UL 746B

STANDARD FOR SAFETY

Polymeric Materials – Long Term Property Evaluations

UL Standard for Safety for Polymeric Materials – Long Term Property Evaluations, UL 746B

Fourth Edition, Dated April 4, 2013

SUMMARY OF TOPICS

This revision of the Fourth Edition of ANSI/UL 746B is being issued to address the following change in requirements:

Generic RTI for Silicone - Two-Component, Addition-Cure, Vinyl, Platinum Catalyzed

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The revised requirements are substantially in accordance with Proposal(s) on this subject dated April 12, 2013.

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The requirements in this Standard are now in effect, except for those paragraphs, sections, tables, figures, and/or other elements of the Standard having future effective dates as indicated in the note following the affected item. The prior text for requirements that have been revised and that have a future effective date are located after the Standard, and are preceded by a ″SUPERSEDED REQUIREMENTS″ notice.

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April 4, 2013
(Title Page Reprinted: May 30, 2013)

ANSI/UL 746B-2013

UL 746B

Standard for Polymeric Materials – Long Term Property Evaluations

First Edition – September, 1975
Second Edition – June, 1979
Third Edition – August, 1996

Fourth Edition

April 4, 2013

This ANSI/UL Standard for Safety consists of the Fourth Edition including revisions through May 30, 2013.

The most recent designation of ANSI/UL 746B as an American National Standard (ANSI) occurred on May 29, 2013. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, or effective date information. Any other portions of this ANSI/UL standard that were not processed in accordance with ANSI/UL requirements are noted at the beginning of the impacted sections.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at http://csds.ul.com.

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INTRODUCTION

INTRODUCTION

1 Scope

1.1 These requirements cover long-term test procedures to be used for the evaluation of materials used for parts intended for specific applications in end products.

1.2 Together with the Standards mentioned in Supplementary Test Procedures, Section 3, these investigations provide data with respect to the physical, electrical, flammability, thermal, and other properties of the materials under consideration and are intended to provide guidance for the material manufacturer, the molder, the end-product manufacturer, safety engineers, and other interested parties.

2 References

2.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

3 Supplementary Test Procedures

3.1 The Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, covers flammability of polymeric materials used for parts in devices and appliances. The Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, contains short-term test procedures to be used for the evaluation of materials used for parts intended for specific applications in electrical end products. The Standard for Polymeric Materials – Fabricated Parts, UL 746D, contains requirements for traceability and performance of parts molded and fabricated from polymeric materials.

3.2 Programs for the investigation of material part modifications, such as the plating of plastics or the use of flame-retardant paints, are contained in the Standard for Polymeric Materials– Use in Electrical Equipment Evaluations, UL 746C.

3.3 Data concerning the effect of various environments and contaminants upon the properties of materials can also be obtained through standard test procedures. The more commonly used procedures are briefly described in the Standard for Polymeric Materials– Short Term Evaluations, UL 746A.

3.4 Test procedures are provided in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluation, UL 746C, for the evaluation of polymeric materials in specific applications in end products. These test procedures include references to the data obtained from the standard property tests as well as other practical means of evaluation.

3.5 Requirements for materials that have been modified to match the requirements of a specific application, including the use of recycled and regrind materials, the use of additives and colorants, and the blending of two or more materials, are described in the Standard for Polymeric Materials – Fabricated Parts, UL 746D.

4 Characteristics of Polymeric Materials

4.1 Polymeric materials include thermoplastic, thermosetting, and elastomeric materials. A thermoplastic material can be easily softened and resoftened by repeated heating. A thermosetting material cures by chemical reaction and, when cured, cannot be resoftened. An elastomeric material is capable of being stretched at room temperature to at least twice its length under low stress and recovers to its original length when released from the stress.

4.2 Characteristics of polymeric materials that necessitate additional consideration include:

a) Mold stresses

b) Insulating quality

c) Resistance to ignition

d) Extinguishing characteristics

e) Production of smoke and gases

f) Mechanical Strength

g) Compatibility with solvents

h) Melting or distortion

i) Cold flow, if under stress

j) Fuel contribution

k) Dimensional stability

5 Use of Polymeric Materials

5.1 The reduction to an acceptable level of the risks of electric shock, fire, and personal injury from electrical equipment depends upon the selection of materials, design, and processing of parts as well as the assembly, mounting, and relative positions of these parts.

5.2 The properties needed by individual parts are defined by the function or functions of the part. An enclosure, for example, must ordinarily be designed to withstand mechanical abuse. Accordingly, a material known to have substantial impact strength would normally be used although a material that has a lower impact strength, but is reinforced, might also be acceptable.

5.3 Electrical equipment of necessity employs many materials that usually have divergent properties. The ability to match the demands of the application with the characteristics of a material as well as the ability to compare the properties of one material with those of another can lead to an acceptable selection of materials.

5.4 The information gained from the data obtained from these tests can be used as an aid in the evaluation of electrical equipment using parts made of polymeric materials. Knowledge of materials can be obtained from an analysis of data from standard tests conducted on small specimens.

DETERMINATION OF THE RELATIVE THERMAL INDICES OF POLYMERIC MATERIALS

6 General

6.1 A relative thermal index of a material is an indication of the material's ability to retain a particular property (physical, electrical, etc.) when exposed to elevated temperatures for an extended period of time. It is a measure of the material's thermal endurance. For each material, a number of relative thermal indices can be established, each index related to a specific property and a specific thickness of the material.

6.2 In determining the relative thermal index of a material, the basic concepts to be followed are stated in the Institute of Electrical and Electronics Engineers Specifications No. 1, General Principles for Temperature Limits in the Rating of Electrical Equipment; No. 98, Guide for the Preparation of Test procedures for the Thermal Evaluation of Electrical Insulating Materials; No. 101, Guide for the Statistical Analysis of Thermal Life Test Data.

6.3 The relative thermal index of a material is to be based upon an evaluation of long-term thermal-aging data obtained under the program described in Relative Thermal Index – Based Upon Long-Term Thermal-Aging Programs, Section 8. Thermal indices on a generic basis have been established through knowledge of extensive field-service records, as outlined in Relative Thermal Index– Based Upon Historical Record, Section 7. Relative thermal indices may also be established based upon a study and evaluation of the interrelationship of all of the data mentioned in Supplementary Test Procedures, Section 3, which can also be coupled with knowledge concerning the material's performance in insulating systems gained through experience or long-term aging tests.

6.4 A comparison of the thermal-aging characteristics of one material of proven field service at a particular temperature level with the thermal-aging characteristics of another material with no field service history provides a means for estimating the relative thermal index level at which the second material might also provide acceptable field service.

6.5 Another explanation of a relative thermal index is the maximum temperature below which a material maintains its characteristics over a reasonable period. This relative thermal index serves the very great need to evaluate materials that are exposed to heat sources in electrical products in which they are not used as part of an insulating system and in which they are not subjected to other major degradation influences. It is to be assumed that neither excessively long nor excessively short duty cycles are involved.

6.6 To be valid for use in a specific application, a relative thermal index of a material must be established by a study of the degradation rates of all properties that are relied upon in that application. As a corollary to this principle, more than one relative thermal index can be assigned to a material depending on the relative degradation rates of the properties of the material and depending on which of these properties are considered in establishing the indices.

7 Relative Thermal Index – Based Upon Historical Record

7.1 Table 7.1 presents a list of materials, each of which is assigned a relative thermal index based on acceptable service experience, the chemical structure of the material, and a knowledge of the performance of the material in tests of insulating systems and electrical equipment. The assigned relative thermal index is applicable to each member of the generic material class.

7.2 Unless otherwise indicated in Table 7.1, the generic thermal index of a material is to be considered 50°C (122°F).

7.3 Unless otherwise indicated in Table 7.1, the generic thermal index of a material is independent of thickness and pigmentation.

Table 7.1
Relative thermal indices based upon past field-test performance and chemical structure[a]

Table 7.1 revised May 30, 2013

Material	ISO designation	Generic thermal index,°C
Polyamide [b]	PA	65
Polycarbonate[b]	PC	80
Polycarbonate/Siloxane Copolymer[k]	PC/Siloxane	80
Polyethylene terephthalate –		
molding resin[b]	PET	75
film (0.25 mm maximum)	PET	105
Polybutylene (polytetramethylene) terephthalate[b]	PBT	75
Polyphenylene Ether (including PS, PA, PP, or TPE modified)[j]	PPE	65
Polypropylene[b,h]	PP	65
Polyetherimide[g]	PEI	105
Polyethersulfone	PES	105
Polyether Ether Ketone	PEEK	130
Polyphenylene Sulfide[b]	PPS	130
Polyimide film (0.25 mm maximum)	PI	130
Molded phenolic[c]	PF	150
Molded melamine[c,d] and Molded melamine/phenolic[c,d] –		
specific gravity < 1.55		130
specific gravity ≥ 1.55		150
Polytetrafluoroethylene	PTFE	180
Polychlorotrifluoroethylene	PCTFE	150
Fluorinated ethylene propylene	FEP	150
Poly(tetrafluoroethylene, hexafluoropropylene, vinylidenefluoride)[l]	TFE/HFP/VDF	130
Ethylene/Tetrafluoroethylene	E/TFE	105
Urea Formaldehyde[c]	UF	100
Acrylonitrile – butadiene – styrene[b]	ABS	60
Silicone – molding resin[c,d]		150
Silicone rubber –		
molding resin	SIR	150
two-component, addition-cure, vinyl, platinum catalyzed		150

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Table 7.1 Continued

Material	ISO designation	Generic thermal index,°C
room-temperature vulcanizing, condensation or heat-cured paste	RTV	105
Epoxy –		
molding resin[c,d]		130
powder coating materials		105
casting or potting resin[b,i]	EP	90
Molded diallyl phthalate[c,d]		130
Molded unsaturated polyester[c,d]	UP	
alkyd (AMC), bulk (BMC), dough (DMC), sheet (SMC),		
thick (TMC), and pultrusion molding compounds		105[e] (electrical)
		130 (mechanical)
Liquid crystalline thermotropic aromatic polyester[f]	LCP	130
Ligno-cellulose laminate		60
Vulcanized fiber		90
Cold-molded phenolic, melamine or melamine-phenolic compounds[d] –		
specific gravity< 1.55		130
specific gravity ≥ 1.55		150
Cold-molded inorganic (hydraulic-cement, etc.) compounds		200
Integrated mica, resin-bonded –		
epoxy, alkyd or polyester binder		130
phenolic binder		150
silicone binder		200

[a] Generic thermal index is for homopolymer and for the compounding of the same type or relative resins, either grafted or ungrafted only, unless a specific copolymer or blend is indicated. In the case of alloys, the lowest generic index of any component shall be assigned to the composite. The term ″grafted″ means all of the monomer reacts to form a polymer, and the polymer chain forms a chemical bond. The term ″ungrafted″ means that the two types of polymer chains entwine with each other by mechanical blending to form a chemical composite.

