)

C.1.1 General

The standard is accompanied by a CDROM.

This CDROM contains three programs for calculation of the Relative Thermal Endurance Index of an insulating material, from data in accordance with IEC 60216-1 and 60216-3. It also contains a pair of data files for trial purposes. 31

All programs are supplied as source code, suitable for Microsoft Quick Basic 4.5 or Professional Basic v.7 (to enable use with Visual Basic, considerable editing will probably be required) and as executable program files to run in a DOS window under any variety of Windows. For optimum performance, the DOS window should be full screen.

C.1.2 Entry.exe and Entry.bas

This is identical to the data entry file supplied in an annex of IEC 60216-3. A separate set of data is required for each material, Control and Candidate.

C.1.3 IEC 216-5.exe and IEC 216-5.bas

This program is an enhanced version of the program supplied in an annex of IEC 60216-3. It has been enhanced by addition of a procedure to record to a data file the intermediate data required for calculation of RTE. When the experimental data are processed, the intermediate data are automatically saved to a file with the same name as the experimental data file and the ending “.int”. For example, a data file n3.dst of destructive test data would generate an intermediate file n3.int. The thermal endurance graph is drawn to screen for each material, and the statistical test results are reported.

C.1.4 RTE.exe and RTE.bas

This program requests the intermediate data files for Control and Candidate, and performs the calculations of IEC 60216-5, giving the RTE and its confidence interval, the halving intervals of both materials (HIC), the correlation time and the ratio of the correlation time to the longest time-to-endpoint (extrapolation). These values are required for the purposes of 6.1 and 6.2 of the standard.

C.2 Data file structure

C.2.1 Experimental data

The structure of these files is explained in IEC 60216-3.

C.2.2 Intermediate data

The following values are recorded, one to each line in the file, which is a simple ASCII text file.

General mean of *x*-values (reciprocal Kelvin temperatures): $\bar{x}$

General mean of *y*-values (logarithm of time values) : $\bar{y}$

Moyenne générale des valeurs de *y* (logarithme des durées): $\bar{y}$

Non-regression variance of *y*-values: *s*

Number of y-values: *n*

Regression slope: *b*

Regression intercept: *a*

Longest ageing time to endpoint: *υ*

C.3 Data files

There are two data files, Control.dta and Candidate.dta. For simplicity, these are non-destructive test data, although in practice, destructive tests are much more widely used in RTE work. If used as input for iec216-5.exe, they will generate the corresponding intermediate variable files (which are also provided on the diskette for confirmation purposes).

The operation of RTE.exe can be demonstrated using these files Control.int and Candidate.int.

C.1 General

C.1.1 Overview

The program supplementing this document as well as IEC 60216-3:2021 and IEC 60216-6:–, is written in the programming language Java®[1] and makes use of the JavaFX technology for graphical user interfaces. It is for use in conjunction with a Java Runtime Environment (JRE) from Oracle® in version 1.8.101 or later. The JRE is available for download at https://www.java.com/download for several operating systems[2] running on either 32-bit or 64-bit computers.

The package itself is available for download from https://www.iec.ch/tc112/supportingdocuments **32**. The downloaded files are stored in the standard unencrypted zip-format. Such file archives can be extracted with any zip tool, see for example https://download.cnet.com/s/zip-tools/.

NOTE 1 All hyperlinks can be subjected to change, which is not under control of the authors of this document.

The package consists of the following parts:

– Compiled Java code and 3rd party program libraries:
  - IEC60216fx.jar (main program)
  - IEC60216fx.exe (optional program launcher for Windows)
  - lib/commons-math3-3.6.1 (statistical functions)
  - lib/poi-3.17.jar (Import and Export in OOXML format (*.xlsx))
– Example data files
  - Cenex3.dta – see IEC 60216-3:2021, Table D.1
  - Test2.dta – see IEC 60216-3:2021, Table D.2
  - N3.dst and N3_selected.xlsx – see IEC 60216-3:2021, Table D.3
  - Control.dta – example reference EIM raw data (non-destructive test method)

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1 Java® and Oracle® are registered trademarks of Oracle and/or its affiliates. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the products named. Equivalent products may be used if they can be shown to lead to the same results.

2 Microsoft Windows®, Linux® and Apple macOS® are examples of suitable products available. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of these products.

- Candidate.dta – example candidate EIM raw data (non-destructive test method)
- Control.ftd and Control_selected.xlsx – see IEC 60216-6
- The usage of the deprecated intermediate file formats such as *.int and *.ftc is not supported in the graphical user interface. However, the application programming interface (API) implements methods to read and write these file formats.

– Java source code

- Package: datamodel – class AgingData and subclasses to comprise raw data
- Package: mathematics – calculate results
- Package: fxml_gui – the JavaFX graphical user interface
- Package: ressources – example files as listed above

– Javadoc

- A number of automatically generated linked html pages for offline usage with a web browser. They describe the classes, constructors and methods of the packages ‘datamodel’ and ‘mathematics’ for use by Java programmers. New or modified user interfaces can be developed which use the tested class AgingData to store and evaluate aging data.

– JUnit tests

- The testing refers to packages ‘datamodel’ and ‘mathematics’. The output of all JUnit tests is compiled in one document named Testing_2017-10-12.pdf.

The IEC60216fx.jar is suitable for direct execution by the JRE. In a terminal window change to the directory or folder, where this file is stored and type <JRE8 root path>\jre\bin\java.exe -jar "IEC60216fx.jar". Thereby, <JRE8 root path> stands for the directory or folder, where the JRE is stored.

NOTE 2 In Windows, the directory separator is a “\”, while in Linux and macOS it is a “/”.

There are three different ways, how to make the execution of the program more convenient. They are described in C.1.2. The first is the recommended method, because it implies the least system requirements.

C.1.2 Convenience program execution

C.1.2.1 First (and default) method

It is important to know, that Java programs do not need installation/setup in a conventional way. Instead, the JAR files residing in one folder and the JRE residing in another folder just need to be linked together:

- download and decompress the file dist_v100.zip in a folder with write access (e.g. Documents\IEC60216fx\dist);
- download and decompress the JRE in any other folder with write access (e.g. Documents\JRE);
- create a new shortcut on the Desktop
  a) Command: <JRE8 root path>\jre\bin\java.exe -jar "IEC60216fx.jar"
  b) Folder Path: <Application root path>\dist.

In MS-Windows (screenshot: Windows 7, English language version), the shortcut properties look like:

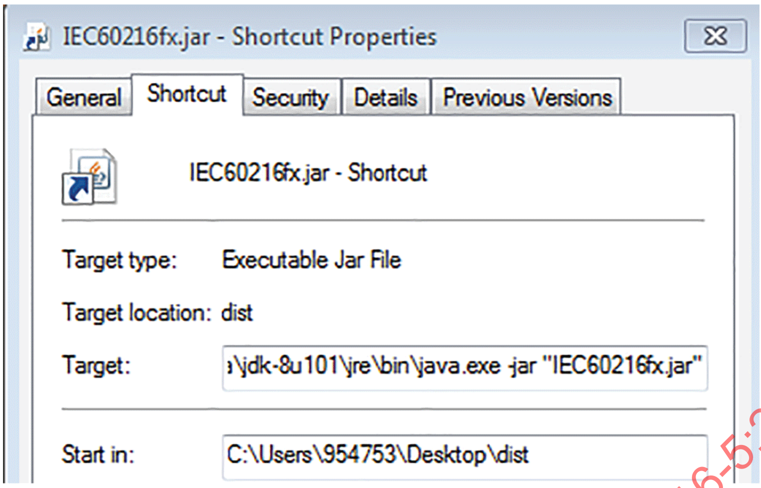

Figure C.1 – Shortcut property dialog for program launch

A double-click on the short-cut launches the application. Likewise, such a shortcut can be created in other operating systems and used for convenience program execution.

C.1.2.2 Second method

The IEC60216fx.exe is provided with the IEC60216fx.jar file in the same zip archive. It is a convenience launcher for MS-Windows, that runs the program directly with a double-click. It requires one of the following:

a) The JRE version 1.8.101 or later is properly installed (i.e. registered) on the computer. OR

b) Administrator privileges are granted: in that case, the launcher will first download and install the appropriate JRE and then run the program. For the second and further launches, Administrator privileges are no longer required, unless the JRE was uninstalled meanwhile.

NOTE If the JRE is installed correctly, a double-click on the IEC60216fx.jar file will also launch the application.

C.1.2.3 Third method

Similarly, a double-click on the file IEC60216fx.html provided with the IEC60216fx.jar in the same zip archive, attempts to launch the program in the default web browser of the system. However, this functionality is blocked in many browsers by default. It needs to be enabled manually in the browser properties and may create a system vulnerability.

NOTE The file IEC60216fx.jnlp is a text file in XML format to configure this functionality.

C.2 Structure of data files used by the program 33

The required data files and formats are described in IEC 60216-3:2021, Clause E.2. Examples are given in IEC 60216-3:2021, Clause E.3.

C.3 Executing the calculation of RTI

The program allows to open several data files at the same time. In a first step, the separate calculations for the reference and candidate EIM in accordance with IEC 60216-3 shall be made and reports generated. If two such files are opened, the RTI dialogue in the menu gets enabled. It allows to set the candidate and reference EIM and its ATI.

