**IEEE Std 98-2002™**
(Revision of IEEE Std 98-1984™)

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# IEEE Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials

## IEEE Electrical Insulation Society

Sponsored by the
Standards Coordinating Committee 4 on Thermal Rating

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# IEEE Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials

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**Standards Coordinating Committee 4 on Thermal Rating of the IEEE Electrical Insulation Society**

Approved 13 May 2002

**IEEE-SA Standards Board**

**Abstract:** Principles for the development of test procedures to evaluate the thermal endurance of solid electrical insulating materials in air are given in this standard.
**Keywords:** diagnostic test, relative temperature index, temperature index, thermal capability, thermal endurance

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# Introduction

(This introduction is not part of IEEE Std 98-2002™, IEEE Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Insulating Materials.)

IEEE Std 98-1984™ reflected many of the concepts incorporated in IEC 60216-1974 while maintaining many of the practical considerations from the initial IEEE Std 98-1972™.

IEEE Std 98-2002™ updates IEEE Std 98-1984™ to incorporate additional changes in the IEC 60216 standards and to introduce the Fixed Time Frame Method (FTFM) of sampling for the thermal evaluation of materials.

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# IEEE Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials

## 1. Overview

### 1.1 Scope

This standard gives principles for the development of test procedures to evaluate the thermal endurance of solid electrical insulating materials in air. The results of accelerated thermal endurance tests, which are conducted according to prescribed procedures, shall be used to establish temperature indexes (TIs) for insulating materials. Thermal endurance tests and TIs can be used to provide relative comparisons between the thermal capability of new materials and older, more established materials.

TIs, while giving guidance on materials, should not in themselves be taken to predict the relationship between temperature and life of an insulation material in service.

Thermal endurance tests provide a means for determining the rate at which important properties of insulating materials deteriorate irreversibly as a function of temperature and time. Such tests and the TIs derived from them can aid in selecting insulating materials for use in electrical equipment operating under a wide variety of service conditions.

The test procedures covered by this standard apply to solid insulating materials, including processed compositions of raw materials, before they are fabricated into insulating structures identified with specific parts of electric equipment.

Tests for specific types of insulating materials, such as wire enamel, varnish, sheet, tape, etc., are not within the scope of this standard; procedures should be developed for each specific type.

The mechanical, chemical, and electrical properties of the materials when new should be evaluated separately by test methods not within the scope of thermal endurance test procedures. The properties so determined may indicate that one or more, or combinations of these, will be the limiting factor in a particular application rather than thermal endurance.

These procedures may not apply to the aging characteristics of dielectric fluids or of porous materials impregnated with dielectric fluids.

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A distinction between material tests and tests to evaluate the performance of insulation systems is necessary because the details of the particular use of a material may not be known to its manufacturer.

NOTE—General principles for designating the thermal capability of insulating systems are given in IEEE Std 1-2000™ [B4][1]. See also IEEE Std 99-1980™ [B5] and IEC 60611-1978 [B2].

## 2. References

This standard shall be used in conjunction with the following publications. When the following standards are superceded by an approved revision, the revision shall apply.

ASTM D5374-93 (1999), Standard Test Methods for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation.[2]

ASTM D5423-1993 (1999), Standard Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation

IEC 60216-2 (1990-06), Guide for the Determination of Thermal Endurance Properties of Electrical Insulating Materials. Part 2: Choice of Test Criteria.[3]

IEEE Std 101-1987™ , IEEE Guide for the Statistical Analysis of Thermal Life Test Data.[4]

UL 746B-1996, Polymeric Materials—Long Term Property Evaluations.[5]

## 3. Definitions

For the purpose of this standard, the following terms and definitions apply. IEEE 100™ [B3] should be referenced for terms not defined in this clause.

**3.1 diagnostic test:** A test applied to a test specimen to determine if thermal degradation has occurred.

**3.2 relative temperature index (RTI):** The number that corresponds to the accepted temperature index of the reference electrical insulating material. (See 7.4.)

**3.3 temperature index (TI):** The number that corresponds to the temperature in degrees Celsius (°C) presented graphically, but calculated mathematically from the thermal endurance relationship of an electrical insulating material at a specific time. (See 7.4.)

**3.4 thermal capability:** The ability to withstand without failure the maximum short time operating temperatures and the long time integrated degradative effect of temperature and time.