[b] Includes glass-fiber reinforcement and/or talc, asbestos, mineral, calcium carbonate, compounding of the same type of resins, either grafted or ungrafted and other inorganic fillers.

[c] Includes only compounds molded by high-temperature and high-pressure processes such as injection, compression, pultrusion, and transfer molding and match-metal die molding; excludes compounds molded by open-mold or low-pressure molding processes such as hand lay-up spray-up, contact bag, filament winding, rotational molding, and powder coating (fluidized bed, electrostatic spray, hot dip, flow coating).

[d] Includes materials having filler systems of fibrous (other than synthetic organic) types but excludes fiber reinforcement systems using resins that are applied in liquid form. Synthetic organic fillers are to be considered acceptable at temperatures not greater than 105°C.

[e] Except 130°C generic thermal index if the material retains at least 50% of its unaged dielectric strength after a 504-hour exposure at 180°C in an air circulating oven. Specimens are to be tested in a dry, as molded, condition. Specimens that are removed from the oven are to be cooled over desiccant for at least 2 hours prior to testing.

[f] Includes only wholly aromatic liquid crystalline thermotropic polyesters; wholly aromatic polyester/amides and wholly aromatic polyester/ethers; excluding amorphous, lyotropic and liquid crystalline aliphatic-aromatic polyesters which are aliphatic in the backbone chain or main chain, and substituted aromatic polyesters (except for methyl or aromatic).

[g] Includes only polyetherimide molding resin.

[h] Includes polypropylene copolymers containing not more than 25% ethylene comonomer, by weight.

[i] Multi-part liquid epoxy materials incorporating acid anhydride or aromatic amine curing agents receive a 130°C generic thermal index.

Table 7.1 Continued on Next Page

Table 7.1 Continued

Material	ISO designation	Generic thermal index,°C
[j] Includes only those polyphenylene ether materials (polystyrene, polyamide, polypropylene, or thermoplastic elastomer modified) in which the PPE component is not less than 30% of the total composition by weight and that have a Heat Deflection Temperature of at least 70°C at a load (fiber stress) of 1.80 M Pa (264 psi).		
[k] PC/Siloxane Copolymers in which siloxane comprises less than, or equal to, 5% of the total material composition by weight.		
[l]Must have a minimum peak melting point of 160 °C, with less than 25% VDF monomer by weight and the remainder being fully fluorinated monomers.		

8 Relative Thermal Index – Based Upon Long-Term Thermal-Aging Programs

8.1 The properties of a polymeric material degrade with time when exposed to various environments. A prime cause of degradation is exposure to heat.

8.2 The behavior of a material that is subjected to thermal aging in air cannot be assumed to be the same as its behavior under service conditions; however, a knowledge of the thermal-aging behavior of a material can be used as a basis for comparison of polymeric materials.

8.3 The thermal-aging characteristics of a material can be determined by measuring the changes in its properties to a predetermined level by aging test specimens at each of several elevated temperatures; plotting log of time-to the specified end point at each temperature against the reciprocal of absolute temperature; and plotting the best-fit straight line by regression analysis. The plotted line is often referred to as the life-line of a material.

8.4 Unless specified otherwise, a 50-percent loss of property value due to thermal degradation shall be considered as the property end point.

8.5 The manufacturer of the material is responsible for:

a) The estimation of the different applications in which the material can be used, and

b) The selection of the temperatures, properties, and thicknesses that are to be measured during the thermal-aging investigation.

If products of decomposition of one material are suspected of having an adverse effect on the other, for example, if two materials are not of the same generic type or if a flame retardant or other additive in one material adversely affects the other material, then they should not be aged simultaneously in the same oven. It is desirable that the oven exhaust be positively vented outside the test facility.

9 Apparatus

9.1 Ovens

9.1.1 The thermal-aging ovens that are used in the aging program shall comply with the Standard Test Methods for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation, ASTM D 5374-93[a], and with the Standard Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation, ASTM D 5423-93[a] for Type I ovens, primarily with respect to Rate of Ventilation, Set Temperature, Temperature Variation and Thermal Lag Time.

Exception: Non air-circulating static ovens and/or forced-draft circulating-air convection ovens not capable of providing replacement of fresh air at the rate of not less than 5 changes per hour may be employed provided that:

a) The oven is capable of maintaining the Set Temperature, Temperature Variation and Thermal Lag Time described in ASTM D 5423-93[a]. The Thermal Lag Time is not applicable if the oven is not subjected to frequent openings, and if the ratio of oven aging time to open-oven time is large.

b) The products of the material decomposition are not expected to further degrade the polymer – in other words, shall not be autocatalytic, and

c) A control material of known performance is aged in the same ovens and for the same time duration as the candidate materials.

[a] ASTM standards are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

9.1.2 The oven temperature control is to be capable of long-term operation. It is desirable that the oven be provided with a timer and also with an oven-temperature cut-off to prevent loss of specimens, loss of data, or loss of test continuity. Ordinarily, at least four ovens of applicable capacity are needed to contain the aging specimens; however, two ovens can be effectively used by completing the work at the two higher thermal-aging temperatures first and then switching the oven settings to the two lower thermal-aging temperatures.

9.1.3 Temperatures for heat aging are to be accurately controlled and monitored. At the start of the program, oven temperatures are to be checked frequently. The use of several thermocouple locations to check variations throughout the ovens is required. As the test progresses, monitoring can be done less frequently.

10 Scope of Test Programs

10.1 Selection of test properties

10.1.1 The specific properties to be evaluated in the thermal-aging program shall be determined.

10.1.2 The contemplated applications of the material (as intended by the manufacturer of the material), the flammability characteristics, and the physical and electrical properties that the material needs to have for these applications are to be considered.

10.1.3 Table 10.1 provides a list of properties that can serve as an aid in the determination of the properties to fall within the scope of the investigation. The properties are to be as nearly as possible representative of the properties required for the end application.

Table 10.1
List of properties and test methods

Property [a]	Test Method
Mechanical Properties	
Maximum Tensile Stress or Flexural Strength	UL 746A
Tensile Impact, Izod Impact, or Charpy Impact[b]	UL 746A
Electrical Properties	
Dielectric Strength	UL 746A
Flammability Properties	
Vertical Burning	UL 94

[a]The list of properties given in this table is not complete. Other properties that are critical in a particular end-use application are to be included in the program.

[b]For unaged materials that do not exhibit break upon impact testing, the RTI Mechanical Impact can not be determined and therefore the RTI Mechanical Impact is not applicable (N/A).

10.1.4 The results of Tensile, Charpy or Izod Impact testing of standard specimens in either the nominal 3 mm or 4 mm thickness, as appropriate for the specified test method, can be considered representative of the testing of reduced thicknesses provided such reduced thicknesses have been evaluated for non-impact mechanical properties. The assigned relative thermal indices for impact properties in the reduced thicknesses shall be lowered by an offset equal to the corresponding lower offset, if any, of the relative thermal indices of the non-impact properties at the reduced thicknesses. Table 10.2 illustrates a hypothetical example of this offset. It is appropriate to consider temperature interval classification described in 23.1 while assigning the RTI-impact values at <3 mm thickness.

Table 10.2
Example of applying offset principle to assigning impact ratings

Measured RTI				Assigned RTI considering the temperature interval classification		
Min. thick. (mm)	Elec	Imp	Str	Elec	Imp	Str
0.75[c]	245[a]	169[b]	231[a]	240[d]	160[d]	220[d]
1.5	245	171[b]	233[a]	240[d]	170[d]	220[d]
3.0	245	183[a]	245[a]	240[d]	180[d]	240[d]

[a] Measured Thermal Indices assigned based on actual testing at thicknesses.

[b] Measured Thermal Indices assigned based on the results of testing the 3.0 mm or 4.0 mm thickness, reduced by the corresponding offsets of 245°C - 233°C = 12°C and 245°C - 231°C = 14°C at 1.5 and 0.75 mm, respectively.

[c] Offset principle for impact ratings also applies to minimum thicknesses less than 0.75 mm provided that they have been tested to Table 10.2 requirements.

[d] Relative Thermal Indices assigned for a given grade based on the Measured Thermal Indices at different thicknesses considering the temperature interval classification mentioned in 23.1.

10.1.5 The term Measured Relative Thermal Index (or Indices) represents the relative thermal index (or indices) of the material under investigation as determined by use of the relevant time-temperature plot without adjustments based on the application of the temperature interval classifications defined in 23.1. Table 10.2 illustrates a hypothetical example of this offset principle.