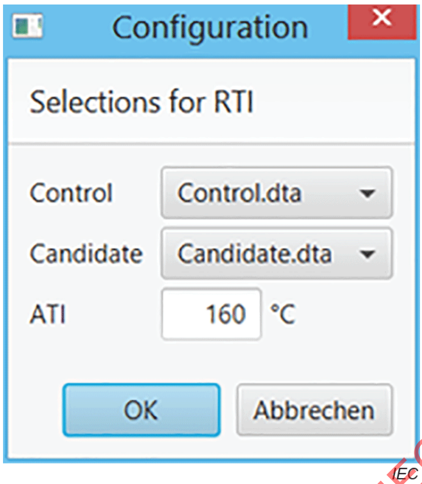

Figure C.2 – Thermal endurance graphs

C.4 Output files and graph

The program generates no further output files. Calculation results are displayed on two different windows:

- Report: a text representation of the calculated results;
- Life Time chart: the thermal endurance graphs.

Each window has a copy button, which can be clicked on or activated by the **Control + C** shortcut. It copies the content of the window into the operating systems clipboard for further usage in other program, e.g. word processors to create a report. Thereby, the content of the report window is copied as text and that of a chart as bitmap graphic.

The example set in Figure C.2 will report the following results:

RTI = 156 °C (F)

ATI = 160 °C (F)

Correlation Time = 24 829 h

Halving Interval = 12.17 °C

Conf. Interval = 8.55 (Reference: 5.10; Candidate: 6.86)

Extrapolation factor = 3.6

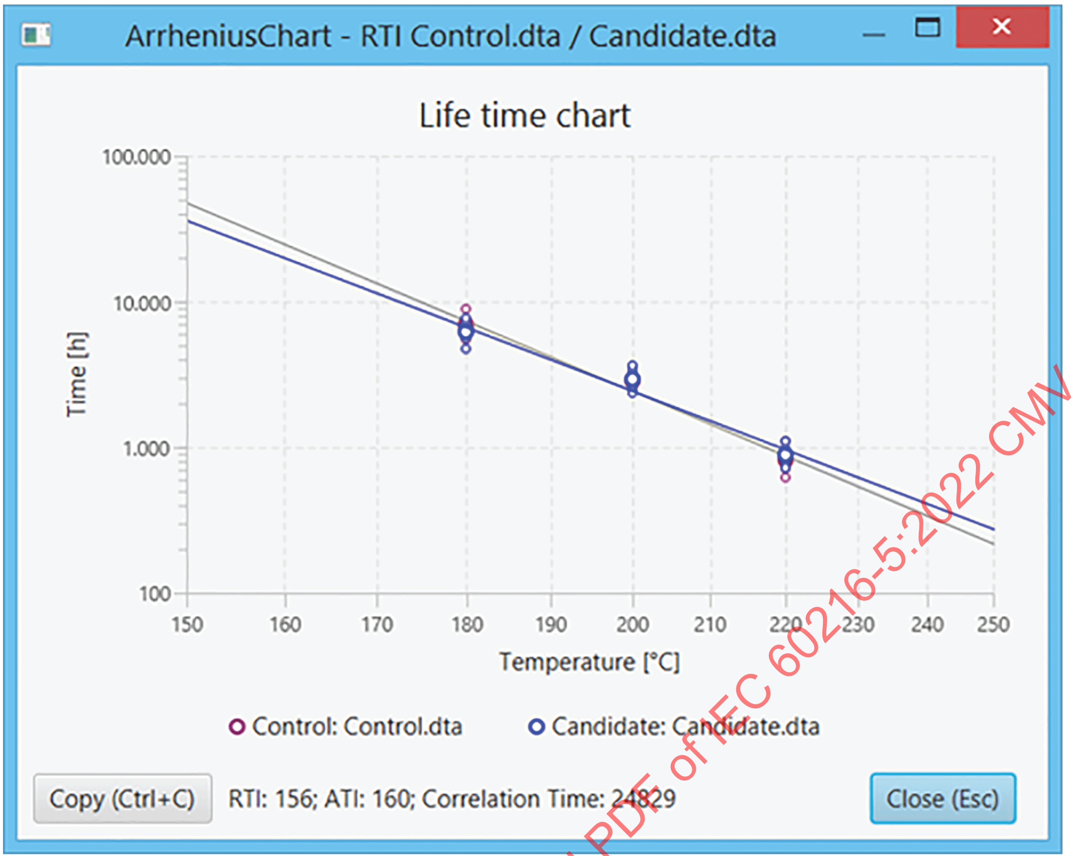

Figure C.3 – Example thermal endurance graphs

Annex D
(informative)

Selection of the reference EIM

D.1 Overview

The reference EIM should be selected from the materials that have known and stable thermal endurance characteristics, preferably derived from service experience. The expected ageing mechanisms and rates of both materials should be similar, and relevant to the application.

Details of the service experience and the basis for selection of the reference EIM should be presented to concerned parties who accept and utilize the reference EIM to develop the ~~RTE~~ RTI of a candidate EIM.

D.2 Designation of reference EIM

The designation of reference EIM is to be specified according to this document.

The selector for the reference EIM clarifies:

a) application if available;
b) service experience if available;
c) criteria for selecting the property and the end point values;
d) limits of usage for reference EIM if available.

D.3 Reporting items for reference EIM

The following items ~~have to~~ shall **34** be reported:

a) Identification of the selected material
   1) Name of manufacturer
   2) Product name, brand and symbol
   3) Generic type of material
   4) Composition e.g. additives. reinforcement, filler, impregnant, combined (or laminated) material, etc.
   5) Type of processing (e.g. moulding, extrusion, casting, laminating, coating, etc.)
b) Service experience of the reference EIM in the electric equipment if available
   1) Role of the insulating material (e.g. main wall insulation, interturn insulation, intercircuit insulation, etc.)
   2) Condition in the electric device (exclusive usage, combination with other materials)
   3) Minimum thickness of the reference EIM where it fulfils its function
c) Running condition and life of the electric equipment if available, where the reference EIM was used
   1) Kind of electric equipment (e.g. cable, generator, motor, transformer, reactor, etc.)
   2) Environmental conditions if any specialities (e.g. gas or liquid, corrosive atmosphere, humidity, chemicals, radiations)
   3) Rated voltage, frequency, power
   4) Operating conditions (e.g. continuous, intermittent, short time, others)
   5) Maximum temperature in the insulation system or thermal class of the electric equipment
   6) Experienced life time or operated time

Bibliography

IEC 60085, *Electrical insulation – Thermal evaluation and designation*

List of comments

1 In the title as well as all occurrences of this document the term “relative thermal endurance (RTE)” is replaced. This emphasizes its material nature (index) and conceptual proximity to the Underwriters Laboratories standard UL 746B. In contrast, endurance properties should refer to electrical insulation systems (EIS).

2 It means an option, not permission.

3 It means an option, not permission.

4 It means an option, not permission.

5 This clarifies the term.

6 This further clarifies the relationship between EIM and EIS testing.

7 Update: the current edition was published 2013.

8 This clarifies the referenced edition.

9 Update: the current edition was published 2021 preceding the work on this document. Both parts are supplemented by the same computer program.

10 Abbreviations are part of some of the term definitions but are not used independently.

11 This paragraph references availability of new online resources for terminology.

12 Reworded for clarification. However, the intended target group of materials to be considered an EIM should remain the same.

13 Reworded for clarification and to emphasize its affiliation to materials not systems like EIS. All occurrences of ATE are replaced by ATI.

14 Reworded for clarification and to mention a second source of information.

15 This tries to clarify, that the correlation time used for RTI is a property specific for the reference EIM and its ATI.

16 It means an option, not permission.

17 Reworded for clarification and to emphasize its affiliation to materials not systems like EIS. All occurrences of RTE are replaced by RTI.

18 It means an option, not permission.

19 This paragraph contains requirements and therefore is not just a note.

20 As described below, the standard allows an overlapping range of oven temperature for the two EIMs. This requirement only makes sense, for the common temperatures.

21 Figure replaced to update the terms RTE by RTI and ATE by ATI.

22 Figure replaced to update the terms RTE by RTI and ATE by ATI.

23 Updated to reflect features of the new computer program.

24 This clarifies a requirement.

25 This clarifies the content of this clause.

26 Added a number rounding rule in line with IEC 60216-1:2013.

27 Added a number rounding rule in line with IEC 60216-1:2013.

28 It means an option, not permission.

29 It means an option, not permission.

30 Correction/clarification: the F-test is a linearity test, that basically compares two different types of variances (s_2^1 and s_2^2). Details are given in IEC 60216-3:2021 and even more fundamentally in IEC 60493-1:2011, Annex A.

31 One of the main reasons for the publication of new editions of IEC 60216 parts -3, -5, -6 was the replacement of an outdated supplementing computer program. The use of such a program was and still is optional. However, the old program relied on MS-DOS and MS Quick Basic 4.5, both of which run on 16-bit computers and are no longer available.

The new computer program is written in the programming language Java, for which run time environments for all modern PC operating systems exists. The compiled code as well as the source code are published under an open-source software licence and are available for free download as described in the entirely reworked Annex C.

