

UL 746E

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Polymeric Materials – Industrial
Laminates, Filament Wound
Tubing, Vulcanized Fibre, and
Materials Used In Printed-
Wiring Boards

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UL Standard for Safety for Polymeric Materials – Industrial Laminates, Filament Wound Tubing, Vulcanized Fibre, and Materials Used In Printed-Wiring Boards, UL 746E

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Text that has been changed in any manner is marked with a vertical line in the margin. Changes in requirements are marked with a vertical line in the margin and are followed by an effective date note indicating the date of publication or the date on which the changed requirement becomes effective.

The following table lists the future effective dates with the corresponding item.

Future Effective Dates	References
February 7, 2003	Paragraphs 18.2.3, 18.2.4, and 18.2.5
February 7, 2004	Paragraphs 5.6, 6.6, 6.6.1, and 7.10 Section 8A Figures 6.7 – 6.31

The new and/or revised requirements are substantially in accordance with UL's Bulletin(s) on this subject dated May 7, 2001. The bulletin is now obsolete and may be discarded.

The revisions dated November 28, 2001 include a reprinted title page (page1) for this Standard.

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UL 746E

**Standard for Polymeric Materials – Industrial Laminates, Filament Wound
Tubing, Vulcanized Fibre, and Materials Used In Printed-Wiring Boards**

First Edition – November, 1985

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June 30, 2000

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Revisions of this Standard will be made by issuing revised or additional pages bearing their date of issue. A UL Standard is current only if it incorporates the most recently adopted revisions, all of which are itemized on the transmittal notice that accompanies the latest set of revised requirements.

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ANNEX A

TGA Conformance Criteria

FOREWORD

A. This Standard contains basic requirements for products covered by Underwriters Laboratories Inc. (UL) under its Follow-Up Service for this category within the limitations given below and in the Scope section of this Standard. These requirements are based upon sound engineering principles, research, records of tests and field experience, and an appreciation of the problems of manufacture, installation, and use derived from consultation with and information obtained from manufacturers, users, inspection authorities, and others having specialized experience. They are subject to revision as further experience and investigation may show is necessary or desirable.

B. The observance of the requirements of this Standard by a manufacturer is one of the conditions of the continued coverage of the manufacturer's product.

C. A product which complies with the text of this Standard will not necessarily be judged to comply with the Standard if, when examined and tested, it is found to have other features which impair the level of safety contemplated by these requirements.

D. A product that contains features, characteristics, components, materials, or systems new or different from those covered by the requirements in this standard, and that involves a risk of fire or of electric shock or injury to persons shall be evaluated using appropriate additional component and end-product requirements to maintain the level of safety as originally anticipated by the intent of this standard. A product whose features, characteristics, components, materials, or systems conflict with specific requirements or provisions of this standard does not comply with this standard. Revision of requirements shall be proposed and adopted in conformance with the methods employed for development, revision, and implementation of this standard.

E. UL, in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. The opinions and findings of UL represent its professional judgment given with due consideration to the necessary limitations of practical operation and state of the art at the time the Standard is processed. UL shall not be responsible to anyone for the use of or reliance upon this Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon this Standard.

F. Many tests required by the Standards of UL are inherently hazardous and adequate safeguards for personnel and property shall be employed in conducting such tests.

INTRODUCTION

1 Scope

1.1 These requirements cover test procedures to be used for the evaluation of industrial laminates, filament wound tubing, vulcanized fibre, and materials for use in fabricating printed wiring boards.

1.2 These requirements provide data with respect to the physical, electrical, flammability, thermal, and other properties of the materials, that are intended to provide guidance to the material manufacturer, the fabricator, the end product manufacturer, safety engineers and other interested parties.

1.3 *Deleted November 28, 2001*

2 Glossary

2.1 For the purpose of this standard the following definitions apply.

2.2 CONFORMAL COATING – A protective covering applied on a printed-wiring board to increase the dielectric voltage-withstand capability between conductors and to protect against environmental conditions.

2.3 ETCHED – A laminate material in which the conductive layer has been removed by a chemical process.

2.4 FILAMENT WOUND TUBING – A tube composed of continuous monofilaments or yarns with controlled orientation in a matrix of cured thermosetting resin.

2.5 FILM – A sheet material having a nominal thickness not greater than 0.25 mm (0.010 inch).

2.6 METAL CLAD – A laminate material with a conductive pattern.

2.7 RESIST COATING – Material supplied in liquid or film form to mask or to protect selected areas of a pattern from the action of an etchant, solder or plating, which remains on the printed wiring board after processing.

2.8 RIGID INDUSTRIAL LAMINATE – Fibrous reinforcing material that is impregnated or coated with a thermosetting resin binder and consolidated under high temperature and pressure into dense solid product.

2.9 UL/ANSI TYPE MATERIAL – A specific type designation for materials defined in this standard as having certain base material, resin, thermal index and profiles of minimum performance.

2.10 UNCLAD – A laminate material without foil.

2.11 VULCANIZED FIBRE – A dense material of partially regenerated cellulose in which the fibrous sheet structure is retained in varying degrees, depending on the grade of fibre.

3 Units of Measurement

3.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

3A Test Measurement Accuracy

3A.1 A measuring device shall be capable of measuring the specified parameter with an accuracy within 10 percent of the measured parameter.

3A.1 added November 28, 2001

4 Supplementary Test Procedures

4.1 These requirements are intended to be used in conjunction with the following requirements or standards:

- a) The Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, and the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, contain programs for investigating polymeric materials. UL 746C is intended for the evaluations of polymeric materials in specific applications in end products.
- b) The Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, contains methods for evaluating the flammability of polymeric materials that are intended to be used in electrical equipment.
- c) The Standard for Printed Wiring Boards, UL 796, covers the minimum performance requirements for printed wiring boards.
- d) The Standard Test Method for Rapid Thermal Degradation of Solid Electrical Insulating Materials by the Thermogravimetric Method, ASTM D3850 (1994) covers the identification of laminates.

4.1 revised November 28, 2001

INDUSTRIAL LAMINATES

5 General

5.1 Profiles of minimum performance, relative thermal indices, and major constituents of industrial laminates are given in Tables 5.1 – 5.3. These profiles are minimum characteristics required for an industrial laminate to be assigned a UL/ANSI type designation.

5.2 Industrial laminates are evaluated for designation as a specific UL/ANSI material type or other designation by using the procedures in this Standard to obtain a profile of performance for comparison with those of known UL/ANSI material types. Figure 5.1 shows the procedures to be followed in this evaluation.

5.2 revised November 28, 2001

5.3 An industrial laminate that is tested on the basis of the abbreviated test program in Section 6, and found to be in compliance with the criteria in Figure 5.1, need not be tested to the full program in Section 7. An industrial laminate that is not in compliance shall additionally be subject to the test program in Section 7, with the number of aging points and rating assignments as indicated in Figure 5.1.

5.3 revised February 7, 2001

5.4 An industrial laminate having acceptable results from the abbreviated test program, shall have either the full testing or selected parts of the full test program, as indicated in Section 7, to obtain profile of performance values when needed for end product use.

5.5 Where modification of a previously tested grade consists of a variation of the original percentage of dye or pigment of not more than 5 percent inorganic or 0.3 percent organic, only flammability testing in accordance with the requirements for tests for flammability of plastic materials for parts in devices and appliances, UL 94, is required. Higher loading requires additional one point aging for flexural or dielectric strength properties and flammability.

5.6 Industrial laminates may be evaluated for creating a "Laminate Family." All industrial laminates to be included in the "Laminate Family" shall have identical IR scans. There shall be one IR reference scan used for future comparison purposes per family. If the performance profile indexing values of each industrial laminate are not the same value, the "Laminate Family" shall be assigned the mechanical and electrical RTI's and performance profile indexing values of the lowest rated material within the "Laminate Family." Industrial laminates included within the "Laminate Family" shall not be assigned higher mechanical and electrical RTI's and performance profile indexing values outside of the family under the same grade designations.

Added 5.6 effective February 7, 2004

Table 5.1
Rigid industrial laminate profiles of performance

Table 5.1 revised November 28, 2001

UL/ANSI GRADE	Thickness		Flam class	Min HAI		Min HWI PLC	Max HVAR PLC	Max HVTR PLC	D495 PLC	Min die str KV/mm	Min flex str psi	CTI PLC	Vol resis ohm-cm x10 ³	Water ab %Chg
	mm	inch		OS	AS									
X	0.71	0.028	HB	3	0	5	0	4	—	—	22,000	—	—	—
	1.57	0.062	HB	3	0	4	0	4	3	9.6/—	25,000	—	—	—
XP	0.71	0.028	—	4	0	4	0	4	—	26.9/—	12,000	—	—	—
	1.57	0.062	HB	3	0	4	0	4	—	19.4/—	13,000	—	—	—
XPC	0.71	0.028	HB	4	0	4	3	4	—	—	—	—	—	—
	1.57	0.062	HB	3	0	4	0	4	3	21.8/—	10,000	—	—	—
XX	0.71	0.028	HB	4	0	5	0	4	—	29.9/—	15,000	—	—	—
	1.45	0.057	HB	4	0	4	0	4	—	19.5/—	15,000	—	—	—
XXP	0.71	0.028	HB	4	0	5	0	4	—	—	14,000	—	—	—
	1.45	0.057	HB	3	0	4	0	4	3	15.7/—	14,000	—	—	—
XXX	0.71	0.028	—	4	0	4	0	4	—	—	13,500	—	—	—
	1.57	0.062	HB	4	0	4	0	4	3	—	13,500	—	—	—

