

Electrical insulating materials — Thermal endurance properties —

Part 3: Instructions for calculating thermal endurance characteristics

The European Standard EN 60216-3:2002 has the status of a British Standard

ICS 17.220.99; 19.020; 29.035.01

National foreword

This British Standard is the official English language version of EN 60216-3:2002. It is identical with IEC 60216-3:2002. It supersedes BS EN 60216-3-2:1995 and BS 5691-3-1:1995 which are withdrawn.

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

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

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This British Standard, having been prepared under the direction of the Electrotechnical Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on 17 September 2002

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 63 and a back cover.

The BSI copyright date displayed in this document indicates when the document was last issued.

Amendments issued since publication

Amd. No.	Date	Comments

© BSI 17 September 2002

ISBN 0 580 40354 8

EUROPEAN STANDARD

EN 60216-3

NORME EUROPÉENNE

EUROPÄISCHE NORM

April 2002

ICS 17.220.99;19.020;29.035.01

Supersedes HD 611.3.1 S1:1992 & EN 60216-3-2:1995

English version

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

Matériaux isolants électriques -
Propriétés d'endurance thermique
Partie 3: Instructions pour le calcul
des caractéristiques d'endurance thermique
(CEI 60216-3:2002)

Elektroisolierstoffe -
Eigenschaften hinsichtlich
des thermischen Langzeitverhaltens
Teil 3: Anweisungen zur Berechnung
thermischer Langzeitkennwerte
(IEC 60216-3:2002)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Ref. No. EN 60216-3:2002 E



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Foreword

The text of document 15E/162/FDIS, future edition 1 of IEC 60216-3, prepared by SC 15E, Methods of test, of IEC TC 15, Insulating materials, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60216-3 on 2002-03-01.

This European Standard supersedes HD 611.3.1 S1:1992 and EN 60216-3-2:1995.

The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2002-12-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2005-03-01

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

Annexes designated "informative" are given for information only.

In this standard, annexes A, B and ZA are normative and annexes C, D and E are informative.

Annex ZA has been added by CENELEC.

A computer-readable medium (diskette or CD-ROM) containing the computer programme given in Annex E is an integral part of the national implementation of this European Standard.

Endorsement notice

The text of the International Standard IEC 60216-3:2002 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

IEC 60216-3 series of publications was previously conceived as having four sections. Two of these have been published, i.e. IEC 60216-3-1 and IEC 60216-3-2. The remaining two sections were under consideration. Of these, section 4 is not now required, since the relative temperature index is no longer included in the thermal endurance characteristics. This part of IEC 60216 is now combining the three sections into one standard, with substantial elimination of replicated matter.

At the same time, the scope has been extended to cover a greater range of data characteristics, particularly with regard to incomplete data, as often obtained from proof test criteria. The greater flexibility of use should lead to more efficient employment of the time available for ageing purposes.

Some minor errors in mathematical usage have also been eliminated.

The procedures specified in this part of IEC 60216 have been extensively tested and have been used to calculate results from a large body of experimental data obtained in accordance with other parts of the standard.

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

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

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

ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

Part 3: Instructions for calculating thermal endurance characteristics

1 Scope

This part of IEC 60216 specifies the calculation procedures to be used for deriving thermal endurance characteristics from experimental data obtained in accordance with the instructions of IEC 60216-1 and IEC 60216-2.

The experimental data may be obtained using non-destructive, destructive or proof tests. Data obtained from non-destructive or proof tests may be incomplete, in that measurement of times taken to reach the endpoint may have been terminated at some point after the median time but before all specimens have reached end-point.

The procedures are illustrated by worked examples, and suitable computer programs are recommended to facilitate the calculations.

2 Normative references

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

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

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

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

3.1 Terms and definitions

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

3.1.1

ordered data

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

NOTE In this standard ascending order in this standard implies that the data is ordered in this way, the first being the smallest.