32 That is the important link for downloading the new computer program. It is planned but not implemented yet, to provide future program versions on GitHub, see https://github.com/iec60216.

33 Without repeating all the details here, the computer program allows the continuous use of old text files, except that an exponential is indicated by letter “E” instead of “D” previously and needs to be replaced manually before loading such a file.

However, much more convenient is the Office-Open XML-Format (*.xlsx) as also used by e.g. MS-Excel and LibreOffice Calc. When used as an export format, these files also contain the text report and charts as bitmap. Example files are provided in the download package.

34 It means a requirement.

IEC 60216-5

Edition 4.0 2022-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

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

IEC 60216-5:2022-11(en-fr)

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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

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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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.

IMPORTANT – The "colour inside" logo on the cover page of this document 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.

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

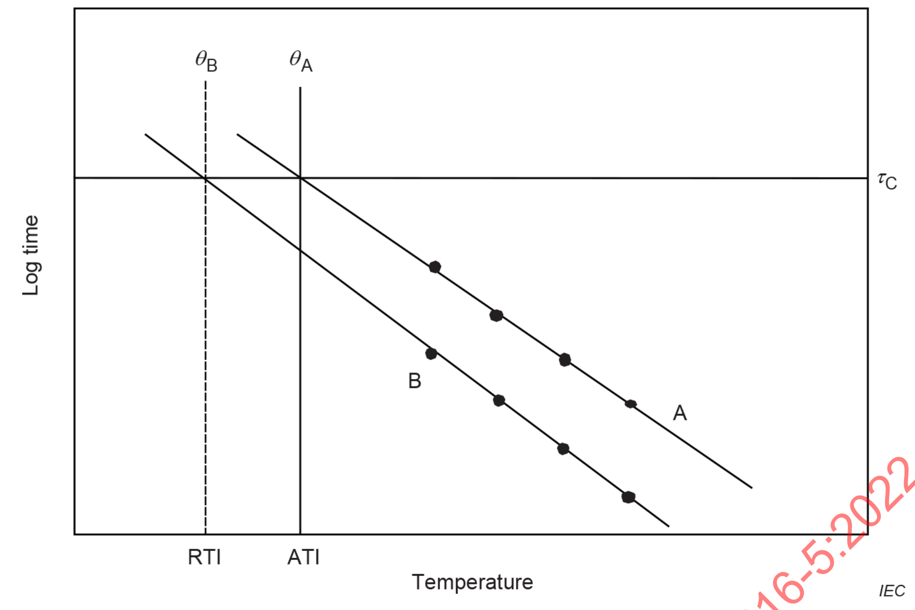
The diagnostic test shall be one considered relevant to the application for which the RTI is required. The same test shall be applied to both reference and candidate EIM.

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.

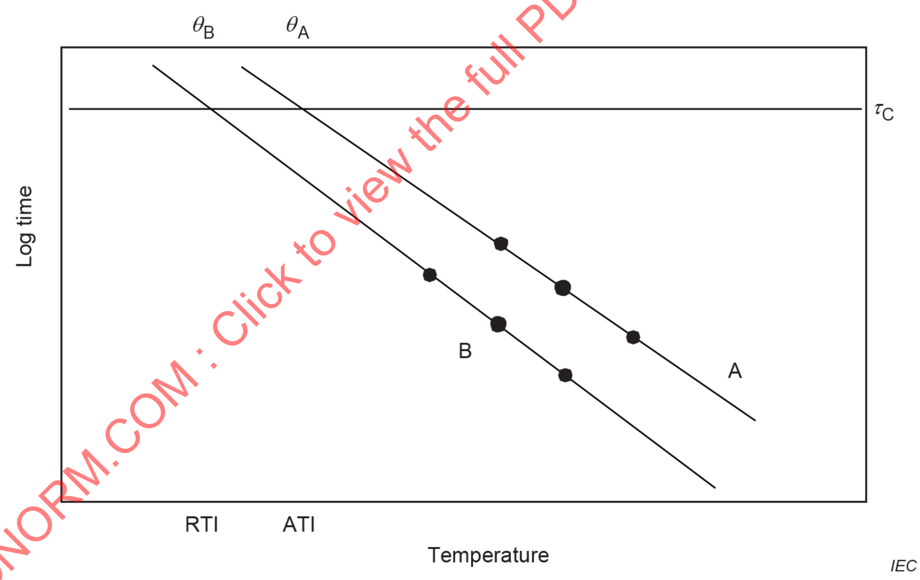


Key

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	$\bar{x}$	(26)	$\bar{x}_A$	$\bar{x}_B$
Central 2nd moment of x values	$\mu_2(x)$	(31)	$\mu_{2(A)}$	$\mu_{2(B)}$
Weighted mean of y values	$\bar{y}$	(27)	$\bar{y}_A$	$\bar{y}_B$
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	$\bar{y}_k$	–	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:

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

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

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

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.

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

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

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

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

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:

$$\mu_{2(B)} = \frac{1}{n_B}\sum_{i=1}^{k} n_{i(B)} \left(x_{i(B)} - \bar{x}_{(B)}\right)^2 \tag{7}$$

(see IEC 60216-3:2021, 6.2.2 for details).

The lower confidence limit of θ_A, $\theta_{c(A)}$ is calculated as above for a time equal to τ_c and subtracted from θ_A to give the confidence interval Δ_A.

The lower confidence interval of RTI, Δ_R, is then equal to the "Pythagorean" (orthogonal) vector sum of the above two intervals:

$$\Delta_R = \sqrt{\left(\Delta_A^2 + \Delta_B^2\right)} \tag{8}$$

6.3.4 Extrapolation

The extrapolation required to estimate the correlation time is calculated for both reference and candidate EIMs as the difference between the logarithm of the correlation time and the greatest value of the mean of the logarithms of the ageing times to endpoint (υ_A or υ_B). The extrapolation required is the greater of these two values.

7 Results and report

7.1 Results of statistical and numerical tests

The following criteria apply:

a) linearity of thermal endurance relationships and confidence intervals of TI results of both reference and candidate EIMs (see IEC 60216-3:2021, 6.3.2 and 6.3.3) which shall satisfy the requirements of IEC 60216-3, 7.3.1 and 7.3.2;

b) extrapolation to the correlation time (see 6.3.4 above): the extrapolation, expressed as the ratio of correlation time to greatest geometric mean ageing time shall be less than 4;

c) lower confidence interval of RTI (see 6.3.3 above): The value of Δ_R shall be less than the halving interval ($HIC_{B(c)}$) of the candidate EIM at a time equal to the correlation time (see IEC 60216-3:2021, 7.1).

$$HIC_{B(c)} = b_B \left[\frac{1}{\left(\left(\ln \tau_c / 2\right) - a_B\right)} - \frac{1}{\left(\ln \tau_c - a_B\right)} \right] \tag{9}$$

7.2 Results

The results shall be determined from the calculations of 6.2 and 6.3.3 as follows.

a) If all three test criteria (see 7.1) are met, the result shall be the value of RTI. The result shall be reported in the format: "RTI according to IEC 60216-5 = xxx" rounded to one full degree Celsius.

b) If one of the test criteria is not met, the result shall be the lower 95 % confidence limit of RTI. The result shall be reported in the format: "RTI lower 95 % confidence limit = xxx" rounded to one full degree Celsius.

c) If two or more of the criteria are not met, a result in accordance with the requirements of IEC 60216-5 cannot be reported. The result may be reported in the format: "RTI = xxx. (Result not validated by the statistical analysis)".

7.3 Report

The report shall comprise the following:

a) the result;

b) the identification of the reference EIM and its ATI (see Annex D);

c) the diagnostic test employed and the endpoint;

d) the thermal endurance reports according to IEC 60216-1 for the reference and candidate EIMs;

e) the details of the failure of statistical validation for a result in category 7.2 c).

8 Material testing by short-term thermal ageing

There is often a need for short-term thermal ageing tests on materials, e.g. to compare thermal performances of materials having slight chemical modifications with respect to a known reference EIM, or in quality reference testing of insulation containing anti-oxidant constituents, where ageing at the rated temperature of the material for a period of a few thousand hours could be employed.

The interpretation of such tests can be quite difficult, particularly if the ageing is at a single temperature, with property measurement after a single fixed time. The absence of testing for compliance with a chemical kinetic model leads to a liability to systematic errors caused by equipment or material changes.

It is recommended that in such cases, a reference EIM of similar type and rating as the test material should be aged simultaneously and tested after the same time. A similar analysis to that of Annex A can then be applied to the two sets of property values to establish whether there are significant differences between

a) the candidate EIM and the reference EIM, or

b) the current test values of the reference EIM and the historical values obtained on the same material.

In this analysis, s_1^2 and s_2^2 are the variances of the groups of property values after ageing at the test temperature; $\bar{y}_1$ and $\bar{y}_2$ are the means of these groups (see Equations (A.1) to (A.4)).

Unless otherwise specified, the test for significant difference shall be made at a level of 0,05 (see Table B.2).

If significant differences are not found, it can be assumed that the thermal endurance performances of the two materials being compared are the same. If significant differences are found in case a) above, it is likely that the performance of the candidate EIM will not be the same as that of the reference. If significant differences are found in case b) above, then it is likely that the ageing conditions differ in some way from those originally employed: they should be investigated, and the cause established.