Table 5.1 Continued on Next Page

Table 5.1 Continued

UL/ANSI GRADE	Thickness		Flam class	Min HAI		Min HWI PLC	Max HVAR PLC	Max HVTR PLC	D495 PLC	Min die str KV/mm	Min flex str psi	CTI PLC	Vol resis ohm-cm x10 ^a	Water ab %Chg
	mm	inch		OS	AS									
XXXP	0.71	0.028	HB	3	0	5	0	4	—	38.4/ 18.6	12,000	—	—	—
	1.57	0.062	HB	3	0	4	0	4	3	—	12,000	4	—	—
XXXPC	0.71	0.028	HB	4	0	5	0	4	—	—	12,000	—	—	—
	1.57	0.062	HB	3	0	5	0	4	—	—	12,000	4	7,5	—
C	0.63	0.025	—	4	0	4	0	4	—	—	17,000	—	—	—
	1.40	0.055	HB	4	0	4	0	4	3	8.9/—	17,000	—	—	—
CE	0.63	0.025	—	4	0	4	0	4	—	18.3/—	16,500	—	—	—
	1.40	0.055	HB	4	0	4	0	4	3	15.9/—	16,500	—	—	—
L	0.63	0.025	—	4	0	5	0	4	—	—	16,500	—	—	—
	1.45	0.057	HB	4	0	5	0	4	3	7.3/—	16,500	—	—	—
LE	0.63	0.025	—	4	0	4	0	4	—	—	16,000	—	—	—
	1.45	0.057	HB	4	0	4	0	4	3	11.0/—	16,000	—	—	—
G-3	0.63	0.025	HB	4	0	4	0	4	—	30.6/—	18,000	—	—	—
	1.57	0.062	HB	4	0	3	0	4	—	16.3/—	20,000	—	—	—
G-5	0.63	0.025	V-0	3	0	4	0	0	—	—	55,000	—	—	—
	1.57	0.062	V-0	2	0	3	0	0	2	28.0/—	50,000	—	—	—
G-7	0.63	0.025	V-0	4	0	3	0	0	—	14.8/—	10,000	—	—	—
	1.57	0.062	V-0	4	0	4	0	0	—	7.7/—	20,000	—	—	—
G-9	0.63	0.025	V-0	2	0	5	0	4	—	23.2/—	—	—	—	—
	1.57	0.062	V-0	1	0	3	0	0	—	25.2/—	60,000	—	—	—
G-10	0.63	0.025	HB	2	0	4	0	0	—	32.0/ 29.8	60,000	—	—	—
	1.57	0.062	HB	2	0	4	0	0	2	—	60,000	4	9,9	0.20
G-11	0.63	0.025	HB	4	1	4	0	4	—	39.0/—	60,000	—	—	—
	1.40	0.055	HB	4	0	3	0	4	—	34.1/—	60,000	—	—	—
FR-1	0.71	0.028	V-1,V-0	3	0	3	0	4	2	—	—	—	—	—
	1.57	0.062	V-0	3	0	3	0	4	2	19.7/ 15.7	10,000	4	9,7	—
FR-2	0.71	0.028	V-1,V-0	3	0	4	0	4	—	32.6/ 23.0	12,000	—	—	—
	1.45	0.057	V-1,V-0	3	0	4	0	4	2	—	12,000	4	7,6	—

Table 5.1 Continued on Next Page

Table 5.1 Continued

UL/ANSI GRADE	Thickness		Flam class	Min HAI		Min HWI PLC	Max HVAR PLC	Max HVTR PLC	D495 PLC	Min die str KV/mm	Min flex str psi	CTI PLC	Vol resis ohm-cm x10 ^a	Water ab %Chg
	mm	inch		OS	AS									
FR-3	0.71	0.028	V-1,V-0	0	0	2	0	4	—	31.2/26.1	20,000	—	—	—
	1.45	0.057	V-1,V-0	0	0	0	0	4	—	—	20,000	4	8,8	—
FR-4	0.63	0.025	V-1,V-0	3	0	0	0	4	—	31.8/30.7	60,000	—	—	—
	1.57	0.062	V-1,V-0	2	0	0	0	4	3	—	60,000	4	9,9	0.20
FR-5	0.63	0.025	V-1,V-0	3	0	3	0	4	—	31.2/29.6	60,000	—	—	—
	1.40	0.055	V-1,V-0	2	0	2	0	4	3	—	60,000	4	9,9	0.20
CEM-1	0.63	0.025	V-0	2	0	3	1	4	—	38.6/35.9	50,000	—	—	—
	1.57	0.062	V-0	2	0	1	1	4	2	30.3/28.1	35,000	3	8,8	0.14
CEM-3	0.63	0.025	V-0	2	0	0	1	4	—	29.5/—	50,000	—	—	—
	1.57	0.062	V-0	2	0	0	1	4	—	35.4/35.4	40,000	3	8,21	0.21
GPO-2	0.63	0.025	HB	0	0	2	0	1	—	14.4/8.8	—	—	—	—
	1.40	0.055	V-0	0	0	1	0	0	2	—	18,000	0	7,6	0.20
GPO-3	0.63	0.025	HB	0	0	1	0	0	—	17.2/—	—	—	—	—
	1.40	0.055	V-0	0	0	0	0	0	1	—	18,000	1	—	0.28
GPY	0.63	0.025	HB	3	0	0	3	0	—	38.9/37.8	65,000	—	8,14	—
	1.40	0.055	V-1,V-0	3	0	0	0	0	1	—	53,500	4	—	—

NOTES

- 1 For dielectric strength and volume resistivity the double values are:
Dry/Wet = (40 hours/23°C/50% R.H.)/(96 hours/35°C/90% R.H.)
- 2 HAI— high-current arc ignition
- 3 HWI — hot wire ignition
- 4 HVTR — high-voltage tracking rate
- 5 HVAR— high-voltage arc resistance
- 6 Flam class — flammability classification
- 7 Die str — dielectric strength
- 8 CTI — comparative tracking index (All samples for the CTI are to be 3.2 mm or 0.125 inch thick.)
- 9 Flex str — flexural strength
- 10 Vol resis — volume resistivity
- 11 Water ab — water absorption
- 12 The exponent "a" in the "Vol resis" column corresponds to the pairs of numbers shown in the column. The first number in the pair corresponds to a wet condition, whereas the second number corresponds to a dry condition.

Table 5.2
Rigid industrial laminate and relative thermal index

Table 5.2 revised November 28, 2001

UL/ANSI Type	Minimum thickness		Temperature index	
	mm	(inch)	Electrical	Mechanical
X	0.71	(0.028)	130	130
XP	0.71	(0.028)	130	130
XPC	0.71	(0.028)	130	130
XX	0.71	(0.028)	130	130
	1.45	(0.057)	140	140
XXP	0.71	(0.028)	130	130
	1.45	(0.057)	140	140
XXX	0.71	(0.028)	130	130
	1.45	(0.057)	140	140
XXXP	0.71	(0.028)	125	125
XXXPC	0.71	(0.028)	125	125
C	0.63	(0.025)	85	115
	1.40	(0.055)	115	125
CE	0.63	(0.025)	85	115
	1.40	(0.055)	115	125
L	0.63	(0.025)	85	115
	1.45	(0.057)	115	125
LE	0.63	(0.025)	115	85
	1.45	(0.057)	115	125
G-3	0.63	(0.025)	140	170
G-5	0.63	(0.025)	50	140
G-7	0.63	(0.025)	170	220
G-9	0.63	(0.025)	50	140
G-10	0.63	(0.025)	130	140
G-11	0.63	(0.025)	140	160
	1.40	(0.055)	170	180
FR-1	0.71	(0.028)	130	130
FR-2	0.71	(0.028)	75	75
	1.45	(0.057)	105	105
FR-3	0.71	(0.028)	90	90
	1.45	(0.057)	110	110
FR-4	0.63	(0.025)	130	140
FR-5	0.63	(0.025)	140	160
	1.40	(0.055)	170	180
CEM-1	0.63	(0.025)	130	140
CEM-3	0.63	(0.025)	130	140
GPO-2	0.63	(0.025)	c	c
	1.40	(0.055)	105 ^a	160
GPO-3	0.63	(0.025)	c	c
	1.40	(0.055)	105 ^b	140
GPY	0.63	(0.025)	140	160
	1.40	(0.055)	170	180

^a A temperature index of 130°C may be assigned on successful completion of a one point thermal aging test.

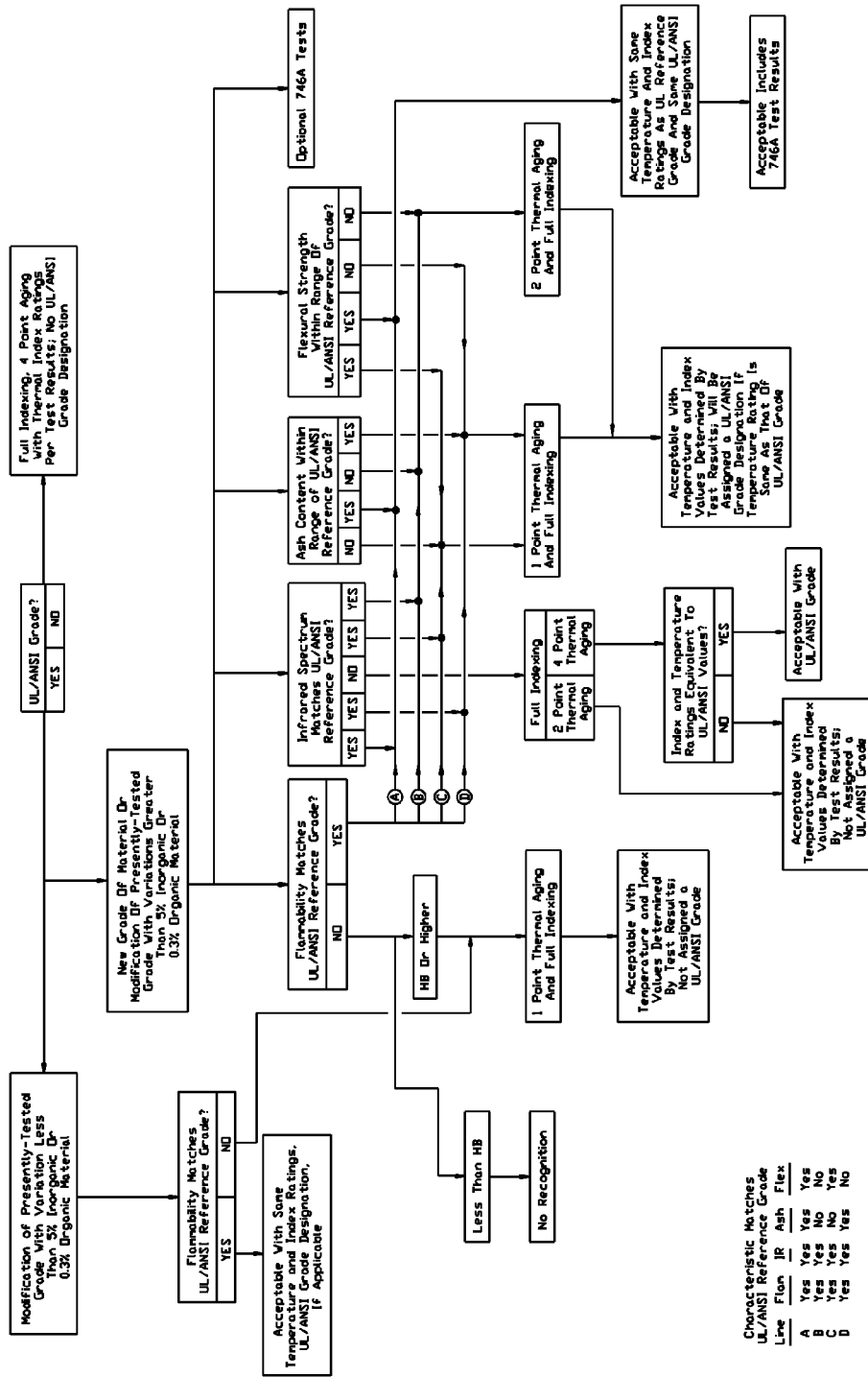
^b A temperature index of 120°C may be assigned on successful completion of a one point aging program.

^c For 0.63 mm (0.025 inch) thick material, a 2 point aging program is required before a temperature rating is assigned.

