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Electrical insulating materials – Thermal endurance properties –

Part 6: Determination of thermal endurance indices (TI and RTE) of an insulating material using the fixed time frame method

International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

Part 6: Determination of thermal endurance indices (TI and RTE) of an insulating material using the fixed time frame method

FOREWORD

International Standard IEC 60216-6 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems.

This second edition cancels and replaces the first edition, published in 2003. This edition constitutes a technical revision.

The significant technical changes with respect to the previous edition are as follows.

− This new edition has been supplemented by Annex G and the corresponding software.

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

FDIS	Report on voting
112/28/FDIS	112/32/RVD

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

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

IEC 60216, under the general title *Electrical insulating materials – Thermal endurance properties,* consists of the following parts:

Part 1: Ageing procedures and evaluation of test results

Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria

Part 3: Instructions for calculating thermal endurance characteristics

Part 4: Ageing ovens

Part 5: Determination of relative thermal endurance index (RTE) of an insulating material

Part 6: Determination of thermal endurance indices (TI and RTE) of an insulating material using the fixed time frame protocol

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

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- withdrawn;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

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ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

Part 6: Determination of thermal endurance indices (TI and RTE) of an insulating material using the fixed time frame method

1 Scope

This part of IEC 60216 specifies the experimental and calculation procedures for deriving the thermal endurance characteristics, temperature index (TI) and relative thermal endurance index (RTE) of a material using the "fixed time frame method (FTFM)".

In this protocol, the ageing takes place for a small number of fixed times, using the appropriate number of ageing temperatures throughout each time, the properties of the specimens being measured at the end of the relevant time interval. This differs from the procedure of IEC 60216-1, where ageing is conducted at a small number of fixed temperatures, property measurement taking place after ageing times dependent on the progress of ageing.

The diagnostic tests employed in the fixed time frame method are restricted to destructive tests. The method has not as yet been applied to non-destructive or proof test procedures.

Both the TI and the RTE determined according to the FTFM protocol are derived from experimental data obtained in accordance with the instructions of IEC 60216-1 and IEC 60216-2 as modified in this standard. The calculation procedures and statistical tests are modified from those of IEC 60216-3 and IEC 60216-5.

2 Normative references

The following referenced documents are indispensable for the application 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 60212, *Standard conditions for use prior to and during the testing of solid electrical insulating materials*

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

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

IEC 60216-3:2002, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

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

IEC 60216-4-2, *Electrical insulating materials – Thermal endurance properties – Part 4-2: Ageing ovens – Precision ovens for use up to 300 °C*

IEC 60216-4-3, *Electrical insulating materials – Thermal endurance properties – Part 4-3: Ageing ovens – Multi-chamber ovens*

IEC 60216-5, *Electrical insulating materials – Thermal endurance properties – Part 5: Determination of relative thermal endurance index (RTE) of an insulating material*

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

3 Terms, definitions, symbols and abbreviated terms

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

3.1 Terms, abbreviations and definitions

3.1.1
assessed thermal endurance index
ATE
numerical value of the temperature in degrees Celsius, up to which the control material possesses known, satisfactory service performance in the specified application

NOTE 1 The ATE of a specific material may vary between different applications of the material.

NOTE 2 ATE is sometimes referred to as “absolute” thermal endurance index.

3.1.2
ageing temperature
temperature in degrees Celsius at which a group of specimens is thermally aged

3.1.3
end-point temperature
temperature in degrees Celsius at which a specimen is considered to have reached end-point after ageing for a specified time

3.1.4
candidate material
material for which an estimate of the thermal endurance is required to be determined

NOTE The determination is made by simultaneous thermal ageing of the material and a control material.

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
95 % confidence limit
statistical parameter, calculated from test data, which with 95 % confidence constitutes an upper or lower limit for the true value of a quantity estimated by statistical analysis

NOTE 1 This implies that there is only 5 % probability that the true value of the quantity estimated is actually larger (or smaller) than the upper (or lower) confidence limit.

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

3.1.7
control material
material with known assessed thermal endurance index (ATE), preferably derived from service experience, used as a reference for comparative tests with the candidate material

3.1.8
correlation coefficient
number expressing the completeness of the relation between members of two data sets, equal to the covariance divided by the square root of the product of the variances of the sets

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

NOTE 2 In this standard, the two data sets are the values of the independent variable and the means of the corresponding dependent variable groups.

3.1.9
correlation time (RTE)
estimated time to end-point of the control material at a temperature equal to its ATE in degrees Celsius

3.1.10
correlation time (TI)
hypothetical time to end-point used to calculate TI

NOTE Its usual value is 20 000 h.

3.1.11
covariance (of data sets)
for two sets of data with equal numbers of elements where each element in one set corresponds to one in the other, sum of the products of the deviations of the corresponding members from their set means, divided by the number of degrees of freedom

3.1.12
degrees of freedom
number of data values minus the number of parameter values

3.1.13
destructive test
diagnostic property test, where the test specimen is irreversibly changed by the property measurement, in a way which precludes a repeated measurement on the same specimen

NOTE An example of a destructive test is measurement of electric strength. An example of a non-destructive test is measurement of tg δ.

3.1.14
end-point line
line parallel to the temperature axis intercepting the property axis at the end-point value

3.1.15
halving interval
HIC
numerical value of the temperature interval in kelvins which expresses the halving of the time to end-point taken at a time equal to TI

3.1.16
regression analysis
process of deducing the best fit line expressing the relation of corresponding members of two data groups by minimizing the sum of squares of deviations of members of one of the groups from the line

3.1.17
regression coefficients
coefficients of the equation of the best fit line derived by regression analysis

3.1.18
relative thermal endurance index
RTE
estimate of the thermal endurance of a candidate material, made by thermal ageing simultaneously with the control material, as described in this standard

NOTE The value of RTE is the value of the temperature in degrees Celsius at which the estimated time to end-point of the candidate material is the same as the estimated time to end-point of the control material at a temperature equal to its ATE.

3.1.19
significance
probability of a value of a statistical function greater than a specified value

NOTE The value is equal to $(1–p)$ where p is the cumulative distribution function value. Significance is conventionally printed in upper case (P).

3.1.20
standard deviation
square root of the variance of a data group or sub-group

3.1.21
standard error of an estimate of the true value of a data group property
value of the standard deviation of the hypothetical sampling population of which the group property may be considered to be a member

NOTE For an estimate of the group mean, the standard error 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 estimate of the true value of the mean. This standard is concerned only with means and the difference between two means.

3.1.22
temperature index
TI
numerical value of the temperature in degrees Celsius derived from the thermal endurance relationship at a time of 20 000 h (or other specified time)

3.1.23
temperature group (of specimens)
number of specimens being exposed together to thermal ageing at the same temperature in the same oven

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

3.1.24
test group (of specimens)
number of specimens removed together from a temperature group for destructive testing

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

3.1.25
thermal endurance graph
graph in which the logarithm of the time to reach a specified end-point in a thermal endurance test is plotted against the reciprocal thermodynamic (absolute) test temperature

3.1.26
thermal endurance graph paper
graph paper having a logarithmic time scale as the ordinate and values proportional to the reciprocal of the thermodynamic (absolute) temperature as the abscissa

NOTE The ordinate is usually graduated in powers of ten (from 10 h to 100 000 h is often a convenient range). The abscissa is usually graduated in a non-linear (Celsius) temperature scale oriented with temperature increasing from left to right.

3.1.27
time group (of specimens)
all test groups removed for testing at the same time

3.1.28
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 The reference level may, for example be a mean value (1 parameter) or a line (2 parameters, here intercept on the axis of the independent variable and slope).

3.2 Symbols and abbreviated terms

The following symbols are used in the calculations of Clauses 6, 7 and 12.

Symbol	Description	Clause
a	Regression coefficient: intercept of regression line with x-axis	6.4.3
b	Regression coefficient: slope of regression line relative to y-axis	6.4.3
b_{r}	Parameter derived from b for calculation of $\hat{Y}_{\mathrm{c}}$	6.5.3
b_p	Regression coefficient for destructive test calculations	6.3.4
c	Parameter in calculation of χ^2	6.5.1
F	F-distributed variance ratio for linearity test	6.3.3, 6.5.2
g, h, i, j	Indexing parameters for regression calculations	6.3, 6.4
HIC	Halving interval	7.1
k	Number of ageing times	6.1.1
N	Total number of x_{ij} values	6.4.2
n_i	Number of x_{ij} values in time group i	6.1.1
P	Significance of the value of a statistical test function	Annexes A, B, and C
p_{e}	End-point property value	6.3

p_{gh}	Property value h in temperature group g (time group i implied)	6.3
$\overline{p}_g$	Mean property value in temperature group g (time group i implied)	6.3
q	Base of logarithms in calculation of χ^2	6.5.1
r	Number of temperature groups selected in time group i	6.3.2
r^2	Square of correlation coefficient	6.4.3
s^2	Total (non-regression) variance of x-values	6.5.2
s_{1g}^2	Variance of property values in temperature group g (time group i implied)	6.3.2
s_a^2	Value of s^2 adjusted to allow for acceptable non-linearity	6.5.2
s_r^2	Parameter derived from s^2 for calculation of $\hat{Y}_\mathrm{c}$	6.5.3
t	Student's t-distributed stochastic variable	6.5.3
TC, $\mathrm{TC_a}$	Lower confidence limit of TI or $\mathrm{TI_a}$ (see s_a^2 above)	7.1
$t_{p,N}$	Value of t with probability p and N degrees of freedom	6.5.3
x_{ij}	Value of x, index number j , in time group i	6.3.4
$\overline{x}$	General mean of x-values	6.4.2
$\hat{X}$, $\hat{X}_\mathrm{c}$	Estimate of x, and its confidence limit	6.5.3
y_i	Value of y for time group i	6.1.1
$\overline{y}$	General mean of y-values	6.4.2
$\hat{Y}$, $\hat{Y}_\mathrm{c}$	Estimate of y, and its confidence limit	6.5.3
z_{ij}	Reciprocal kelvin temperature for ϑ_{ij}	6.1.1
$\mu_2(y)$	Central 2nd moment of y values	6.4.2
ν	Total number of property values in time group (i implied)	6.3.2
χ^2	χ^2 distributed variable for variance equality (Bartlett's) test	6.5.1
ϑ_{ij}	Ageing temperature for specimen group j in time group i	6.1.1
Θ_0	273,15 K (corresponding to 0 °C)	6.1.1
τ_i	Ageing time for time group i	6.1.1

4 FTFM protocol

4.1 Principles and objectives

4.1.1 Principles of FTFM protocol

The FTFM (fixed time frame method) protocol is based upon the principle that thermal ageing for determination of thermal endurance characteristics is carried out over a small number of fixed times, with a sufficient range of ageing temperatures at each time to ensure that the property values determined reach the end-point in a satisfactory manner.

In this it differs from the fixed temperature frame procedure of IEC 60216-1, where a small number of ageing temperatures is employed, with ageing being carried out with testing at intervals, until the end-point has been reached.

4.1.2 Objective of FTFM protocol

The objective of the protocol is to achieve the following advantages:

The determination of thermal endurance characteristics is completed in a fixed, pre-determined time.

This enables much more efficient planning of the determination, and will often have substantial commercial advantage. A simple TI determination will be completed in 5 kh, whereas by the fixed temperature frame procedure, it may be necessary for ageing to be considerably prolonged past this time to achieve the end-point at the lowest chosen ageing temperature.

Each temperature to end-point (i.e. time-group mean) in the thermal endurance regression is based on the temperatures selected in a time group. The number of temperatures selected may be any number between three (3) and the number of temperature groups in a time group.

Since the largest source of systematic error in the fixed temperature frame procedure is temperature error (actual indication error or temperature distribution error), systematic errors can be considerably reduced. Errors from this source can lead to results which are either inaccurate or invalid through incorrect assessment of linearity.

5 TI determination

5.1 Ageing procedures

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

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

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

5.2 Ageing times and temperatures

In the majority of cases, the required thermal endurance characteristics are for a projected duration of 20 000 h. However, there is often a need for such information related to other, longer or shorter times. In cases of longer times, the times given as requirements or recommendations in the text of this standard (e.g. 5 kh for the minimum value of the longest ageing time) shall be increased in the ratio of the actual specification time to 20 kh.

In cases of shorter specification times, the related times may be decreased in the same ratio if necessary.

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

Recommendations for ageing times and temperatures are given in Annex D.

5.3 Test specimens

5.3.1 Preparation

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

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

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

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

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

The tolerances of specimen dimensions shall be the same as those normally used for general testing. Where specimen dimensions need smaller tolerances than those normally used, these special tolerances shall be given.