9 Insulation classification

When required, the candidate EIM may be assigned to an insulation thermal class in accordance with Annex B, Table B.1.

Annex A
(informative)

Repeatability of correlation time

A.1 Overview

Where a reference EIM has been tested on a previous occasion, the values of τ_c should be compared. A significant difference can imply a change in the reference EIM itself, or possibly a change in the oven equipment or a change in the test apparatus. The cause should be investigated and reported.

The comparison is made using the Student's t-test for the difference of two means, by the procedures below. The suffixes 1 and 2 refer to the two sets of data. In the equations, the values $\bar{y}_1$ and $\bar{y}_2$ are the logarithms of the two values of correlation time.

A.2 *F*-test for linearity

The variances of the y-values for the reference EIMs in the present and previous determinations (s_1^2 and s_2^2) shall be calculated in accordance with the instructions of IEC 60216-3:2021 [6.3.2, Equation (41) or (42)]. Their ratio is then tested for linearity i.e. equality of the variances by the F-test on a significance level of 0,05 with degrees of freedom n_1-2 and n_2-2 (see Table B.2).

NOTE The symbols s_1^2 and s_2^2 here refer to the estimates of variance for the material on occasions 1 and 2, and not to the within and between classes as given in IEC 60216-3:2021, Equations (41) and (42).

A.3 Standard error of the difference of two means

The values of variance are combined using Equations (A.1) and (A.2) if the values are not significantly different:

$$s_D^2 = \frac{s_1^2\,(n_1-1)+s_2^2\,(n_2-1)}{(n_1+n_2-2)}\left(\frac{1}{n_1}+\frac{1}{n_2}\right) \tag{A.1}$$

$$n_D = (n_1+n_2-2) \tag{A.2}$$

If the values of variance are significantly different, then Equations (A.3) and (A.4) shall be used. In this case the value n_D may not be an integer. The nearest integer (rounded up or down as appropriate) shall then be employed in subsequent calculations.

$$s_D^2 = \frac{s_1^2}{n_1}+\frac{s_2^2}{n_2} \tag{A.3}$$

$$n_{\mathrm{D}}=\frac{\left(s_{\mathrm{D}}^{2}\right)^{2}}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1-1}+\frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2-1}} \tag{A.4}$$

The square root of the value of s_{D}^2 is the standard error, s, of the difference of the general means of the y-values.

NOTE When the values of n_1 and n_2 are equal, Equations (A.1) and (A.3) become identical.

A.4 Student's *t*-test for difference of two means

When two estimates of a mean value (which in this case includes estimates by linear regression) are obtained from separate sets of data and the true values are expected to be the same, their equality may be tested by the Student's t-test. The principle of this test is to calculate the ratio of the difference of the mean estimates to the standard error of this difference. The variances of the two data sets are combined in the same way as the variances in Clause A.3 and the standard error calculated.

The value of t is the ratio of the difference of the means to the standard error:

$$t=\frac{\left(\bar{y}_1-\bar{y}_2\right)}{\sqrt{s_{\mathrm{D}}^2}} \tag{A.5}$$

The associated number of degrees of freedom is n_{D} or the nearest integer. If the value of t is greater than the value for a significance level of 0,05 given in Table B.3, the difference is considered to be significant and its cause should be investigated.

For the purposes of 6.3.2, in the calculations of Equations (A.1) to (A.5), the values of s_1^2 and s_2^2 are obtained using Equation (45) of IEC 60216-3:2021, 6.3.3, which is:

$$s_Y^2=\frac{s^2}{N}\left[1+\frac{\left(X-\bar{x}\right)^2}{\mu_2(x)}\right]$$

$$s_1^2=\left|N\ s_Y^2\right|_1 \quad \text{and} \quad s_2^2=\left|N\ s_Y^2\right|_2 \tag{A.6}$$

The values of $\bar{y}_1$ and $\bar{y}_2$ are the logarithms of the two values of τ_{c}.

A.5 Combination of data

If the two results for correlation time and the two values of variance are not significantly different, a more precise estimate of the logarithm of correlation time may be obtained by merging the two sets of data:

$$\bar{y} = \frac{\left(n_1\bar{y}_1 + n_2\bar{y}_2\right)}{\left(n_1 + n_2\right)} \tag{A.7}$$

$$s^2 = \frac{s_1^2\left(n_1 - 1\right) + s_2^2\left(n_2 - 1\right)}{\left(n_1 + n_2 - 2\right)} \tag{A.8}$$

Annex B
(informative)

Thermal class assignment

Table B.1 relates the thermal class assignment, when required, to the value of ATI/RTI, in accordance with IEC 60085.

Table B.1 – Thermal class equivalents for insulating material

ATI/RTI °C		Thermal class °C	Letter designation
≥90	<105	90	Y
≥105	<120	105	A
≥120	<130	120	E
≥130	<155	130	B
≥155	<180	155	F
≥180	<200	180	H
≥200	<220	200	N
≥220	<250	220	R
≥250	<275	250	

[a] If desired, the letter designation may be added in parentheses, e.g. Class 180 (H). Where space is a factor, such as on a nameplate, the product TC may elect to use only the letter designation.

[b] Designations of thermal classes over 250 shall increase by increments of 25 and be designated accordingly.

Table B.2 and Table B.3 give the values of F and of Student's t for significance levels of 0,05 and 0,005.

NOTE 1 The significance, p, is equal to 1-P, where P is the probability of the stochastic variable (F or t) being less than the tabulated value.

The columns of the F table (Table B.2) represent the number of degrees of freedom of the numerator and the rows the number of degrees of freedom of the denominator.

The columns of the t table (Table B.3) represent the number of degrees of freedom and the rows the significance level (p).

NOTE 2 The tables include significance levels of 0,05 and 0,005 in case they are needed at any time. For present purposes, the 0,005 values can be deleted, but they are on record for future use.

Table B.2 – F– function; p = 0,05

	10	11	12	13	14	15	16	17	18	19	20	25	30	40	50	100	500
10	2,978	2,943	2,913	2,887	2,865	2,845	2,828	2,812	2,798	2,785	2,774	2,730	2,700	2,661	2,637	2,588	2,548
11	2,854	2,818	2,788	2,761	2,739	2,719	2,701	2,685	2,671	2,658	2,646	2,601	2,570	2,531	2,507	2,457	2,415
12	2,753	2,717	2,687	2,660	2,637	2,617	2,599	2,583	2,568	2,555	2,544	2,498	2,466	2,426	2,401	2,350	2,307
13	2,671	2,635	2,604	2,577	2,554	2,533	2,515	2,499	2,484	2,471	2,459	2,412	2,380	2,339	2,314	2,261	2,218
14	2,602	2,565	2,534	2,507	2,484	2,463	2,445	2,428	2,413	2,400	2,388	2,341	2,308	2,266	2,241	2,187	2,142
15	2,544	2,507	2,475	2,448	2,424	2,403	2,385	2,368	2,353	2,340	2,328	2,280	2,247	2,204	2,178	2,123	2,078
16	2,494	2,456	2,425	2,397	2,373	2,352	2,333	2,317	2,302	2,288	2,276	2,227	2,194	2,151	2,124	2,068	2,022
17	2,450	2,413	2,381	2,353	2,329	2,308	2,289	2,272	2,257	2,243	2,230	2,181	2,148	2,104	2,077	2,020	1,973
18	2,412	2,374	2,342	2,314	2,290	2,269	2,250	2,233	2,217	2,203	2,191	2,141	2,107	2,063	2,035	1,978	1,929
19	2,378	2,340	2,308	2,280	2,256	2,234	2,215	2,198	2,182	2,168	2,155	2,106	2,071	2,026	1,999	1,940	1,891
20	2,348	2,310	2,278	2,250	2,225	2,203	2,184	2,167	2,151	2,137	2,124	2,074	2,039	1,994	1,966	1,907	1,856
25	2,236	2,198	2,165	2,136	2,111	2,089	2,069	2,051	2,035	2,021	2,007	1,955	1,919	1,872	1,842	1,779	1,725
30	2,165	2,126	2,092	2,063	2,037	2,015	1,995	1,976	1,960	1,945	1,932	1,878	1,841	1,792	1,761	1,695	1,637
40	2,077	2,038	2,003	1,974	1,948	1,924	1,904	1,885	1,868	1,853	1,839	1,783	1,744	1,693	1,660	1,589	1,526
50	2,026	1,986	1,952	1,921	1,895	1,871	1,850	1,831	1,814	1,798	1,784	1,727	1,687	1,634	1,599	1,525	1,457
100	1,927	1,886	1,850	1,819	1,792	1,768	1,746	1,726	1,708	1,691	1,676	1,616	1,573	1,515	1,477	1,392	1,308
500	1,850	1,808	1,772	1,740	1,712	1,686	1,664	1,643	1,625	1,607	1,592	1,528	1,482	1,419	1,376	1,275	1,159