NOTE—It constitutes a design limitation on the use of insulating materials in electrical and electronic equipment to the extent that both thermal softening (or other short term effects) and long-term aging affect functional properties.

**3.5 thermal endurance:** The retention of important properties as functions of temperature and time.

---

[1]The numbers in brackets correspond to those of the bibliography in Annex C.

[2]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

[3]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[5]UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).


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# 4. General considerations

The practice to assess the thermal endurance of insulating materials is to age the materials at higher temperatures than the intended service temperature and to conduct diagnostic tests at ambient temperature to determine retention of properties.

## 4.1 Results of thermal endurance tests

The results of thermal endurance tests can be described by the Arrhenius relationship between the logarithm of time to a certain degree of property change and the reciprocal of the absolute temperature, *K*. This relationship is often used for extrapolating the times to the same degree of property change at lower temperatures. Performing thermal endurance tests at three or more temperatures serves a double purpose: first, the confidence limits of the extrapolation are improved and, second, a check is provided of the basic assumption that a linear relationship exists between the logarithm of time and the reciprocal absolute temperature. This linearity may not exist if there is more than one dominant deterioration mechanism in the range of aging temperatures. An extrapolation of the results may not be justified if this check is negative.

The aging curve may be extrapolated (see 7.3) to a length of time (usually between 20 000 h and 40 000 h) which is specified in the thermal evaluation procedure for a particular insulating material. The TI for that material is the number that is equal to the value of the temperature obtained from the life-temperature curve at the arbitrarily specified time.

The aging curve gives the most complete information about the results of an accelerated thermal aging test. Such curves can also be used to compare materials expeditiously.

## 4.2 End-point criteria

The TI of the material is determined by end-point criteria based on the material's ability to withstand stresses such as electric field, mechanical tension, or flexure, etc., or is based on changes in a property of the material. All the properties of a material subjected to heat aging do not deteriorate at the same rate and, consequently, TIs should be obtained for all properties related to possible modes of failure of the material in service. A material may therefore be assigned more than one TI derived from the measurement of different properties

## 4.3 Test procedures and conditions

Different test procedures have been and are to be developed for different kinds of insulating materials such as impregnating varnishes, sheet insulation, etc. Experience has shown that some insulating materials in combination influence one another during the thermal aging process. This interaction may increase or decrease the relative thermal life compared with the life of either material tested alone. For example, the thermal life of enameled magnet wire may be either increased or decreased, depending upon the insulating varnish used to impregnate windings containing the enameled wire. Metals in contact with insulating materials may also affect the thermal aging of the materials. Since insulating materials are often utilized in combination, test procedures may provide for evaluating combinations of materials.

## 4.4 Variability

It is recognized that insulating materials will be used under widely different conditions. Factors such as voltage stress, irradiation, mechanical shock and vibration, environmental conditioning, and chemical contamination shall, therefore, be carefully considered. The test procedure may be modified to provide methods for evaluating the effects of these factors as the material deteriorates thermally. Because materials are used in

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many different applications and in equipment operating under varying degrees of severity, care shall be taken not to over emphasize any one of these factors.

Experience has shown that the results of thermal endurance tests for comparable insulating materials vary between different manufacturers and from lot to lot. Experience also indicates that thermal degradation often will be more pronounced for some materials when tested in certain shapes or in thin sections. The choice of specimen shape and thickness may, therefore, affect the test results and cause variations that may be greater than variations introduced by slight differences in sample preparation, handling, and test technique. For this reason, rigorous specifications in a test procedure will not prevent variations in test results. More importantly, if requirements that are too strict are specified, the tests may be costly and impractical for general use. In any case, the test method should give reliable results consistent with the inherent variations in the material under test and should provide data free from bias of the tester.

## 5. Use of thermal evaluation data

The procedures covered by this standard provide data on the long-time characteristics of insulating materials which give the designer and development engineer information for the selection of materials

A TI should not be used by itself to determine the limitations for the acceptable use of an insulating material in service. However, if a material is used in isolation from others, and if test and specimen parameters are directly comparable to service conditions, then a determination of an operating temperature may be reasonable. In such cases, the results of tests on familiar, widely used materials may be compiled for convenient reference so that comparisons between new and old materials can be made.