Screening measurements ensure that specimens are of uniform quality and typical of the material to be tested.

5.3.2 Number of specimens

The accuracy of endurance test results depends largely on the number of specimens aged at each temperature.

The total number of specimens (N) is derived as follows:

$$N = a \times b \times c + d$$

where

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

b is the number of treatments, i.e. total number of exposure temperatures, at one time;

c is the number of ageing time levels;

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

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

5.4 Diagnostic tests

If IEC material specifications are available, property requirements in terms of acceptable lower limits of TI values are usually given. If such material specifications are not available, a selection of properties and methods for the evaluation of thermal endurance is given in IEC 60216–2.

If such a method cannot be found, an international, national or institution standard or a specially devised method should be used in that order of preference. In this case, the diagnostic test shall be stated in the report, including the property, measurement procedure and end-point.

5.5 Selection of end-points

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

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

a) as a percentage increase or decrease in the measured value of the property from the original level. This approach will provide comparisons among materials but bears a poorer relationship than item b) to the property values required in normal service. For the determination of the initial value, see 5.6;

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

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

5.6 Establishment of initial property value

Select the specimens for the determination of the initial value of the property to constitute a random subset of those prepared for ageing. Before determining the property value these specimens shall be conditioned by exposure to the lowest level of ageing temperature of the test (see 5.2), for two days (48 ± 6) h.

NOTE In some cases (e.g. very thick specimens) times greater than two days may be necessary to establish a stable value.

Unless otherwise stated in the method for determining the diagnostic property (for example, parts of materials specifications dealing with methods of test, or a method listed in IEC 60216-2), the initial value is the arithmetic mean of the test results.

5.7 Ageing conditions

5.7.1 Ageing ovens

Throughout the heat ageing period, ageing ovens shall maintain, in that part of the working space where specimens are placed, a temperature with tolerances as given in IEC 60216-4. Unless otherwise specified, IEC 60216-4-1 shall apply. IEC 60216-4-2 and 60216-4-3 may be specified in special cases.

The circulation of the air within the oven, and the exchange of the air content should be adequate to ensure that the rate of thermal degradation is not influenced by accumulation of decomposition products or oxygen depletion (see 5.7.2).

5.7.2 Environmental conditions

Unless otherwise specified, the ageing shall be carried out in ovens operating in the normal laboratory atmosphere. However, for some materials very sensitive to the humidity in the ovens, more reliable results are obtained when the absolute humidity in the ageing oven room is maintained at the value equal to the absolute humidity of standard atmosphere B according to IEC 60212. This, or other specified conditions, shall then be reported.

NOTE The effects of special environmental conditions such as extreme humidity, chemical contamination or vibration in many cases may be more appropriately evaluated by insulation systems tests. Although environmental conditioning, the influence of atmospheres other than air and immersion in liquids, such as oil, may be important, these are not the concern of this standard.

5.7.3 Conditions for property measurement

Unless otherwise specified, the specimens shall be conditioned before measurement, and measured under conditions as stated in the material standard specification.

5.8 Procedure for ageing

Establish a testing scheme, as for example outlined in Annex D.

Prepare a number of specimens following the instructions of 5.3.2. If necessary, determine the initial value of the property as specified in 5.6. Divide the specimens by random selection into test groups appropriate for the testing scheme. Place the appropriate numbers of groups in each of the ovens at the required temperature.

NOTE Attention should be given to the recommendation in Annex D (NOTE 2) to prepare extra groups of specimens should the thermal endurance characteristics of the material be unsuited to the basic recommendation of Annex D.

After each ageing time, select at random one group from each of the appropriate ageing ovens and remove it from the oven. Allow to cool to room temperature unless otherwise specified. If specified, condition for the specified time in the specified atmosphere, and test the specimens by the specified test procedure.

It is recommended to carry out calculations as data become available, particularly for the shortest exposure time.

Evaluate the results as specified in Clause 6.

6 Calculation procedures

6.1 General principles

6.1.1 Thermal endurance calculation

The general calculation procedures and instructions given in 6.4 are based on the principles set out in IEC 60493-1, modified as follows (see 3.7.1 of IEC 60493-1:1974).

a) The relation between the mean of the reciprocals (x) of the thermodynamic (absolute) temperatures at which the specified end-point is reached and the logarithm (y) of the ageing time is linear.

b) The values of the deviations of the values of x from the linear relation are normally distributed with a variance which is independent of the ageing time.

The data used in the general calculation procedures are obtained from the experimental data by a preliminary calculation. Calculation data comprise values of z, y, n and k, where

$z_{ij} = 1/\left(\vartheta_{ij} + \Theta_0\right)$	= reciprocal of thermodynamic value in K of ageing temperature ϑ_{ij} in °C;
$y_i = \log \tau_i$	= logarithm of value of ageing time in h (τ_i);
n_i	= number of z values in group number i aged for time τ_i ;
k	= number of ageing times or groups of x values.

NOTE Any number may be used as the base for logarithms, provided consistency is observed throughout calculations. The use of natural logarithms (base e) is recommended, since most computer programming languages and scientific calculators have this facility.

6.1.2 Property value – equivalent temperature transform

(Calculation of hypothetical ageing temperature derived from the value of a property)

When destructive test criteria are employed, each test specimen is destroyed in obtaining a property value: for this reason, time and/or temperature values necessary to reach end-point cannot be directly measured. To enable estimates of the times to end-point to be obtained, the following assumptions are made that in the vicinity of the end-point (for one ageing time):

a) the relation between the mean property values and the reciprocals of the thermodynamic temperatures is approximately linear;

b) the values of the deviations of the individual property values from this linear relation are normally distributed with a variance which is independent of the temperature;

c) the curves of property versus reciprocal of the ageing (thermodynamic) temperature for the individual test specimens are straight lines parallel to the line representing the relation of a) above.

For application of these assumptions, an ageing curve is drawn of the data obtained at each of the ageing times. The curve for each ageing time is obtained by plotting the mean value of property for each specimen group against the reciprocal of its ageing temperature (thermodynamic) If possible, ageing is conducted at sufficiently high and low ageing temperatures that at least one group mean is above and at least one below the end-point level. An approximately linear region of this curve is drawn (including at least three group means) in the vicinity of the end-point (Figure E.1).

NOTE A non-linear temperature scale graduated in °C is usually employed as the abscissa axis (see Figure E.1).

A statistical test (F-test) is carried out to decide whether deviations from linearity of the selected region are acceptable (see 6.3.3). If acceptable, then on the same graph points representing the properties of the individual specimens are drawn. A line parallel to the ageing line is drawn through each individual specimen data point: the estimate of the value of x for that specimen is then the value of the reciprocal of the (thermodynamic) temperature corresponding to the intersection of the line with the end-point line (Figure E.1).

With some limitations, an extrapolation of the linear mean value graph to the end-point level is permitted.

The above operations are executed numerically in the calculations detailed in 6.3.2 and 6.3.3.

6.2 Precision of calculations

Many of the calculation steps involve summing of the differences of numbers or the squares of these differences, where the differences may be small by comparison with the numbers. In these circumstances it is necessary that the calculations be made with an internal precision of at least six significant digits, and preferably more, if precision of three digits is to be achieved in the result. In view of the repetitive and tedious nature of the calculations it is strongly recommended that they be performed using a programmable calculator or microcomputer, in which case internal precision of ten or more digits is easily available.

6.3 Derivation of temperatures equivalent to property values

Within the groups of specimens aged for each time τ_i, carry out the procedures described in 6.3.1 to 6.3.3.

6.3.1 Preliminary calculations

Calculate the value of y corresponding to each ageing time τ

$$y_i = \log \tau_i \tag{1}$$

Calculate the value of z corresponding to each ageing temperature ϑ

$$z_{ij} = 1/\left(\vartheta_{ij} + \Theta_0\right) \tag{2}$$

6.3.2 Regression calculations (property on temperature)

Calculate the mean property value for the data group obtained at each ageing temperature (see equation (3)) and the corresponding value of z. Plot these values on a graph with the property value p as ordinate and z as abscissa (see Figure E.1).

Fit by visual means a smooth curve through the mean property points.

Select a temperature range within which the curve so fitted is approximately linear (see 6.3.3). Ensure that this temperature range includes at least three mean property values with at least one point on each side of the end-point line $p = p_e$. If this is not the case, and further measurements at higher temperatures cannot be made (for example, because no specimens remain), a small extrapolation is permitted, subject to the conditions of 6.3.3.

The index i is omitted from the expressions in 6.3.2 and 6.3.3 in order to avoid confusing multiple index combinations in print. The calculations of these subclauses shall be carried out separately on the data from each ageing time.

Let the number of selected mean values (and corresponding value groups) be r, the reciprocals of the individual ageing temperatures be z_g and the individual property values be p_{gh}, where

$g = 1 \ldots r$ is the order number of the selected group aged at temperature ϑ_g ;

$h = 1 \ldots n_g$ is the order number of the property value within group number g;

n_g is the number of property values in group number g.

NOTE In most cases the numbers n_g of specimens tested at all test temperatures are identical, but this is not a necessary condition, and the calculation can be carried out with different values of n_g for different groups.

Calculate the mean value $\bar{p}_g$ and the variance s_{1g}^2 for each selected property value group.

$$\bar{p}_g = \sum_{h=1}^{n_g} p_{gh} / n_g \tag{3}$$

$$s_{1g}^2 = \left(\sum_{h=1}^{n_g} p_{gh}^2 - n_g \bar{p}_g^2 \right) \Big/ \left(n_g - 1 \right) \tag{4}$$

Make the following calculations:

$$\nu = \sum_{g=1}^{r} n_g \tag{5}$$

$$\bar{z} = \sum_{g=1}^{r} z_g n_g / \nu \tag{6}$$

$$\bar{p} = \sum \bar{p}_g n_g / \nu \tag{7}$$

Calculate the coefficients of the regression equation, $p = a_p + b_p z$

$$a_p = \bar{p} - b_p \bar{z} \tag{8}$$

$$b_p = \frac{\left(\sum_{g=1}^{r} n_g z_g \bar{p}_g - \nu \bar{z} \bar{p} \right)}{\left(\sum_{g=1}^{r} n_g z_g^2 - \nu \bar{z}^2 \right)} \tag{9}$$

Calculate the pooled variance within the property groups

$$s_1^2 = \sum_{g=1}^{r} \left(n_g - 1 \right) s_{1g}^2 \;/\; (\nu - r) \tag{10}$$

Calculate the weighted variance of the deviations of the property group means from the regression line

$$s_2^2 = \sum n_g \left(\bar{p}_g - \hat{P}_g \right)^2 / \,(r - 2) \tag{11}$$

where

$$\hat{P}_g = a_p + b_p \, z_g \tag{12}$$

This may also be expressed as

$$s_2^2 = \left[\left(\sum_{g=1}^{r} n_g \bar{p}_g^2 - \nu \bar{p}^2 \right) - b_p \left(\sum_{g=1}^{r} n_g z_g \bar{p}_g - \nu \bar{z} \bar{p} \right) \right] \Big/ (r - 2) \tag{13}$$

6.3.3 Linearity test

Make the F-test for non-linearity at significance level 0,05 by calculating

$$F = s_2^2 \,/\, s_1^2 \tag{14}$$

If the calculated value of F exceeds the tabulated value F_1 with $f_n = r - 2$ and $f_d = \nu - r$ degrees of freedom (see Table C.3), change the selection in 6.3.2 and repeat the calculations.

If it is not possible to satisfy the F-test on the significance level 0,05 with $r \geq 3$, make the F-test at a significance level 0,005 by comparing the calculated value of F with the tabulated value F_2 with $f_n = r - 2$ and $f_d = \nu - r$ degrees of freedom (see Table C.4).

If the test is satisfied at this level, the calculations may be continued, but the adjustment of TI according to 7.2.2, equation (48) is not permitted.

If the F-test on significance level 0,005 (i.e. $F \leq F_2$) cannot be satisfied, or the property points plotted in 6.3.2 are all on the same side of the end-point line, an extrapolation may be permitted, subject to the following condition:

If the F-test on significance level 0,05 can be met for a range of values (with $r \geq 3$) where all mean values $\bar{p}_g$ are on the same side of the end-point value p_e, an extrapolation may be made provided that the absolute value of the difference between the end-point value p_e and the mean value $\bar{p}_g$ closest to the end-point (usually $\bar{p}_r$) is less than one quarter of the absolute value of the difference $\left(\bar{p}_1 - \bar{p}_r\right)$.