F– function; p = 0,005

	10	11	12	13	14	15	16	17	18	19	20	25	30	40	50	100	500
10	5,847	5,746	5,661	5,589	5,526	5,471	5,422	5,379	5,340	5,305	5,274	5,153	5,071	4,966	4,902	4,772	4,666
11	5,418	5,320	5,236	5,165	5,103	5,049	5,001	4,959	4,921	4,886	4,855	4,736	4,654	4,551	4,488	4,359	4,252
12	5,085	4,988	4,906	4,836	4,775	4,721	4,674	4,632	4,595	4,561	4,530	4,412	4,331	4,228	4,165	4,037	3,931
13	4,820	4,724	4,643	4,573	4,513	4,460	4,413	4,372	4,334	4,301	4,270	4,153	4,073	3,970	3,908	3,780	3,674
14	4,603	4,508	4,428	4,359	4,299	4,247	4,200	4,159	4,122	4,089	4,059	3,942	3,862	3,760	3,698	3,569	3,463
15	4,424	4,329	4,250	4,181	4,122	4,070	4,024	3,983	3,946	3,913	3,883	3,766	3,687	3,585	3,523	3,394	3,287
16	4,272	4,179	4,099	4,031	3,972	3,920	3,875	3,834	3,797	3,764	3,734	3,618	3,539	3,437	3,375	3,246	3,139
17	4,142	4,050	3,971	3,903	3,844	3,793	3,747	3,707	3,670	3,637	3,607	3,492	3,412	3,311	3,248	3,119	3,012
18	4,030	3,938	3,860	3,793	3,734	3,683	3,637	3,597	3,560	3,527	3,498	3,382	3,303	3,201	3,139	3,009	2,901
19	3,933	3,841	3,763	3,696	3,638	3,587	3,541	3,501	3,465	3,432	3,402	3,287	3,208	3,106	3,043	2,913	2,804
20	3,847	3,756	3,678	3,611	3,553	3,502	3,457	3,416	3,380	3,347	3,318	3,203	3,123	3,022	2,959	2,828	2,719
25	3,537	3,447	3,370	3,304	3,247	3,196	3,151	3,111	3,075	3,043	3,013	2,898	2,819	2,716	2,652	2,519	2,406
30	3,344	3,255	3,179	3,113	3,056	3,006	2,961	2,921	2,885	2,853	2,823	2,708	2,628	2,524	2,459	2,323	2,207
40	3,117	3,028	2,953	2,888	2,831	2,781	2,737	2,697	2,661	2,628	2,598	2,482	2,401	2,296	2,230	2,088	1,965
50	2,988	2,900	2,825	2,760	2,703	2,653	2,609	2,569	2,533	2,500	2,470	2,353	2,272	2,164	2,097	1,951	1,821
100	2,744	2,657	2,583	2,518	2,461	2,411	2,367	2,326	2,290	2,257	2,227	2,108	2,024	1,912	1,840	1,681	1,529
500	2,562	2,476	2,402	2,337	2,281	2,230	2,185	2,145	2,108	2,075	2,044	1,922	1,835	1,717	1,640	1,460	1,260

Table B.3 – *t*–function

	10	11	12	13	14	15	16	17	18	19	20	25	30	40	50	100	500
p = 0,05	1,812	1,796	1,782	1,771	1,761	1,753	1,746	1,740	1,734	1,729	1,725	1,708	1,697	1,684	1,676	1,660	1,648
p = 0,005	3,169	3,106	3,055	3,012	2,977	2,947	2,921	2,898	2,878	2,861	2,845	2,787	2,750	2,704	2,678	2,626	2,586

Annex C
(informative)

Computer program

C.1 General

C.1.1 Overview

The program supplementing this document as well as IEC 60216-3:2021 and IEC 60216-6:–, is written in the programming language Java®[1] and makes use of the JavaFX technology for graphical user interfaces. It is for use in conjunction with a Java Runtime Environment (JRE) from Oracle® in version 1.8.101 or later. The JRE is available for download at https://www.java.com/download for several operating systems[2] running on either 32-bit or 64-bit computers.

The package itself is available for download from https://www.iec.ch/tc112/supportingdocuments. The downloaded files are stored in the standard unencrypted zip-format. Such file archives can be extracted with any zip tool, see for example https://download.cnet.com/s/zip-tools/.

NOTE 1 All hyperlinks can be subjected to change, which is not under control of the authors of this document.

The package consists of the following parts:

– Compiled Java code and 3rd party program libraries:
  - IEC60216fx.jar (main program)
  - IEC60216fx.exe (optional program launcher for Windows)
  - lib/commons-math3-3.6.1 (statistical functions)
  - lib/poi-3.17.jar (Import and Export in OOXML format (*.xlsx))
– Example data files
  - Cenex3.dta – see IEC 60216-3:2021, Table D.1
  - Test2.dta – see IEC 60216-3:2021, Table D.2
  - N3.dst and N3_selected.xlsx – see IEC 60216-3:2021, Table D.3
  - Control.dta – example reference EIM raw data (non-destructive test method)
  - Candidate.dta – example candidate EIM raw data (non-destructive test method)
  - Control.ftd and Control_selected.xlsx – see IEC 60216-6
  - The usage of the deprecated intermediate file formats such as *.int and *.ftc is not supported in the graphical user interface. However, the application programming interface (API) implements methods to read and write these file formats.

1 Java® and Oracle® are registered trademarks of Oracle and/or its affiliates. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the products named. Equivalent products may be used if they can be shown to lead to the same results.

2 Microsoft Windows®, Linux® and Apple macOS® are examples of suitable products available. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of these products.

– Java source code
  - Package: datamodel – class AgingData and subclasses to comprise raw data
  - Package: mathematics – calculate results
  - Package: fxml_gui – the JavaFX graphical user interface
  - Package: ressources – example files as listed above
– Javadoc
  - A number of automatically generated linked html pages for offline usage with a web browser. They describe the classes, constructors and methods of the packages ‘datamodel’ and ‘mathematics’ for use by Java programmers. New or modified user interfaces can be developed which use the tested class AgingData to store and evaluate aging data.
– JUnit tests
  - The testing refers to packages ‘datamodel’ and ‘mathematics’. The output of all JUnit tests is compiled in one document named Testing_2017-10-12.pdf.

The IEC60216fx.jar is suitable for direct execution by the JRE. In a terminal window change to the directory or folder, where this file is stored and type <JRE8 root path>\jre\bin\java.exe -jar "IEC60216fx.jar". Thereby, <JRE8 root path> stands for the directory or folder, where the JRE is stored.

NOTE 2 In Windows, the directory separator is a “\”, while in Linux and macOS it is a “/”.

There are three different ways, how to make the execution of the program more convenient. They are described in C.1.2. The first is the recommended method, because it implies the least system requirements.

C.1.2 Convenience program execution

C.1.2.1 First (and default) method

It is important to know, that Java programs do not need installation/setup in a conventional way. Instead, the JAR files residing in one folder and the JRE residing in another folder just need to be linked together:

- download and decompress the file dist_v100.zip in a folder with write access (e.g. Documents\IEC60216fx\dist);
- download and decompress the JRE in any other folder with write access (e.g. Documents\JRE);
- create a new shortcut on the Desktop
  a) Command: <JRE8 root path>\jre\bin\java.exe -jar "IEC60216fx.jar"
  b) Folder Path: <Application root path>\dist.

In MS-Windows (screenshot: Windows 7, English language version), the shortcut properties look like:

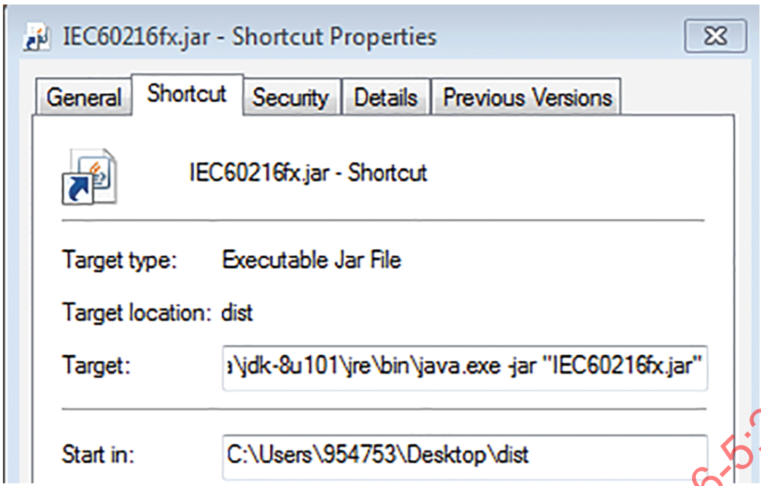


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Figure C.1 – Shortcut property dialog for program launch

A double-click on the short-cut launches the application. Likewise, such a shortcut can be created in other operating systems and used for convenience program execution.

C.1.2.2 Second method

The IEC60216fx.exe is provided with the IEC60216fx.jar file in the same zip archive. It is a convenience launcher for MS-Windows, that runs the program directly with a double-click. It requires one of the following:

a) The JRE version 1.8.101 or later is properly installed (i.e. registered) on the computer. OR

b) Administrator privileges are granted: in that case, the launcher will first download and install the appropriate JRE and then run the program. For the second and further launches, Administrator privileges are no longer required, unless the JRE was uninstalled meanwhile.