11 Property-Evaluation Tests

11.1 General

11.1.1 Table 10.1 provides a list of test specifications that generally are used for property-evaluation tests. Other tests can be used if found to be acceptable for the application.

11.1.2 The tests are to monitor the performance level for each property as the accelerated aging of the material progresses.

11.1.3 The tests selected are to simulate as closely as possible the field-service conditions of the contemplated-use application. Some test methods can be used for only certain forms of polymerics (for example, film or sheet materials).

11.2 Choice of end-point

11.2.1 The Institute of Electrical and Electronic Engineers (IEEE) standards do not specify the method of determining end of life, although several alternatives are presented. Fixed property level and percent-of-unaged property level are two of these that appear to have the most significance in relation to end-use applications. Product design normally involves the factor-of-safety approach. Therefore, the relative thermal index developed by this standard is based on the assumption that a factor of safety exists in the applicable physical and electrical property requirements. It is not expected that a 50-percent loss of property due to thermal degradation results in premature risk of electric shock, fire, or personal injury. The considerations have led to the decision to report the end point at each aging temperature as the time at which a property value has decreased to 50 percent of its unaged level where quantitative evaluation test methods are available.

11.2.2 In certain applications, the reduction to 50 percent of the initial property value may not represent the stresses encountered in actual service. A fixed property level may be used in applications where the anticipated service stress can be defined and where consideration has been given to the expected duty cycle, degree of deterioration over the useful product life and an acceptable factor-of-safety. As an alternative, the relative thermal capability may be determined for each application using the concepts described in the Standard for Polymeric Materials– Use in Electrical Equipment Evaluations, UL 746C.

12 Sampling Programs

12.1 Two sampling techniques are available for conducting a long-term thermal aging investigation: the Fixed Temperature Method in Sections 13 – 21 and the Fixed Time Method in Section 22. Both methods will provide the time-temperature-property values needed to establish the Thermal Index Rating and assign a thermal class rating. The primary difference between the methods is in the sampling technigue employed. Since both methods rely upon a data analysis of the degradation of samples at various temperatures and using specific time intervals, the results of the tests would be expected to be similar regardless of which of the two methods is selected.

12.2 Both the control and the candidate materials shall be evaluated using the same sampling method (Fixed Temperature or Fixed Time).

12.3 The test specimens are to be the same size and shape for both test methods.

12.4 All material properties (i.e., electrical, mechanical, and flammability) can be evaluated using either method.

12.5 All initial (unaged) and aged specimens are to be tested using the same test method for each property.

13 Selection of Oven Temperatures

13.1 At least four oven temperatures are to be selected. The lowest oven temperature (T4) selected is to produce an anticipated end point of the material's property at this temperature in not less than 5,000 hours. The highest oven temperature (T1) selected is to produce an anticipated end point of the material's property at this temperature in not less than 500 hours. The minimum aging time criterion is applicable for each primary property evaluated. See Table 13.1.

13.2 Degradation is a function of the aging characteristics of the particular polymer. Specific aging temperatures cannot therefore be recommended since the test temperatures can differ for each material tested.

13.3 Short-time screening tests at various temperatures can be used to estimate the anticipated end-of-life.

13.4 If degradation cannot be accelerated because of transition points or threshold temperatures, and in consideration of the need for a spread between aging temperatures, it might be necessary to extend the low-temperature test (t4 in Table 13.1) to well beyond the usual 5000-hour minimum value indicated in note [b] to Table 13.1 to obtain significant data.

Table 13.1
Selection of oven temperatures

Test temperature (°C)	t1 (highest)	t2	t3	t4 (lowest)
End Point (Hours)	500 min.	1,500 approx.	3,000 approx.	5,000 min.
Cycle Period [a] Days	3	7	14	28

[a] See 15.2.

13.5 The spread between aging temperatures is to be enough to overcome the small errors in measuring and controlling temperatures, generally at least 10°C (18°F).

13.6 The reason for these test-temperature limitations is to provide accurate data so that extrapolation to determine the acceptable operating temperature for life can be reasonably predicted.

14 Selection of Control Material

14.1 A control material is to be selected and tested in the thermal-aging test program in the same manner as the material under investigation.

14.2 The control material is to be a material that has an established relative thermal index. Preferably, the material is to be one with a record of good field service at its rated temperature. If possible it is to be of the same generic type as the candidate material, is to be tested in the same thickness, and is to have a relative thermal index as close as possible to that expected for the candidate material.

14.3 More than one control material may be tested to insure comparable performance to the candidate, but only one control will be considered in establishing the candidate's RTI for all properties.

14.4 The control shall be tested at the same time as the candidate and conditioned in the same ovens except where the performance ranges of candidate and control are sufficiently different to necessitate different ranges of aging temperatures, or where special contamination problems have been demonstrated. If different ovens are necessitated because of different ranges of aging temperatures, then at least two of the four aging temperatures shall overlap and the same ovens, containing both control and candidate test specimens, shall be used at these overlapping temperatures. The property end points for both the candidate and control material test specimen conditioned in these overlapping ovens shall comply with the minimum aging times indicated in Table 13.1.

15 Specimens

15.1 The physical dimensions of the test specimens are given in the test specifications referred to in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. Normally, 5 specimens constitute a set; however, a greater number might be necessary if the property under evaluation exhibits scattered results. Refer to Aging, Specimen, and Check-Test Schedules, Section 21 for typical sample requirements.

15.2 For each oven temperature, there is to be an assigned cycle period. Usually the cycle period for the highest temperature is to be 3 days, for the next lower temperature 7 days, for the next lower temperature 14 days, and for the lowest temperature 28 days. Refer to Table 21.2.

16 Thermal Aging

16.1 To obtain a measurement of each of the properties at the end of each successive cycle period for each oven-aging temperature, it might require an extremely large number of specimens inasmuch as the material generally survives more than 10 cycles of the test program.

16.2 To conserve on the total number of specimens required, to reduce the frequency of making the measurements, and also to develop data near the time of 50-percent reduction of the initial property value, the procedure in 16.4 – 16.6 can be followed.

16.3 All specimens are to be pre-conditioned for 48 hours at the lowest aging temperature of the program to eliminate any short-term thermal effects.

16.4 Initially for each temperature, 5 sets of specimens are to be placed in the oven. At the end of the first, second, and third cycles an additional set is to be added.

16.5 At the end of the third cycle, some of the original test specimens are to be removed from the oven and subjected to the applicable tests. Assuming that the average property value of these specimens is greater than the end point, the property test is to be repeated on conditioned test specimens every successive third cycle until the results of the property testing are equal to or less than the end point. In common practice, these specimens are selected from the test specimens initially put in the oven.

16.6 When the results of the property testing are equal to or less than the end point , the sets of specimens that were placed in the oven at delayed times are to be removed from the oven and tested. Their performance analysis can result in a more accurate determination of the time to reach the property end point . If the property end point is not obtained at the time that all of the original specimens have been tested, the delayed specimens can be removed from the oven at various times in the test program in order to extend the aging time. This general procedure is to be followed for all tests that involve the determination of the property end point of the test specimens. Table 16.1 summarizes this approach. A typical data sheet that can be used to record the summary of the thermal-aging testing is shown in Figure 16.1.

16.7 Using this technique, a numerical value for each property is to be obtained at the end of each cycle. It is possible to plot a curve showing the relationship between the values of each property and time at each of the 4 aging temperatures. This end point data can then be used to determine a relative thermal index.

16.8 At least two additional data points should be obtained after reaching the property end point to confirm the end-of-life value. These data points should be as close as possible to the property end point to provide a more accurate calculation of the end-of-life value.

16.9 The determination of the properties may require calculations that include the dimensions of the specimens. In such cases, the dimensions of the specimens prior to oven conditioning should be recorded and used in the property calculation.

Exception: For physical properties, if the dimensions of the specimens significantly change as a result of the oven conditioning, the dimensions that result in the lower physical property value should be reported and used in the property calculation.

Table 16.1
Delayed set test procedure primary properties

End of cycle number	Sets put in oven	Sets tested
0	B, C, D, E, F	A (unaged)
1	G[a]	–
2	H[a]	–
3	I[a]	B[b]
4, 5, 6	–	–
7	–	C[b]
8, 9, 10	–	–
11	–	D[b]
12, 13, 14	–	–
15	–	E[b]
16, 17, 18	–	–
19	–	F[b]
20	–	–
21	–	G
22	–	–
23	–	H
24	–	–
25	–	I

[a] Sets G, H, and I are to be put in the oven one or more days later than the end of cycles 1, 2, and 3, respectively. This procedure gives time for further conditioning of sets tested resulting in a decision for removal of the delayed sets.

[b] Should the property end point be reached at the end of 3, 7, 11, 15, or 19 cycles, sets H and I are to be removed from the oven and tested in order to more precisely determine the property end point time. If the property end point is not reached by the end of 19 cycles, sets G, H, and I are to be tested as shown.

Figure 16.1
Thermal aging data summary (Destructive testing)

Manufacturer_____
Material_____

Oven Temp._____**°C; HRS/CYCLE**_____
Sample
Thickness_____
Property_____

Oven Temp._____**°C; HRS/CYCLE**_____
Sample
Thickness_____
Property_____

Cycle Number	Elapsed Hours	Averaged Test Value (Units _____)	Elapsed Hours	Averaged Test Value (Units_____)
0	0		0	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

Figure 16.1 Continued on Next Page

Figure 16.1 Continued

Manufacturer_____					
Material_____					
Oven Temp._____°C; HRS/CYCLE_____			Oven Temp._____°C; HRS/CYCLE_____		
Sample			Sample		
Thickness_____			Thickness_____		
Property_____			Property_____		
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					

17 End-of-Life

17.1 Primary properties

17.1.1 When there is no information as to which of the properties (flammability, dielectric strength, flexural strength, etc.) might be the first to degrade to an unacceptable value, complete testing is to be generally carried out for each property. However, where specific properties are known to degrade more rapidly, and the relative thermal index of the material is to be based on these properties, the other properties in the program are to be measured only at the end-point of the property that is tested full scale. The properties that are monitored throughout the program are to be referred to as primary properties.