NOTE In Figure E.1, if p_e were 5 000, the calculation would be as follows:

$\bar{p}_1$ is the value of the mean of the leftmost data group in the selection box, $\bar{p}_r$ of the rightmost. The condition is then

$$\left|\bar{p}_r - p_e\right| \leq \left|\bar{p}_1 - \bar{p}_r\right| / 4$$

The enclosing vertical lines imply the absolute value of the content.

In this case calculations can be continued, but again it is not permitted to carry out the adjustment of TI according to 7.2.2, equation (48).

6.3.4 Estimation of end-point temperatures equivalent to property values

For each of the h values of property in each of the g selected groups, calculate the equivalent reciprocal end-point temperature:

$$x_{ij} = z_g - \frac{\left(p_{gh} - p_e\right)}{b_p} \tag{15}$$

and

$$n_i = \nu \tag{16}$$

where

$j = 1 \ldots n_i$ is the order number of the x-value in the group of estimated x-values at ageing time τ_i and z_g is the reciprocal of the ageing temperature;

the n_i values of x_{ij} are reciprocal end-point temperature values to be used in the calculations of 6.4.

6.4 Regression analysis (temperature on time)

NOTE Where the determination is part of the determination of RTE (see Clause 3) the results from some equations will be required as input data for both control and candidate materials. If the calculations are made by computer program, a subroutine to save them to a data file will be useful.

Results from equations (19), (20), (21), (23), (25), (26), (33) or (34) and (46) will be required. In addition the value of the logarithm of the longest ageing time will be required to complete the input data.

6.4.1 Group means and variances

Calculate the mean and variance of the group of x-values, x_{ij}, obtained at each ageing time τ_i:

$$\bar{x}_i = \sum_{j=1}^{n_i} x_{ij} / n_i \tag{17}$$

$$s_{1i}^2 = \left(\sum_{j=1}^{n_i} x_{ij}^2 - n_i \ \bar{x}_i^2 \right) \Big/ (n_i - 1) \tag{18}$$

6.4.2 General means and variances

Calculate the total number of x_{ij} values, N, the weighted mean value of x, $(\bar{x}_i)$, and the weighted mean value of y, $(\bar{y})$:

$$N = \sum_{i=1}^{k} n_i \tag{19}$$

$$\bar{x} = \sum n_i \bar{x}_i \,/\, N \tag{20}$$

$$\bar{y} = \sum n_i y_i \,/\, N \tag{21}$$

Calculate the pooled variance within the data groups:

$$s_1^2 = \sum_{i=1}^{k} (n_i - 1) s_{1i}^2 \,/\, (N - k) \tag{22}$$

Calculate the second central moment of the y values:

$$\mu_2(y) = \frac{\left(\sum_{i=1}^{k} n_i y_i^2 - N \bar{y}^2 \right)}{N} \tag{23}$$

6.4.3 Regression

In the expression for the regression line:

$$x = a + by \tag{24}$$

Calculate the slope:

$$b = \frac{\left(\sum_{i=1}^{k} n_i \bar{x}_i y_i - N \bar{x} \bar{y} \right)}{\left(\sum_{i=1}^{k} n_i y_i^2 - N \bar{y}^2 \right)} \tag{25}$$

the intercept on the y-axis

$$a = \bar{x} - b \bar{y} \tag{26}$$

and the square of the correlation coefficient:

$$r^2 = \frac{\left(\sum_{i=1}^{k} n_i \bar{x}_i y_i - N\,\bar{x}\,\bar{y}\right)^2}{\left(\sum_{i=1}^{k} n_i \bar{x}_i^2 - N\,\bar{x}^2\right)\left(\sum_{i=1}^{k} n_i y_i^2 - N\,\bar{y}^2\right)} \quad (27)$$

Calculate the variance of the deviations of the x-means from the regression line:

$$s_2^2 = \sum_{i=1}^{k} \frac{n_i\left(\bar{x}_i - \hat{X}_i\right)^2}{(k-2)} \quad , \quad \hat{X}_i = a + b\,y_i \quad (28)$$

or

$$s_2^2 = \frac{\left(1 - r^2\right)}{(k-2)}\left(\sum_{i=1}^{k} n_i \bar{x}_i^2 - N\,\bar{x}^2\right) \quad (29)$$

6.5 Statistical tests

6.5.1 Variance equality test

Calculate the value of Bartlett's χ^2 function:

$$\chi^2 = \frac{\ln \mathrm{q}}{c}\left[(N-k)\log_{\mathrm{q}} s_1^2 - \sum_{i=1}^{k}(n_i - 1)\log_{\mathrm{q}} s_{1i}^2\right] \quad (30)$$

where

$$c = 1 + \frac{\left(\sum_{i=1}^{k} \frac{1}{(n_i - 1)} - \frac{1}{(N-k)}\right)}{3(k-1)} \quad (31)$$

q is the base of the logarithms used in this equation. It need not be the same as that used in the calculations elsewhere in this clause.

If q = 10, ln q = 2,303; if q = e, ln q = 1.

Compare the value of χ^2 with the tabulated value for $f = (k\text{-}1)$ degrees of freedom (Table C.1).

If the value of χ^2 is greater than the value tabulated for a significance level of 0,05, report the value of χ^2 and the significance level tabulated for the highest value less than χ^2.

Alternatively, if both χ^2 and its significance level are calculated by a computer program, report these.

6.5.2 Linearity test (F-test)

The variance of the deviations from the regression line s_2^2 is compared with the pooled variance within the k groups of measurements s_1^2 by the F-test at a significance level of 0,05.

Calculate the ratio

$$F = s_2^2 / s_1^2 \quad (32)$$

and compare its value with the tabulated value F_0 with $f_n = k - 2$ and $f_d = N - k$ degrees of freedom (Table C.3).

$$F_0 = F(0{,}95,\ k\ \text{-}2,\ N - k)$$

a) If $F \le F_0$ calculate the pooled variance estimate

$$s^2 = \frac{(N-k)s_1^2 + (k-2)s_2^2}{(N-2)} \tag{33}$$

b) If $F > F_0$, adjust s_1^2 to $\left(s_1^2\right)_a = s_1^2\left(F / F_0\right)$ and calculate an adjusted value of s^2

$$s_a^2 = \frac{(N-k)\left(s_1^2\right)_a + (k-2)s_2^2}{(N-2)} \tag{34}$$

6.5.3 Estimates of *x* and *y* and their confidence limits

Obtain the tabulated value of Student's t with N-2 degrees of freedom at a confidence level of 0,95, $t_{0{,}95,\ N\text{-}2}$ (Table C.2).

a) X-estimates

Calculate the Y-value corresponding to the time, τ, at which the estimate is required:

Calculate the estimated value of X corresponding to the given Y, and its upper 95 % confidence limit $\hat{X}_c$:

$$\hat{X}_c = \hat{X} + t\,s_x \quad ; \quad \hat{X} = a - bY \quad ; \quad t = t_{0{,}95,\ N-2} \tag{35}$$

$$s_x^2 = \frac{s^2}{N}\left[1 + \frac{(Y - \bar{y})^2}{\mu_2(y)}\right] \tag{36}$$

where

$$Y = \log \tau \tag{37}$$

Calculate the temperatures corresponding to the values of $\hat{X}$ and $\hat{X}_c$:

$$\vartheta = \frac{1}{X} - \Theta_0 \tag{38}$$

For the confidence limit curve of the thermal endurance graph (see 6.6), $\hat{X}_c$ is calculated for several values of Y over the range of interest, and a smooth curve drawn through the points ($\hat{X}_c$,Y) plotted on the graph.

If $F > F_0$ the value of s^2 shall be replaced by s_a^2 (equation 34).

b) Y-estimates

Calculate the value of $\hat{Y}$ and its lower 95 % confidence limit, corresponding to an end-point temperature ϑ_f

$$\hat{Y}_c = \bar{y} + \frac{(X - \bar{x})}{b_r} - \frac{t\,s_r}{b_r} \quad , \quad t = t_{0{,}95,\ N-2}, \tag{39}$$

$$X = 1/\left(\vartheta_f + \Theta_0\right) \quad : \quad \hat{Y} = (X - a)/b \tag{40}$$

$$b_r = b - \frac{t^2 s^2}{N\, b\, \mu_2(y)} \tag{41}$$

$$s_r^2 = \frac{s^2}{N}\left(\frac{b_r}{b} + \frac{\left(\hat{Y} - \bar{y}\right)^2}{\mu_2(y)}\right) \tag{42}$$

The time estimate and its lower 95 % confidence limit shall be calculated from the corresponding Y estimate and its lower confidence limit :

$$\tau = \mathrm{q}^{\hat{Y}} \quad , \quad \tau_c = \mathrm{q}^{\hat{Y}_c} \tag{43}$$

where q is the base of the logarithms used in the calculations (see Note in 6.1.1).

6.6 Thermal endurance graph

When the regression line has been established, it is drawn on the thermal endurance graph, i.e. a graph with y = log(τ) as ordinate and $x = 1/(\vartheta + \Theta_0)$ as abscissa. Usually x is plotted as increasing from right to left and the corresponding values of ϑ in degrees Celsius (ºC) are marked on this axis (see Figure E.2). Special graph paper is obtainable for this purpose.

Alternatively a computer program executing this calculation may include a subroutine to plot the graph on the appropriate non-linear scale.

The individual values x_{ij} and the mean values $\bar{x}_i$ obtained as in 6.4.1 are plotted on the graph at the corresponding values of y_i:

$$y_i = \log \tau_i \tag{44}$$

The thermal endurance graph may be completed by drawing the lower 95 % confidence curve (see 6.5.3).

7 Calculation and requirements for results

7.1 Calculation of thermal endurance characteristics

Using the regression equation

$$y = (x - a)/\, b \tag{45}$$

(the coefficients a and b being calculated according to 6.4.3), calculate the temperature in degrees Celsius (ºC) corresponding to a time to end-point of 20 kh, TI_{20}. The numerical value of this temperature is the temperature index, TI.

Calculate by the same method the numerical value of the temperature corresponding to a time to end-point of 10 kh, TI_{10}. The halving interval HIC is :

$$\mathrm{HIC} = \mathrm{TI}_{10} - \mathrm{TI}_{20} \tag{46}$$

Calculate by the method of 6.5.3 a), with Y = log 20 000, the lower 95 % confidence limit of TI: TC or TC_a if the adjusted value s_a^2 is used.

Determine the value of (TI – TC)/HIC or (TI – TC_a)/HIC.

Plot the thermal endurance graph (see 6.6).

7.2 Reporting of results

7.2.1 Summary of statistical tests and reporting

In Annex B, if the condition in the column headed "Test" is not met, the action is as indicated in the final column. If the condition is met, the action is as indicated at the next step. The same sequence is indicated in the decision flow chart for thermal endurance calculations, (see Annex A).

7.2.2 Report format

If the value of (TI – TC)/HIC is $\leq$ 0,6, the test result shall be reported in the format

$$\mathrm{TI}\left(\mathrm{HIC}\right):\quad .....\left(.....\right) \tag{47}$$

in accordance with 6.8 of IEC 60216-1.

If 0,6 < (TI – TC)/HIC $\leq$1,6 and at the same time, $F \leq F_0$ (see 6.3.2), the value

$$\mathrm{TI_a} = \mathrm{TC} + 0{,}6\,\mathrm{HIC} \tag{48}$$

together with HIC shall be reported as TI (HIC):....(...).

In all other cases the result shall be reported in the format

$$\mathrm{TI_g} = ...:\mathrm{HIC_g} = ... \tag{49}$$

8 Report

The test report shall include:

a) a description of the tested material including dimensions and any conditioning of the specimens;

b) the property investigated, the chosen end-point, and, if it was required to be determined, the initial value of the property;

c) the test method used for determination of the property (for example by reference to an IEC publication);

d) any relevant information on the test procedure, for example ageing environment;

e) the individual test times, the ageing temperatures and individual property values, with the graphs of variation of property with ageing temperature;

f) the thermal endurance graph;

g) the temperature index and halving interval reported in the format defined in 7.2.2;

h) the value of χ^2 and P if required by 6.5.1.

9 RTE determination

9.1 Objectives of RTE 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 initial assessment of service temperature of a material for which there is relatively little service experience (by comparison with a known control material – see Clauses 11 and 12).

NOTE In the majority of cases, this will involve extrapolation to a longer time or lower temperature than is present in the experimental data. This extrapolation should be kept to a minimum by appropriate choice of ageing temperatures and times (see Clause D.2 and Figure E.5), since the uncertainty in the result increases rapidly as the extrapolation is increased. However, even when there is no extrapolation, there is still a non-zero uncertainty, on account of the variances of the experimental data and other 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 control material 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 control and candidate will at least partially compensate for systematic changes. Statistical procedures for use in assessing the significance of changes are outlined in Annex F.