3.1.2

order-statistics

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

3.1.3

incomplete data

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

3.1.4

censored data

incomplete data, where the number of unknown values is known. If the censoring is begun above/below a specified numerical value, the censoring is Type 1. If above/below a specified order-statistic it is Type 2

NOTE This standard is concerned only with Type 2.

3.1.5

degrees of freedom

number of data values minus the number of parameter values

3.1.6

variance of a data set

sum of the squares of the deviations of the data from a reference level defined by one or more parameters, for example a mean value (one parameter) or a line (two parameters, slope and intercept), divided by the number of degrees of freedom

3.1.7

central second moment of a data set

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

3.1.8

covariance of data sets

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

3.1.9

regression analysis

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

NOTE The parameters are referred to as the regression coefficients.

3.1.10

correlation coefficient

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

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

3.1.11

end-point line

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

3.2 Symbols and abbreviated terms

		Clause
a	Regression coefficient (y -intercept)	4.3, 6.2
a_p	Regression coefficient for destructive test calculations	6.1
b	Regression coefficient (slope)	4.3, 6.2
b_p	Regression coefficient for destructive test calculations	6.1
b_r	Intermediate constant (calculation of $\hat{X}_c$)	6.3
c	Intermediate constant (calculation of χ^2)	6.3
f	Number of degrees of freedom	Tables C.2, C.3
F	Fisher distributed stochastic variable	4.2, 6.1, 6.3
F_0	Tabulated value of F (linearity of thermal endurance graph)	4.4, 6.3
F_1	Tabulated value of F (linearity of property graph – significance 0,05)	6.1
F_2	Tabulated value of F (linearity of property graph – significance 0,005)	6.1
g	Order number of ageing time for destructive tests	6.1
h	Order number of property value for destructive tests	6.1
HIC	Halving interval at temperature equal to T_I	4.3, 7
HIC _{g}	Halving interval corresponding to TI_g	7.3
i	Order number of exposure temperature	4.1, 6.2
j	Order number of time to end-point	4.1, 6.2
k	Number of ageing temperatures	4.1, 6.2
m_i	Number of specimens aged at temperature ϑ_i	4.1, 6.1
N	Total number of times to end-point	6.2
n_g	Number of property values in group aged for time τ_g	6.1
n_i	Number of values of y at temperature ϑ_i	4.1, 6.1

$\bar{p}$	Mean value of property values in selected groups	6.1
p	Value of diagnostic property	6.1
P	Significance level of χ^2 distribution	4.4, 6.3.1
p_e	Value of diagnostic property at end-point for destructive tests	6.1
$\bar{p}_g$	Mean of property values in group aged for time τ_g	6.1
p_{gh}	Individual property value	6.1
q	Base of logarithms	6.3
r	Number of ageing times selected for inclusion in calculation (destructive tests)	6.1
r^2	Square of correlation coefficient	6.2.3
s^2	Weighted mean of s_1^2 and s_2^2	6.3
s_1^2	Weighted mean of s_{1i}^2 , pooled variance within selected groups	4.3, 6.1 - 6.3
$(s_1^2)_a$	Adjusted value of s_1^2	4.4, 6.3
s_{1g}^2	Variance of property values in group aged for time τ_g	6.1
s_{1i}^2	Variance of y_{ij} values at temperature ϑ_i	4.3, 6.2
s_2^2	Variance about regression line	6.1 - 6.3
s_a^2	Adjusted value of s^2	6.3
s_r^2	Intermediate constant	6.3
s_Y^2	Variance of Y	6.3
t	Student distributed stochastic variable	6.3
t_c	Adjusted value of t (incomplete data)	6.3
TC	Lower 95 % confidence limit of TI	4.4, 7
TC _a	Adjusted value of TC	7.1
TI	Temperature Index	4.3, 7
TI ₁₀	Temperature Index at 10 kh	7.1
TI _a	Adjusted value of TI	7.3
TI _g	Temperature index obtained by graphical means or without defined confidence limits	7.3
x	Independent variable: reciprocal of thermodynamic temperature	
$\bar{x}$	Weighted mean value of x	6.2
X	Specified value of x for estimation of y	6.3
$\hat{X}$	Estimated value of x at specified value of y	6.3
$\hat{X}_c$	Upper 95 % confidence limit of $\hat{X}$	6.3
x_i	Reciprocal of thermodynamic temperature corresponding to ϑ_i	4.1, 6.1