Great care should be exercised in the publication and interpretation of TI values for specific materials as the derivation of the TI described in 7.4 will usually be influenced by the characteristics of the aging ovens.

Use of the relative temperature index (RTI) helps to overcome such difficulties because it involves a comparison with tests on a material of recognized service experience under precisely the same test procedure in the same ovens. These test procedures require simultaneous thermal aging of the new material and the comparison material.

## 6. Experimental procedure guidelines

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

### 6.1 Selection of test methods

Each test procedure should specify the test methods to be applied to the specimens to obtain end-points of aging. The test method and the end-point should be appropriately selected to indicate significant deterioration of the insulating material.

The tests should determine properties which can be conveniently measured with reasonable accuracy such as dielectric strength, insulation resistance, dissipation factor, flexural or tensile strength, elongation, weight loss, impact strength, and flame retardancy.

The test chosen should evaluate a property that is likely to be of significance in practice and, when possible, should be a well-established national or international method of test.


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A selection of accepted test methods for determining thermal endurance properties of electrical insulating materials is given in IEC 60216-2 (1990-06)[6].

When it is desired to determine the thermal endurance of materials aged in atmospheres other than air (such as nitrogen or other gas or liquid), the test procedure shall give details of such special tests.

## 6.2 Selection of end-points

Each test procedure shall fix a clearly defined end-point. There are two ways in which the end-point may be defined, both of which are equally acceptable:

a) As a percentage increase or decrease in the measured value from the original value. The original value of the property is defined, unless otherwise specified, as the average value of at least 10 specimens after exposure to the lowest aging temperature for 48 h.
b) As a fixed value of the property.

A selection of end-point criteria is given in IEC 60216-2 (1990-06). In some cases, other end-point criteria may be better suited for a specific material or a specific purpose and should be specified in the test procedure of a specification for that material.

## 6.3 Preparation of test specimens

When not included in the test method, test procedures shall contain instructions for preparing test specimens. Drawings and photographs should be included when applicable.

Using the test methods selected in 6.1, specimens in an unaged condition shall be tested to ensure that specimens are of uniform quality and that test results are typical of the material to be tested.

## 6.4 Number of test specimens

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

It is recommended that additional unaged specimens from a batch of material be allocated for future contingencies such as the need to test at additional temperatures in case of nonlinearity of data (see 7.3).

### 6.4.1 Number of specimens for non-destructive test

In most cases, a group of 10 specimens for each exposure temperature will be adequate.

### 6.4.2 Number of specimens for proof test

In most cases, a group of 11 specimens for each exposure temperature will be required.

### 6.4.3 Number of specimens for destructive test

The number ($N$) of specimens is determined as follows:

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

[6]For information on references, see Clause 2.

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where

*a* is the number of specimens in a test group undergoing identical treatment at one temperature and discarded after determination of a property (usually five)
*b* is the number of cycle times, i.e. the total number of cycles times at one temperature
*c* is the number of aging temperatures, and
*d* is the number of specimens in the group used to establish the initial value of the property.

## 6.5 Establishment of initial property value

Randomly select specimens for the determination of the initial property value. Before determining the property value, condition these specimens for two days (48 ± 6 h) by exposure to the lowest aging temperature. This initial property value shall be used for the duration of the test even when the range of aging temperatures must be expanded or modified.

Unless otherwise stated in the test method for determining the diagnostic property, the initial value is the arithmetic mean of the test results.

## 6.6 Temperature exposures and times

Each test procedure shall specify the temperature and time to which test specimens shall be subjected.

Test specimens shall be exposed to a sufficient range of aging temperatures to establish the relationship between temperature and time to failure.

To reduce the error in extrapolating thermal endurance data to obtain the TI, the overall temperature range of exposure should be carefully selected. The lowest exposure temperature shall give an average measured life of more than 5000 h. An exposure temperature which gives a life of less than 100 h is generally considered too high. It is recommended that exposure temperatures differ by approximately 20 °C. The difference may be reduced to approximately 10 °C, if the higher exposure temperature gives an unacceptably short time to failure, or exceeds the melting or softening point of the material. Closer control of oven temperatures will be necessary as the difference between the test temperatures is decreased. The lowest exposure temperature shall be chosen so that the extrapolation necessary to establish the TI will not be more than 25 °C.