17.2 Secondary properties

17.2.1 The properties that are to be measured only initially are to be referred to as secondary properties after the property end point of the prime property occurs. If the secondary-property measurements indicate the material has passed through the end point of the secondary property , retesting – with check tests throughout aging – is then required to establish the life-temperature relationships. Delayed sets of specimens can effectively be used in this case. See Table 17.1.

Table 17.1
Delayed set test procedure – secondary properties

End of cycle number	Sets put in oven	Sets tested
0	N	M (unaged)
1	O	–
2	P	–
3	Q	–
4	R	–
5, 6, 7 etc.	–	[a]

[a] All sets are to be removed from the oven and tested at the time that the earliest primary property passes through the 50–percent point as determined by the method shown in Table 16.1. If set N shows that it does not pass through the 50–percent point, the remaining sets need not be tested. If set N passes through the 50–percent point, then sets O, P, Q, and R are to be tested in turn. These sets are not aged as long as those initially put in the oven.

18 Proof Testing

18.1 In some cases, to keep the number of specimens in the oven to a minimum, proof testing can be employed. In this case, the property is not to be measured in an absolute manner on aged specimens. Instead, the numerical value of the property is to be determined on unaged specimens to establish a reference value. At the end of each cycle during the aging-test program (see Table 16.1), all test specimens (usually 10) are to be subjected to a property stress at a level of 50 percent of the initial property value. Specimens that do not have the ability to comply with this property stress are to be removed from the test program and the length of time each specimen was in the oven is to be noted. The end-of-life is to be assumed as having occurred half way through the cycle preceding removal of the specimen from the oven. Specimens that have the ability to comply with the property stress are to be returned to the oven for further aging, and the property stress is to be repeated at the end of the following cycle. This procedure is to be continued until the property end point for all specimens is obtained. The average log life is to be determined and used to establish a relative thermal index. This type of proof testing usually is to be employed when dielectric strength is the property to be evaluated. In this case, only a single end point can be determined, and this is usually 50 percent of the initial value of the property.

Exception No. 1: It has been observed from empirical data, that the logarithm of time to degrade to 50 percent of the initial property level is generally distributed normally at any given temperature. The probit method of analysis described in the National Institute of Standards and Technology Handbook 91 entitled Experimental Statistics, may be employed to estimate the log average life, provided that at least half of the samples have reached the property end point at that test temperature.

Exception No. 2: For polypropylene, observation of crazing on 10 percent of the total surface area of the test specimen, rather than 50 percent retention of the initial property value, is to be used in determining the property end point time.

19 Analysis and Evaluation

19.1 After accumulating the data, it is necessary to evaluate the insulating material in terms of operating temperature and life expectancy. Also, it is important to provide a clear statement of the accuracy and uniformity of these results so that the degree of reliance can be determined.

19.2 When destructive testing is employed, it is first necessary to determine the aging time at which the property level decreases to the property end point at the accelerated-aging temperature. The degradation mechanism is usually a complex combination of effects due to chain scission, oxidation, change in crystalinity, formation of a dense cross-linked skin, etc., and the time-temperature relationship may not accurately be defined in terms of a continuous simple relationship. It may be possible to generate a simpler relationship by transforming the graph of property versus time at the different aging temperatures into discrete strength lines by use of applicable functions of time, u = f(t) or property, v = f(p).

19.3 If an acceptable amount of data can be obtained around or near the property end point , a third-order polynomial equation is useful to interpolate most of the data that is encountered. This method generally is not to be used for extrapolation to the property end point . The equation has the form:

$$y = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$

in which:

y is a measure of the attribute (property level), and

t is time expressed in hours.

Other relationships may be employed in place of the best-fit third-order polynomial if it can be shown that a better portrayal of the data set is achieved.

19.4 The polynomial constants may be solved by using the following matrix equation:

In the equation, n is the number of data points used in the calculations and all summations are from 1 to n. This represents four equations with four unknowns, and these can be used to solve for the coefficients a_0, a_1, a_2, and a_3 in terms of the known sums determined from the data points. Usually, at least five data points are required to establish a useful relationship.

19.5 For the purpose of illustration, consider the following data set:

$$\begin{bmatrix} \Sigma y \\ \Sigma ty \\ \Sigma t^2 y \\ \Sigma t^3 y \end{bmatrix} \quad \begin{bmatrix} n & \Sigma t & \Sigma t^2 & \Sigma t^3 \\ \Sigma t & \Sigma t^2 & \Sigma t^3 & \Sigma t^4 \\ \Sigma t^2 & \Sigma t^3 & \Sigma t^4 & \Sigma t^5 \\ \Sigma t^3 & \Sigma t^4 & \Sigma t^5 & \Sigma t^6 \end{bmatrix} \cdot \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

Time (elapsed hours)	Tensile strength (MPa)		
0	84.5	|	
504	92.6	|	
1478	53.8	|	
1915	37.2	}	Data Points used in the example calculation
1948	35.9	|	
1982	39.9	|	
2016	36.4	|	

A judgment was made to eliminate the 0-hours, 84.5-megapascal data point from the matrix equation due to its distance away from the property end point . The matrix of 19.4 is generated in a manner that is typified by the following:

$$\Sigma t \quad 504-1478+1915+1948-1982$$

$$\Sigma t^2 = (504)^2+(1478)^2+(1915)^2+(1948)^2+(1982)^2+(2016)^2$$

$$\Sigma t^3 y = (504)^3 92.6+(1478)^3 53.8+(1915)^3 37.2+(1948)^3 35.9+(1982)^3 39.9+(2016)^3 36.4$$

When the simultaneous equations derived from the matrix equation are solved, the following polynomial equation is obtained to represent the data:

$$y = 43.4075 + (1.813 \times 10^{-1}) t - (1.9084 \times 10^{-4}) t^2 + (4.936 \times 10^{-8}) t^3$$

At the property end point , y = 1/2 (initial property level). In the example, this corresponds to y = 42.25 megapascals. The value of t when y = 42.25 megapascals may be determined by iteration, using computer techniques. A calculated time of 1707 hours was determined using the best-fit cubic polynomial. An alternative is to express the equation coefficients as a function of percent property retention (z) versus time (t). For this alternative, the cubic equation is expressed as:

$$z = 51.436 + (2.2576 \times 10^{-1}) t - (2.2576 \times 10^{-4}) t^2 + (5.8390 \times 10^{-8}) t^3$$

The value of time corresponding to z = 50 percent initial property value may be calculated as 1707 hours.

19.6 The life expectancy is to be considered a function of temperature. The Arrhenius equation describing the temperature dependence of the velocity coefficient of chemical reactions can be used to approximate the relationship between material life and temperature. This equation, as applied in this case, indicates that the logarithm of material life is a linear function of the reciprocal of the absolute temperature. The best fit of the slope and intercept of the straight line that relates the logarithm of material life to the reciprocal temperature is to be determined by the least-squares method of linear regression analysis.

19.7 The Arrhenius equation for reaction rate is given by k=Ae to the power (–E/RT) in which k is the specific reaction rate, E is the activation energy (relatively constant for a small temperature change), R is a gas constant, T is the absolute temperature, A is the frequency factor (constant), and e is 2.718284.

19.8 The Arrhenius equation can be simplified by taking natural logarithms in the following form:

$$\log_e k = \log_e A - \frac{E}{RT}$$

letting $Y = \log_e k$, $a = \log_e A$, $b = -E/R$, and $X = 1/T$, we then have $Y = a + bx$. This relates the two variables Y and X in the form of a linear equation, assuming a and b are constant.

19.9 The evaluation of the insulation is completed by the regression analysis. This method of analysis is concerned with the study of the relationship between two or more variables. In this instance, a study is to be made of the relationship between material property life and operating conditions. Property life is denoted as the dependent variable represented by the letter Y, and the operating condition as the independent variable, represented by the letter X. Thus, the regression analysis becomes a study of Y ($\log_e$ of specific reaction rate) as a function of X (reciprocal of operating temperature).

19.10 After the Arrhenius equations for both the candidate material and the control material are determined and plotted, a comparison is to be made to establish a relative thermal index of the candidate material.

19.11 The insert in Figure 19.1 illustrates the curve obtained as the result of aging the material under investigation at four elevated temperatures. In the example, the properties of impact strength, tensile strength, and dielectric strength are investigated. At each temperature, the first property to reduce to 50 percent of its unaged property value is impact strength. The time to reach 50 percent at each temperature for this property is then to be used to construct the time-temperature plot shown in curve B.

19.12 Curve A represents the plot of a control material having a relative thermal index of 100°C (212°F), based either on previously accumulated long-time data or on the knowledge of a long, known service experience in general-use applications. This known material shows a correlation factor in this example of 60,000 hours when tested in the manner described in this program.

19.13 The time-temperature plot of the material under investigation crosses the 60,000-hour line at a temperature of 140°C (284°F). Therefore the material can reasonably be expected to be as useful at a temperature of 140°C (284°F) as the control material is at 100°C (212°F).

19.14 In the absence of comparison data for a control material, it might be difficult to correlate the long-time-endurance program with actual service conditions. Although there is some evidence to show that an arbitrary life of 60,000 hours under this long-time program can be assumed when determining a relative thermal index, until this correlation is more definitely established, a longer value of time is to be assumed. In place of applicable control data, an extrapolated life of 100,000 hours is to be used to assign the relative thermal index.