$\bar{y}$	Weighted mean value of y	6.2
y	Dependent variable: logarithm of time to end-point	
$\hat{Y}$	Estimated value of y at specified value of x	6.3
Y	Specified value of y for estimation of x	6.3
$\hat{Y}_c$	Lower 95 % confidence limit of $\hat{Y}$	6.3
$\bar{y}_i$	Mean values of y_{ij} at temperature ϑ_i	4.3, 6.2
y_{ij}	Value of y corresponding to τ_{ij}	4.1, 6.1
$\bar{z}$	Mean value of z_g	6.1
z_g	Logarithm of ageing time for destructive tests – group g	6.1
α	Censored data coefficient for variance	4.3, 6.2
β	Censored data coefficient for variance	4.3, 6.2
ε	Censored data coefficient for variance of mean	4.3, 6.2
Θ_0	The temperature 0 °C on the thermodynamic scale (273,15 K)	4.1, 6.1
$\hat{\vartheta}$	Estimate of temperature for temperature index	6.3.3
$\hat{\vartheta}_c$	Confidence limit of $\hat{\vartheta}$	6.3.3
ϑ_i	Ageing temperature for group i	4.1, 6.1
μ	Censored data coefficient for mean	4.3, 6.2
$\mu_2(x)$	Central second moment of x values	6.2, 6.3
v	Total number of property values selected at one ageing temperature	6.1
τ_f	Time selected for estimate of temperature	6.3
τ_{ij}	Times to end-point	6.3
χ^2	χ^2 -distributed stochastic variable	6.3

4 Principles of calculations

4.1 General principles

The general calculation procedures and instructions given in clause 6 are based on the principles set out in IEC 60493-1. These may be simplified as follows (see 3.7.1 of IEC 60493-1):

- the relation between the mean of the logarithms of the times taken to reach the specified end-point (times to end-point) and the reciprocal of the thermodynamic (absolute) temperature is linear;
- the values of the deviations of the logarithms of the times to end-point from the linear relation are normally distributed with a variance which is independent of the ageing temperature.

The data used in the general calculation procedures are obtained from the experimental data by a preliminary calculation. The details of this calculation are dependent on the character of the diagnostic test: non-destructive, proof or destructive (see 4.2). In all cases the data comprise values of x , y , m , n and k ,

where

$x_i = 1/(\vartheta_i + \Theta_0)$ = reciprocal of thermodynamic value of ageing temperature ϑ_i in °C;

$\Theta_0 = 273,15$ K;

$y_{ij} = \log \tau_{ij}$ = logarithm of value of time (j) to end-point at temperature ϑ_i ;

n_i = number of y values in group number i aged at temperature ϑ_i ;

m_i = number of samples in group number i aged at temperature ϑ_i (different from n_i for censored data);

k = number of ageing temperatures or groups of y 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.

4.2 Preliminary calculations

In all cases, the reciprocals of the thermodynamic values of the ageing temperatures are calculated as the values of x_i .

The values of y_{ij} are calculated as the values of the logarithms of the individual times to end-point τ_{ij} obtained as described below.

In many cases of non-destructive and proof tests, it is advisable for economic reasons, (for example, when the scatter of the data is high) to stop ageing before all specimens have reached the end-point, at least for some temperature groups. In such cases, the procedure for calculation on censored data (see 6.2.1.2) shall be carried out on the (x, y) data available.

Groups of complete and incomplete data or groups censored at a different point for each ageing temperature may be used together in one calculation in 6.2.1.2.