10 Additional symbols

These symbols are additional to those of 3.2 and are relevant only to Clauses 11 to 13.

Symbol	Description	Clause
A	Subscript indicating control material	
ATE	Known thermal endurance characteristic of control material	12.3
B	Subscript indicating candidate material	
$HIC_{B(c)}$	Halving interval of candidate material at correlation time	13.1
N_D	Total number of values in combined data of candidate and control materials	12.4
RTE	Estimated thermal endurance characteristic of candidate material (temperature index at correlation time)	12.3
s_D^2	Variance of combined data of candidate and control materials	12.4
s_D	Standard error of RTE (square root of s_D^2)	12.4
x_A	Reciprocal thermodynamic temperature of ATE	12.3
x_B	Reciprocal thermodynamic temperature of RTE	12.3
$X_{c(B)}$	Confidence limit of x_B	12.4
Y_c	Logarithm of correlation time	12.3
τ_c	Correlation time (time corresponding to ATE of control material)	12.3

τ_k	Longest ageing time	12.5
ϑ_{RTE}	Value of RTE in degrees Celsius	12.3
$\vartheta_{\mathrm{c(B)}}$	Confidence limit of RTE (upper or lower)	12.4
ϑ_{lc}	Lower confidence limit of RTE	12.4
Δ_R	Lower confidence interval of RTE	12.4

11 Experimental procedures

11.1 Selection of control material

The primary requirement for the control material is that the value of ATE for the application under consideration is known. The ATE, if determined by a thermal endurance procedure, shall be supported by actual service experience. The basis of the ATE shall be reported.

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

11.2 Selection of diagnostic test for extent of ageing

The diagnostic test shall be one considered relevant to the application for which the RTE is required. The same test and end-point shall be applied to both control and candidate material.

11.3 Ageing procedures

The number and type of test specimens and the ageing times and temperatures for both materials shall be as specified in Clause 5. If employing the recommendations of Annex D, the lowest ageing temperature should be the lower of the expected TI values for the two materials.

At each ageing temperature, the oven load shall comprise appropriate numbers of specimens of both materials. The specimens shall be distributed in the oven so that there is likely to be no systematic difference between the conditions applied to the specimens of the two materials.

12 Calculation procedures

12.1 General principles

The basis of the calculations is to calculate the thermal endurance characteristics of both materials (see 6.1.1 and 9.1a)).

From the thermal endurance data obtained for the control material, the time is calculated at which the temperature index is equal to its known temperature characteristic (this is the time referred to as the "correlation time"). From the thermal endurance data obtained for the candidate material, the temperature index is calculated at the correlation time. This value is the desired RTE.

The confidence intervals associated with this result are calculated by standard statistical procedures.

12.2 Input data

For both materials, control and candidate, the following intermediate data values are required from the calculations of TI (see 6.4).

Intermediate value	Symbol	Equation
Slope of regression line relative to y-axis	b	(25)
Intercept of regression line on x-axis	a	(26)
Weighted mean of y-values	$\bar{y}$	(21)
Central 2nd moment of y-values	$\mu_2(y)$	(23)
Weighted mean of data x-values	$\bar{x}$	(20)
Pooled total variance of data x-values	s^2	(33) or (34)
Number of x-values	N	(19)
Halving interval	HIC	(46)
Longest ageing time	τ_k	

12.3 RTE

Calculate the reciprocal thermodynamic temperature of ATE:

$$x_\mathrm{A} = \frac{1}{(\mathrm{ATE} + \Theta_0)} \qquad (50)$$

Calculate the correlation time τ_c and Y_c, its logarithm

$$Y_\mathrm{c} = \frac{(x_\mathrm{A} - a_\mathrm{A})}{b_\mathrm{A}} \qquad \tau_\mathrm{c} = \mathrm{q}^{Y_\mathrm{c}} \qquad (51)$$

where q is the base of logarithms used in the calculations (see Note in 6.1.1).

Calculate the estimate of x at the correlation time for the candidate material

$$x_\mathrm{B} = a_\mathrm{B} + Y_\mathrm{c}\, b_\mathrm{B} \qquad (52)$$

The value of RTE is

$$\vartheta_\mathrm{RTE} = \frac{1}{x_\mathrm{B}} - \Theta_0 \qquad (53)$$

12.4 Confidence limits

Calculate the estimate of x at the correlation time for the control material

$$x_\mathrm{A} = a_\mathrm{A} + Y_\mathrm{c}\, b_\mathrm{A} \qquad (54)$$

NOTE Numerically, x_A is equal to X_A. However, the latter is a scalar (i.e. non-variable) quantity while the former is random and normally distributed. The variance of the estimate of RTE is determined by the variance of the difference of x_A and x_B.

Calculate the variance of x_A

$$s_A^2 = \left[s^2 \left(1 + \frac{(Y_c - \bar{y})^2}{\mu_{2(y)}} \right) \right]_A \tag{55}$$

Similarly, calculate the variance of x_B

$$s_B^2 = \left[s^2 \left(1 + \frac{(Y_c - \bar{y})^2}{\mu_{2(y)}} \right) \right]_B \tag{56}$$

Calculate the value of the variance ratio, F

$$F = \frac{s_B^2}{s_A^2} \text{ if } s_B^2 > s_A^2 \text{, otherwise } F = \frac{s_A^2}{s_B^2} \tag{57}$$

If the value of F is less than the value in Table C.3 for $f_n = N_A - 2$ and $f_d = N_B - 2$ degrees of freedom, then the variances are not considered significantly different. In this case, merge the variances, using equations (58) and (59), otherwise using equations (60) and (61).

Statistically equal variances:

$$s_D^2 = \frac{s_A^2 (N_A - 2) + s_B^2 (N_B - 2)}{(N_A + N_B - 4)} \left(\frac{1}{N_A} + \frac{1}{N_B} \right) \tag{58}$$

$$N_D = (N_A + N_B - 4) \tag{59}$$

Statistically unequal variances:

$$s_D^2 = \frac{s_A^2}{N_A} + \frac{s_B^2}{N_B} \tag{60}$$

$$N_D = \frac{\left(s_D^2 \right)^2}{\frac{\left(\frac{s_A^2}{N_A} \right)^2}{N_A - 2} + \frac{\left(\frac{s_B^2}{N_B} \right)^2}{N_B - 2}} \tag{61}$$

If, in the second case, N_D is not integral, round its value to the nearest integer.

Calculate the confidence limits of X_{B}

$$X_{\mathrm{c(B)}} = X_{\mathrm{B}} \pm t_{(N_{\mathrm{D}})}\, s_{\mathrm{D}} \tag{62}$$

where $t_{(N_{\mathrm{D}})}$ is the value of t in Table C.2 for N_{D} degrees of freedom.

The confidence limits of RTE are

$$\vartheta_{\mathrm{c(B)}} = \frac{1}{X_{\mathrm{B}} \pm t_{(N_{\mathrm{D}})}\, s_{\mathrm{D}}} - \Theta_0 \tag{63}$$

Normally, the lower confidence limit of RTE, ϑ_{lc} is required, corresponding to the upper confidence limit of X_{B}.

The lower confidence interval Δ_R shall be calculated by equation (64)

$$\Delta_R = \vartheta_{\mathrm{RTE}} - \vartheta_{\mathrm{lc}} \tag{64}$$

12.5 Extrapolation

Calculate the extrapolation as the ratio $\dfrac{\tau_{\mathrm{c}}}{\tau_k}$.

13 Results and report

13.1 Results of statistical and numerical tests

The following criteria apply.

a) Linearity of thermal endurance relationship (see 6.3.2 and 6.3.3 of IEC 60216-3). Both control and candidate data shall satisfy the requirements of IEC 60216-3.

b) Extrapolation to the correlation time (see 12.5). The extrapolation, expressed as the ratio of correlation time to greatest ageing time, shall be less than 4.

c) Lower confidence interval of RTE (see 12.4). The value of Δ_R shall be less than the halving interval ($\mathrm{HIC}_{\mathrm{B(c)}}$) of the candidate material at a time equal to the correlation time (see 7.1 of IEC 60216-3).

$$\mathrm{HIC}_{\mathrm{B(c)}} = b_{\mathrm{B}} \left[\frac{1}{(\ln(\tau_{\mathrm{c}}/2) - a_{\mathrm{B}})} - \frac{1}{(\ln \tau_{\mathrm{c}} - a_{\mathrm{B}})} \right] \tag{65}$$

13.2 Result

The result shall be determined from the calculations of 12.4 and 12.5 and expressed as follows.

a) If all three test criteria (see 13.1) are satisfied, the result shall be the value of RTE. The result shall be reported in the format
"RTE according to IEC 60216-6 = xxx"

b) If one of the test criteria is not satisfied, the result shall be the lower 95 % confidence limit of RTE. The result shall be reported in the format
"RTE according to IEC 60216-6 = xxx"

c) If two or more of the criteria are not satisfied, a result in accordance with the requirements of IEC 60216-6 cannot be reported. The result may be reported in the format
"RTE = xxx. (Result not validated by the statistical analysis)"

13.3 Report

The report shall comprise the following:

a) the result;

b) the identification of the control material, its ATE and the basis of the ATE;

c) the diagnostic test employed and the end-point;

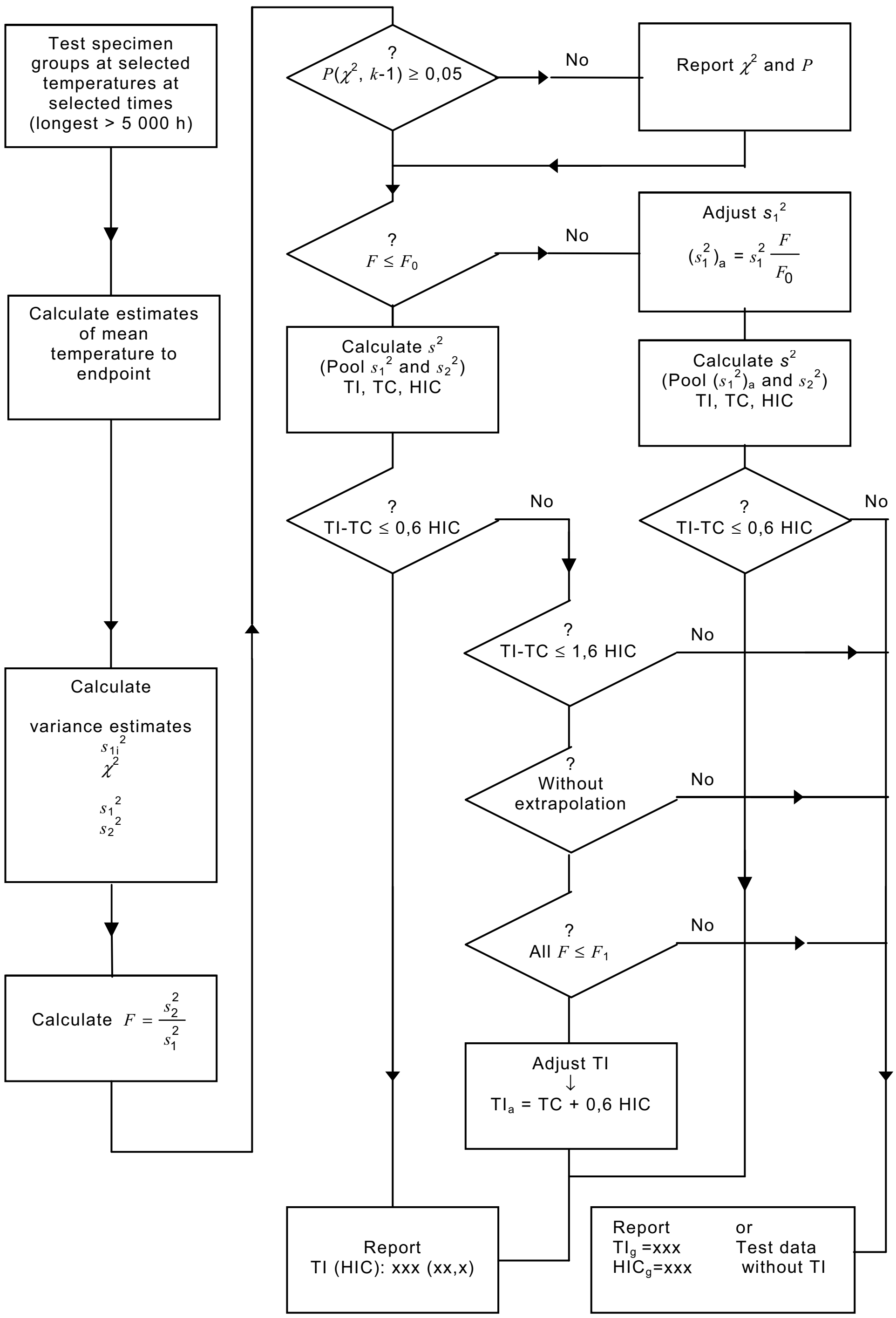
d) the thermal endurance reports according to IEC 60216-1 for the control and candidate materials;

e) for a result in category 13.2 c) above, the details of the failure of statistical validation.