Table 5.3
Industrial laminate constituents

UL/ANSI type	Resin	Base material
X	Phenolic	Paper
XP	Phenolic	Paper
XPC	Phenolic	Paper
XX	Phenolic	Paper
XXP	Phenolic	Paper
XXX	Phenolic	Paper
XXXP	Phenolic	Paper
XXXPC	Phenolic	Paper
C	Phenolic	Cotton fabric
CE	Phenolic	Cotton fabric
L	Phenolic	Cotton fabric
LE	Phenolic	Cotton fabric
G-3	Phenolic	Continuous filament woven glass fabric
G-5	Melamine	Continuous filament woven glass fabric
G-7	Silicone	Continuous filament woven glass fabric
G-9	Melamine	Continuous filament woven glass fabric
G-10	Epoxy	Continuous filament woven glass fabric
G-11	Epoxy	Continuous filament woven glass fabric
FR-1	Phenolic	Paper
FR-2	Phenolic	Paper
FR-3	Epoxy	Paper
FR-4	Epoxy	Continuous filament woven glass fabric
FR-5	Epoxy	Continuous filament woven glass fabric
CEM-1	Epoxy	Continuous filament woven glass fabric surfaces, cellulose paper core
CEM-3	Epoxy	Continuous filament woven glass fabric surfaces, nonwoven glass core
GPO-2	Polyester	Random laid material of glass fibers
GPO-3	Polyester	Random laid material of glass fibers
GPY	Polyimide	Continuous filament woven glass fabric

Figure 5.1
UL testing and evaluation program for rigid industrial laminates



Characteristic Matches UL/ANSI Reference Grade

Line	Flam	IR	Ash	Flex
A	Yes	Yes	Yes	Yes
B	Yes	Yes	No	No
C	Yes	Yes	No	Yes
D	Yes	Yes	Yes	No

SB2974B

6 Abbreviated Test Program

6.1 Industrial laminates may be evaluated on the basis of the abbreviated unaged property test program, shown in Table 6.1. Additional tests are required for evaluating industrial laminates at ultrathin thicknesses, see Section 8.

6.1 revised November 28, 2001

Table 6.1
Industrial laminate abbreviated unaged property test program testing and sample requirements

Table 6.1 revised November 28, 2001

Tests
1. Infrared analysis comparison 2. Flexural strength 3. Ash content (when applicable) (See Table 6.2) 4. Vertical or horizontal flammability 5. Thermogravimetric analysis (TGA) 6. GPO-2 or GPO-3 thermal aging (Optional – see 6.8 and 6.9).
Samples
When samples are copper clad, they are to be prepared by etching a clad sheet, cut in the machine (grain) direction. A. 20 specimens: 100 mm (4 inches) long, 25 mm (1 inch) wide, and 1.6 mm (0.062 inch) thick. Additionally, 0.8 mm (0.031 inch) samples are required for CEM-1 and CEM-3, and where 1.6 mm (0.062 inch) samples are not available. B. 30 bars – 125 mm (5 inches) long, 12.7 mm (0.5 inch) nominal, 13.2 mm (0.52 inch) maximum, wide, 1.6 mm (0.062 inch) thick. The edges are to be smooth and the radius on the corners is not to exceed 1.3 mm (0.05 inch). C. 30 bars – 125 mm (5 inches) long, 12.7 mm (0.5 inch) wide, 13.2 mm (0.52 inch) maximum, 0.8 mm (0.031 inch) thick. The edges are to be smooth and the radius on the corners is not to exceed 1.3 mm (0.05 inch). Thermal aging of GPO-2 or GPO-3 (optional – see 6.8 and 6.9). D. 30 squares which are 100 mm (4 inches) on each side, 1.4 mm (0.055 inch) thick. E. 60 squares which are 100 mm (4 inches) on each side, 0.71 mm (0.028 inch) thick. F. 50 specimens which are 100 mm (4 inches) long, 25 mm (1 inch) wide, and 0.8 mm (0.031 inch) thick.

6.2 An industrial laminate having acceptable characteristics of flammability, infrared analysis, ash content (where applicable), flexural strength, and thermal aging (when required), as described in this section for a UL/ANSI type industrial laminate of the same generic type, shall be assigned the UL/ANSI type designation, the profile of performance values shown in Table 5.1 and the relative thermal index shown in Table 5.2 for that UL/ANSI material. An industrial laminate not intended to be a UL/ANSI type and/or having unacceptable fundamental variations in the IR spectra as indicated in 6.6 shall be evaluated per the full test program. See Section 7.

6.2 revised November 28, 2001

6.3 The criteria in 6.4 – 6.9 is to be applied when comparing industrial laminates with UL/ANSI material types.

6.4 Flammability tests shall be conducted in accordance with the requirements for tests for flammability of plastic materials for parts in devices and appliances, UL 94. Sample thicknesses are given in Table 6.2. A laminate shall have a flammability classification in each thickness as indicated in Table 6.2, except that a laminate, subjected additionally to the testing indicated in 6.5, shall have a flammability class of HB or higher.

6.5 When the UL 94 flammability classification (see 6.4) is greater or less than that of the UL/ANSI reference type (see Table 6.2), the material shall be subjected to full indexing and one point thermal aging as described in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B. See Table 7.1 for the test samples required. The laminate shall not be designated as a UL/ANSI type material.

6.6 A qualitative infrared shall be made from resin obtained by surface scraping of the glossy side of the industrial laminates in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. The spectrum obtained shall indicate the same basic composition as that recorded in the spectrum of the UL/ANSI type. Typical infrared analysis spectra are shown in Figures 6.1 – 6.17, for each UL/ANSI type. A fundamental variation in composition from the typical spectra is not acceptable. Examples of unacceptable fundamental variations are as follows:

- a) The absence of a significant absorption band which was present in the UL/ANSI type.
- b) The presence of a significant band which was not present in the UL/ANSI type.
- c) An indication of the presence of a different member of the same homologous series (a series of hydrocarbon compounds each differing by a carbon and two hydrogen atoms).
- d) A significant variation in the absorption coefficient (a value indicating the fraction of incident light absorbed) from the UL/ANSI type [“significant variation” cannot be defined by a specific numerical value because the extent of variation per unit (percent transmittance) is dependent upon the dipole moment of the particular chemical family].

Exception: A material that has unacceptable fundamental variations qualifies for additional testing of full indexing and two or four point thermal aging as described in the Full Test Program, Section 7. A relative thermal index equivalent to the UL/ANSI type shall be assigned to the material, if the test results so warrant. The material shall not be designated as a UL/ANSI type unless 4-point aging is done under the full test program, the test results permit assignment to the material of the same relative thermal index as shown in Table 5.2, and the infrared spectrum indicates the same generic resin system, including the flame retardant and other significant components, as the requested UL/ANSI type. Significant components will be determined using the guidelines given in Table 19.1 of the Standard for Polymeric Materials - Long Term Property Evaluations, UL 746B.

Revised 6.6 effective February 7, 2004

6.6.1 As an example of applying the Exception to 6.6, a material is considered a generic equivalent to a UL/ANSI FR-4 type if it is comprised of a glass cloth impregnated with one, or a combination of, epoxy resins not considered to be UL/ANSI FR-4 types. As another example, a material is not considered a generic equivalent to a UL/ANSI FR-4 type if it is comprised of a glass cloth impregnated with any resin other than an epoxy resin.

Added 6.6.1 effective February 7, 2004

6.7 An ash content analysis is to be conducted in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, on materials that contain a noncombustible reinforcement such as fiberglass. To determine compliance, the ash content shall fall within the range of values shown in Table 6.2

Exception No. 1: When ash content is not as shown in Table 6.2 but flammability, infrared analysis, and flexural strength are acceptable, full indexing and one point thermal aging shall be conducted as described in the Full Test Program, Section 7. When test results are determined to be equivalent to the UL/ANSI type, a relative thermal index and a UL/ANSI type designation shall be assigned.

Exception No. 2: When ash content and flexural strength are not as shown in Table 6.2 but flammability and infrared analysis are acceptable, full indexing and two point thermal aging shall be conducted. See Table 7.1. When test results are determined to be equivalent to the UL/ANSI type, a relative thermal index and a UL/ANSI type designation shall be assigned.

6.8 A flexural strength test is to be conducted in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, on samples cut in the machine (grain) direction. To determine compliance, the flexural strength values shall not be less than the minimum values indicated in Table 6.2.

Exception: When flexural strength is not as shown in Table 6.2 but flammability, infrared analysis, and ash content are acceptable, full indexing and a one point thermal aging shall be conducted as described in the Full Test Program, Section 7. When test results are determined to be equivalent to the UL/ANSI type, a relative thermal index and a UL/ANSI type designation shall be assigned.

6.9 A thermal aging program for UL/ANSI Type GPO-2 and GPO-3 industrial laminates shall be conducted in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

- a) The electrical temperature index values shall compare favorably with the values shown in Table 5.2.
- b) An electrical temperature index of 105°C (221°F) shall be assigned without conducting a thermal aging program.
- c) An electrical temperature index higher than 105°C (221°F) may be assigned as the result of a one point thermal aging program on 1.40 mm (0.055 inch) thick samples, or a two point aging program on 0.71 mm (0.028 inch) thick samples. See 7.3.

6.9 revised November 28, 2001

6.10 Thermogravimetric Analysis (TGA) shall be conducted in accordance with the Standard Test Method for Rapid Thermal Degradation of Solid Electrical Insulating Materials by the Thermogravimetric Method, ASTM D3850 (1994), for characterization of the laminate.

Table 6.2
Industrial laminates abbreviated program

Table 6.2 revised November 28, 2001

ANSI grade	Acceptable values			UL 94 flame class ^{a,b}
	Minimum flexural strength PSI		Range of ash content ^{a,b,d} (% by weight)	
	Nominal thickness			
	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)		
X	22,000	25,000	–	HB
XP	12,000	13,000	–	HB
XPC	–	10,000	–	HB
XX	15,000	15,000	–	HB
XXP	14,000	14,000	–	HB
XXX	13,500	13,500	–	HB
XXXP, XXXPC	12,000	12,000	–	HB
C	17,000	17,000	–	HB
CE, L	16,500	16,500	–	HB

Table 6.2 Continued on Next Page

Table 6.2 Continued

ANSI grade	Acceptable values			UL 94 flame class ^{a,b}
	Minimum flexural strength PSI		Range of ash content ^{a,b,d} (% by weight)	
	Nominal thickness			
	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)		
LE	16,000	16,000	–	HB
G-3	18,000	20,000	57.7 – 67.2	HB
G-5	55,000	50,000	55.0– 63.3	V-0
G-7	10,000	20,000	85.3 – 91.6	V-0
G-9	–	60,000	55.0 – 63.3	V-0
G-10	60,000	60,000	55.0– 67.7	HB
G-11	60,000	60,000	60.5 – 70.0	HB
FR-1	–	10,000	–	V-0 or V-1
FR-2	12,000	12,000	–	V-0 or V-1
FR-3	20,000	20,000	–	V-0 or V-1
FR-4	60,000	60,000	55.0– 67.7	V-0 or V-1
FR-5	60,000	60,000	60.5 – 70.0	V-0 or V-1
CEM-1	50,000	35,000	32.6 – 39.8 ^a 16.4 – 23.3 ^b	V-0
CEM-3	50,000	40,000	42.7 – 68.3 ^a 29.7 – 44.9 ^b	V-0
GPO-2	–	18,000	44.6 – 60.2	V-0 ^c
GPO-3	–	18,000	47.8 – 57.2	V-0 ^c
GPY	65,500	53,500	58.5 – 71.5	HB, V-0, or V-1

^a Approximately 0.8 mm (0.031 inch) thickness.
^b Approximately 1.6 mm (0.062 inch) thickness.
^c 1.6 mm (0.062 inch) thickness only.
^d If not specified otherwise, both the 0.8 mm (0.031 inch) and 1.6 mm (0.062) thicknesses shall be tested.