19.15 In considering the usefulness of the relative thermal index in the example given in Figure 19.1, consideration is to be given to the properties that are evaluated in the program. If the properties being stressed in the end-product are also considered in arriving at the general-use thermal index, the relative thermal index resulting from this analysis is valid and can be used in the evaluation of the material in the end product. If the property being stressed in the end product is not evaluated in the long-term-aging program, the relative thermal index might not be applicable to the use of the material in that particular application.

Figure 19.1
Plot of typical time and temperature data

19.16 In considering the example shown in Figure 19.1, it is possible that more than one temperature rating can result from analysis of the data accumulated during the long-time investigation. In the example described in 19.11 the most critical property being investigated is impact strength and the general-use relative thermal index of 140°C (284°F) is applicable to all applications involving all of the properties investigated, including impact strength. However, there can be applications of this material in which impact strength is not a critical property, such as in an application in which the material is shielded from mechanical abuse as is the case for some insulating materials, terminal boards, wire connectors, etc. In that event, a time-temperature plot could be made for the unknown material considering all properties except impact strength. In such an example, it might be possible to have a relative thermal index of, say 155°C (311°F), for applications in which impact strength is not a critical property and 140°C (284°F) for applications in which impact strength is required.

19.17 Care is to be exercised in the use of any general-use relative thermal index achieved by the method of analysis described in this standard. If it is felt that the end-product application of the material involves unusual service conditions, the acceptability of the material at the relative thermal index is judged by this method is to be reviewed. If service conditions associated with an end-product application are less severe than those considered in arriving at the relative thermal index, higher operating temperatures may be acceptable.

20 Related Material – Coverage of Variations in Material Composition

20.1 General

20.1.1 Commercially available brands of insulating materials are usually obtainable in different molecular weights and colors, and with differing types and quantities of fillers and additives. A separate analysis of each of these variations is not necessary to an evaluation in a thermal-endurance program.

20.1.2 The least favorable performance of the unfilled and maximum-level filled or reinforced material shall be considered representative of intermediate levels of filler or reinforcement without additional testing.

20.2 Thermoplastic materials

20.2.1 Thermoplastic materials that are related to others in the program can, in accordance with 20.2.2 – 20.2.8, and Table 9.1 and Table 9.2 of UL 746A, be evaluated in an abbreviated test program. This program applies specifically to families of thermoplastic materials in which each of the related materials is intended to have properties that differ slightly from the basic material and generally is assigned a different compound designation.

20.2.2 In cases where the limits in Table 9.1 of UL 746A are exceeded, testing will include one or two temperature aging (UL 746B) using the unaltered basic material as the control reference. Both the impact and non-impact mechanical properties tested in the nominal 3 mm thickness can be considered representative of other properties and thicknesses, however, if a lowering of the non-impact mechanical index is indicated, then the electrical index not tested will be automatically lowered by the same amount and materials may need to be checked after additional aging for retention of flame retardancy.

20.2.3 Reference materials to be considered as the unaltered basic material for application of the limits in Table 9.1 of UL 746A, and for use as a control in any required tests, shall be a material that has actually been subjected to thermal aging tests and not a material with an assigned temperature index based solely on a previous application of this analysis.

20.2.4 If testing of a related material is not indicated in Table 9.1 of UL 746A, the material can be assigned the same temperature rating as the original material.

20.2.5 A comparison of the results of aging at one temperature (neither the highest nor the lowest used in the investigation of the basic material) with the life-line (Arrhenius curve) of the basic material is to be conducted, assuming parallel performance and extrapolated to the life value corresponding to the relative thermal index of the base material. If the difference between the extrapolated life of both materials is within 5°C (9°F), then the related material is to be assigned the same relative thermal index as that determined for the basic material. If the difference between the extrapolated lives of both materials is not within 5°C (9°F), the related material cannot be assigned a relative thermal index unless the additional aging described in 20.2.6 is conducted. See 20.2.9 for an illustrative example.

20.2.6 If comparison of the results of aging at the two mid-temperatures, used in the investigation on the basic material but displaced so as to have the best fit with the two new points, extrapolates to within 5°C (9°F) of the relative thermal index of basic material, the related material is to be assigned the same relative thermal index as that determined for the basic material. In the event that the extrapolation is to a temperature in excess of 5°C (9°F) of the basic material's relative thermal index, the related material is to be assigned a relative thermal index at the corresponding reduced value. See 20.2.10 for an illustrative example.

20.2.7 A related material is to be assigned a temperature rating not more than 10°C (18°F) above the rating of the basic material based on extrapolation of an Arrhenius curve having the same slope as the original curve but displaced so as to have the best fit with the results of aging of the related material at the two mid-temperatures of the investigated basic material.

20.2.8 A related material is to be assigned a temperature rating more than 10°C (18°F) above the rating of the basic material only on the basis of an aging program at four temperatures.

20.2.9 The following data on a base material compared to data obtained on a related material aged and tested under the same procedure and condition is intended as an illustration:

	Material life Time (hours) to reach the property end point	
Temperature, °C	Base material	Related material
200	1200	–
190	1824	1150
180	3288	–
170	5232	–

Using the procedure in Analysis and Evaluation, Section 19, linear regression analysis on the base material's data results in the relationship:

$$\log_{10}(\text{life}) = \frac{4559.5739}{°C + 273.16} - 6.5641$$

A relative thermal index of 125°C is assigned to the base material, which corresponds to a 77,179 hour correlation time (life).

It is to be assumed that the slope of the related material is identical to the slope of the base material, and that the equations differ only in the value of the ordinate intercept. The equation for the related material can be found by substituting the known data point as follows:

$$\log_{10}(1150) = \frac{4559.5739}{190 + 273.16} + A$$

$$\text{thus } A = -6.7838$$

Hence, the relationship between time and temperature for the related material is given by:

$$\log_{10}(\text{life}) = \frac{4559.5739}{\circ\quad\quad\hat{\circ}} - 6.7838$$

At the base material correlation time, the related material's relative thermal index is given by:

$$\log_{10}(77{,}179) = \frac{4559.5739}{°C + 273.16} - 6.5641$$

which can be calculated as 118.8°C. This value is not within the 5°C differential indicated in 20.2.5 and the related material is not eligible for a relative thermal index unless additional tests are conducted.

20.2.10 Continuing the example in 20.2.9, assume that the manufacturer generates additional data at 180°C (356°F) that results in a material life of 2200 hours – that is,

T_1 = 463.16K (190°C) Life_1 = 1150 hours

T_2 = 453.16K (180°C) Life_2 = 2200 hours

This data can be expressed as a single arithmetic mean value as:

$$\frac{(Y_1 + Y_2}{2} \qquad \frac{}{2}$$

$$\bar{X} = \frac{\frac{1}{T_1} + \frac{1}{T_2}}{2} \qquad \bar{Y} = \frac{\log_{10}(life_1) + \log_{10}(life_2)}{2}$$

$$2T_1 \quad T_2 \qquad \bar{Y} = \frac{\log_{10}(life_1 \cdot life_2)}{2}$$

$$\bar{X} = \frac{1}{458.1054} \qquad \bar{Y} = 3.2016$$

The equation for the related material is to be found by substituting the mean data as follows:

$$5\,2016 = \frac{.5739}{58\,1054}$$

or

$$A_1 = -6.7515$$

Hence, the between time and temperature relationship for the related material is given by:

$$\log_{10}(\text{life}) = \frac{4559.5739}{°C + 273.16} - 6.7515$$

At the base material correlation time, the related material's relative thermal index is given by:

$$\log_{10}(\qquad \frac{1^{\Gamma}59.5739}{°C + 273.16} - 6.7515$$

which can be calculated as 118.6°C. Using the procedures in 20.2.6, the material would be assigned a relative thermal index of 115°C.

20.3 Thermosetting molded materials

20.3.1 Thermosetting materials that are related to other materials evaluated under the aging program in the same manner and within the same limits as thermoplastic materials as described in 20.2.1 – 20.2.8 and Table 9.1 of UL 746A are also eligible for the abbreviated test program. In addition, because periodic variations are often necessary in the formulation of thermosetting materials in order to adapt to variable sources of supply and to adjust for variable molding conditions, it is acceptable if the limits specified in Table 9.1 of UL 746A are exceeded, provided that the same numerical compound designation is used and the conditions in 20.3.2 and 20.3.3 are met.

20.3.2 An abbreviated heat-aging test is to be conducted in accordance with 20.2.5 or 20.2.6. Property, time, temperature, and percent retention of the property are to be selected based on information obtained in the long-time thermal-aging program.

20.3.3 Analytical measurements are to be used to ascertain that the materials have essentially the same formulation ingredients, proportions, and properties. Infra-red analysis and Thermogravimetry determinations are to be included. Differential Scanning Calorimetry may also be included where applicable.

21 Aging, Specimen, and Check-Test Schedules

21.1 General

21.1.1 Tables 21.1 – 21.3 are for use in assisting manufacturers in formulating a long-time thermal-aging program.

21.1.2 The schedules shown in Table 21.1 – 21.3 are examples for demonstration purposes only. Specific aging temperatures, tests, specimen sizes, etc. are to be applicable to the specific polymer and end use. In most cases, five specimens per measurement are to be employed but, in some cases, ten specimens are needed.

21.1.3 The number of specimens tabulated is based on the presumption of attaining the property end point within the number of aging cycles indicated in the delayed-set schedules.

21.1.4 Described in 21.2.1 – 21.3.13, are particular test programs for materials or procedures of unusual nature that do not follow the general procedures shown in Tables 21.1 – 21.3.

21.2 Polypropylene

21.2.1 For polypropylene, it is observed that the occurrence of visible crazing indicates the severe and sudden loss of material properties. The thermal-aging procedure described in Tables 21.1 – 21.3 may be considerably reduced since surface crazing can be used as a preliminary indication of material-property loss. The quantity and sizes of samples required for a polypropylene thermal-aging program are described in Table 21.4.