4.2.1 Non-destructive tests

Non-destructive tests, (for example, loss of mass on ageing) give directly the value of the diagnostic property of each specimen each time it is measured at the end of an ageing period. The time to end-point τ_{ij} , is therefore available, either direct or by linear interpolation between consecutive measurements.

4.2.2 Proof tests

The time to end-point τ_{ij} for an individual specimen is taken as the mid-point of the ageing period immediately prior to reaching the end-point (6.3.2 of IEC 60216-1).

4.2.3 Destructive tests

When destructive test criteria are employed, each test specimen is destroyed in obtaining a property value and its time to end-point cannot therefore be measured direct.

To enable estimates of the times to end-point to be obtained, the assumptions are made that in the vicinity of the endpoint

- a) the relation between the mean property values and the logarithm of the ageing time 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 ageing time;
- c) the curves of property versus logarithm of time 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 for the data obtained at each of the ageing times. The curve is obtained by plotting the mean value of property for each specimen group against the logarithm of its ageing time. If possible, ageing is continued at each temperature until at least one group mean is beyond the end-point level. An approximately linear region of this curve is drawn in the vicinity of the end-point line (see figure D.2).

A statistical test (*F*-test) is carried out to decide whether deviations from linearity of the selected region are acceptable (see 6.1.4.4). 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 logarithm of the time to end-point for that specimen (y_{ij}) is then the value of the logarithm of time corresponding to the intersection of the line with the end-point line (figure D.2).

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 6.1.4.

4.3 Variance calculations

Commencing with the values of x and y obtained as above, the following calculations are made:

For each group of y_{ij} values, the mean $\bar{y}_i$ and variance s_{ii}^2 are calculated, and from the latter the pooled variance within the groups, s_1^2 , is derived, weighting the groups according to size.

For incomplete data the calculations have been developed from those originated by Saw [1]¹⁾ and given in 6.2.1.2. The coefficients required (μ for mean, α , β for variance and ε for deriving the variance of mean from the group variance) are given in table C.1. For multiple groups, the variances are pooled, weighting according to the group size. The mean value of the group values of ε is obtained without weighting, and multiplied by the pooled variance.

From the means $\bar{y}_i$ and the values of x_i , the coefficients a and b (the coefficients of the best fit linear representation of the relationship between x and y) are calculated by linear regression analysis.

From the regression coefficients the values of TI and HIC are calculated. The variance of the deviations from the regression line is calculated from the regression coefficients and the group means.

¹⁾ Figures in square brackets refer to the bibliography.

4.4 Statistical tests

The following statistical tests are made:

- a) Fisher test for linearity (F -test) on destructive test data prior to the calculation of estimated times to end-point (see 4.2.3);
- b) variance equality (Bartlett's χ^2 -test) to establish whether the variances within the groups of y values differ significantly;
- c) F -test to establish whether the ratio of the deviations from the regression line to the pooled variance within the data groups is greater than the reference value F_0 , i.e. to test the validity of the Arrhenius hypothesis as applied to the test data.

In the case of data of very small dispersion, it is possible for a non-linearity to be detected as statistically significant which is of little practical importance.

In order that a result may be obtained even where the requirements of the F -test are not met for this reason, a procedure is included as follows:

- 1) increase the value of the pooled variance within the groups (s_1^2) by the factor F/F_0 so that the F -test gives a result which is just acceptable (see 6.3.2);
- 2) use this adjusted value $(s_1^2)_a$ to calculate the lower confidence limit TC_a of the result;
- 3) if the lower confidence interval ($TI - TC_a$) is found acceptable, the non-linearity is deemed to be of no practical importance (see 6.3.2);
- 4) from the components of the data dispersion, (s_1^2) and (s_2^2) the confidence interval of an estimate is calculated using the regression equation.