Figure 6.1
Typical IR spectrum for industrial laminates UL/ANSI Types X, XP, XPC

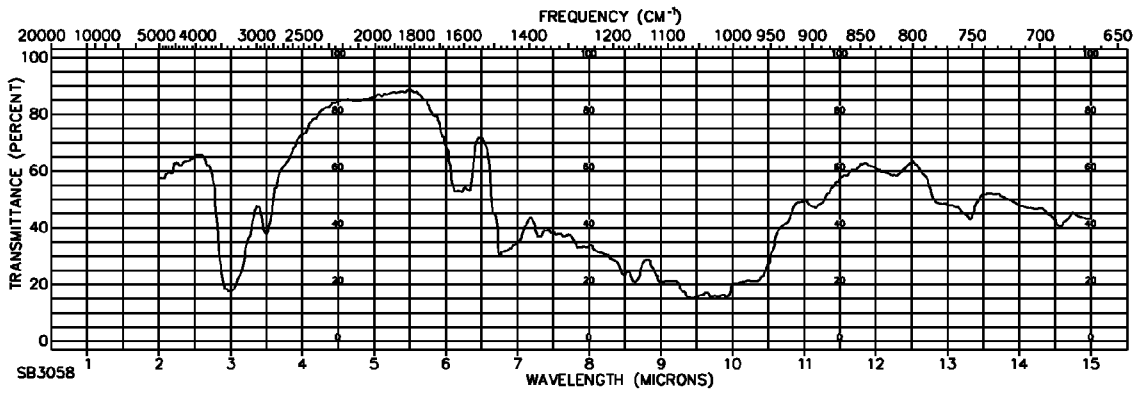


Figure 6.2
Typical IR spectrum for industrial laminates UL/ANSI Types XX, XXP, XXX

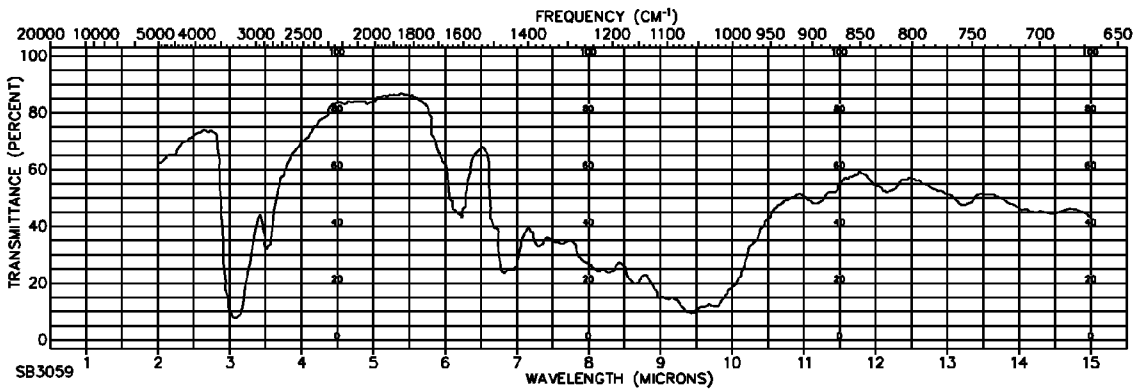


Figure 6.3
Typical IR spectrum for industrial laminates UL/ANSI Types XXXP and XXXPC

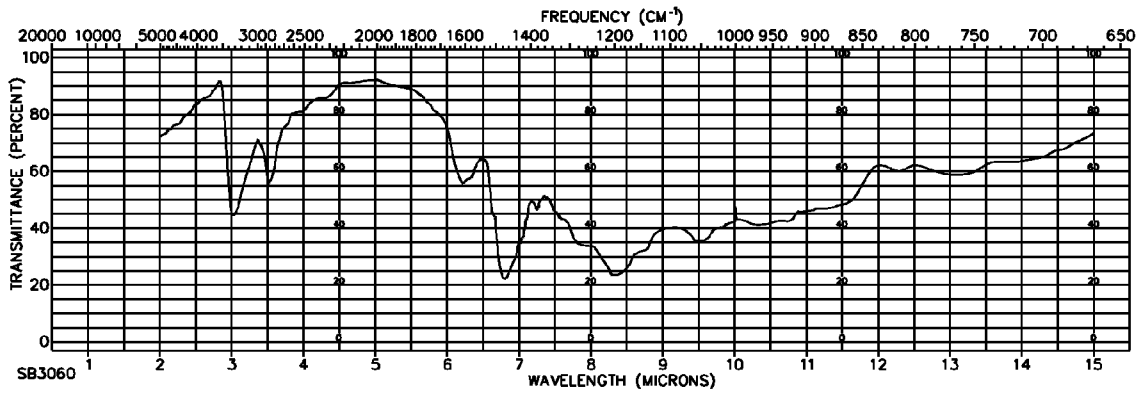


Figure 6.4
Typical IR spectrum for industrial laminates UL/ANSI Types C, CE, L, and LE

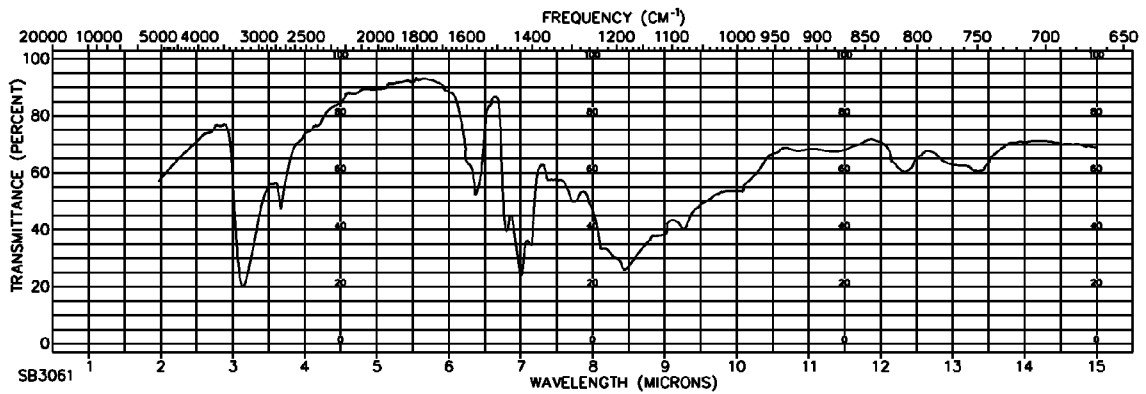


Figure 6.5
Typical IR spectrum for industrial laminates UL/ANSI Types G-5 and G-9