Two different sampling techniques may be employed to select the aging temperatures and exposure cycle times for a specific test procedure:

a) Fixed time; variable temperature (for more details, see Annex A)
b) Fixed temperature; variable time (for more details, see Annex B)

## 6.7 Aging ovens

The reliability of the test results depends upon the precision of the measured aging temperature and the accuracy to which it is maintained during testing. Even slight temperature variation may considerably influence life.

Two types of temperature variation shall be considered: variation with time (both cyclic and long-term drift) and variation at different locations in the oven. The thermal-aging ovens that are used in the aging program shall comply with ASTM D 5374-93 and ASTM D 5423-93 and shall be capable of providing at least a minimum of 5 air changes per hour.


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## 6.8 Procedure for aging

Three test types may be used to evaluate the thermal endurance of an insulating material:

a) Non-destructive test
b) Proof test
c) Destructive test

Establish the exposure temperatures and times in accordance with the instructions of 6.6 (see also Annex A or Annex B).

Prepare a number of specimens following the instructions in 6.4. If necessary, determine the initial value of the property as specified in 6.5. Divide the specimens by random selection into as many groups as there are exposure temperatures and/or times.

Place one group of specimens for exposure in each of the ovens complying with 6.7, maintained as closely as possible to the temperatures selected.

### 6.8.1 Procedure using a non-destructive test

At the end of each cycle, remove the group of specimens from the oven and allow to cool to room temperature. Apply the appropriate test to each specimen and then return the group to the oven from which they came, at the same temperature as before, and expose for a further cycle. Continue the cycles of temperature exposure, cooling, and application of the test until the average measured value for the specimens in the group has reached the specified end-point and at least one data point beyond the end-point has been obtained.

### 6.8.2 Procedure using a proof test

Specimens for testing shall be selected randomly from the group of specimens that have successfully withstood screening by the proof test.

At the end of each temperature exposure cycle remove all specimens from the aging oven. Allow the specimens to cool to room temperature and then subject each specimen to the proof test. Return specimens that withstand the proof test to the oven from which they were removed and expose for an additional cycle.

Continue the cycles of temperature exposure, cooling, and application of the proof test until the failure of the median specimen (number $[m + 1]/2$ if the number of specimens ($m$) is odd, or $[m/2 + 1]$ if the number of specimens is even). If the test results show that the time to the end-point is likely to be reached in ten cycles of exposure, there is no need to alter the cycle time originally selected. If the results do not show this, the cycle time may be changed so that the median results may be expected in at least seven cycles provided this change in cycle time is made before the fourth cycle.

### 6.8.3 Procedure using a destructive test

For each aging oven, select at random, a test group of the assigned number (see Annex A or Annex B) of specimens. At the selected cycle times, remove only the number of specimens to be tested. After the removal, allow those specimens to cool to room temperature prior to testing, unless otherwise specified. Specimens are normally discarded after the test unless they are retained for other tests or to provide a visual chronological record.

Continue to remove at the selected cycle times until the property being measured has reached the specified end-point and at least one data point beyond the end-point has been reached.

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# 7. Evaluation

## 7.1 Numerical analysis of thermal aging data

The methods for analyzing the data obtained should be described in detail in the test procedure. Regression analysis, based on the method of least squares, is the preferred procedure as detailed in IEEE Std 101-1987™. This method provides the parameters necessary for expressing the aging time and temperature relationship in mathematical form.

## 7.2 Times/temperatures to end-point criterion

For each group of specimens at a given temperature, a property value after each aging period is obtained. From these values it is necessary to determine either the time or temperature required to reach the end-point criterion.

### 7.2.1 Non-destructive tests

The value of the property measured on each specimen after aging is plotted as a function of the logarithm of time. The point at which this graph intersects the horizontal line corresponding to the end-point criterion is taken as the time to the end-point of the specimen. The time to end-point of the temperature group is the mean of the specimen times.

### 7.2.2 Proof tests

The time to failure of a given specimen is taken as the time at which that specimen failed to pass the proof test, minus half the duration of the period just prior to failure. Unless otherwise specified, the time to failure at each temperature for the group of specimens exposed at that temperature is taken as the median value of the times to failure of the individual specimens.