21.2.2 Thermal aging is to be conducted at four oven temperatures as described in Table 13.1, for example 160, 150, 140 and 130°C (320, 302, 284, and 266°F). Samples are to be aged at all four temperatures for evaluation of the primary properties of tensile impact and tensile strength. Samples are to be aged at either of the two intermediate test temperatures for evaluation of the secondary properties of flammability and dielectric strength.

21.2.3 Ovens at each temperature are to be loaded with one set of test samples initially (set A). The second set of samples (set B) is to be placed in each oven at a later time than the initial batch (set A) in accordance with Table 21.5.

21.2.4 Using the proof testing method described in 18.1, for each different sample configuration, thickness and test temperature, the property end point is to be determined by noting the time at which each initial set of test samples (set A) shows crazing on 10 percent of the total surface area of each specimen. When this crazing occurs, the oven time is to be recorded and all crazed samples are to be removed from the oven. When all the initial samples (set A) have crazed, the delayed samples (set B) and secondary-property samples are to be removed from the oven. Prior to property testing, of the delayed (set B) and secondary-property samples, the samples are to be conditioned in accordance with Table 21.1.

21.2.5 The proof testing method described in Exception No. 2 of 18.1 is to be used to determine the average log life for the 10 initial test samples (set A) for each different configuration and test temperature. The second set of tensile strength, tensile impact and dielectric strength samples (set B) shall retain at least 50 percent of the initial property value and the flammability classification shall not change.

21.3 Coating powders

21.3.1 The testing of coating powders to determine a relative thermal index for use as ground insulation in motors, transformers, bus bars, and the like, operating at higher than Class 105 temperatures, is covered in 21.3.2 – 21.3.13.

21.3.2 This subsection under coating powders is to be considered only as a guide for establishing a testing program, as specific details must be worked out for each material and end-use application. The tests are to include consideration of all variations in chemical composition, color percentage mix, molecular weight, etc.

21.3.3 The end-product evaluation is to result in the final judgment concerning the test performance (such as for insulation), constructional requirements (such as thickness), and other considerations, such as:

a) Normal and abnormal tests.

b) Additional abnormal tests necessitated by the specific polymeric material.

c) Effect of adjacent insulation on performance at points of material contact.

d) The general maximum voltage rating under this program is 600 volts. If higher voltages are a consideration, additional testing is necessary – higher dielectric-strength potentials, resistance to partial discharge, etc.

Table 21.1
Conditioning before property measurement
(Example)

Property	
Tensile or flexural strength Tensile, Izod, or Charpy impact	Min. 40 h exposure to 50 ±5 percent relative humidity at 23.0 ±3.0°C (73.4 ±5.4°F)
Dielectric strength[a]	Min. 40 h exposure to 50 ±5 percent relative humidity at 23.0 ±3.0°C (73.4 ±5.4°F)
Flammability (material rated V–2 or better)	Cooled in desiccators a minimum of 4 hours after oven exposure

[a] The surrounding medium for the dielectric strength test should be air, or oil using shrouded electrodes in accordance with ASTM D149.

Table 21.2
Typical aging schedule
(Example)

Material	Thickness mm	Aging temperature, °C				Cycle periods, days[a]			
		A	B	C	D	A	B	C	D
Candidate (proposed)	3.2	130	140	150	160	28	14	7	3
	1.6	–	140	150	–	–	14	7	–
	0.8	–	140	150	–	–	14	7	–
Control (known)	3.2	130	140	150	160	28	14	7	3

[a] Cycle period subject to change as more data becomes available.

Table 21.3
Number of specimens required for thermal aging (example)

Test material	Test		Thickness mm	Specimens			
	Property	Method		Number per set[c] (B - L)	Number for initial tests[c]	Minimum number for all temperatures	Total[b,d]
Candidate (proposed)	Tensile or flexural strength	UL 746A	3.0	5	10	220	230
			1.5	5	10	110	120
			0.75	5	10	110	120
	Tensile, Izod, or Charpy impact	UL 746A	4.0[e]	5	10	220	230
	Dielectric strength	UL 746A	0.75	5	10	220	230
	Flammability (materials rated V-2, VTM-2, or better)	UL 94	MT[a]	10	10	160	170
Control (known)	Tensile or flexural strength	UL 746A	3.0	5	10	220	230
	Tensile, Izod, or Charpy impact	UL 746A	4.0[e]	5	10	220	230
	Dielectric strength	UL 746A	0.75	5	10	220	230

Table 21.3 Continued on Next Page

Table 21.3 Continued

Test material	Test		Thickness mm	Specimens			
	Property	Method		Number per set[c] (B - L)	Number for initial tests[c]	Minimum number for all temperatures	Total[b,d]

[a] MT represents the minimum thickness evaluated.

[b] It is recommended to prepare samples in excess of this total in case there is a dispute of the results and a reevaluation is considered necessary.

[c] See Table 16.1.

[d] For example, 5 specimens per 5 initial sets (B – F) plus 5 specimens per 3 delayed sets (G – I) plus 5 specimens for 3 extra sets (J – L) equals 55 specimens, multiplied by 4 temperatures equals 220 specimens plus 10 unaged (set A) specimens equals 230 total specimens.

[e] Impact test specimens in a thickness less than 4.0 mm but greater than or equal to 3.0 mm may also be used but may increase the risks of dimensional deviations or handling problems after thermal aging.

Table 21.4
Number of specimens required for a typical polypropylene thermal aging program

Test material	Test		Thickness mm		Specimens			
	Property	Method	ASTM	ISO	Number per set	Number for initial tests	Number for all temperatures (sets A and B)	Total
Candidate (proposed)	Tensile strength	UL 746A	3.2	4.0	10	10	80	90
	Tensile or Charpy impact	UL 746A	3.2	4.0	10	10	80	90
			1.6	2.0	10	10	40	50
	Dielectric strength	UL 746A	1.6	2.0	5	10	20	30
	Flammability (materials rated V-2 or better)	UL 94	MT[a]		5	10	20	30
Control (known)	Tensile strength	UL 746A	3.2	4.0	10	10	80	90
	Tensile or Charpy impact	UL 746A	3.2	4.0	10	10	80	90

[a] MT represents the minimum thickness evaluated.

Table 21.5
Delay time for insertion of verification samples in polypropylene aging programs

Aging temperature °C (°F)	Delay time to insert second sample set (Set B) in oven after start of program, days
160 (320)	3
150 (302)	7
140 (284)	14
130 (266)	28

21.3.4 The test specimens to be used for motor or transformer ground insulation are to be steel U-channels of the shape and size shown in Figure 21.1. The scale on the interior surface of the specimen is to be removed by means of sandblasting or an acid rinse followed by a water rinse, an alkaline rinse, and a final water rinse. Each specimen is to be machined as indicated in Figure 21.1 to a 32-microinch (810-micrometer) finish. The specimens are then to be coated with powder in the thickness specified by the manufacturer using a typical process. The powder is then to be cured as advised by the manufacturer. One end of the specimen is to be left uncoated for attaching the specimen to a vibration machine and also for making an electrical connection during the dielectric-strength tests. Prior to aging, all specimens are to be subjected to a screening test in order to remove defective units.

Exception: Ground tool-steel bits as illustrated in Figure 21.2 may be employed in place of U-channels.

Table 21.6
Typical Number of specimens required for thermal aging of film materials

Test			Specimens				
Test material	Property	Method	Thickness mm	Number per set	Number for initial tests	Number for all temperatures	Total[b,c]
Candidate (proposed)	Tensile strength	UL 746A	0.127	5	10	220	230
			MT[a]	5	10	110	120
	Dielectric strength	UL 746A	MT[a]	5	10	220	230
	Flammability (materials rated VTM-2 or V-2 or better)	UL 94	MT[a]	10	10	160	170
Control (known)	Tensile strength	UL 746A	0.127	5	10	220	230
	Dielectric strength	UL 746A	MT[a]	5	10	220	230

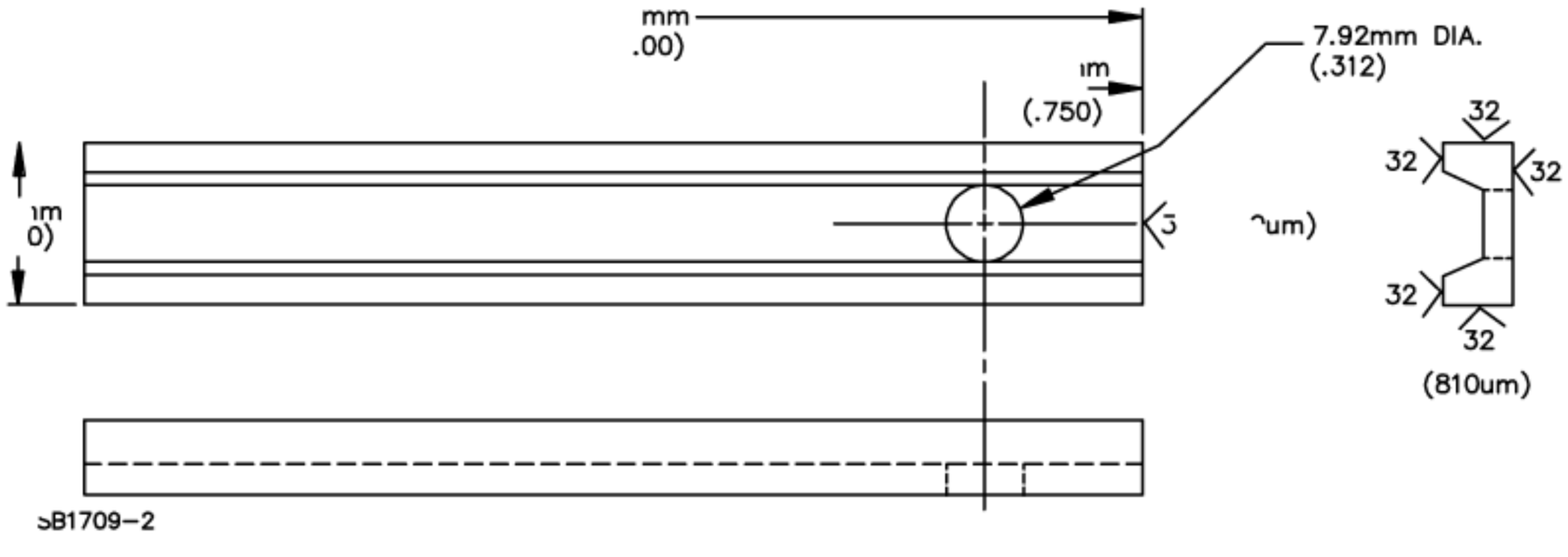
[a] MT represents the minimum thickness evaluated.