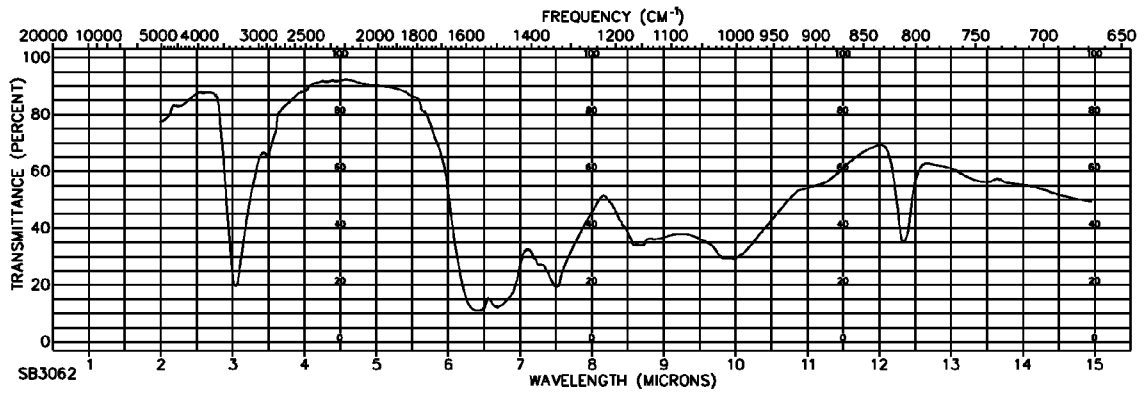


Figure 6.6
Typical IR spectrum for industrial laminates UL/ANSI Type G-7

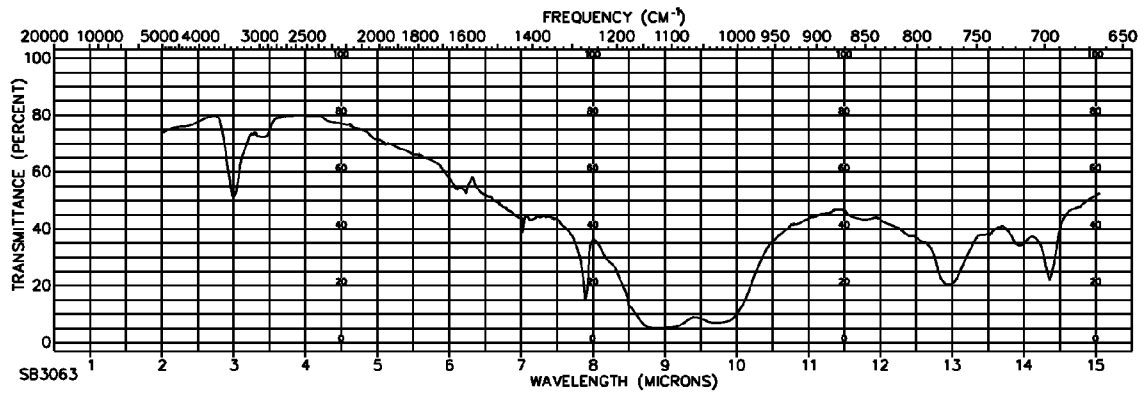


Figure 6.7
Typical IR spectrum for industrial laminates UL/ANSI Types G-10

Revised Figure 6.7 effective February 7, 2004

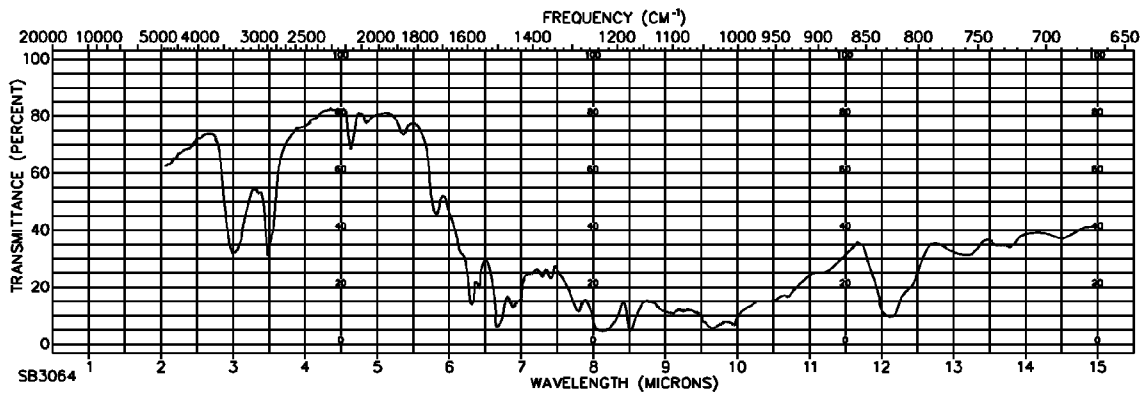
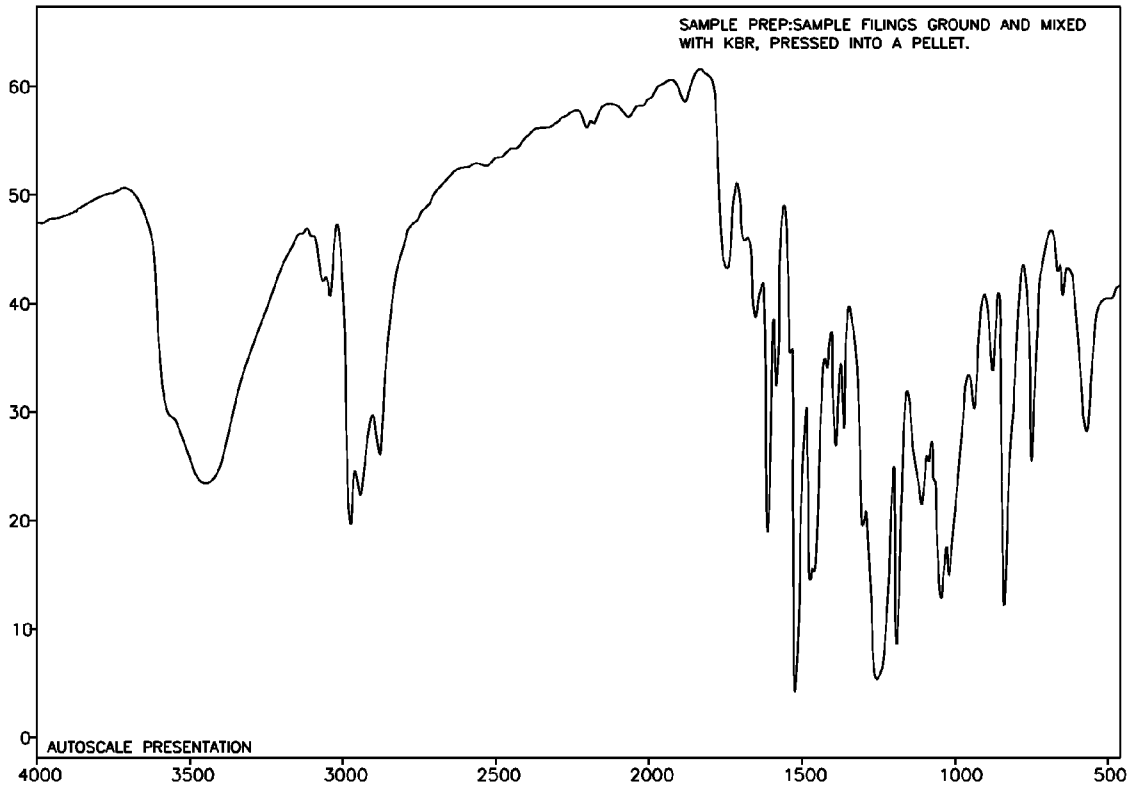


Figure 6.8

Revised Figure 6.8 effective February 7, 2004



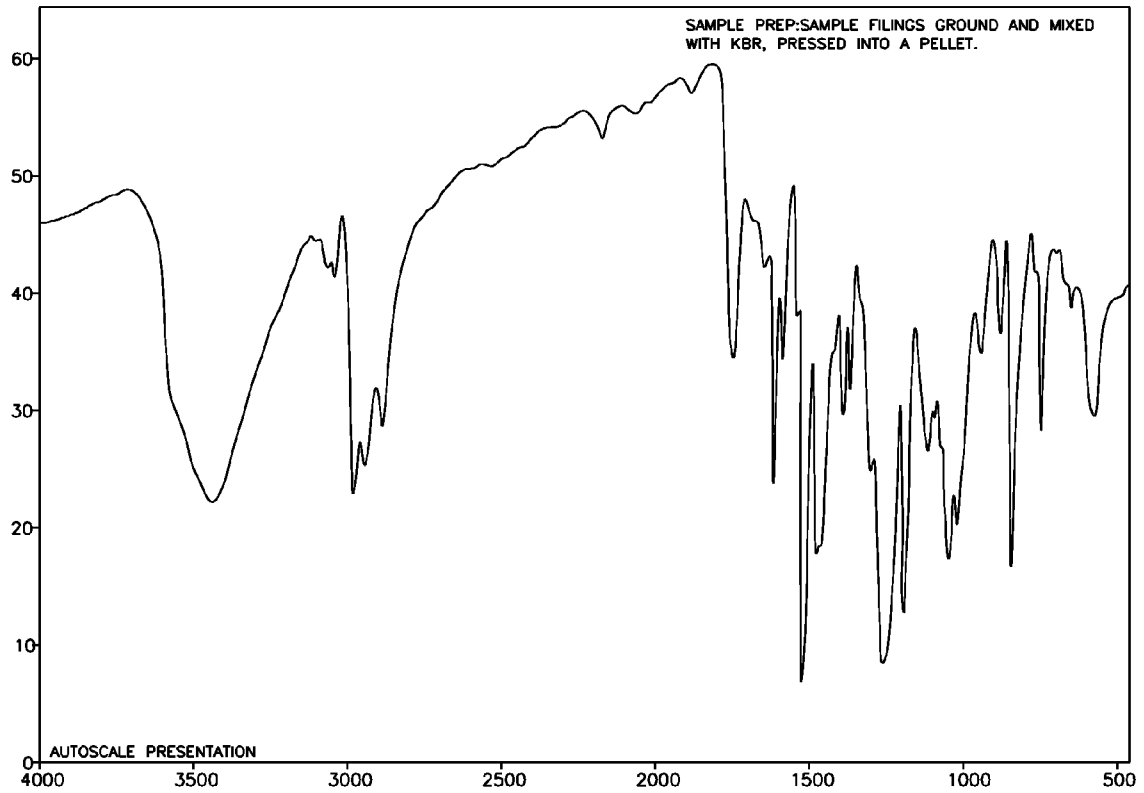
Transmittance/Wavenumber (cm-1)

File#1: NEMAO010

S5140

Figure 6.9

Revised Figure 6.9 effective February 7, 2004



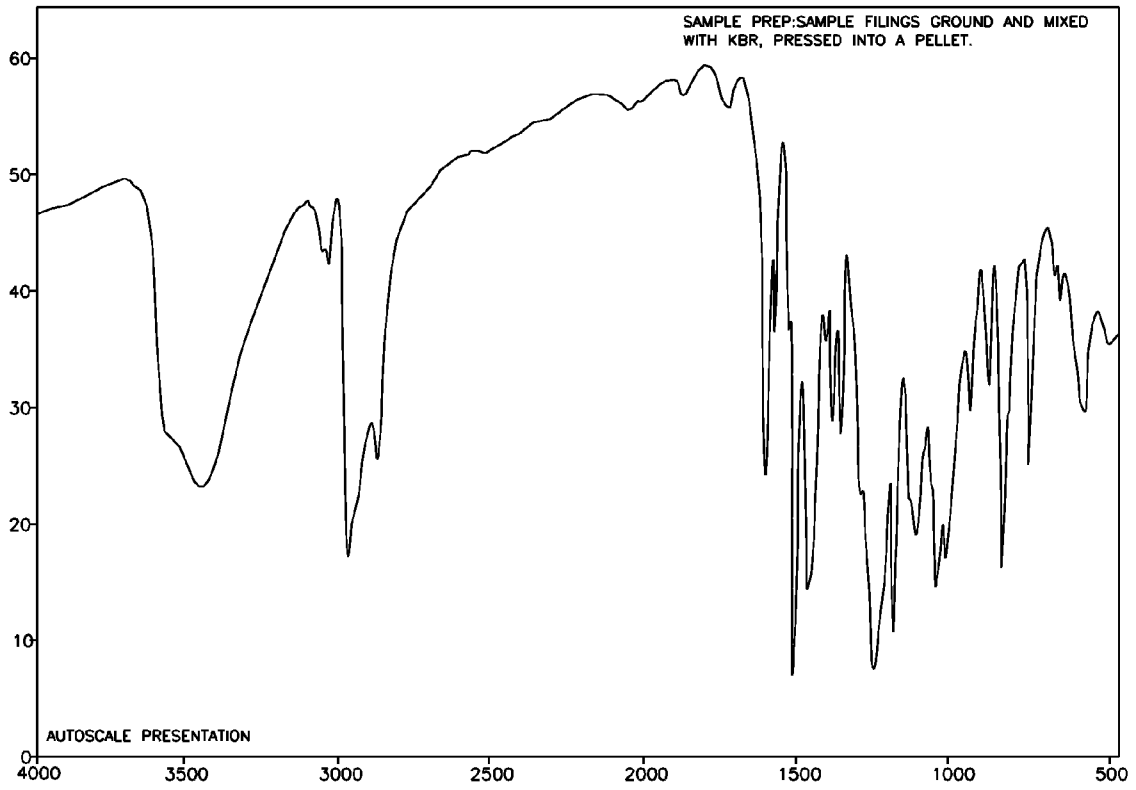
Transmittance/Wavenumber (cm-1)