NOTE If the JRE is installed correctly, a double-click on the IEC60216fx.jar file will also launch the application.

C.1.2.3 Third method

Similarly, a double-click on the file IEC60216fx.html provided with the IEC60216fx.jar in the same zip archive, attempts to launch the program in the default web browser of the system. However, this functionality is blocked in many browsers by default. It needs to be enabled manually in the browser properties and may create a system vulnerability.

NOTE The file IEC60216fx.jnlp is a text file in XML format to configure this functionality.

C.2 Structure of data files used by the program

The required data files and formats are described in IEC 60216-3:2021, Clause E.2. Examples are given in IEC 60216-3:2021, Clause E.3.

C.3 Executing the calculation of RTI

The program allows to open several data files at the same time. In a first step, the separate calculations for the reference and candidate EIM in accordance with IEC 60216-3 shall be made and reports generated. If two such files are opened, the RTI dialogue in the menu gets enabled. It allows to set the candidate and reference EIM and its ATI.

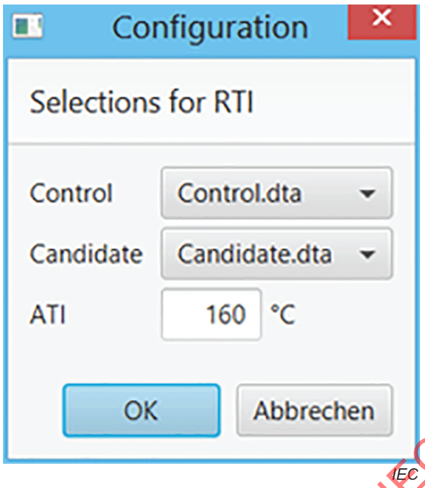

Figure C.2 – Thermal endurance graphs

C.4 Output files and graph

The program generates no further output files. Calculation results are displayed on two different windows:

- Report: a text representation of the calculated results;
- Life Time chart: the thermal endurance graphs.

Each window has a copy button, which can be clicked on or activated by the **Control + C** shortcut. It copies the content of the window into the operating systems clipboard for further usage in other program, e.g. word processors to create a report. Thereby, the content of the report window is copied as text and that of a chart as bitmap graphic.

The example set in Figure C.2 will report the following results:

RTI = 156 °C (F)

ATI = 160 °C (F)

Correlation Time = 24 829 h

Halving Interval = 12.17 °C

Conf. Interval = 8.55 (Reference: 5.10; Candidate: 6.86)

Extrapolation factor = 3.6

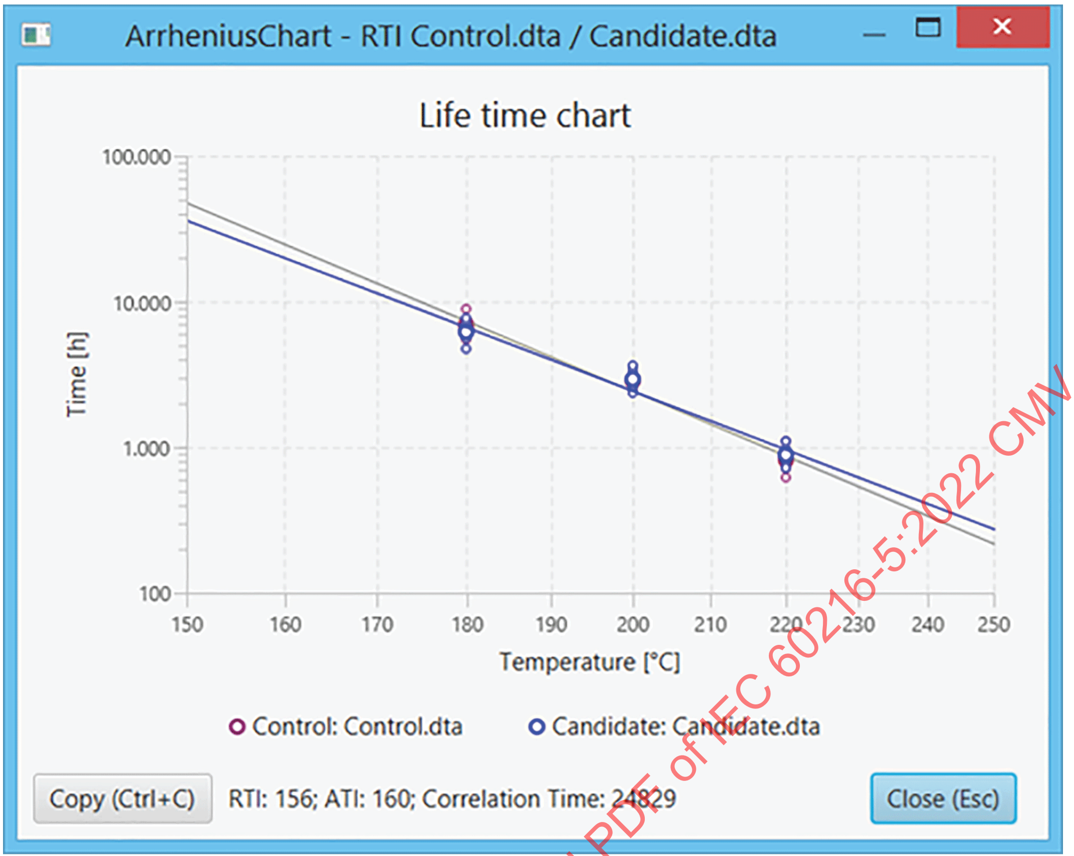

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Figure C.3 – Example thermal endurance graphs

Annex D
(informative)

Selection of the reference EIM

D.1 Overview

The reference EIM should be selected from the materials that have known and stable thermal endurance characteristics, preferably derived from service experience. The expected ageing mechanisms and rates of both materials should be similar, and relevant to the application.

Details of the service experience and the basis for selection of the reference EIM should be presented to concerned parties who accept and utilize the reference EIM to develop the RTI of a candidate EIM.

D.2 Designation of reference EIM

The designation of reference EIM is to be specified according to this document.

The selector for the reference EIM clarifies:

a) application if available;
b) service experience if available;
c) criteria for selecting the property and the end point values;
d) limits of usage for reference EIM if available.

D.3 Reporting items for reference EIM

The following items shall be reported:

a) Identification of the selected material
   1) Name of manufacturer
   2) Product name, brand and symbol
   3) Generic type of material
   4) Composition e.g. additives. reinforcement, filler, impregnant, combined (or laminated) material, etc.
   5) Type of processing (e.g. moulding, extrusion, casting, laminating, coating, etc.)
b) Service experience of the reference EIM in the electric equipment if available
   1) Role of the insulating material (e.g. main wall insulation, interturn insulation, intercircuit insulation, etc.)
   2) Condition in the electric device (exclusive usage, combination with other materials)
   3) Minimum thickness of the reference EIM where it fulfils its function
c) Running condition and life of the electric equipment if available, where the reference EIM was used
   1) Kind of electric equipment (e.g. cable, generator, motor, transformer, reactor, etc.)
   2) Environmental conditions if any specialities (e.g. gas or liquid, corrosive atmosphere, humidity, chemicals, radiations)
   3) Rated voltage, frequency, power
   4) Operating conditions (e.g. continuous, intermittent, short time, others)
   5) Maximum temperature in the insulation system or thermal class of the electric equipment
   6) Experienced life time or operated time

Bibliography

IEC 60085, *Electrical insulation – Thermal evaluation and designation*

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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MATÉRIAUX ISOLANTS ÉLECTRIQUES – PROPRIÉTÉS D'ENDURANCE THERMIQUE –

Partie 5: Détermination de l’indice de température relatif (ITR) d’un matériau isolant

AVANT-PROPOS

L'IEC 60216-5 a été établie par le comité d’études 112 de l’IEC: Évaluation et qualification des systèmes et matériaux d’isolement électrique. Il s'agit d'une Norme internationale.

Cette quatrième édition annule et remplace la troisième édition parue en 2008. Cette édition constitue une révision technique.

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

a) l’Annexe C "Programme informatique" a été complètement remaniée;

b) en 3.1, les termes "ATE" et "RTE" ont été remplacés par "ATI" et "ITR" pour souligner leur référence à un matériau isolant électrique (MIE).

Cette norme doit être lue conjointement avec l'IEC 60216-1:2013, l'IEC 60216-2:2005 et l'IEC 60216-3:2021.

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

Projet	Rapport de vote
112/582/FDIS	112/588/RVD

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

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

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

Une liste de toutes les parties de la série IEC 60216, publiées sous le titre général *Matériaux isolants électriques – Propriétés d'endurance thermique*, se trouve sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
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IMPORTANT – Le logo "colour inside" qui se trouve sur la page de couverture de ce document indique qu'il contient des couleurs qui sont considérées comme utiles à une bonne compréhension de son contenu. Les utilisateurs devraient, par conséquent, imprimer ce document en utilisant une imprimante couleur.