### 7.2.3 Destructive tests

For the fixed time frame procedure (see Annex A), a graph of property values at each fixed exposure time is plotted against temperature. A straight line corresponding to the selected end-point, which may be either a specified value or a percentage of the original value, is drawn on the graph. The point where the curve drawn from the plotted points crosses the straight line indicating the end-point is read as the measured temperature to failure at each exposure time.

For the fixed temperature procedure (see Annex B), a graph of property values determined at the end of each exposure period is plotted against time of exposure. The straight line corresponding to the selected end-point, which may be either a fixed value or a percentage of the original value, is drawn on the graph (see Figure 1). The point where the curve drawn from the plotted points crosses the straight line indicating the end-point is read as the measured time to failure at each exposure temperature.


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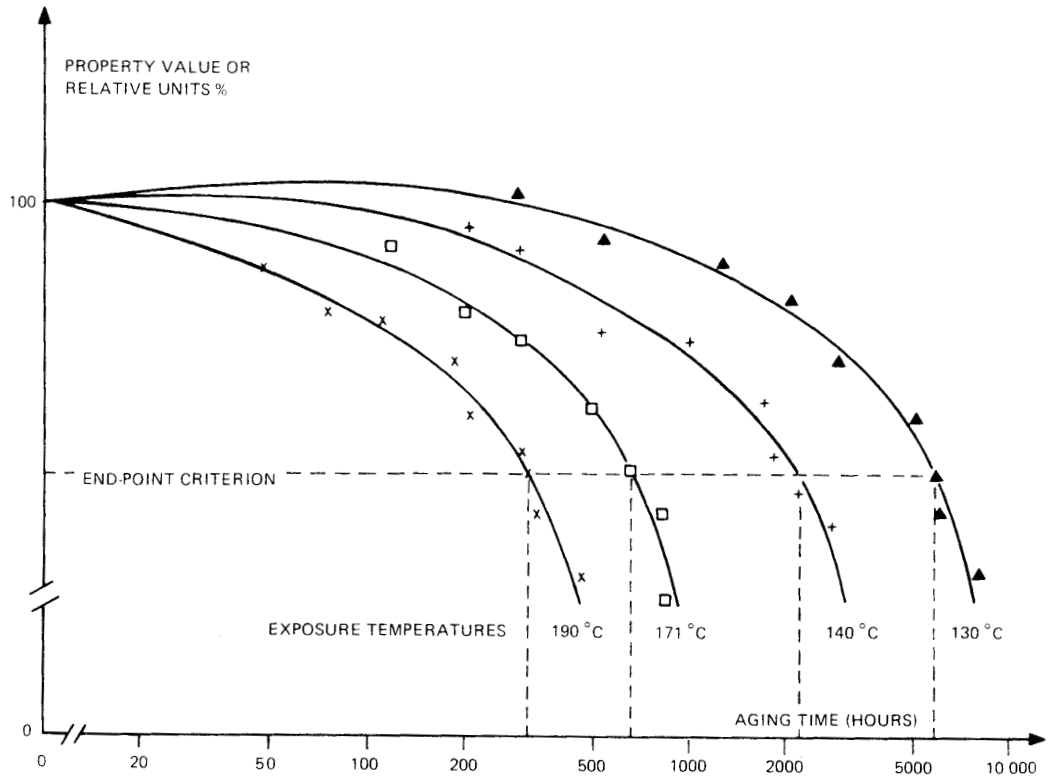



**Figure 1—Determination of time to reach end-point (property evaluation)**

## 7.3 Extrapolation of the data

For the fixed time frame method, the temperatures to reach the end-point at each fixed time are plotted on a graph with the logarithm of time as the ordinate and the reciprocal of the absolute temperature, *K*, as the abscissa.

For the fixed temperature method, the times to reach the end-point temperature are plotted on a graph identical to the one in the fixed time frame method.

Regression analysis using the analytical procedures outlined in IEEE Std 101-1987™ is the preferred method of drawing the thermal endurance graph. In some cases, a straight line drawn to visually fit the data points is satisfactory. IEEE Std 101-1987™ also outlines methods to determine whether the data are linear and to calculate the confidence limit of the thermal endurance graph at chosen temperatures or time. Computer programs exist for this purpose. The data points should always be shown even with computer plots.