File#: NEMA0011

S5141

Figure 6.10

Revised Figure 6.10 effective February 7, 2004



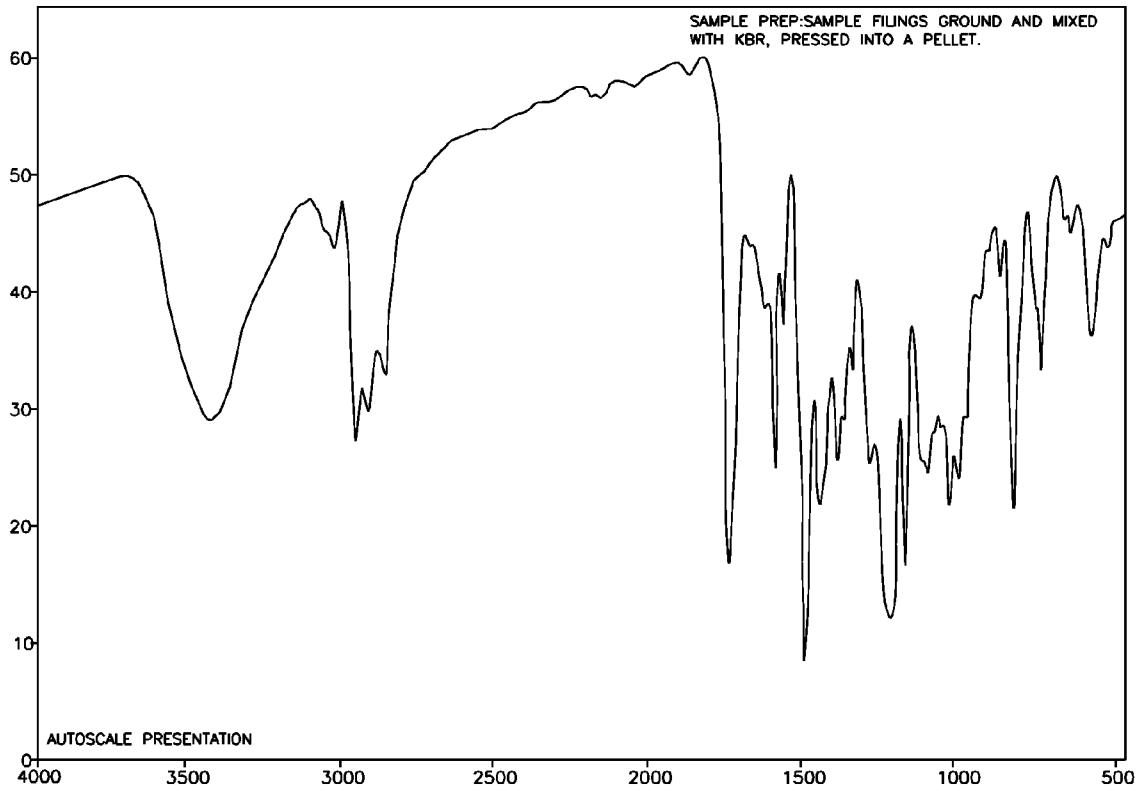
Transmittance/Wavenumber (cm-1)

File #1: NEMA0012

S5142

Figure 6.11

Revised Figure 6.11 effective February 7, 2004



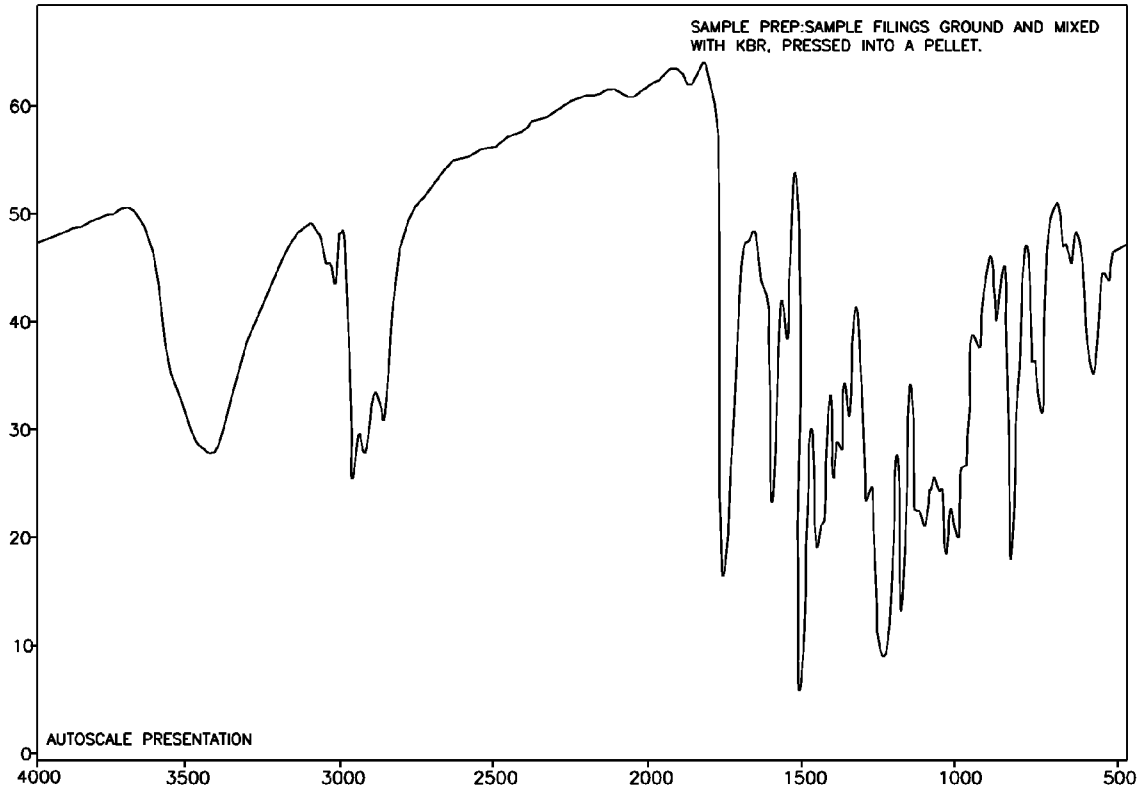
Transmittance/Wavenumber (cm-1)

File #2: NEMA0013

SS143

Figure 6.12

Revised Figure 6.12 effective February 7, 2004



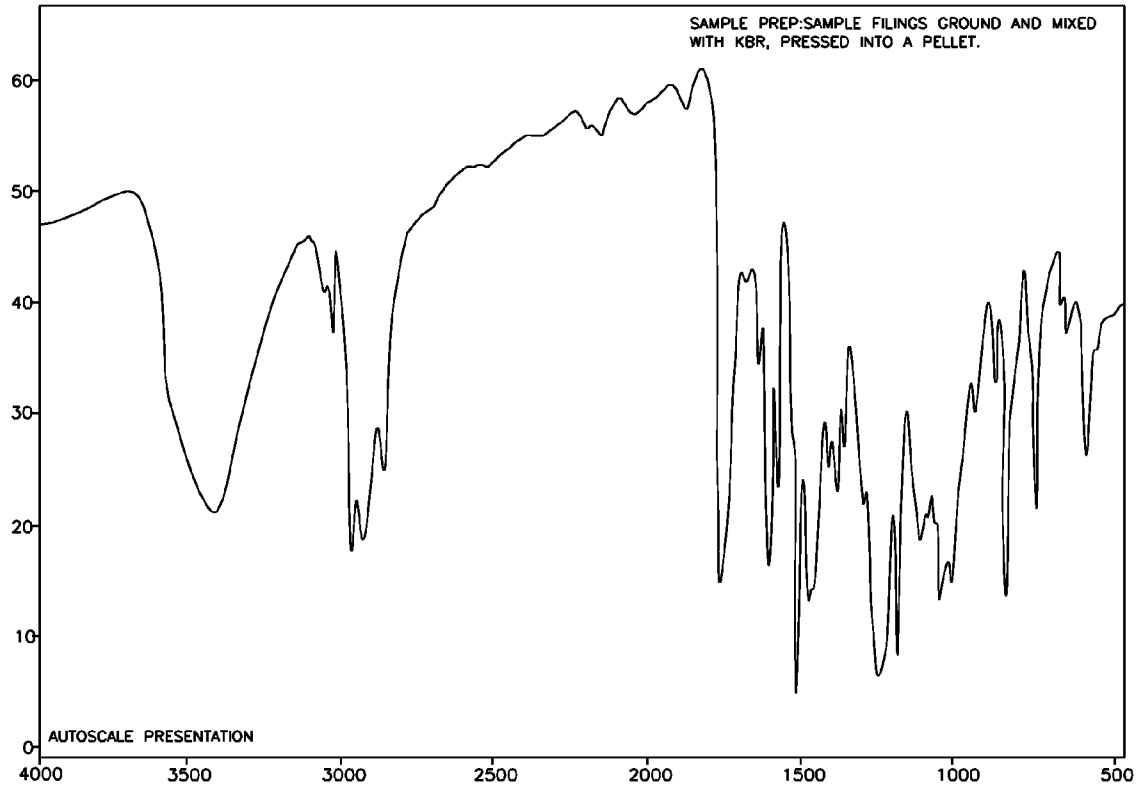
Transmittance/Wavenumber (cm-1)

File #1: NEMA0014

S5144

Figure 6.13

Revised Figure 6.13 effective February 7, 2004



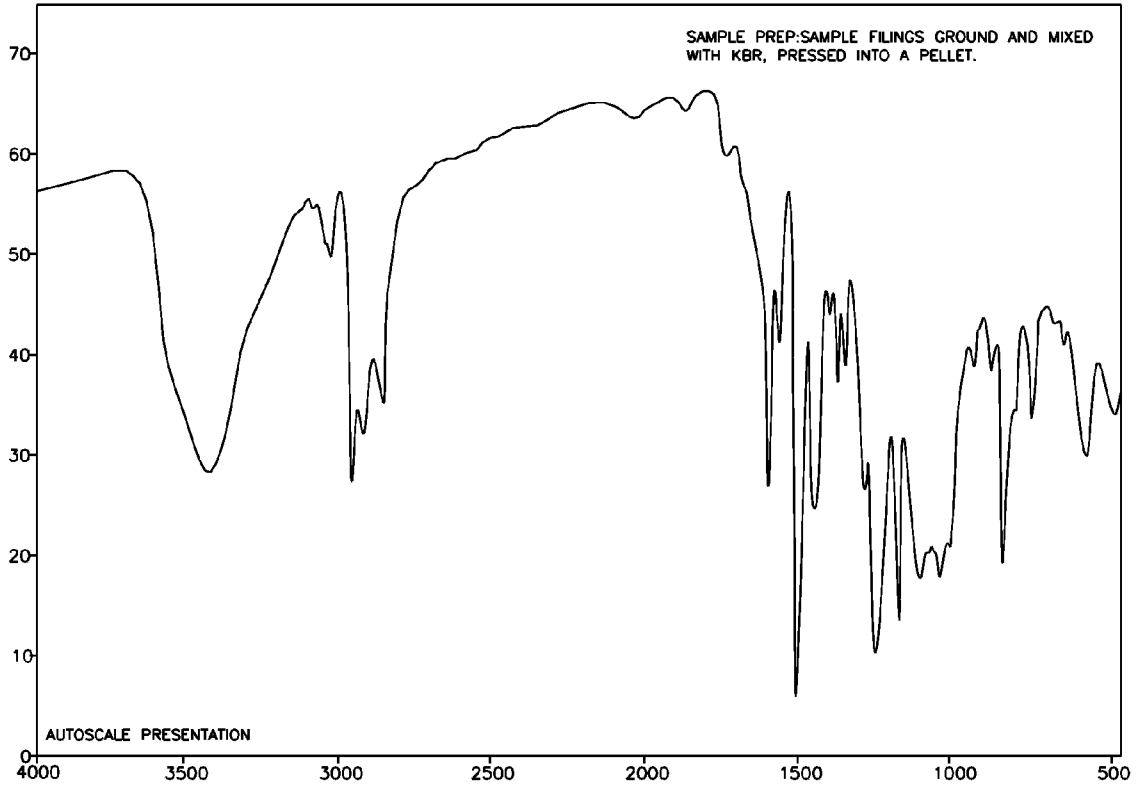
Transmittance/Wavenumber (cm-1)