[b] It is recommended to prepare samples in excess of this total in case there is a dispute of the results and a reevaluation is considered necessary.

[c] For example, 5 specimens per 5 initial sets (B - F) plus 5 specimens per 3 delayed sets (G - I) plus 5 specimens for 3 extra sets (J - L) equals 55 specimens, multiplied by 4 temperatures equals 220 specimens plus 10 unaged (set A) specimens equals 230 total specimens.

21.3.5 The test specimens to be used for evaluating integral bus-bar insulation systems are to be copper and/or aluminum specimens of the size and shape shown in Figure 21.2.

Figure 21.1
Specimen dimensions
All dimensions in mm (inch)



Material: American Iron and Steel Institute Type C1020 steel, U-channel, standard 19.05 by 7.94 by 3.18 mm (3/4 by 5/16 by 1/8 inch) bar stock. Modified as follows:

1) The outer surfaces and the end of the specimen that is to be coated are to be machined to a 810-micrometer (32-microinch) finish.

2) The finished dimensions are not critical.

3) Burrs are to be removed without rounding the edges.

21.3.6 To determine an initial dielectric-strength level, specimens are to be selected at random and subjected to a voltage breakdown test. To prevent flashover, the unaged specimens may need to be provided in a length greater than 127 mm (5 inch). One electrode of the tester is to be connected to the uncoated end of the specimen and approximately 50.8 mm (2 inch) of the coated end of the specimen are to be immersed into a 10-percent-salt-water solution, which is the other electrode of the tester. The voltage from the tester is to be increased at a rate of approximately 500 volts per second until breakdown occurs. The average breakdown value of the ten specimens is to be recorded as the initial breakdown voltage of the material. At least ten specimens are to be placed in each of four ovens, the temperatures of which are to be determined by the manufacturer. The highest temperature is to result in a life of at least 500 hours while the lowest temperature is to result in a life of at least 5,000 hours.

21.3.7 To provide approximately equal exposures to the other conditionings and to more accurately determine the property end point , the heat aging time per cycle is to be less for the higher aging temperatures– for example:

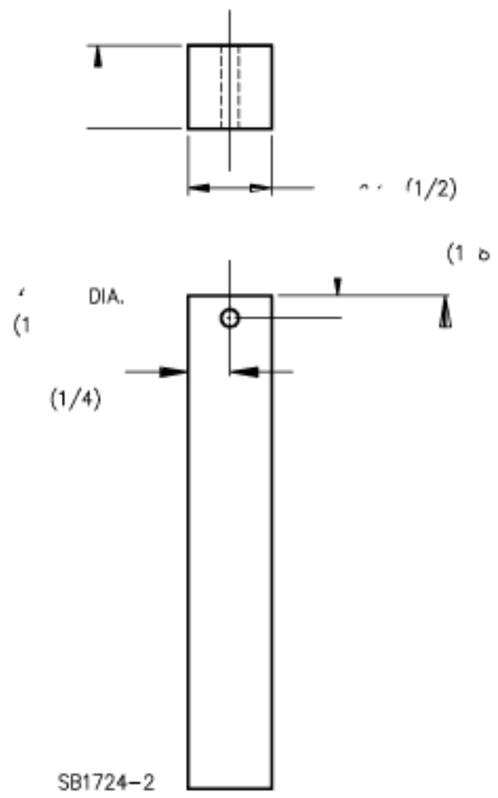
a) Highest oven temperature – 1 or 2 days per cycle

b) Next oven temperature – 2 to 4 days per cycle

c) Next oven temperature – 4 to 14 days per cycle

d) Lowest oven temperature – 3 to 7 weeks per cycle

Figure 21.2
Alternate tool-steel and bus-bar test specimens All dimensions in mm (inch)



NOTE –

Substrate material is to be ground square to within 0.01 mm (0.001 inch) with sharp (no measurable radius) edges. 810-micrometer (32-microinch) finish on four long sides.

21.3.8 At the end of each exposure in the oven, all samples are to cool to room temperature for approximately 1 hour. All samples are then to be subjected to a cold shock for 1 hour. If the coating resin is intended for outdoor applications, the temperature of the cold box is to be minus 20.0 ±2.0°C (minus 4.0 ±3.6°F). If the coating resin is intended for indoor applications only, the temperature of the cold box is to be 0.0 ±2.0°C (32.0 ±3.6°F).

21.3.9 Following the cold shock, all samples are to stand for 1 hour at room temperature. All samples are then to be subjected to a vibration test consisting of 10,000 cycles of vibration at an acceleration of 7 G's. If the motion of the specimen during the vibration test is simple harmonic, the maximum peak-to-peak deflection is to be 0.97 mm (0.038 inch), if the frequency of vibration is 60 hertz. The direction of the vibration is to be parallel to the shortest dimension of the specimen and orthogonal to the largest flat surface of the specimen.

21.3.10 Following the vibration test, all samples are to be subjected to a humidity test for a period of 24 hours at 25 – 30°C (77 – 86°F) with the relative humidity adjusted to 95 – 100 percent.

21.3.11 Within 1 hour after the humidity test, all specimens are to be subjected to a proof voltage test. The applied voltage is to be raised from zero at a rate of approximately 500 volts per second until the voltage reaches a value equal to 50 percent of the initial breakdown voltage of the material. This value of the voltage is to be maintained for 5 seconds, and the voltage is then to be removed from the specimen. Specimens that do not break down during this test are to be returned to the oven for further testing.

21.3.12 The aging-test program is to be continued until all specimens have exhibited breakdown. The time to breakdown for each specimen is to be recorded.

21.3.13 The data is to be evaluated by the proof-testing method described in Proof Testing, Section 18.

22 Fixed Time Sampling Method

22.1 General

22.1.1 As an alternate to the Fixed Temperature Method in Sections 13 – 21, the sampling method described in this section may be used to conduct the long-term heat aging program. The primary difference between the methods is in the sampling technique employed. Since both methods rely upon a data analysis of the degradation of samples at various temperatures and using specific time intervals, the results of the tests would be expected to be similar regardless of which of the two methods is selected.

22.1.2 Section 14, Selection of Control Material, and Section 15, Specimens, are applicable to the Fixed Time sampling method.

22.1.3 This sampling method was developed with the objective of completing most evaluations within approximately 5,000 hours of testing. This is accomplished through a more intensive selection of aging temperatures in the early portion of the program (the screening procedure) and by using the aging temperatures as the dependent variables while aging interval are the controlled variable.

22.1.4 To determine the performance characteristics of the material, a series of specimens is to be tested for property retention levels following fixed time frame aging intervals. The aging temperatures for the Fixed Time Frame Method are normally not established until after the screening procedure described in Section 22.2 is completed.

22.2 Screening Procedure

22.2.1 As a general guideline in selecting the temperatures to be used for conditioning of the thermal aging specimens, select four or more aging temperatures starting approximately 40°C above the expected RTI of the candidate material. Alternatively, temperatures may be chosen based on prior experience. The aging temperatures selected shall be at increments of at least 10°C. The control material should also be aged in the screening procedure. The temperatures selected for the control and the candidate materials should cover the same range but due to differences, melt temperatures, or other circumstances the range of aging temperatures for the control and candidate may not be the same but should overlap.

22.2.2 The selected screening temperatures should span the property end point value; at least one measured value being above and one measured value being below the property end point value. If the initial temperatures selected do not result in at least one value above and one below the property end point, additional aging temperatures shall be added to the screening program. A minimum of four temperatures shall be included in the screening so as to provide at least one value above and one below the property end point value (using the calculations presented later in this section).

22.2.3 A set of specimens shall be placed into the aging oven for each property to be evaluated. The preferred aging time for the Screening Test is 552 hours; however, other lengths of aging may be used. At the completion of the selected aging interval, all of the specimens are to be pulled, conditioned and tested for retention of properties.

22.2.4 Calculate the average percentage of retention of properties for each set of specimens as follows. Using the initial (unaged) measurement for each property, express the individual average property values as a percent of the initial value. This calculation will provide four sets of temperature-percent retention values. Using the four sequential/percent retention values meeting the conditions from paragraph 22.2.2, calculate the temperature at which the property end point value can be assigned. The property end point values shall be based on a linear regression through the set of temperature-percent retention values.

22.2.5 The calculated property end point value is the temperature that is 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 thermal index value in accordance with Section 19. This time-temperature can be designed as $t_{time\ interval}$.

22.2.6 If the results of the screening test are not consistent with a simple (linear) thermal degradation, such as with polypropylene materials, aging temperatures should instead be selected based on a study of the physical characteristics, or test history of materials with similar chemical composition.