The straight line is extrapolated to at least the number of hours required by the index [see Figure 2(a)]. The extent to which thermal endurance curves are extrapolated should be limited. It is recommended that the extrapolation from the lowest exposure temperature not exceed 25 ºC.

If nonlinearity is apparent in the thermal endurance curve, data at additional temperatures should be obtained so as to ensure appropriate extrapolation of the linear portion of the curve at the lower temperatures.

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In practice, values between 20 000 h and 40 000 h have been selected as the time for which the corresponding temperature on the extrapolated thermal endurance curve gives the nominal value of the TI. It is the responsibility of the appropriate standardizing body to define the time upon which the TI of specific insulating materials is to be based.

## 7.4 Determination of temperature index (TI)

The TI is deduced from the graph, at the desired time, and the number of thousands of hours shall prefix the index. For example, the TI at 20 000 h will be expressed as follows:

TI 20kh/164 [see Figure 2(a)]

An alternative procedure is to include in the test a material of recognized service experience in the same ovens, to plot the thermal endurance graph for both materials on the same sheet, to find the point on the graph for the known material which corresponds to its recognized service temperature, and then to use this time for obtaining the TI of the second material [see Figure 2(b)].

**CAUTION**
Caution in the use of this procedure is called for when the thermal endurance graphs have significantly different slopes.

When the TI is determined in this way, it is called the RTI and is expressed, for example, as follows:

RTI/141

Care should be taken that the increments for expressing TI and RTI are not too small so as to avoid the impression that a high degree of precision is inherent in the procedure or that very fine discrimination can be made among insulating materials. One scheme which has been used, UL 746B-1996, uses the following graduations:

— 5 ºC increments up to 130 ºC
— 10 ºC increments from 130 ºC to 180 ºC, except to include 155 ºC
— 20 ºC increments over 180 ºC

Different thermal endurance curves may be obtained when different failure (end-point) criteria are used. It is desirable, therefore, to describe the TIs with the end-point criteria shown parenthetically. For example:

— TI (tensile strength)
— TI (voltage breakdown)
— TI (impact strength)


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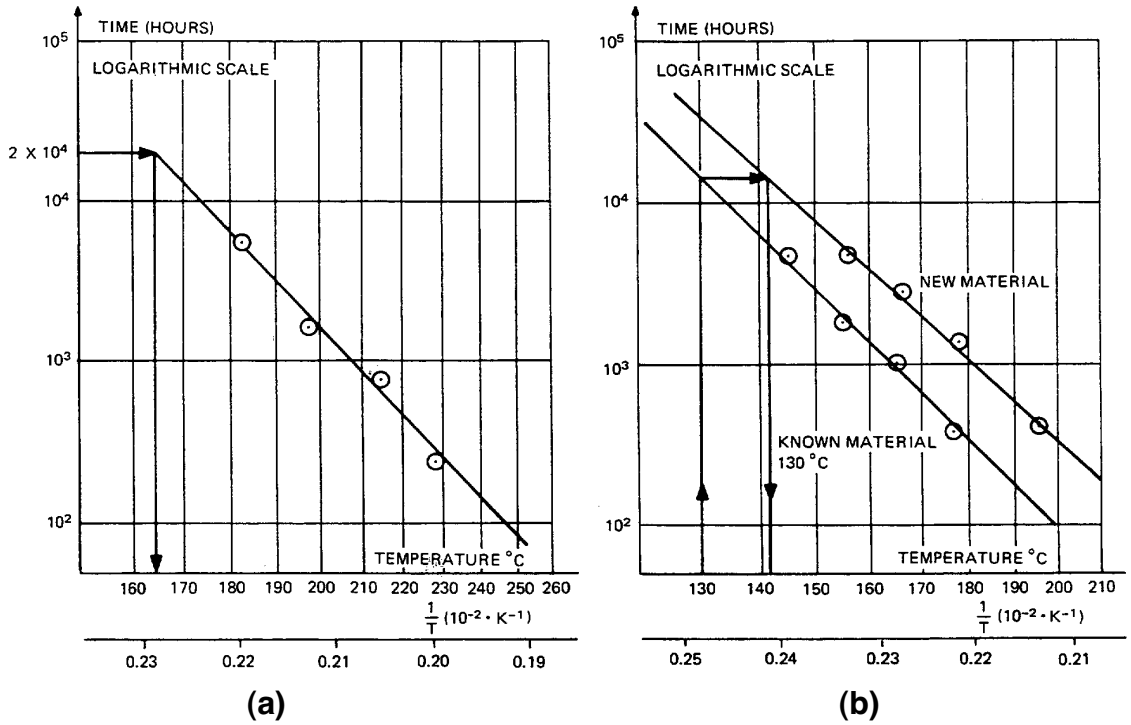