File #1: NEMAO017

S5145

Figure 6.14

Revised Figure 6.14 effective February 7, 2004



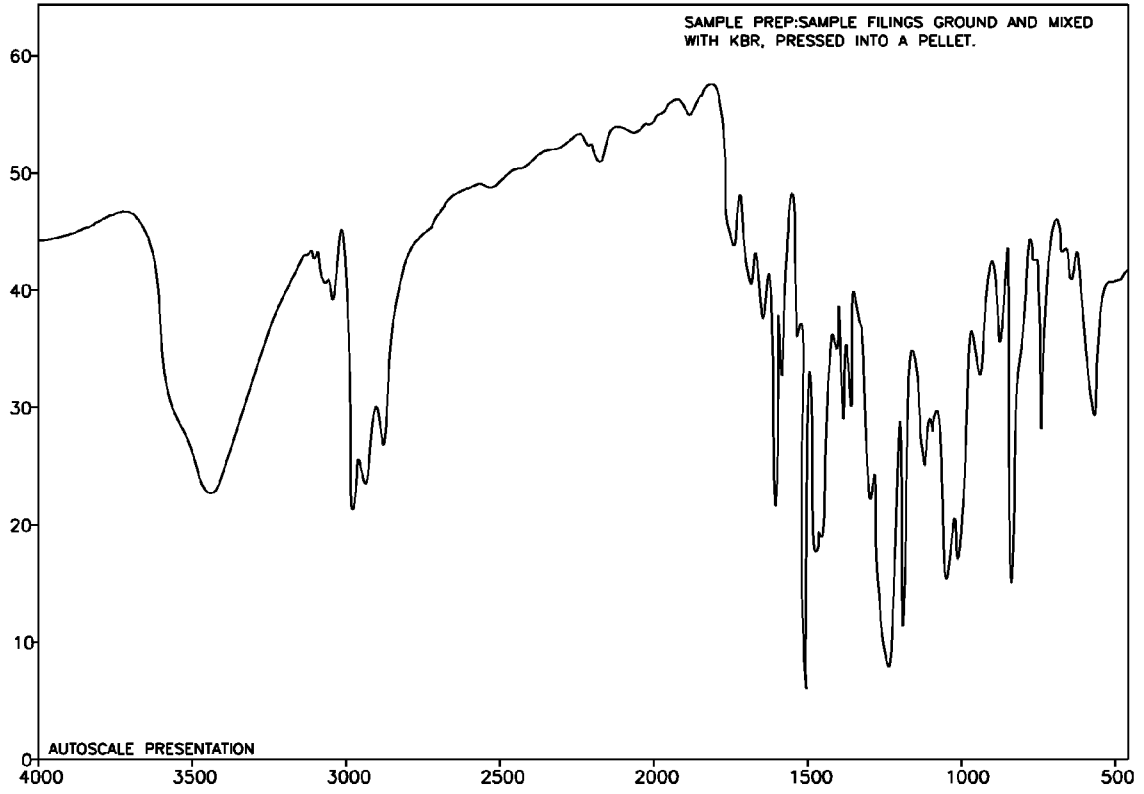
Transmittance/Wavenumber (cm-1)

File #1: NEMA0018

S5146

Figure 6.15

Revised Figure 6.15 effective February 7, 2004



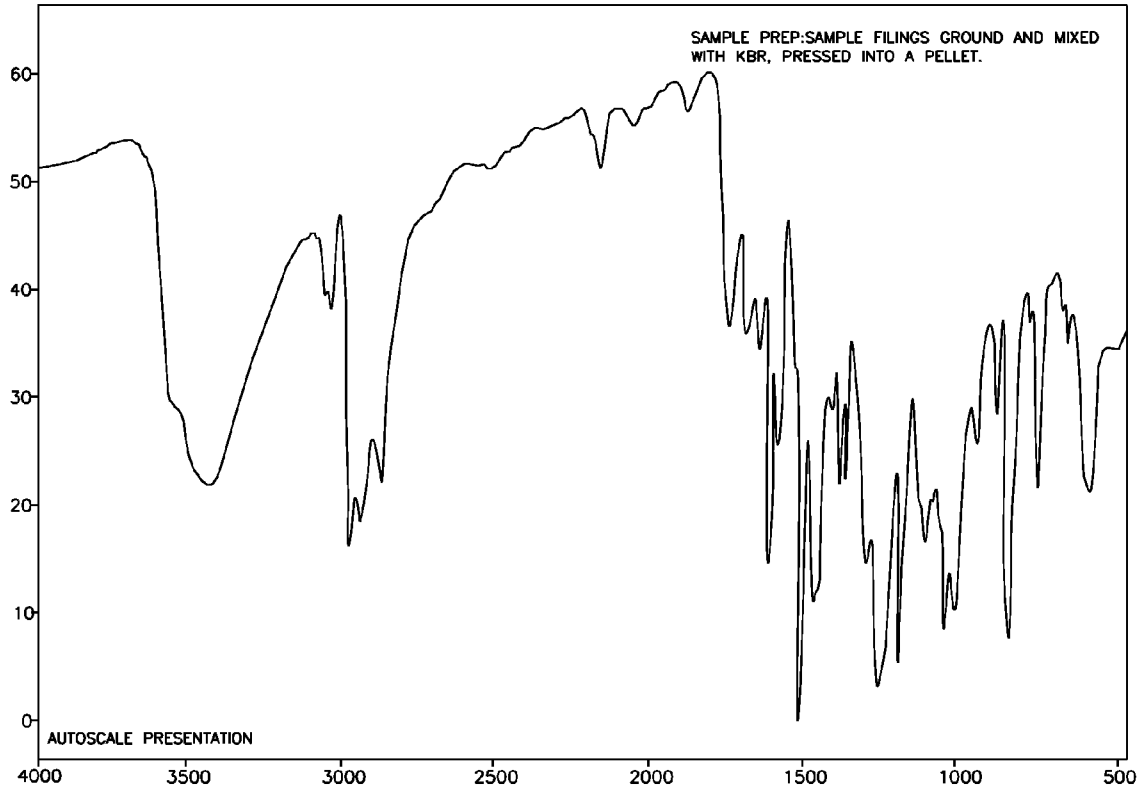
Transmittance/Wavenumber (cm-1)

File #2: NEMO0021

55147

Figure 6.16

Revised Figure 6.16 effective February 7, 2004



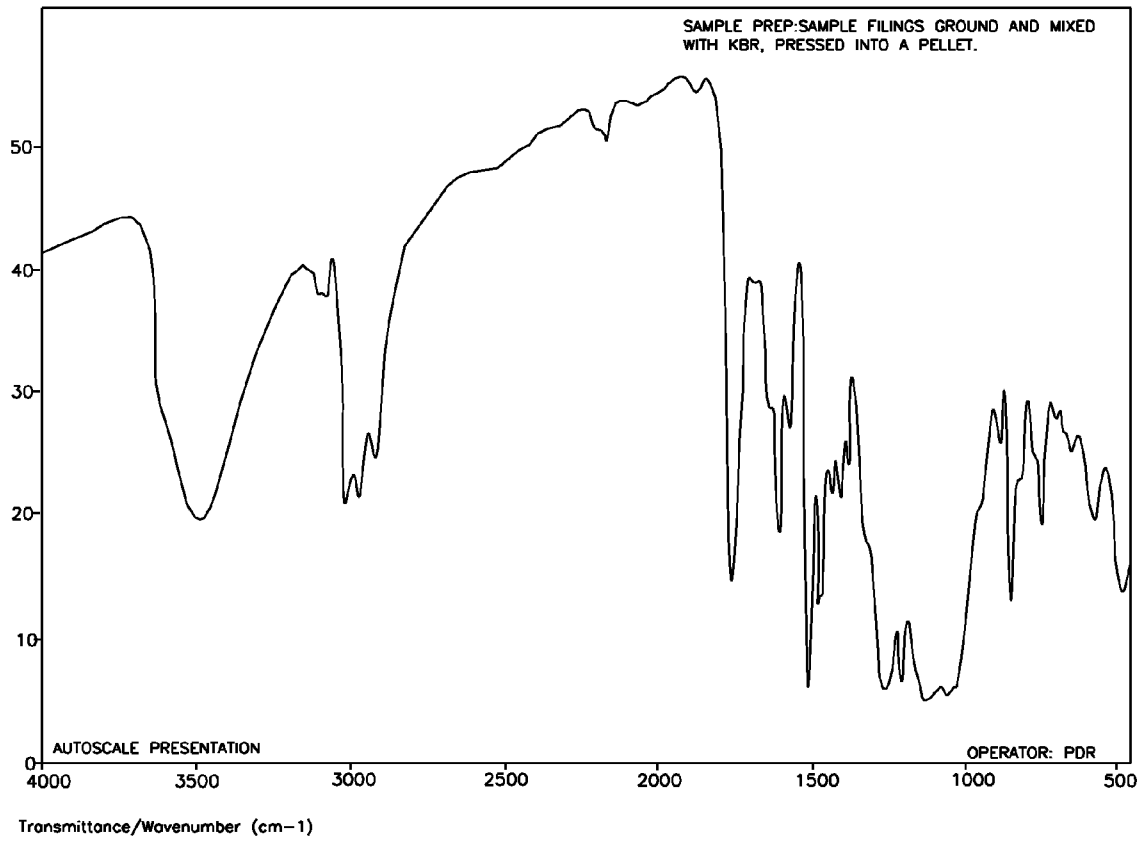
Transmittance/Wavenumber (cm-1)