22.3 Remainder of Fixed Time Sampling Method

22.3.1 Based on usable results of the screening procedure, additional Fixed Time sampling method intervals can then be selected and the remainder of the sampling (aging program) begun. The preferred additional aging intervals are 1,008 hours, 2,016 hours, and 5,040 hours. Using the pattern in the results of the screening procedure, select four, or more, aging temperatures for the two additional aging intervals. The aging temperatures shall be at increments of at least 10°C.

22.3.2 Following the test format described in the screening procedure, use the four aging evenly-spaced temperatures for each aging interval that have at least one measured value above and one below the property end point value. Calculate the temperature at which the property end point values can be assigned. Designate each value as $t_{time\ interval}$ (preferred t_{1008}, t_{2016}, and t_{5040}).

22.3.3 Analysis of the data obtained (at the 1,008, 2,016, and 5,040 hour points) using the Fixed Time sampling method shall be as described in Section 19.

RELATIVE THERMAL INDEX CLASS

23 Assignment of Temperature Classifications

23.1 The relative thermal index of insulation materials is to be assigned in accordance with the following standard temperature classifications:

a) 5°C (9°F) increments up to 130°C (266°F).

b) 10°C (18°F) increments from 130°C (266°F) through 180°C (356°F).

Exception: Includes 155°C (311°F).

c) 20°C (36°F) increments over 180°C (356°F).

Exception: Includes 190°C (374°F) and 210°C (410°F) providing that the temperature differential of the test ovens are within 3.0°C (5.4°F) of the nominal oven aging temperature.

MARKING

24 General

24.1 Material containers shall be marked with the following:

a) The manufacturer's or private labeler's name or identifying symbol.

b) A distinctive material designation.

24.2 If a manufacturer produces the material at more than one factory, each material container shall have a distinctive marking to identify it as the product of a particular factory.

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SUPPLEMENT SA - FOLLOW-UP INSPECTION INSTRUCTIONS

INTRODUCTION

SA1 Scope

SA1.1 This Supplement describes the manufacturer's production program necessary to verify that the product continues to be in compliance with the requirements in this Standard.

SA1.2 This Supplement also describes the duties and responsibilities of the field representative of the certification organization.

SA1.3 Recognizing that manufacturers are required to have quality assurance systems in place for the control of their production processes and products, this Supplement only covers the sampling inspections, tests, and other measures taken by the manufacturer and considered to be the minimum requirements of the certification organization. Such inspections, tests, and measures are supplemented by the certification organization as an audit of the means that the manufacturer exercises to determine conformance of products with the certification organization's requirements.

SA1.4 The certification organization shall have additional authority specified in legally binding agreements, signed by both the certification organization and manufacturer, to control the use and application of the certification organization's registered mark(s) for product, packaging, advertising, and associated literature. The legal agreements shall cover the control methods to be used by the certification organization and the manufacturer's options for appeal. Any additional inspections, tests, or other measures deemed necessary by the certification organization but to be taken by the manufacturer are to be applied in order to control the use and application of the certification organization's registered Mark(s).

SA2 Glossary

SA2.1 For the purposes of this Supplement, the following definitions apply.

SA2.2 CERTIFICATION ORGANIZATION – A third party organization independent of the manufacturer who, under a legally binding contract with the manufacturer, evaluates a product for compliance with requirements specified in the Standard, and who maintains periodic inspection of production of these products to verify compliance with the specifications in the Procedure and this Supplement.

SA2.3 FIELD REPRESENTATIVE – An authorized representative of the certification organization who makes periodic unannounced visits to the manufacturer's facilities for purposes of conducting inspections and monitoring the manufacturer's production program.

SA2.4 INSPECTION REPORT – The report generated by the field representative summarizing the results of the inspection visit.

SA2.5 MANUFACTURER – The authorized party who maintains and operates the facilities where a Recognized Component is produced or stored and where the product is inspected and/or tested as described in this Supplement.

SA2.6 PROCEDURE – The document issued by the certification organization, upon determination that a product is eligible for Recognition, for use by the manufacturer and the field representative. The document contains requirements and other provisions and conditions regarding the Recognized product and provides the authorization for the manufacturer to use the Recognition Marking on products fulfilling these requirements.

SA2.7 RECOGNIZED COMPONENT – A part or subassembly intended for use in other equipment and that has been investigated for certain construction or performance, or both, characteristics. A Recognized Component is incomplete in construction features or is restricted in performance capabilities so as not to warrant its acceptability as a field-installed component. It is intended solely as a factory-installed component of other equipment where its acceptability is determined by the certification organization.

SA2.8 RECOGNITION MARKING – A distinctive Mark of the certification organization that the manufacturer is authorized to apply to Recognized Components as the manufacturer's declaration that they conform to the requirements of the Standard.

SA2.9 VARIATION NOTICE (VN) – A document used to record observed differences between a product or manufacturing process and the description of the product or process in the Procedure and/or Standard.

SA3 Responsibility of the Manufacturer

SA3.1 It is the manufacturer's responsibility to restrict the use of the Recognition Marking to those products specifically authorized by the certification organization that are found by the manufacturer's own quality assurance program to comply with the Procedure description.

SA3.2 The manufacturer shall confine all Recognition Markings to the location or locations authorized in the Procedure.

SA3.3 During hours in which the manufacturer's facilities are in operation, the manufacturer shall permit the field representative free access to any portion of the premises where the plastic material is being produced, stored or tested.

SA3.4 The Field Representative shall be permitted to select a sufficient quantity of material, representative of current production. The manufacturer shall mold this material into test specimens, of a size and quantity, as indicated in the Procedure, for the purposes of the Follow-Up Test Program at the Certification Organization. The packaging and shipment of these samples is the responsibility of the manufacturer.

SA3.5 A material that is found to no longer be in compliance with the requirements of the certification organization shall be corrected by the manufacturer if the Recognition Mark is to be used on the product. If the noncompliance was the result of a manufacturing process, the manufacturer shall check subsequent production until it is certain that the process has been corrected and the noncompliance will not reoccur.

SA4 Responsibility of the Field Representative

SA4.1 At each visit to the manufacturer's facility, the Field Representative shall review a representative sampling of plastic production which bears the Recognition Marking, to assure that the Recognition Marking has been applied in accordance with this supplement, and the Procedure description. An inspection report shall be completed after each visit.

SA4.2 Any observed differences between the product marking and the description of the marking in the Procedure and/or Standard shall immediately be called to the attention of the manufacturer. Any observed differences shall be confirmed in a Variation Notice.

SA4.3 Production that is found to no longer be in compliance with the requirements of the certification organization shall be brought into compliance by the manufacturer if the Recognition Marking is to be used on the product's packaging. If the non-compliance was the result of a manufacturing process, the manufacturer shall check subsequent production until it is certain that the process has been corrected and the noncompliance will not recur. The Field Representative shall verify that the product marking continues to be in compliance with the requirements of the certification organization.

SA4.4 Production that does not comply with the provisions of these follow-up inspection instructions shall have the Recognition Marking removed or obliterated. The manufacturer shall satisfy the field representative that all Recognition markings are removed or obliterated from rejected material. Those Recognition markings not destroyed during the removal from the product packaging shall be turned over to the field representative for destruction. If rejection of production is questioned by the manufacturer, the manufacturer may hold the material at the point of inspection, typically at the factory, pending an appeal.

SA5 Selection of Samples for Follow-Up Testing

SA5.1 The Field Representative shall randomly select representative samples of production for the purposes of follow-up testing at the Certification organization. The sample selection interval shall be specified by the Certification organization, and the Field Representative shall assure that all selected samples are properly identified through the use of sample identification tags provided by the Certification organization. The follow-up tests performed at the Certification organization are described in the ″Follow-Up Test Program″ Section of this Supplement.

SA6 Follow-Up Test Program

SA6.1 The following tests are to be performed by the Certification organization on samples received from the Field Representative.

SA6.1.1 FLAMMABILITY TEST – Test specimens are to be subjected to the appropriate burning tests, indicated in the Procedure, in accordance with the methods described in UL 94, Tests for Flammability of Plastic Materials for Parts in Devices and Appliances . The classifications obtained in the Follow-Up Tests are to be the same as those indicated in the Procedure.

SA6.1.2 QUALITATIVE INFRARED ANALYSIS – An infrared spectrum of the material is to be obtained by means of an infrared spectrophotometer in accordance with the methods described in Infrared Spectroscopy, Section 43 of UL 746A, Polymeric Materials – Short Term Property Evaluation. Instrument settings used in obtaining the spectrum shall be identical to those used in obtaining the original spectrum of the material referenced in the procedure. The spectrum obtained shall indicate the same composition as that recorded in the spectrum obtained under the original investigation.

SA6.1.3 THERMOGRAVIMETRY – A thermogram of the material is to be obtained by means of a thermal analyzer with a thermogravimetic module in accordance with the methods described in Thermogravimetry, Section 46 of UL 746A, Polymeric Materials – Short Term Property Evaluations. Instrument settings used in obtaining the thermogram shall be identical to those used in obtaining the original thermogram of the material referenced in the procedure. The thermogram obtained shall indicate the same characteristic weight loss over the programmed temperature range as that recorded in the thermogram obtained under the original investigation.

SA6.1.4 A thermogram of the material is to be obtained by means of a thermal analyzer with a DSC (Differential Scanning Calorimetry) module in accordance with the methods described in Section 47 of UL 746A, Polymeric Materials– Short Term Property Evaluations. Instrument settings used in obtaining the thermogram shall be identical to those used in the original thermogram of the material referenced in this procedure. The thermogram obtained shall indicate the same general thermal response over the programmed temperature range as that recorded in the thermogram obtained under the original investigation.

SA6.2 Upon completion of follow-up testing, the Certification organization shall report the results to the manufacturer.