MATÉRIAUX ISOLANTS ÉLECTRIQUES – PROPRIÉTÉS D'ENDURANCE THERMIQUE –

Partie 5: Détermination de l'indice de température relatif (ITR) d'un matériau isolant

1 Domaine d'application

La présente partie de l'IEC 60216 spécifie les procédures expérimentales et de calcul à utiliser pour déduire l'indice de température relatif d'un matériau à partir des données expérimentales obtenues conformément aux instructions de l'IEC 60216-1 et de l'IEC 60216-2. Les procédures de calcul s'ajoutent à celles indiquées dans l'IEC 60216-3.

Des recommandations sont également données pour évaluer le vieillissement thermique après une seule durée déterminée et une seule température, sans extrapolation.

Les données expérimentales peuvent en principe être obtenues en utilisant des essais destructifs, des essais non destructifs ou des essais d'épreuve, même si les essais destructifs ont été utilisés de manière beaucoup plus étendue. Les données obtenues à partir d'essais non destructifs ou d'essais d'épreuve peuvent être "censurées", en ce sens que le mesurage du temps nécessaire pour atteindre le point limite a été interrompu à un moment situé après le temps médian, mais avant que toutes les éprouvettes n'aient atteint le point limite (voir l'IEC 60216-1).

Des recommandations sont données pour l'affectation préliminaire d'une classe thermique pour un matériau isolant électrique (MIE), fondée sur les performances de vieillissement thermique.

Bien que la classification thermique d'un MIE ne soit pas directement reliée à la classification thermique d'un système d'isolation électrique (EIS - electrical insulation system), celle d'un EIS suit le même concept que dans la série IEC 60216. Les procédures de calcul du présent document sont applicables à la détermination de la classe thermique d'un système d'isolation électrique (EIS) lorsque la contrainte thermique est le facteur de vieillissement prédominant.

2 Références normatives

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

IEC 60216-1:2013, *Matériaux isolants électriques – Propriétés d'endurance thermique – Partie 1: Méthodes de vieillissement et évaluation des résultats d'essai*

IEC 60216-2:2005, *Matériaux isolants électriques – Propriétés d'endurance thermique – Partie 2: Détermination des propriétés d'endurance thermique de matériaux isolants électriques – Choix de critères d'essai*

IEC 60216-3:2021, *Matériaux isolants électriques – Propriétés d'endurance thermique – Partie 3: Instructions pour le calcul des caractéristiques d'endurance thermique*

3 Termes, définitions, symboles et unités

3.1 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

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

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

3.1.1
matériau isolant électrique
MIE
matériau de conductivité électrique faible, utilisé pour séparer des pièces conductrices portées à des potentiels électriques différents ou pour isoler ces pièces de l'environnement

3.1.2
indice de température évaluée
ATI
valeur numérique de l'indice de température en degrés Celsius du MIE de référence

Note 1 à l'article: La valeur d'indice de température évaluée peut varier selon les différentes utilisations de ce matériau.

3.1.3
MIE candidat
matériau pour lequel une estimation de l'endurance thermique doit être réalisée

Note 1 à l'article: L'estimation est réalisée par vieillissement thermique simultané du matériau et d'un MIE de référence.

3.1.4
MIE de référence
matériau à l'endurance thermique connue (déduite de l'expérience en service ou d'une évaluation préalable d'indice de température relatif ou d'indice de température), utilisé comme référence pour des essais comparatifs avec un MIE candidat

3.1.5
moment centré d'ordre 2 d'un groupe de données
somme des carrés des différences entre les valeurs des données et la valeur de la moyenne du groupe divisée par le nombre de données dans le groupe

3.1.6
temps de corrélation pour l'ITR
durée estimée jusqu'au point limite du MIE de référence, obtenue pour une température en degrés Celsius égale à son ATI

Note 1 à l'article: L'abréviation "ATI" est dérivée du terme anglais développé correspondant "assessed temperature index".

3.1.7
degrés de liberté
nombre de valeurs de données diminué du nombre de paramètres

3.1.8
erreur type
erreur type d'une estimation de la valeur vraie d'une propriété d'un groupe de données, c'est la valeur de l'écart-type de la population échantillon retenue par hypothèse pour laquelle la propriété du groupe peut être considérée comme membre de ce groupe

Note 1 à l'article: Pour la moyenne du groupe, elle est égale à l'écart-type du groupe divisé par la racine carrée du nombre de données dans le groupe, et elle indique l'incertitude de la moyenne dans la valeur vraie.

Note 2 à l'article: La présente norme concerne uniquement les moyennes et la différence entre deux moyennes (voir l'Article A.3).

3.1.9
écart-type
racine carrée de la variance d'un groupe ou d'un sous-groupe de données

3.1.10
indice de température relatif
ITR
indice déterminé par essai par rapport aux performances thermiques d'un MIE de référence connu

3.1.11
variance d'un groupe de données
somme des carrés des écarts des données par rapport à un niveau de référence défini par un ou plusieurs paramètres, divisée par le nombre de degrés de liberté

Note 1 à l'article: Le niveau de référence peut être, par exemple, une valeur moyenne (1 paramètre) ou une droite (2 paramètres, dans le présent document, la pente et le point d'intersection avec l'axe y).

3.2 Symboles et unités

a_A	Coefficient de régression (intersection avec l'axe de y) de l'équation d'endurance thermique pour le MIE de référence
a_B	Coefficient de régression (intersection avec l'axe de y) de l'équation d'endurance thermique pour le MIE candidat
b_A	Coefficient de régression (pente) de l'équation d'endurance thermique pour le MIE de référence
b_B	Coefficient de régression (pente) de l'équation d'endurance thermique pour le MIE candidat
X	Variable pour l'analyse statistique égale à $1/(\vartheta + \Theta_0)$
Y	Variable pour l'analyse statistique égale à ln (τ)
ϑ	Température de vieillissement lors de la détermination de l'ITR
Θ_0	Température sur l'échelle de Kelvin égale à 0 °C
τ	Durée jusqu'au point limite
τ_c	Durée estimée jusqu'au point limite d'un MIE de référence pour une température égale à l'ATI ("temps de corrélation")
$\mu_{2(A)}$	Moment centré d'ordre 2 des valeurs de x pour un MIE de référence
$\mu_{2(B)}$	Moment centré d'ordre 2 des valeurs de x pour un MIE candidat
n_A	Nombre de valeurs de y pour les données d'un MIE de référence
n_B	Nombre de valeurs de y pour les données d'un MIE candidat

T	Variable stochastique distribuée t de "Student"
S	Erreur type de la différence de deux moyennes
s_A^2	Variance de valeurs de y pour les données d'un MIE de référence
s_B^2	Variance de valeurs de y pour les données d'un MIE candidat
$\bar{x}_A$	Moyenne générale des valeurs de x pour les données d'un MIE de référence
$\bar{x}_B$	Moyenne générale des valeurs de x pour les données d'un MIE candidat
$\bar{y}_A$	Moyenne générale des valeurs de y pour les données d'un MIE de référence
$\bar{y}_B$	Moyenne générale des valeurs de y pour les données d'un MIE candidat
θ_A	Température en degrés Celsius égale à l'ATI
θ_B	Température en degrés Celsius égale à l'ITR
$\hat{X}_B$	Valeur de x correspondant à θ_B
$\hat{X}_A$	Value de x correspondant à θ_A
$\theta_{c(B)}$	Limite inférieure de confiance de θ_B
$\theta_{c(A)}$	Limite inférieure de confiance de θ_A
$X_{L(B)}$	Valeur de x correspondant à la limite inférieure de confiance de θ_B
$X_{L(A)}$	Valeur de x correspondant à la limite inférieure de confiance de θ_A
Δ_B	Intervalle inférieur de confiance de θ_B
Δ_A	Intervalle inférieur de confiance de θ_A
$IDC_{B(c)}$	Intervalle de division par deux d'un MIE candidat à un instant égal à τ_c
s_D^2	Variance associée à la différence entre les valeurs de la moyenne de y pour les deux matériaux
n_D	Degrés de liberté de s_D^2
υ_A, υ_B	Logarithmes des durées moyennes des plus longues jusqu'au point limite pour les matériaux A et B
b_r	Variable intermédiaire: valeur ajustée de b pour le calcul de l'intervalle de confiance de la température
s_r	Variable intermédiaire: valeur ajustée de s pour le calcul de l'intervalle de confiance de la température

4 Objectifs de la détermination de l'ITR

Les objectifs de la détermination sont comme suit.

a) Exploiter une relation réputée exister entre l'endurance thermique (avec un critère d'essai approprié pour le vieillissement) et les performances en service, et utiliser ce résultat afin de prédire une valeur pour une évaluation préliminaire de la température en service d'un matériau pour lequel l'expérience en service est relativement limitée (par comparaison avec un MIE de référence connu, voir les Articles 5 et 6).

   Dans la majorité des cas, cela implique une extrapolation sur une durée plus longue et/ou à une température plus basse que pour les données expérimentales. Il convient que cette extrapolation soit minimale, par un choix approprié des températures et des temps de vieillissement, car l'incertitude du résultat augmente rapidement avec l'extrapolation. Cependant, même en l'absence d'extrapolation, l'incertitude reste finie compte tenu des variances des données expérimentales et des erreurs expérimentales.

b) Améliorer la précision d'une détermination d'endurance thermique par diminution des erreurs systématiques dans le processus de vieillissement. Si, après vieillissement, les résultats pour le MIE de référence sont considérés comme très différents d'une expérience précédente, cela peut indiquer des variations dans le matériau ou le matériel. Cela peut être vérifié et éventuellement corrigé. Dans tous les cas, le vieillissement simultané du matériau de référence et du matériau candidat compense au moins partiellement les variations systématiques. Les procédures statistiques à utiliser pour évaluer la signification statistique des variations sont présentées à l'Annexe A.

c) Fournir des instructions pour l'affectation d'une classe thermique à un MIE.