When the temperature index (TI), its lower confidence limit (TC) and the halving interval (HIC) have been calculated, (see 7.1), the result is considered acceptable if

$$TI - TC \leq 0,6 \text{ HIC} \quad (1)$$

When the lower confidence interval ($TI - TC$) exceeds 0,6 HIC by a small margin, a usable result may still be obtained, provided $F \leq F_0$, by substituting $(TC + 0,6 \text{ HIC})$ for the value of TC (see clause 7).

4.5 Results

The temperature index (TI), its halving interval (HIC) and its lower 95 % confidence limit (TC) are calculated from the regression equation, making allowance as described above for minor deviations from the prescribed results of the statistical tests.

The mode of reporting of the temperature index and halving interval is determined by the results of the statistical tests (see 7.2).

It is necessary to emphasize the need to present the thermal endurance graph as part of the report, since a single numerical result, TI (HIC), cannot present an overall qualitative view of the test data, and appraisal of the data cannot be complete without this.

5 Requirements and recommendations for valid calculations

5.1 Requirements for experimental data

The data submitted to the procedures of this standard shall conform to the requirements of 5.1 to 5.8 of IEC 60216-1.

5.1.1 Non-destructive tests

For most diagnostic properties in this category, groups of five specimens will be adequate. However, if the data dispersion (confidence interval, see 6.3.3) is found to be too great, more satisfactory results are likely to be obtained by using a greater number of specimens. This is particularly true if it is necessary to terminate ageing before all specimens have reached end-point.

5.1.2 Proof tests

Not more than one specimen in any group shall reach end-point during the first ageing period: if more than one group contains such a specimen, the experimental procedure should be carefully examined (see 6.1.3) and the occurrence included in the test report.

The number of specimens in each group shall be at least five, and for practical reasons the maximum number treatable is restricted to 31 (table C.1). The recommended number for most purposes is 21.

5.1.3 Destructive tests

At each temperature, ageing should be continued until the property value mean of at least one group is above and at least one below the end-point level. In some circumstances, and with appropriate limitations, a small extrapolation of the property value mean past the end-point level may be permitted (see 6.1.4.4). This shall not be permitted for more than one temperature group.

5.2 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, to achieve a result precision of three significant digits. 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 significant digits is easily available.

6 Calculation procedures

6.1 Preliminary calculations

6.1.1 Temperatures and x -values

For all types of test, express each ageing temperature in K on the thermodynamic temperature scale, and calculate its reciprocal for use as x_i :

$$x_i = 1/(\vartheta_i + \Theta_0) \quad (2)$$

where $\Theta_0 = 273, 15$ K.

6.1.2 Non-destructive tests

For specimen number j of group number i a property value after each ageing period is obtained. From these values, if necessary by linear interpolation, obtain the time to end-point and calculate its logarithm as y_{ij} .

6.1.3 Proof tests

For specimen number j of group number i calculate the mid point of the ageing period immediately prior to reaching the end-point and take the logarithm of this time as y_{ij} .

A time to end-point within the first ageing period shall be treated as invalid. Either:

- a) start again with a new group of specimens, or
- b) ignore the specimen and reduce the value ascribed to the number of specimens in the group (m_i) by one in the calculation for group means and variances (see 6.2.1.2).

If the end-point is reached for more than one specimen during the first period, discard the group and test a further group, paying particular attention to any critical points of experimental procedure.

6.1.4 Destructive tests

Within the groups of specimens aged at each temperature ϑ_i , carry out the procedures described in 6.1.4.1 to 6.1.4.5.

NOTE The subscript i is omitted from the expressions in 6.1.4.2 to 6.1.4.4 in order to avoid confusing multiple subscript combinations in print. The calculations of these subclauses shall be carried out separately on the data from each ageing temperature.

6.1.4.1 Calculate the mean property value for the data group obtained at each ageing time and the logarithm of the ageing time. Plot these values on a graph with the property value p as ordinate and the logarithm of the ageing time z as abscissa (see figure D.2). Fit by visual means a smooth curve through the mean property points.