Annex A
(normative)

Decision flow chart

If the time to end-point used to calculate the thermal endurance indices is other than 20 000 h (see 3.1.1), the value of 5 000 h in Annexes A and B shall be replaced by one quarter of the time used.



Annex B
(normative)

Decision table

Table B.1 – Decision table

Step	Test (?) or action	Reference	Action if NO in test
1	Test specimen groups at selected temperatures for selected times (longest > 5 000 h)	5.2	
2	Calculate estimates of mean temperature to endpoint	6.4.1	
3	Calculate estimates of variances s_{1i}^2 Calculate χ^2 Calculate s_1^2 Calculate s_2^2	6.3, 6.4.1 Equation 18 6.5.1 6.4.2 6.4.3	
4	Calculate F	6.5.2	
5	? $P(\chi^2, k\text{-}1) \geq 0{,}05$	6.5.1	Report χ^2 and P: Go to step 6
6	? $F \leq F_0$	6.5.2	Go to step 14
7	Calculate s^2 (Pool s_1^2 and s_2^2) Calculate TI, TC, HIC	6.5.2a)	
8	? TI – TC ≤ 0,6 HIC	7.2.2	Go to step 10
9	Report TI (HIC): ... (..)	7.2.2	
10	? TI – TC ≤ 1,6 HIC	7.2.2	Go to step 18
11	? Were data processed without extrapolation	6.3.4	Go to step 18
12	? Were all values of $F \leq F_1$	6.3.3	Go to step 18
13	Report TI_a = TC+0,6 HIC as TI (HIC): ... (..)	7.2.2	
14	Adjust s_1^2: $(s_1^2)_a = s_1^2 \frac{F}{F_0}$	6.5.2	
15	Calculate s^2: (Pool $(s_1^2)_a$ and s_2^2) Calculate TI, TC_a, HIC	6.5.2	
16	? TI – TC_a ≤ 0,6 HIC	7.2.2	Go to step 18
17	Report TI (HIC): ... (..)	7.2.2	
18	Report TI_g = ..., HIC_g = ..., or test data without TI	7.2.2	

If the time to end-point used to calculate the thermal endurance indices is other than 20 000 h (see 3.1.1), the value of 5 000 h in Annexes A and B shall be replaced by one quarter of the time used.

Annex C
(informative)

Statistical tables

Table C.1 presents the values of χ^2 for significance levels (P) of 0,05, 0,01 and 0,005.

Table C.1 – χ^2-function

Degrees of freedom	P=0,05	P=0,01	P=0,005
1	3,8	6,6	7,9
2	6,0	9,2	10,6
3	7,8	11,3	12,8
4	9,5	13,3	14,9
5	11,1	15,1	16,7
6	12,6	16,8	18,5

Table C.2 gives the values of Student's t for significance levels (p) of 0,05 and 0,005.

The columns of the table represent the number (f) of degrees of freedom and the rows the significance level (P).

Table C.2– t-function

	10	11	12	13	14	15	16	17	18
P = 0,05	1,812	1,796	1,782	1,771	1,761	1,753	1,746	1,740	1,734
P = 0,005	3,169	3,106	3,055	3,012	2,977	2,947	2,921	2,898	2,878

	19	20	25	30	40	50	100	500
P = 0,05	1,729	1,725	1,708	1,697	1,684	1,676	1,660	1,648
P = 0,005	2,861	2,845	2,787	2,750	2,704	2,678	2,626	2,586

Table C.3 gives the values of F for significance level 0,05.

The columns of Tables C.3 and C.4 represent the number of degrees of freedom of the numerator (f_n) and the rows the number of degrees of freedom of the denominator (f_d).

Table C.3 – F-function, P = 0,05

	1	2	3	4	5	6	7	8	9
10	4,965	4,103	3,708	3,478	3,326	3,217	3,135	3,072	3,02
11	4,844	3,982	3,587	3,357	3,204	3,095	3,012	2,948	2,896
12	4,747	3,885	3,49	3,259	3,106	2,996	2,913	2,849	2,796
13	4,667	3,806	3,411	3,179	3,025	2,915	2,832	2,767	2,714
14	4,6	3,739	3,344	3,112	2,958	2,848	2,764	2,699	2,646
15	4,543	3,682	3,287	3,056	2,901	2,79	2,707	2,641	2,588
16	4,494	3,634	3,239	3,007	2,852	2,741	2,657	2,591	2,538
17	4,451	3,592	3,197	2,965	2,81	2,699	2,614	2,548	2,494
18	4,414	3,555	3,16	2,928	2,773	2,661	2,577	2,51	2,456
19	4,381	3,522	3,127	2,895	2,74	2,628	2,544	2,477	2,423
20	4,351	3,493	3,098	2,866	2,711	2,599	2,514	2,447	2,393
25	4,242	3,385	2,991	2,759	2,603	2,49	2,405	2,337	2,282
30	4,171	3,316	2,922	2,69	2,534	2,421	2,334	2,266	2,211
40	4,085	3,232	2,839	2,606	2,449	2,336	2,249	2,18	2,124
50	4,034	3,183	2,79	2,557	2,4	2,286	2,199	2,13	2,073
100	3,936	3,087	2,696	2,463	2,305	2,191	2,103	2,032	1,975
500	3,86	3,014	2,623	2,39	2,232	2,117	2,028	1,957	1,899

	10	11	12	13	14	15	16	17	18
10	2,978	2,943	2,913	2,887	2,865	2,845	2,828	2,812	2,798
11	2,854	2,818	2,788	2,761	2,739	2,719	2,701	2,685	2,671
12	2,753	2,717	2,687	2,66	2,637	2,617	2,599	2,583	2,568
13	2,671	2,635	2,604	2,577	2,554	2,533	2,515	2,499	2,484
14	2,602	2,565	2,534	2,507	2,484	2,463	2,445	2,428	2,413
15	2,544	2,507	2,475	2,448	2,424	2,403	2,385	2,368	2,353
16	2,494	2,456	2,425	2,397	2,373	2,352	2,333	2,317	2,302
17	2,45	2,413	2,381	2,353	2,329	2,308	2,289	2,272	2,257
18	2,412	2,374	2,342	2,314	2,29	2,269	2,25	2,233	2,217
19	2,378	2,34	2,308	2,28	2,256	2,234	2,215	2,198	2,182
20	2,348	2,31	2,278	2,25	2,225	2,203	2,184	2,167	2,151
25	2,236	2,198	2,165	2,136	2,111	2,089	2,069	2,051	2,035
30	2,165	2,126	2,092	2,063	2,037	2,015	1,995	1,976	1,96
40	2,077	2,038	2,003	1,974	1,948	1,924	1,904	1,885	1,868
50	2,026	1,986	1,952	1,921	1,895	1,871	1,85	1,831	1,814
100	1,927	1,886	1,85	1,819	1,792	1,768	1,746	1,726	1,708
500	1,85	1,808	1,772	1,74	1,712	1,686	1,664	1,643	1,625

	19	20	25	30	40	50	100	500
10	2,785	2,774	2,73	2,7	2,661	2,637	2,588	2,548
11	2,658	2,646	2,601	2,57	2,531	2,507	2,457	2,415
12	2,555	2,544	2,498	2,466	2,426	2,401	2,35	2,307
13	2,471	2,459	2,412	2,38	2,339	2,314	2,261	2,218
14	2,4	2,388	2,341	2,308	2,266	2,241	2,187	2,142
15	2,34	2,328	2,28	2,247	2,204	2,178	2,123	2,078
16	2,288	2,276	2,227	2,194	2,151	2,124	2,068	2,022
17	2,243	2,23	2,181	2,148	2,104	2,077	2,02	1,973
18	2,203	2,191	2,141	2,107	2,063	2,035	1,978	1,929
19	2,168	2,155	2,106	2,071	2,026	1,999	1,94	1,891
20	2,137	2,124	2,074	2,039	1,994	1,966	1,907	1,856
25	2,021	2,007	1,955	1,919	1,872	1,842	1,779	1,725
30	1,945	1,932	1,878	1,841	1,792	1,761	1,695	1,637
40	1,853	1,839	1,783	1,744	1,693	1,66	1,589	1,526
50	1,798	1,784	1,727	1,687	1,634	1,599	1,525	1,457
100	1,691	1,676	1,616	1,573	1,515	1,477	1,392	1,308
500	1,607	1,592	1,528	1,482	1,419	1,376	1,275	1,159

Table C.4 gives the values of F for significance level 0,005

The columns of Tables C.3 and C.4 represent the number of degrees of freedom of the numerator (f_n) and the rows the number of degrees of freedom of the denominator (f_d).

Table C.4 – F-function, P = 0,005

	1	2	3	4	5	6	7	8	9
10	12,826	9,427	8,081	7,343	6,872	6,545	6,302	6,116	5,968
11	12,226	8,912	7,6	6,881	6,422	6,102	5,865	5,682	5,537
12	11,754	8,51	7,226	6,521	6,071	5,757	5,525	5,345	5,202
13	11,374	8,186	6,926	6,233	5,791	5,482	5,253	5,076	4,935
14	11,06	7,922	6,68	5,998	5,562	5,257	5,031	4,857	4,717
15	10,798	7,701	6,476	5,803	5,372	5,071	4,847	4,674	4,536
16	10,575	7,514	6,303	5,638	5,212	4,913	4,692	4,521	4,384
17	10,384	7,354	6,156	5,497	5,075	4,779	4,559	4,389	4,254
18	10,218	7,215	6,028	5,375	4,956	4,663	4,445	4,276	4,141
19	10,073	7,093	5,916	5,268	4,853	4,561	4,345	4,177	4,043
20	9,944	6,986	5,818	5,174	4,762	4,472	4,257	4,09	3,956
25	9,475	6,598	5,462	4,835	4,433	4,15	3,939	3,776	3,645
30	9,18	6,355	5,239	4,623	4,228	3,949	3,742	3,58	3,45
40	8,828	6,066	4,976	4,374	3,986	3,713	3,509	3,35	3,222
50	8,626	5,902	4,826	4,232	3,849	3,579	3,376	3,219	3,092
100	8,241	5,589	4,542	3,963	3,589	3,325	3,127	2,972	2,847
500	7,95	5,355	4,33	3,763	3,396	3,137	2,941	2,789	2,665

	10	11	12	13	14	15	16	17	18
10	5,847	5,746	5,661	5,589	5,526	5,471	5,422	5,379	5,34
11	5,418	5,32	5,236	5,165	5,103	5,049	5,001	4,959	4,921
12	5,085	4,988	4,906	4,836	4,775	4,721	4,674	4,632	4,595
13	4,82	4,724	4,643	4,573	4,513	4,46	4,413	4,372	4,334
14	4,603	4,508	4,428	4,359	4,299	4,247	4,2	4,159	4,122
15	4,424	4,329	4,25	4,181	4,122	4,07	4,024	3,983	3,946
16	4,272	4,179	4,099	4,031	3,972	3,92	3,875	3,834	3,797
17	4,142	4,05	3,971	3,903	3,844	3,793	3,747	3,707	3,67
18	4,03	3,938	3,86	3,793	3,734	3,683	3,637	3,597	3,56
19	3,933	3,841	3,763	3,696	3,638	3,587	3,541	3,501	3,465
20	3,847	3,756	3,678	3,611	3,553	3,502	3,457	3,416	3,38
25	3,537	3,447	3,37	3,304	3,247	3,196	3,151	3,111	3,075
30	3,344	3,255	3,179	3,113	3,056	3,006	2,961	2,921	2,885
40	3,117	3,028	2,953	2,888	2,831	2,781	2,737	2,697	2,661
50	2,988	2,9	2,825	2,76	2,703	2,653	2,609	2,569	2,533
100	2,744	2,657	2,583	2,518	2,461	2,411	2,367	2,326	2,29
500	2,562	2,476	2,402	2,337	2,281	2,23	2,185	2,145	2,108

	19	20	25	30	40	50	100	500
10	5,305	5,274	5,153	5,071	4,966	4,902	4,772	4,666
11	4,886	4,855	4,736	4,654	4,551	4,488	4,359	4,252
12	4,561	4,53	4,412	4,331	4,228	4,165	4,037	3,931
13	4,301	4,27	4,153	4,073	3,97	3,908	3,78	3,674
14	4,089	4,059	3,942	3,862	3,76	3,698	3,569	3,463
15	3,913	3,883	3,766	3,687	3,585	3,523	3,394	3,287
16	3,764	3,734	3,618	3,539	3,437	3,375	3,246	3,139
17	3,637	3,607	3,492	3,412	3,311	3,248	3,119	3,012
18	3,527	3,498	3,382	3,303	3,201	3,139	3,009	2,901
19	3,432	3,402	3,287	3,208	3,106	3,043	2,913	2,804
20	3,347	3,318	3,203	3,123	3,022	2,959	2,828	2,719
25	3,043	3,013	2,898	2,819	2,716	2,652	2,519	2,406
30	2,853	2,823	2,708	2,628	2,524	2,459	2,323	2,207
40	2,628	2,598	2,482	2,401	2,296	2,23	2,088	1,965
50	2,5	2,47	2,353	2,272	2,164	2,097	1,951	1,821
100	2,257	2,227	2,108	2,024	1,912	1,84	1,681	1,529
500	2,075	2,044	1,922	1,835	1,717	1,64	1,46	1,26

Annex D
(informative)

Suggested ageing times and temperatures

D.1 TI determination

D.1.1 Correlation time (TI) = 20 000 h

When the time for TI calculation is the conventional 20 000 h (see 7.1) the following four ageing times and ten ageing oven temperatures are suggested.