5 Procédures expérimentales

5.1 Choix du MIE de référence

L'exigence initiale pour le MIE de référence est qu'il ait un indice de température connu (ATI) pour l'application à l'étude. L'indice de température, s'il est déterminé par une procédure ITR, est de préférence étayé par une expérience en service réelle (voir l'Annexe D).

Les mécanismes de vieillissement attendus des deux matériaux et leur vitesse d'évolution doivent être similaires et doivent correspondre à l'application.

5.2 Choix d'un essai de diagnostic pour l'importance du vieillissement

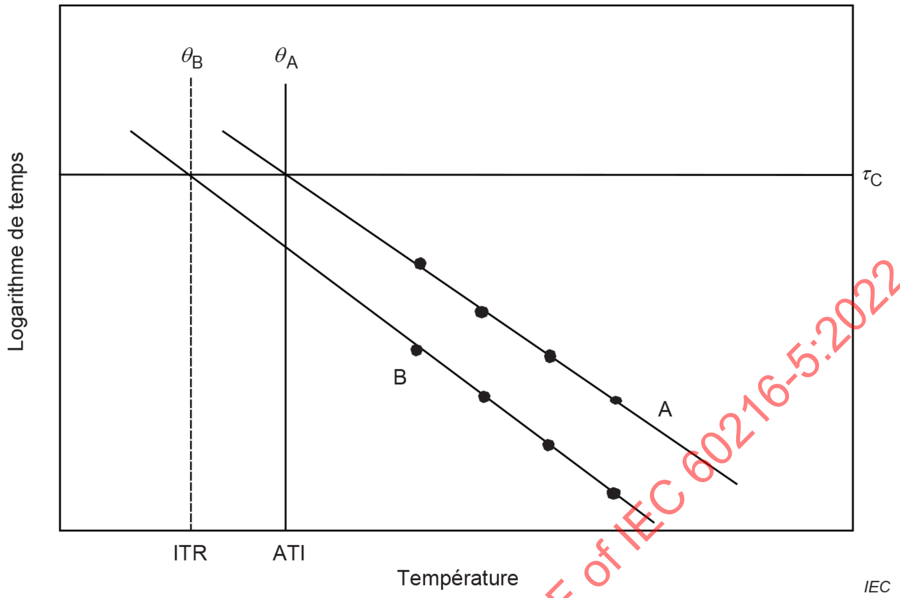
L'essai de diagnostic doit être un de ceux qui sont considérés comme adaptés à l'application pour laquelle l'ITR est exigé. Le même essai doit être appliqué à la fois au MIE de référence et au MIE candidat.

5.3 Procédures de vieillissement

Le nombre et le type d'éprouvettes de chaque matériau, ainsi que les températures et les temps de vieillissement, doivent être conformes aux exigences de l'IEC 60216-1:2013, 5.3.2, 5.4 et premier alinéa du 5.5. Pour chaque température de vieillissement courante, la charge de l'étuve doit comprendre un nombre approprié d'éprouvettes des deux matériaux dans la même étuve. Les éprouvettes doivent être uniformément réparties dans l'étuve de manière à éviter toute différence systématique entre les conditions de vieillissement appliquées aux éprouvettes des deux matériaux. Il est important que les éprouvettes des deux matériaux soient vieillies simultanément à au moins trois des températures destinées à faire partie des calculs.

NOTE Par exemple, tandis que les données représentées à la Figure 1 sont susceptibles d'être acceptables pour les analyses, à partir des données représentées à la Figure 2, le groupe des températures les plus basses du MIE candidat et le groupe des températures les plus élevées du MIE de référence ne peuvent pas être inclus, car dans chaque cas, le groupe d'éprouvettes est constitué d'un seul matériau ou un des deux matériaux n'a pas atteint le point limite choisi pendant la durée de l'essai.

Si, après avoir réalisé le vieillissement aux températures choisies, les résultats de l'un des deux matériaux ne satisfont pas aux exigences du point b) du 7.1 du présent document, un autre groupe d'éprouvettes doit être vieilli, dans la même étuve, à une température appropriée. Ce groupe doit de nouveau être constitué du nombre et du type exigés d'éprouvettes provenant des deux matériaux.

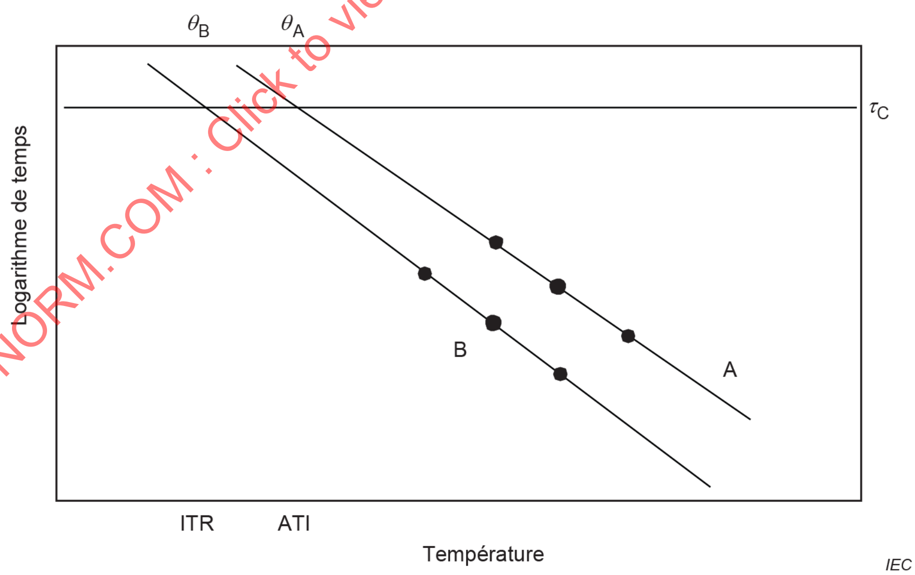


Légende

A = MIE de référence

B = MIE candidat

Figure 1 – Graphique d'endurance thermique



Légende

A = MIE de référence

B = MIE candidat

NOTE Les éprouvettes des deux matériaux ne sont pas vieillies simultanément à au moins trois des températures.

Figure 2 – Graphique d'endurance thermique inacceptable

6 Procédures de calcul

6.1 Données d'endurance thermique – Calcul des paramètres intermédiaires

Les équations d'endurance thermique doivent être calculées conformément aux instructions de l'IEC 60216-3.

Les paramètres d'entrée du Tableau 1 ci-dessous sont nécessaires pour calculer l'ITR et il convient de les noter (chacun des symboles peut avoir un indice A pour le MIE de référence ou un indice B pour le MIE candidat).

Tableau 1 – Paramètres d'entrée pour le calcul de l'ITR

Paramètre	Symbole dans l'IEC 60216-3	Équation dans l'IEC 60216-3	Symbole dans l'IEC 60216-5	
Pente de la droite de régression	b	(33)	b_A	b_B
Intersection avec la droite de régression	a	(34)	a_A	a_B
Moyenne pondérée des valeurs de x	$\bar{x}$	(26)	$\bar{x}_A$	$\bar{x}_B$
Moment centré d'ordre 2 des valeurs de x	$\mu_2(x)$	(31)	$\mu_{2(A)}$	$\mu_{2(B)}$
Moyenne pondérée des valeurs de y	$\bar{y}$	(27)	$\bar{y}_A$	$\bar{y}_B$
Variance des valeurs de y	s^2	(41)	s_A^2	s_B^2
Nombre de valeurs de y	N	(25)	n_A	n_B
Intervalle de division par deux	IDC	(53)	--	$HIC_{B(c)}$
Logarithme de la durée moyenne la plus grande jusqu'au point limite	$\bar{y}_k$	--	υ_A	υ_B
Limite inférieure de confiance de θ	$\hat{\vartheta}_c$	(50)	$\theta_{c(A)}$	$\theta_{c(B)}$
NOTE Si les calculs de l'IEC 60216-3 sont effectués avec le programme informatique recommandé de l'Annexe C, les valeurs de $\theta_{c(A)}$ et de $\theta_{c(B)}$ peuvent être directement calculées dans le programme.				

Le résultat de l'essai de linéarité (IEC 60216-3:2021, 6.3.2) est également nécessaire.

6.2 Calcul de l'ITR

Les coefficients des équations d'endurance thermique doivent être calculés à la fois pour le MIE de référence et le MIE candidat, conformément aux instructions données en 6.1 et 6.2 de l'IEC 60216-3:2021 (voir 6.1 du présent document). À partir de ces coefficients, les valeurs de τ_c et θ_B doivent être calculées comme cela est indiqué ci-dessous (voir également la Figure 1).

a) À partir des coefficients de régression du MIE de référence, calculer la durée τ_c correspondant à son ATI:

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