**Figure 2—Thermal endurance graph**
**(a) temperature index (b) relative temperature index**

## 7.5 Test report

The test report will include the following in all cases:

a) The description of the tested material (including the reference material if an RTI is derived)
b) The nature and magnitude of additional exposure factors, if used
c) The property investigated to evaluate the thermal aging and the individual values obtained
d) The test method used for the determination of the property (for example, by reference to a national or international standard)
e) The nature and magnitude of the failure
f) end-point selected
g) The thermal endurance graph and, where applicable, the graphs of the variation of property versus time
h) The TI expressed in accordance with 7.4 of this standard

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# Annex A

(normative)

# Fixed time frame method (FTFM) of sampling

Acknowledging that it is difficult to know or select the right or best temperatures for a long-term-heat-aging (LTHA) project, the fixed time frame method (FTFM) of sampling is based on fixing the time (aging intervals) as the controlled variable while aging temperature is the dependent variable.

The FTFM utilizes standard test specimens and test methods. The end-of-life values are the same as for the fixed-temperature method of sampling.

The recommended first step in FTFM is a broad temperature screening test. The balance of the test is organized using the results of the screening test.

## A.1 Screening test

a) As a general guideline in selecting the aging temperatures to be used in the screening test, select six or more aging temperatures starting approximately 40 °C above the expected TI/RTI value of the candidate material. The aging temperatures should be at increments of 10 °C.

b) For RTI evaluations, the reference material should also be aged. The selected aging temperatures for the reference and the candidate materials are not required to be identical but there should be overlap of several of the aging temperatures to assist in the comparison and analysis of the candidate material.

   Selection of the aging temperatures may need to be different for the reference and candidate materials due to melt temperatures or other essential conditions.

c) The aging temperatures must span the end-of-life value for the property being evaluated in the screening test. It is recommended that the results of four consecutive aging temperatures be used in calculating the temperature coordinate at which the end-of-life value is found. In order to achieve this it is essential that the results obtained at one of the aging temperatures have a measured property value above the end-of-life value and at least one below the end-of-life value.

d) An appropriately sized set of specimens shall be placed into each aging oven selected for the screening test. The preferred time, fixed time interval, for the screening test is 552 h. All sets of specimens aged at all temperatures selected for the screening test are removed, conditioned, and tested at the completion of the time selected for the screening test.

   Based on the end-of-life value, select four sequential aging temperatures that span the end-of-life value meeting the requirement that at least one value is above and one is below the end-of-life value.

e) Calculate the average percentage of retention of the property being evaluated after aging at each temperature. For each set of specimens use the initial value of property in accordance with 6.5 of this standard, as the reference value for determining the percent of retained property. This calculation will provide a set of temperature-percent retention values. Using the four-sequential/percent retention values meeting the condition from item c) in A.1, calculate the temperature at which the end-of-life can be assigned. The end-of-life retention values shall be based on a linear regression through the set of four temperature-percent retention values.


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f) The calculated end-of-life value is the temperature assigned to the fixed time of the aging interval. This time-temperature value is one of the fixed coordinates needed for the analysis and calculation of the TI or RTI value. This time-temperature can be designated as time interval. For example: T552h.

g) The screening test provides both a time-temperature coordinate as well as a profile of the thermal decomposition of the material being tested.

## A.2 Completion of the test

a) Based on the results of the screening test, additional fixed-time intervals can be selected and the remainder of the needed specimens can be placed under aging for testing after other fixed-time intervals. A minimum of four fixed-time intervals should be used in the calculation of the TI or RTI value.

Since most long-term-heat-aging projects have a 5000-h minimum time requirement, the preferred group of fixed-time intervals is 552 h (from the screening test), 1008 h, 2016 h, 3528 h and 5040 h. Select a minimum of four of these intervals, but for programs with the 5000-h minimum requirement, the 5040-h interval must be included.