The temperatures cover a range of 90 K in intervals of 10 K, the lowest temperature being equal to the expected value of TI, rounded to the nearest multiple of 10. In the following table, each ✸ represents one group of specimens to be loaded into the oven concerned.

Temperature	TI	TI+10	TI+20	TI+30	TI+40	TI+50	TI+60	TI+70	TI+80	TI+90
Ageing time										
5 040 h	✸	✸	✸	✸	✸	✸	✸			
2 016 h		✸	✸	✸	✸	✸	✸	✸		
1 008 h			✸	✸	✸	✸	✸	✸	✸	
552 h				✸	✸	✸	✸	✸	✸	✸

NOTE 1 The above four ageing times are suggested as convenient multiples of 24 h (1 day) or 168 h (1 week), close to the values of ≥500 h, ≈1 000 h, ≈2 000 h and ≥5 000 h, covering a range of 1 to 10 in four approximately equal logarithmic steps.

NOTE 2 These ageing times and temperatures are expected to give acceptable extents of ageing, such that satisfactory selection of data for the regression analyses (see 6.1.2 and 6.3.2) can be made if the expected value of TI is within ±10 K of the actual value and the value of HIC is between 8 K and 13 K. If the values are outside these ranges, it may be necessary to employ an additional higher temperature. In order to allow this, it is recommended to prepare specimens additional to those indicated by the above figures.

For illustration of this, see Figure E.3 and Figure E.4 which show the ageing times and temperatures in relation to the actual thermal endurance graph for hypothetical cases. In the data of Figure E.3, at all ageing times, approximately equal numbers of temperature groups lie above and below the "temperature for end-point", i.e. the intersection with the regression line. This is not true for the data of Figure E.4, where an extrapolation would be required at times of 552 h and 1 008 h.

D.1.2 Other correlation times for TI calculation (see 12.3)

Where the correlation time (time for TI calculation) is greater than 20 000 h, it is advisable to increase the number of times to 5 and of temperatures to 11, making the longest ageing time equal to approximately one quarter of the correlation time, and the lowest temperature equal to the value of TI (see 12.3). The number of ovens providing samples for each ageing time remains at seven (see Figure E.5).

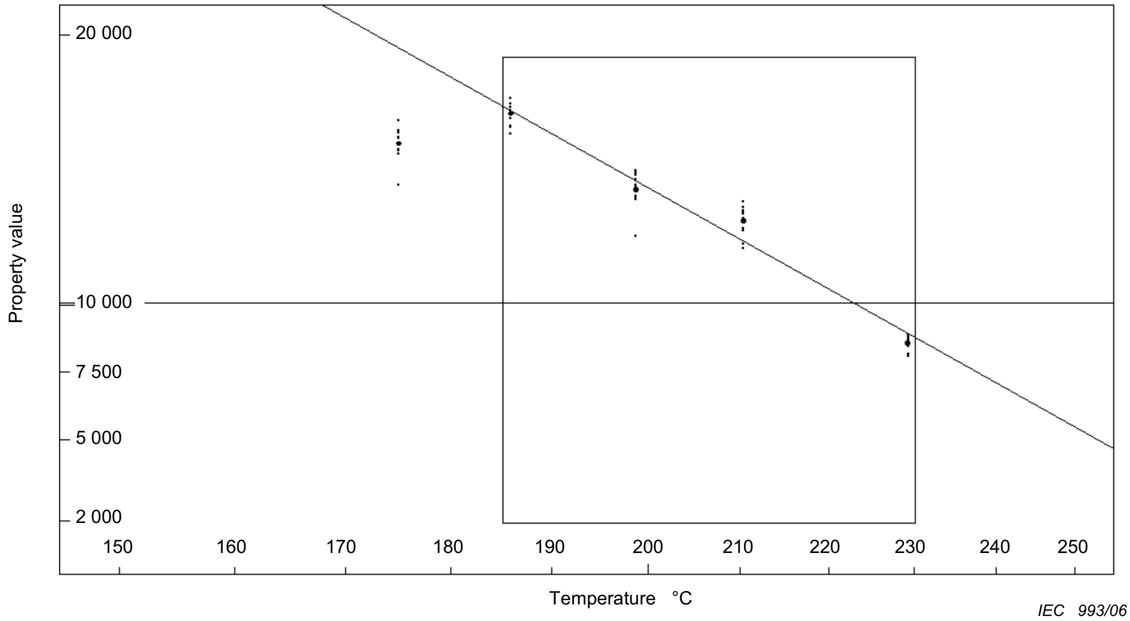
D.2 RTE determination

The start point for the above table should be the lower of the expected TI values for the control and candidate materials, rounded to the nearest 10 K. The remaining temperatures should be chosen as in D.1.2 above.

NOTE It may reasonably be expected that these ageing times and temperatures will be acceptable if both actual TI values are within ±10 K of the chosen value and both HIC values are within the range (8 to 13) K.

Annex E
(informative)

Figures



The data are for ageing time 2 016 h of the data group represented below (Figure E.2). The data selected for regression are in the inner rectangular outline box.

Figure E.1 – Property-temperature graph with regression line

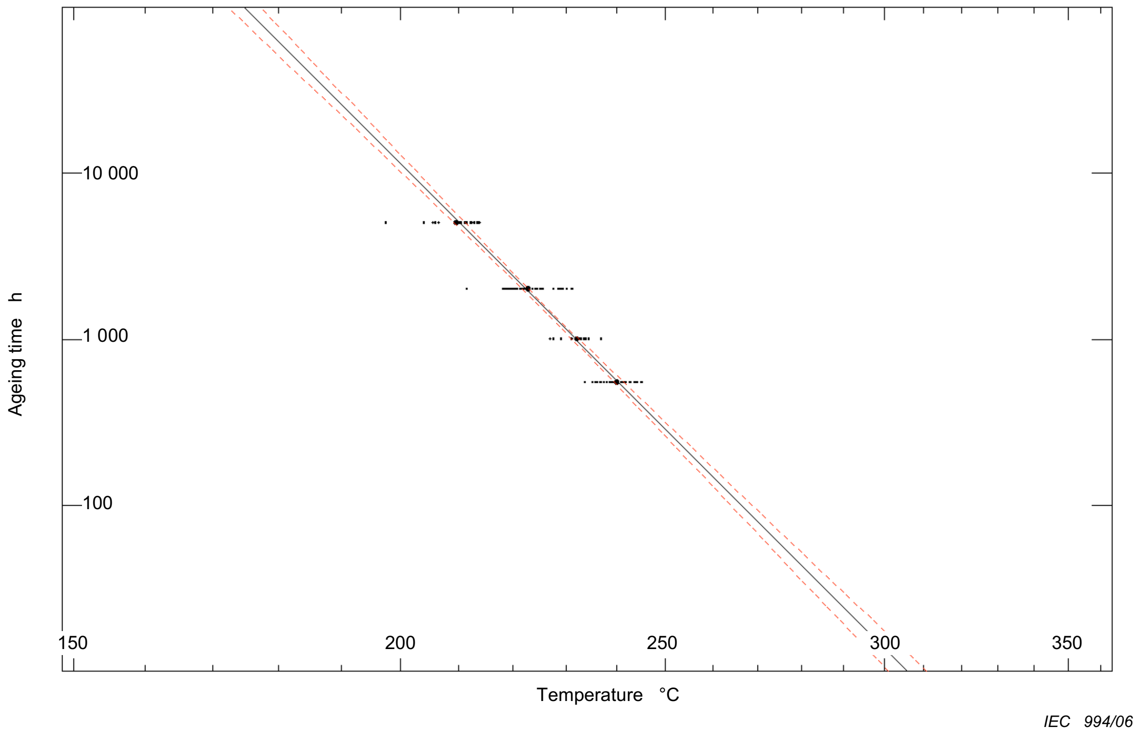
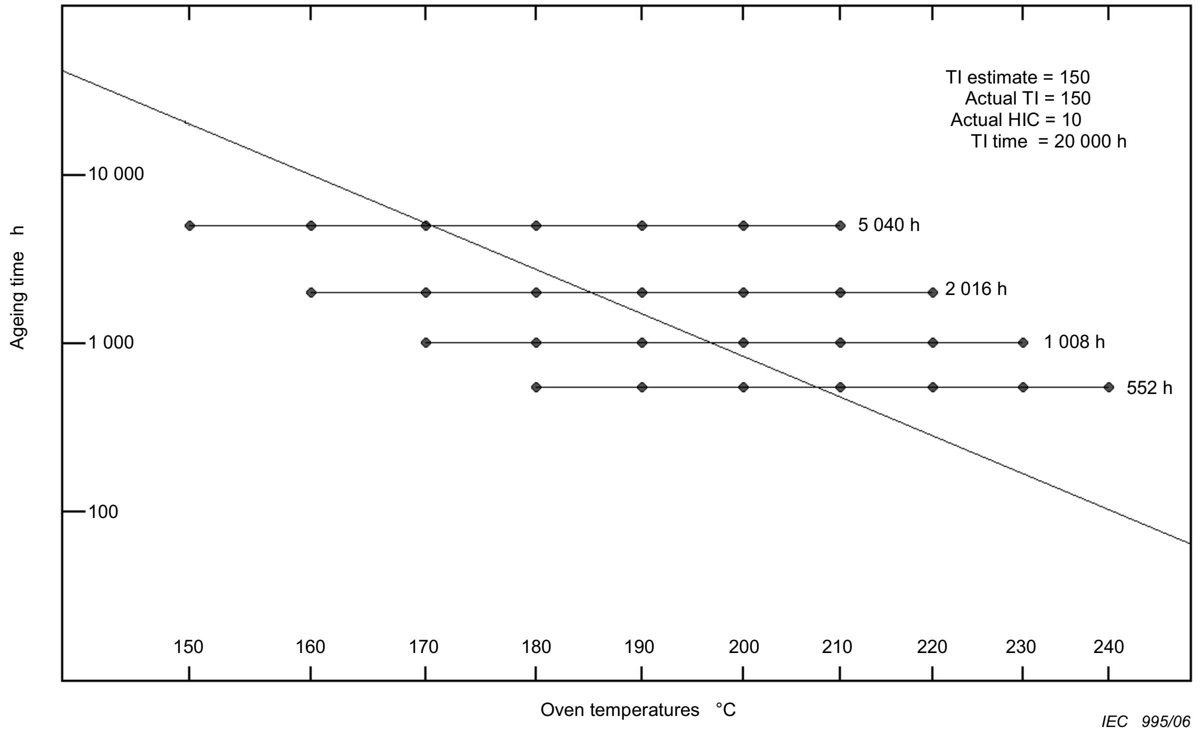
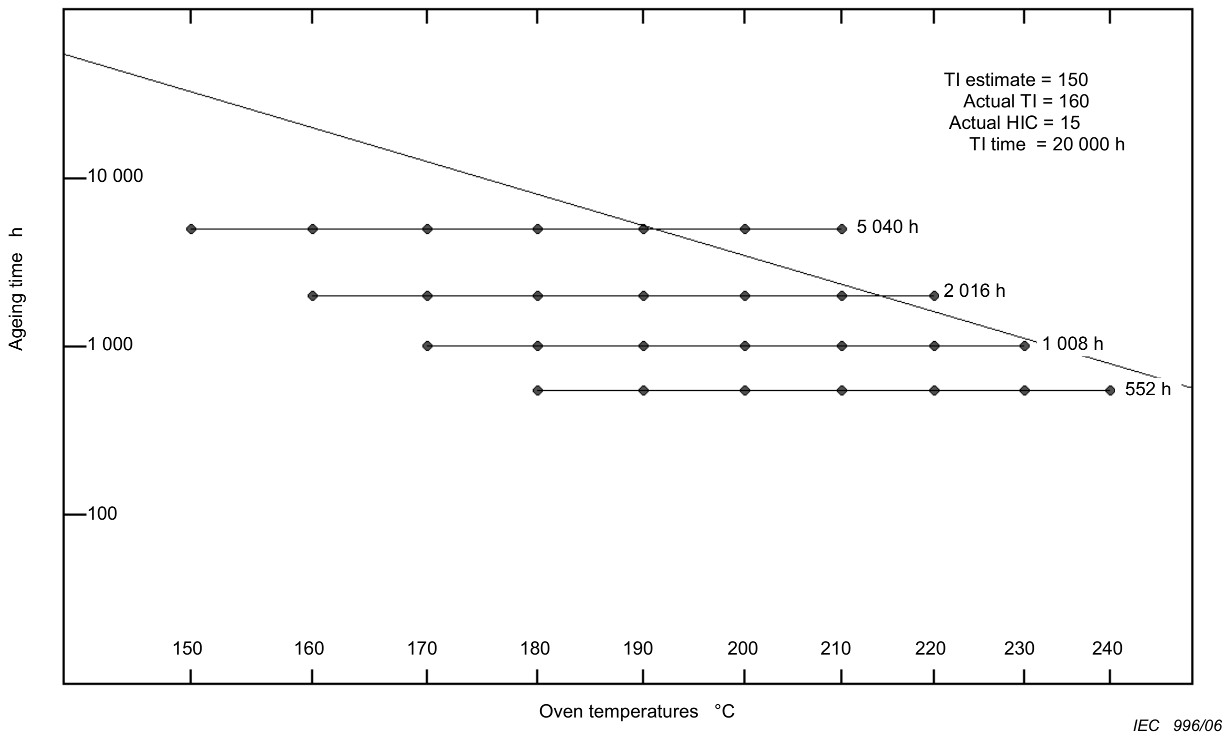