6.1.4.2 Select a time range within which the curve so fitted is approximately linear (see 6.1.4.4). Ensure that this time 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 greater times cannot be made (for example, because no specimens remain), a small extrapolation is permitted, subject to the conditions of 6.1.4.4.

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

$g = 1 \dots r$ is the order number of the selected group tested at time τ_g ;

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

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

In most cases the number n_g of specimens tested at each test time is 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.

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

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

Calculate the logarithms of τ_g :

$$z_g = \log \tau_g \quad (5)$$

6.1.4.3 Calculate the values

$$\nu = \sum_{g=1}^r n_g \quad (6)$$

$$\bar{z} = \sum_{g=1}^r z_g n_g / \nu \quad (7)$$

$$\bar{p} = \sum \bar{p}_g n_g / \nu \quad (8)$$

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

$$a_p = \bar{p} - b_p \bar{z} \quad (9)$$

$$b_p = \frac{\left(\sum_{g=1}^r n_g z_g \bar{p}_g - \nu \bar{z} \bar{p} \right)}{\left(\sum_{g=1}^r n_g z_g^2 - \nu \bar{z}^2 \right)} \quad (10)$$

Calculate the pooled variance within the property groups

$$s_1^2 = \sum_{g=1}^r (n_g - 1) s_{1g}^2 / (v - r) \quad (11)$$

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

$$s_2^2 = \sum n_g (\bar{p}_g - \hat{p}_g)^2 / (r - 2) \quad (12)$$

where

$$\hat{p}_g = a_P + b_P z_g \quad (13)$$

This may also be expressed as

$$s_2^2 = \left[\left(\sum_{g=1}^r n_g \bar{p}_g^2 - v \bar{p}^2 \right) - b_P \left(\sum_{g=1}^r n_g z_g \bar{p}_g - v \bar{z} \bar{p} \right) \right] / (r - 2) \quad (14)$$

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

$$F = s_2^2 / s_1^2 \quad (15)$$

If the calculated value of F exceeds the tabulated value F_1 with $f_n = r - 2$ and $f_d = v - r$ degrees of freedom (see table C.2).

$$F_1 = F(0,95, r - 2, v - r)$$

change the selection in 6.1.4.2 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 $f_d = v - r$ degrees of freedom (see tables C.2 and C.3).

$$F_2 = F(0,995, r - 2, v - r)$$

If the test is satisfied at this level, the calculations may be continued, but the adjustment of TI according to 7.3.2 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 according to 6.1.4.1 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 0,25 of the absolute value of the difference $(\bar{p}_1 - \bar{p}_r)$.

In this case calculations can be continued, but again it is not permitted to carry out the adjustment of TI according to 7.3.2.

6.1.4.5 For each value of property in each of the selected groups, calculate the logarithm of the estimated time to end-point.

$$y_{ij} = z_g - (p_{gh} - p_e) / b_P \quad (16)$$

$$n_i = v \quad (17)$$

where

$j = 1 \dots n_i$ is the order number of the y -value in the group of estimated y -values at temperature ϑ_i and z_g is the logarithm of the ageing time.

The n_i values of y_{ij} are the log(time) values to be used in the calculations of 6.2.1.

6.1.5 Incomplete data

In the case of incomplete data, arrange each group of y values in ascending order (see 3.1.1).

6.2 Main calculations

6.2.1 Calculation of group means and variances

Calculate the mean and variance of the group of y -values, y_{ij} , obtained at each temperature ϑ_i .

6.2.1.1 Complete data

For tests where the data are complete (i.e. not censored) the conventional equations may be used:

$$\bar{y}_i = \sum_{j=1}^{n_i} y_{ij} / n_i \quad (18)$$

$$s_{li}^2 = \left(\sum_{j=1}^{n_i} y_{ij}^2 - n_i \bar{y}_i^2 \right) / (n_i - 1) \quad (19)$$