In each case, four consecutive aging temperatures are to be used at each selected fixed-time interval. It is recommended that more than four aging temperatures be used for each interval but only four sequential temperatures are to be selected for the calculation at each interval.

b) Analyze the data obtained at four or more fixed time intervals using the procedures given in Clause 7 of this standard.

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# Annex B

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# Fixed temperature method of sampling

The selection of aging temperatures and cycle durations for a thermal endurance test is shown in Table B.1. The row in Table B.1 corresponding to the estimated TI/RTI shows suggested aging cycles in days at oven temperatures that appear at the head of the respective columns. The following recommendations and suggestions are useful in establishing aging temperatures and times:

## B.1 Temperatures

The highest exposure temperature should result in a median time to end-point between 100 h and 500 h.

The exposure temperatures should differ by equal intervals and the interval should be at least 10 ºC.

Selection of exposure temperatures involves estimating or knowing beforehand the approximate value of the TI/RTI of the material to be tested. If this information is not available, screening tests as described in Annex A may be performed to predict a value of TI/RTI.

For RTI evaluations the reference material should also be aged. The selected aging temperatures for the reference and the candidate material are not required to be identical, but there should be an overlap of at least two temperatures.

## B.2 Times

### B.2.1 Cyclic aging

For proof tests and non-destructive tests, exposure cycles should be selected so as to give approximately the same number of cycles before failure at each temperature. It is suggested that the exposure time at each temperature be selected so as to subject the specimens to approximately 10 heating and cooling cycles. This ensures that the test specimens are subjected to nearly equal handling, testing and thermal cycling at each temperature.

### B.2.2 Continuous aging

For destructive tests, the aging of each tested group is continuous and, therefore, the length and number of time intervals between testing are not as important. However, it is recommended that the planned number of groups of test specimens at each temperature should be at least five, with ten being preferred. The time interval between tests of groups of specimens should be planned so that at least two groups of specimens are available before the time to end-point and so that at least one group is available after the time to end-point.

If relatively long test periods are selected initially, approximately half of the groups of specimens can be held back and placed in the aging oven at the end of the second or third cycle. When failures take place after a long period of aging, the groups of test specimens held back can be used to define the time to failure more accurately with relatively short exposure times.


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## Table B.1—Suggested exposure temperatures and times

| Estimated value of TI in range (°C) | Exposure temperature (°C) | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 | 210 | 220 | 230 | 240 | 250 | 260 | 270 | 280 | 290 | 300 | 310 | 320 | 330 | 340 | 350 |
| | Duration of exposure cycle (in days) | | | | | | | | | | | | | | | | | | | | | | | |
| 95–104 | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | | | | | | | | | | |
| 105–114 | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | | | | | | | | | |
| 115–124 | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | | | | | | | | |
| 125–134 | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | | | | | | | |
| 135–144 | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | | | | | | |
| 145–154 | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | | | | | |
| 155–164 | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | | | | |
| 165–174 | | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | | | |
| 175–184 | | | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | | |
| 185–194 | | | | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | | |
| 195–204 | | | | | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | | |
| 205–214 | | | | | | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | | |
| 215–224 | | | | | | | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | | |
| 225–234 | | | | | | | | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | | |
| 235–244 | | | | | | | | | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 | |
| 245–254 | | | | | | | | | | | | | | | | 28 | 14 | 7 | | 3 | | 2 | | 1 |

NOTES:
1—The content of Table B.1 is intended primarily for cyclic proof testing and non-destructive tests, but may also be used as a guide for selection of suitable time intervals for destructive tests; in this case, cycle times of 56 days, or even more, may be required.
2—When extending the test program by submitting additional specimens to aging at temperatures below the lower of the originally planned aging temperatures, a temperature interval of 10 K and a cycle duration of 42 days for TI/RTI determination should be considered.

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# Annex C

(informative)

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[B1] IEC 60216-1 (2001-07), Electrical Insulating Materials—Properties of Thermal Endurance—Part 1: Ageing Procedures and Evaluation of Test Results.

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[B3] IEEE 100™ , *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

[B4] IEEE Std 1-2000™ , IEEE Recommended Practice—General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.

[B5] IEEE Std 99-1980 (R2000)™ , IEEE Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment.

[7]IEC 60611-1978 has been withdrawn. IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.


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