Figure E.2 – Thermal endurance graph



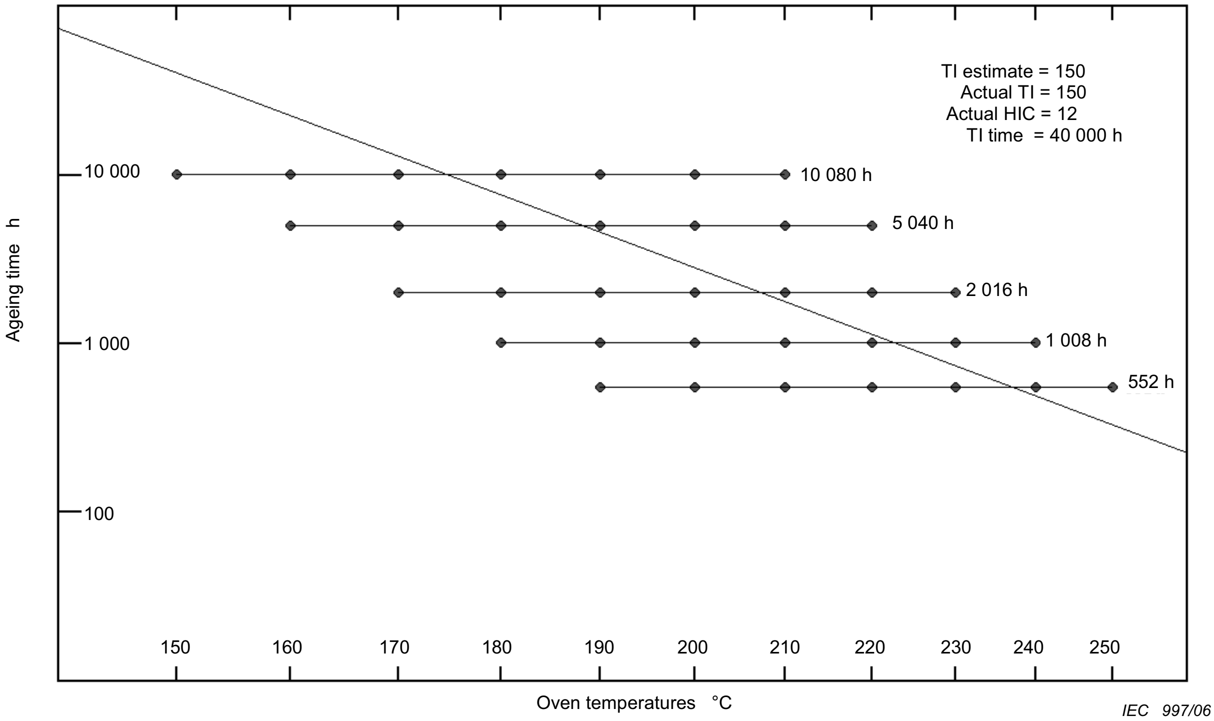
(Accurate expectation value for TI and average HIC)

Figure E.3 – Ageing times and temperatures in relation to thermal endurance graph



(Low expectation of TI and large value of HIC)
Higher ageing temperatures needed

Figure E.4 – Ageing times and temperatures in relation to thermal endurance graph



Extra, longer ageing time for correlation time = 40 kh

The additional ageing time of 10 kh was chosen for illustration as one quarter of 40 kh.

Figure E.5 – Ageing times and temperatures in relation to thermal endurance graph

Annex F
(normative)

Statistical significance of the difference between two regression estimates

Where multiple determinations of a thermal endurance index are made (e.g. the determination may be made several times on a control material), the admissibility of the differences between two results may be assessed using the equations of 12.4.

NOTE In the following discussion, the suffixes A and B refer to the two sets of data on the one material: the first data set (A) is treated as ATE-data, the second set (B) as candidate material data. Data set A may be a pooled value from several other values.

- Calculate the value of x corresponding to the TI value for the first data set (the ATE) (equation 50), the correlation time (equation 51) and the variance of x_A (equation 55).
- At this correlation time, calculate the corresponding values of x_B (equation 52) and its variance (equation 56).
- Calculate the number of degrees of freedom of the difference (x_B-x_A) (equations 58 to 61).
- Calculate the value of t for this difference and compare its value with that in Table C.2 of Annex C, at significance level 0,05.

$$t_{(N_D)} = \frac{\left(x_B - x_A\right)}{s_D}$$

A value greater than that tabulated (Table C.2) implies a significant difference between the results. This may imply a change in the control material or in the conditions of ageing. This should be investigated, and if necessary, corrected.

Annex G
(informative)

Computer programs for IEC 60216-6

G.1 Introduction

The programs on the accompanying CD-ROM for calculations in Part 6 of IEC 60216 are for use in conjunction with the disk operating system MSDOS [1] or equivalent.

CD-ROM content

Annex G.doc		
Entry-6.bas,	Entry-6.exe	
216-6.bas,	216-6.exe	
Rte-6.bas,	Rte-6.exe	
Control.ftd,	Control.ftr,	Control.ftc
Candidat.ftc		

The text based program files (*.bas) may be edited if necessary using either a text editor or the "Quick Basic" programs QB45 or QBX and saved as ASCII files with the filename ending in ".bas". They may then be executed using QB45 or QBX or compiled for stand-alone execution. The resultant executable files will have the ending ".exe" and the same file stem as the ".bas" files.

These executable files are suitable for direct execution in DOS, and may be executed in Windows 95 or later (98, etc.) by creating an icon for the file and double-clicking that icon. The "short-cut" options should be set so that the program is run in a normal window.

To create the icon, in Windows Explorer, right click the file name and select "Create Shortcut", or drag the program into the desktop.

G.2 216-6.bas (or .exe)

The program requires data to be entered in the form of an ASCII text file obtained using the associated program Entry-6.bas described below. As default it assumes the file ending for the data file ".ftd" if no file ending is entered. However, other file endings may be entered.

The file structure is similar to that of destructive test data in IEC 60216-3, modified so that the most significant test variable is time rather than temperature, the roles of time and temperature being interchanged.

Data analysis and statistical tests in accordance with IEC 60216-6 are carried out and the results reported in the appropriate format. The report is recorded in a text file with the ending ".ftr", which may be edited in a word processor program.

Result parameters as required for calculation of RTE are automatically entered into a file having the same name as the experimental data file and with the ending ".ftc".

[1] MSDOS, Quick Basic, Windows 95, Windows 98 and Windows Explorer are the trade names of products supplied by Microsoft, Inc.. 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.

G.3 Entry-6.bas (or .exe)

Data obtained using the procedures of IEC 60216-6 are entered following the screen instructions to generate a data file having by default the ending ".ftd". Other file endings may be entered if required.

The data in the enclosed file "Control.ftd" may be printed and used to gain familiarity with the data entry program.

G.4 RTE-6. bas (or .exe)

Data files obtained using 216-6.exe or 216-6.bas are required for both the control and candidate materials. Statistical tests are carried out, and the results reported, in accordance with the standard. The report may be saved in a file with the same name as that of the candidate material and the extension ".fte".

G.5 Data files

Two data files are provided for entry to RTE-6. These are named Control.ftc and Candidat.ftc. The ATE originally provided for Control.ftd was 170. Control.ftc is derived from Control.ftd.

G.5.1 Content of file Control.ftd

The data on which Control.ftd is based are as follows (S = included in calculations to produce the reports etc supplied on this disc):

Time	Temperature		Property values									
552												
	199		18810	18080	18710	18090	18430	17990	19200	17860	17940	18700
	210	S	18480	18700	18370	18750	18010	17260	18950	18680	16450	18260
	219	S	14290	15130	15930	15000	14520	14840	14430	16540	15840	15380
	229	S	12010	13200	13460	12550	12910	12670	14040	14080	12770	12060
	241	S	10590	9820	10230	9680	9220	9720	10100	9880	10340	10070
	250		5710	5180	5100	6050	5650	5270	5440	5180	4930	5260
1008												
	211		14570	14910	14560	14560						
	221	S	11890	11030	11970	10930	11840					
	228	S	10730	11300	10750	10500	10880					
	240	S	8580	9020	8880	9130	9060					
2016												
	175		15740	15630	14470	16020	16210	16870	16500	16250	16410	15790
	186	S	17470	16950	16670	17480	17190	17340	17240	17670	16610	16370
	199	S	14660	14440	14850	12550	13940	14010	14460	14900	14070	15010
	210	S	11850	11260	10520	11790	11630	10660	11180	12060	11920	12240
	229	S	8210	8560	8470	8810	8900	8720	8700	8740	8690	8130
5040												
	150		15740	15750	15330	15120	15310	15300	15590	14450	14850	14830
	160		15690	15340	14900	15400	14860	16020	15360	15910	15640	16100
	175		15040	15340	15230	15380	15370	15420	15990	14980	15060	15760
	185	S	14590	13940	13850	12360	14610	14930	15170	15140	15100	14940
	200	S	11710	12000	12280	11040	11750					
	210	S	10130	10460	10340	9060	10050					

Endpoint 10080

The actual file content is as shown below (next page). The data in the columns are in the file as one continuous column, one number per line.

The functions of the numbers are indicated in the comments associated with a selection of the numbers.

4 (Number of exposure times)
6 (Max number of temperatures at any time)
10 (Max number of specimens in any temperature group)
552 (Ageing time #1)
6 (Number of temperature groups)
199 (Ageing temperature #1,1)
10 (Number of specimens)
18810 (Property value #1,1,1)
18080 (Property value #1,1,2)
18710
18090
18430
17990
19200
17860
17940
18700
210 (Temperature #1,2)
10
18480
18700
18370
18750
18010
17260
18950
18680
16450
18260
219
10
14290
15130
15930
15000
14520
14840
14430
16540
15840
15380
229
10
12010
13200
13460
12550
12910
12670
14040
14080
12770
12060
241
10
10590
9820
10230
9680
9220
9720
10100
9880
10340
10070
250
10
5710
5180
5100
6050
5650
5270
5440
5180
4930
5260
1008 (Time #2)
4
211 (Temperature #2,1)
4
14570 (Property value #2,1,1)
14910
14560
14560
221
5
11890
11030
11970
10930
11840
228
5
10730
11300
10750
10500
10880
240
5
8580
9020
8880
9130
9060
2016
5
175
10
15740
15630
14470
16020
16210
16870
16500
16250
16410
15790
186
10
17470
16950
16670
17480
17190
17340
17240
17670
16610
16370
199
10
14660
14440
14850
12550
13940
14010
14460
14900
14070
15010
210
10
11850
11260
10520
11790
11630
10660
11180
12060
11920
12240
229
10
8210
8560
8470
8810
8900
8720
8700
8740
8690
8130
5040
6
150
10
15740
15750
15330
15120
15310
15300
15590
14450
14850
14830
160
10
15690
15340
14900
15400
14860
16020
15360
15910
15640
16100
175
10
15040
15340
15230
15380
15370
15420
15990
14980
15060
15760
185
10
14590
13940
13850
12360
14610
14930
15170
15140
15100
14940
200
5
11710
12000
12280
11040
11750
210
5
10130
10460
10340
9060
10050
10080

G.5.2 Report file

The report file generated for the above data is control.ftr; its content is:

filename: d:\temp\control.ftd

The result is TI (HIC): 190.6 (8.8)

Lower 95% confidence limit of TI 188.5

Chi-Squared (DF) 8.3164 (3)

F (nn, nd) 6.095 (2, 111)

Longest mean time to endpoint 5040

Compensated non-linearity

Non-linearity + destructive test non-linearity

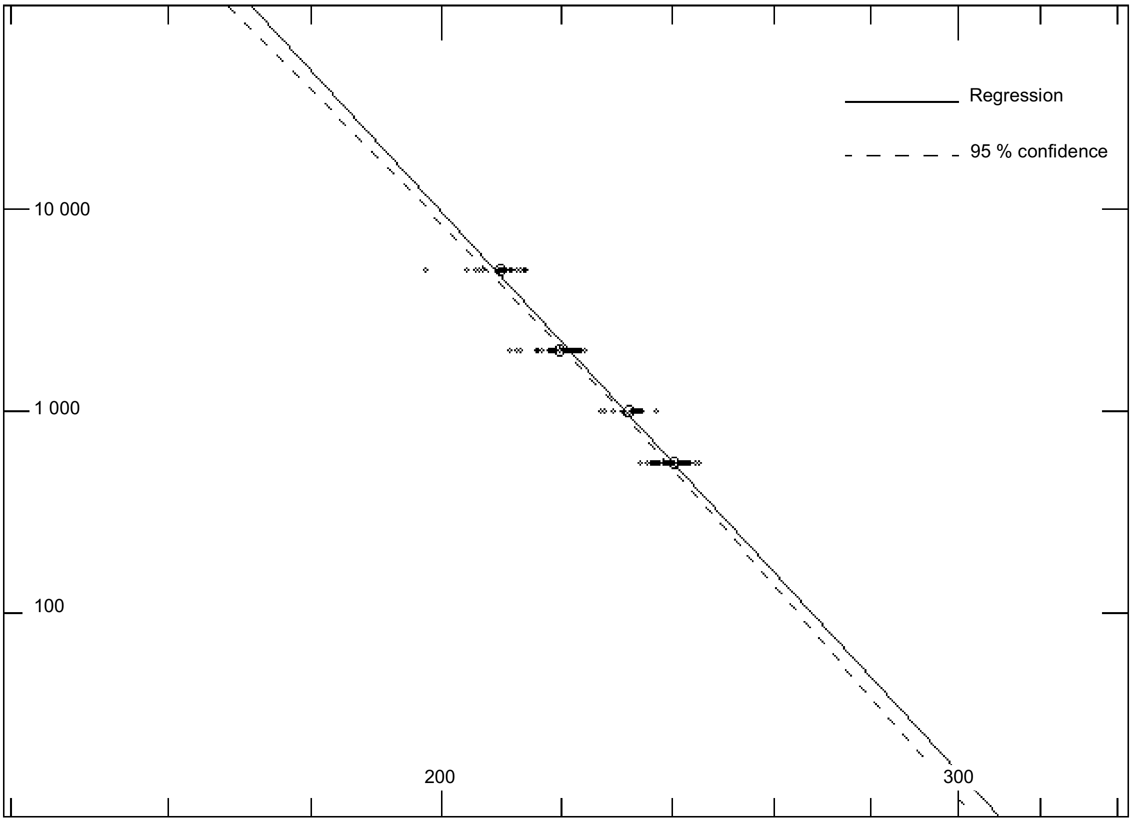
Selected ageing temperatures

Time	552	210	219	229	241
Time	1008	221	228	240	
Time	2016	186	199	210	229
Time	5040	185	200	210	

Linearity tests

Time 552	F = 1.852	F(0.95, 2, 36) = 3.162	F(0.995, 2, 36) = 6.044
Time 1008	F = 1.962	F(0.95, 1, 12) = 4.743	F(0.995, 1, 12) = 11.715
Time 2016	F = 5.294	F(0.95, 2, 36) = 3.162	F(0.995, 2, 36) = 6.044
Time 5040	F = 0.003	F(0.95, 1, 17) = 4.487	F(0.995, 1, 17) = 10.365

G.5.3 Thermal endurance graph



IEC 998/06

Figure G.1 − Thermal endurance graph

The thermal endurance graph is presented in a graphics format which may be copied into the Windows clipboard (see Figure G.1). The graph may then be imported into another Windows program (e.g. a word processor) in the usual way. Graphs for materials having different ageing properties are produced with compatible temperature scales, each being in effect a "window" of fixed width in an infinitely long reciprocal temperature scale.

G.6 Content of file Control.ftc

This file contains the information required for the RTE calculations (a similar file is required for the candidate material). The actual values contained are:

7.2272680519088

0.646666369249988

2.00152633394296D-03

3.38025166055829D-10

115

5.78159898962069D-05

1.58367467727663D-03

5040

These values are as specified in 12.2 of this standard. They are calculated and saved in the file as double precision floating point numbers.

G.7 Copying graphs to word processor reports

If it is required to include the graphs in a report, the word processor program should be started before the 216-6 program, which should be set up to run in a DOS window. Although the graphs are displayed full screen, the change from and back to a DOS (text) window is automatic.

When the graph is displayed, it is copied to the Windows clipboard by pressing Print Screen or ALT + Print Screen key (ALT + Print Screen copies the active window: Print Screen copies the active screen).The word processor my then be brought to the screen by pressing ALT + Esc or ALT + Tab, if necessary, repeatedly. The transfer is then completed by means of the menu function Edit / Paste Special / Device Independent Bitmap. Do not use the Control + V shortcut, as this will insert the graph in an inconvenient format (changing this is a very tedious process). The graph may be edited for size and position in the usual way. Unwanted material can generally be removed with the crop function of the drawing toolbar.

Return to the 216-6 program is then carried out from either the 216-6 label on the Windows taskbar or by (repeatedly) pressing ALT + Tab or ALT + Esc.

The report file *.ftr may be imported directly into a word processor report and edited or formatted in the usual way.

Standards Survey

The IEC would like to offer you the best quality standards possible. To make sure that we continue to meet your needs, your feedback is essential. Would you please take a minute to answer the questions overleaf and fax them to us at +41 22 919 03 00 or mail them to the address below. Thank you!

Customer Service Centre (CSC)

International Electrotechnical Commission
3, rue de Varembé
1211 Genève 20
Switzerland

or

Fax to: **IEC**/CSC at +41 22 919 03 00

Thank you for your contribution to the standards-making process.

Nicht frankieren
Ne pas affranchir

Non affrancare
No stamp required

A Prioritaire

RÉPONSE PAYÉE

SUISSE

Customer Service Centre (CSC)
International Electrotechnical Commission
3, rue de Varembé
1211 GENEVA 20
Switzerland

Q1 Please report on **ONE STANDARD** and **ONE STANDARD ONLY**. Enter the exact number of the standard: *(e.g. 60601-1-1)*

....

Q2 Please tell us in what capacity(ies) you bought the standard *(tick all that apply).* I am the/a:

purchasing agent ❑
librarian ❑
researcher ❑
design engineer ❑
safety engineer ❑
testing engineer ❑
marketing specialist ❑
other...

Q3 I work for/in/as a: *(tick all that apply)*

manufacturing ❑
consultant ❑
government ❑
test/certification facility ❑
public utility ❑
education ❑
military ❑
other...

Q4 This standard will be used for: *(tick all that apply)*

general reference ❑
product research ❑
product design/development ❑
specifications ❑
tenders ❑
quality assessment ❑
certification ❑
technical documentation ❑
thesis ❑
manufacturing ❑
other...

Q5 This standard meets my needs: *(tick one)*

not at all ❑
nearly ❑
fairly well ❑
exactly ❑

Q6 If you ticked NOT AT ALL in Question 5 the reason is: *(tick all that apply)*

standard is out of date ❑
standard is incomplete ❑
standard is too academic ❑
standard is too superficial ❑
title is misleading ❑
I made the wrong choice ❑
other ....

Q7 Please assess the standard in the following categories, using the numbers:
(1) unacceptable,
(2) below average,
(3) average,
(4) above average,
(5) exceptional,
(6) not applicable

timeliness ....
quality of writing....................................
technical contents.................................
logic of arrangement of contents ....
tables, charts, graphs, figures...............
other ....

Q8 I read/use the: *(tick one)*

French text only ❑
English text only ❑
both English and French texts ❑

Q9 Please share any comment on any aspect of the IEC that you would like us to know:

....
....
....
....
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....
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....
....
....
....

Enquête sur les normes

La CEI ambitionne de vous offrir les meilleures normes possibles. Pour nous assurer que nous continuons à répondre à votre attente, nous avons besoin de quelques renseignements de votre part. Nous vous demandons simplement de consacrer un instant pour répondre au questionnaire ci-après et de nous le retourner par fax au +41 22 919 03 00 ou par courrier à l'adresse ci-dessous. Merci !

Centre du Service Clientèle (CSC)

Commission Electrotechnique Internationale
3, rue de Varembé
1211 Genève 20
Suisse

ou

Télécopie: **CEI**/CSC +41 22 919 03 00

Nous vous remercions de la contribution que vous voudrez bien apporter ainsi à la Normalisation Internationale.

Nicht frankieren
Ne pas affranchir

Non affrancare
No stamp required

A Prioritaire

RÉPONSE PAYÉE

SUISSE

Centre du Service Clientèle (CSC)
Commission Electrotechnique Internationale
3, rue de Varembé
1211 GENÈVE 20
Suisse

Q1 Veuillez ne mentionner qu'**UNE SEULE NORME** et indiquer son numéro exact: (*ex. 60601-1-1)*

....

Q2 En tant qu'acheteur de cette norme, quelle est votre fonction?
(cochez tout ce qui convient)
Je suis le/un:

agent d'un service d'achat ❏
bibliothécaire ❏
chercheur ❏
ingénieur concepteur ❏
ingénieur sécurité ❏
ingénieur d'essais ❏
spécialiste en marketing ❏
autre(s)..

Q3 Je travaille:
(cochez tout ce qui convient)

dans l'industrie ❏
comme consultant ❏
pour un gouvernement ❏
pour un organisme d'essais/ certification ❏
dans un service public ❏
dans l'enseignement ❏
comme militaire ❏
autre(s)..

Q4 Cette norme sera utilisée pour/comme
(cochez tout ce qui convient)

ouvrage de référence ❏
une recherche de produit ❏
une étude/développement de produit ❏
des spécifications ❏
des soumissions ❏
une évaluation de la qualité ❏
une certification ❏
une documentation technique ❏
une thèse ❏
la fabrication ❏
autre(s)..

Q5 Cette norme répond-elle à vos besoins:
(une seule réponse)

pas du tout ❏
à peu près ❏
assez bien ❏
parfaitement ❏

Q6 Si vous avez répondu PAS DU TOUT à Q5, c'est pour la/les raison(s) suivantes:
(cochez tout ce qui convient)

la norme a besoin d'être révisée ❏
la norme est incomplète ❏
la norme est trop théorique ❏
la norme est trop superficielle ❏
le titre est équivoque ❏
je n'ai pas fait le bon choix ❏
autre(s) ....

Q7 Veuillez évaluer chacun des critères ci-dessous en utilisant les chiffres
(1) inacceptable,
(2) au-dessous de la moyenne,
(3) moyen,
(4) au-dessus de la moyenne,
(5) exceptionnel,
(6) sans objet

publication en temps opportun ....
qualité de la rédaction..........................
contenu technique ....
disposition logique du contenu ....
tableaux, diagrammes, graphiques, figures ....
autre(s) ....

Q8 Je lis/utilise: *(une seule réponse)*

uniquement le texte français ❏
uniquement le texte anglais ❏
les textes anglais et français ❏

Q9 Veuillez nous faire part de vos observations éventuelles sur la CEI:

....
....
....
....
....
....

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