File #1: NEMA0026

S5148

Figure 6.17

Revised Figure 6.17 effective February 7, 2004

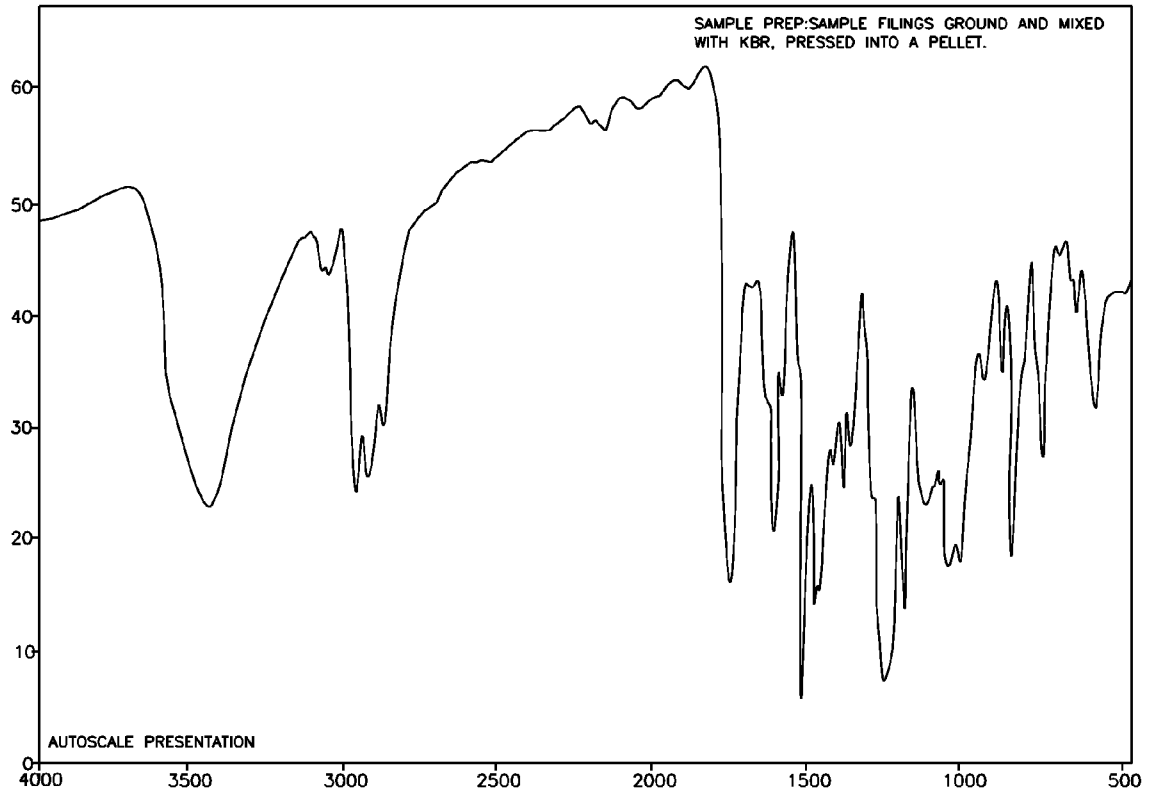


File#1: NEMA0028

S5149

Figure 6.18

Added Figure 6.18 effective February 7, 2004



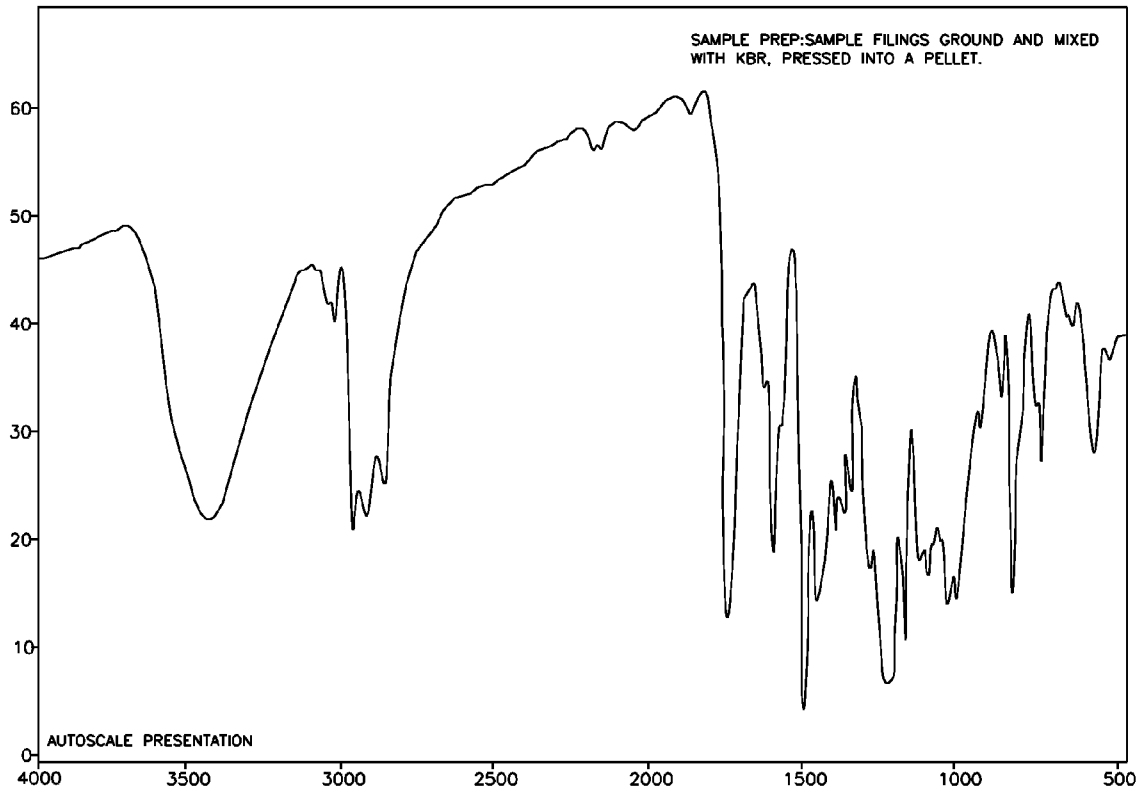
Transmittance/Wavenumber (cm-1)

File #1: NEMA0030

S5150

Figure 6.19

Added Figure 6.19 effective February 7, 2004



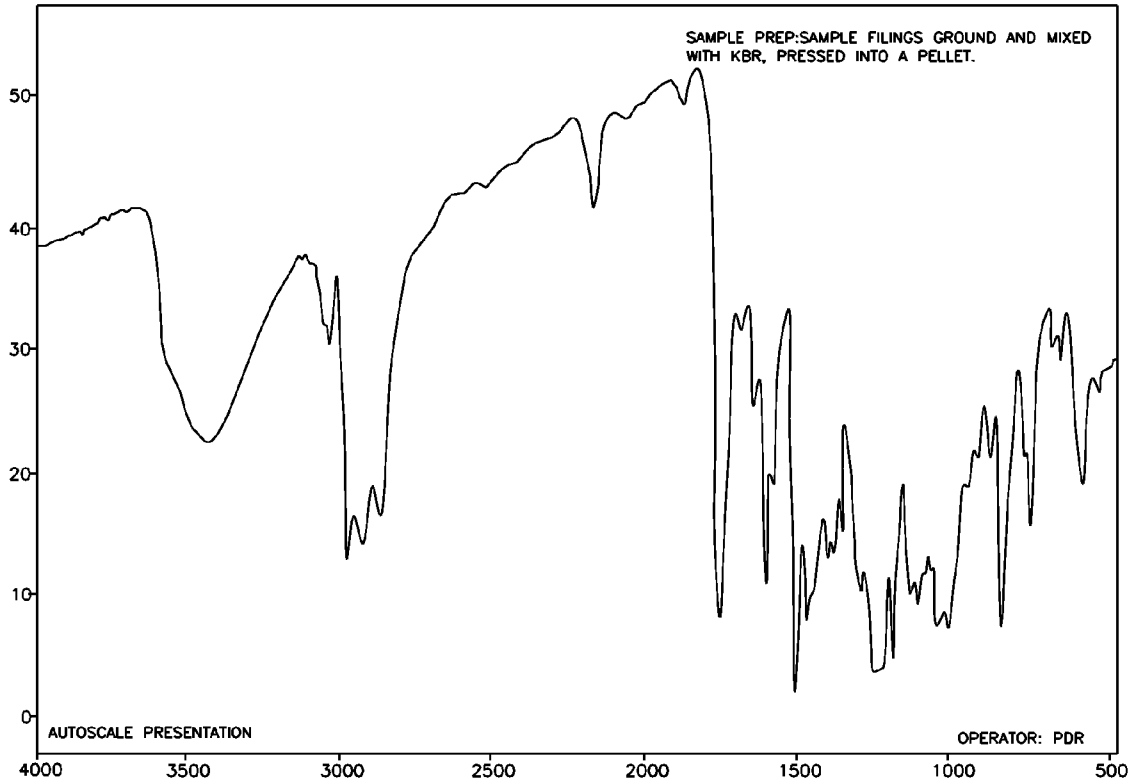
Transmittance/Wavenumber (cm-1)

File #2: NEMA0031

S5151

Figure 6.20

Added Figure 6.20 effective February 7, 2004



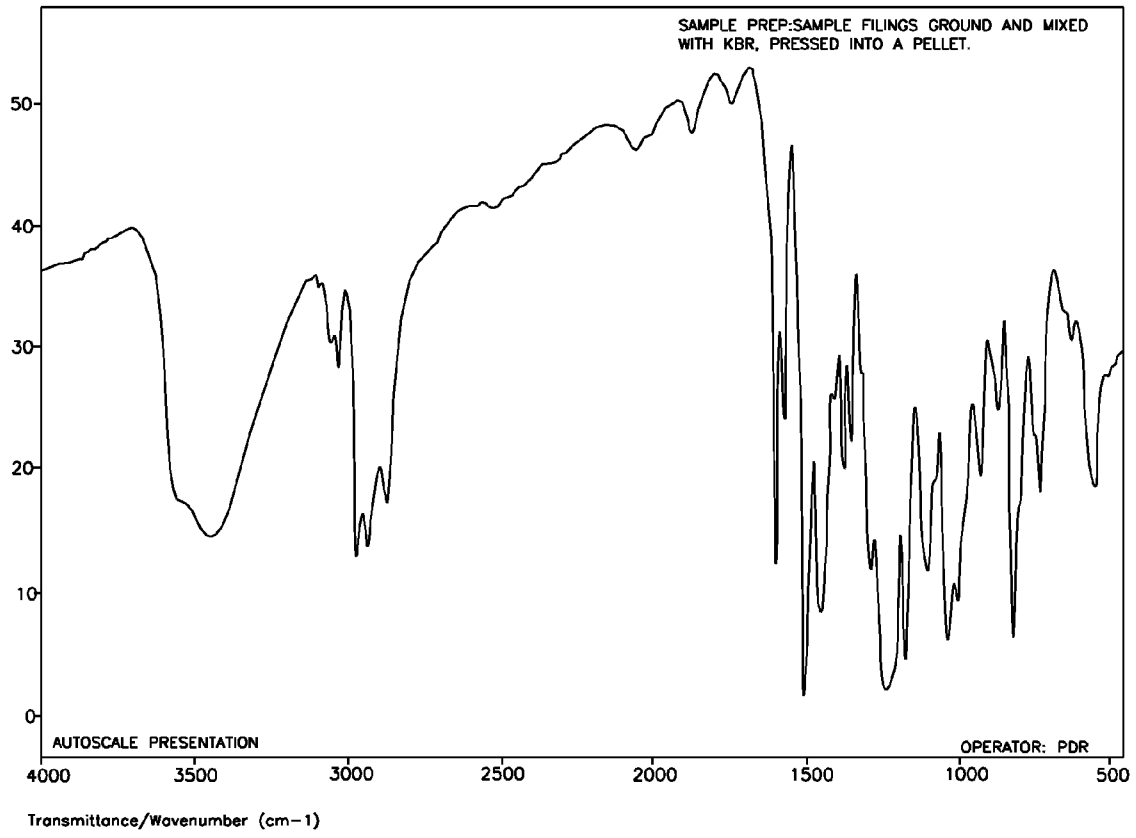
Transmittance/Wavenumber (cm-1)

File #3: NEMA0038

SS152

Figure 6.21

Added Figure 6.21 effective February 7, 2004



File# 1: NEMAD044

S5153

Figure 6.22
Typical IR spectrum for industrial laminates UL/ANSI Types G-11 and FR-5

Added Figure 6.22 relocated from 6.8 effective February 7, 2004

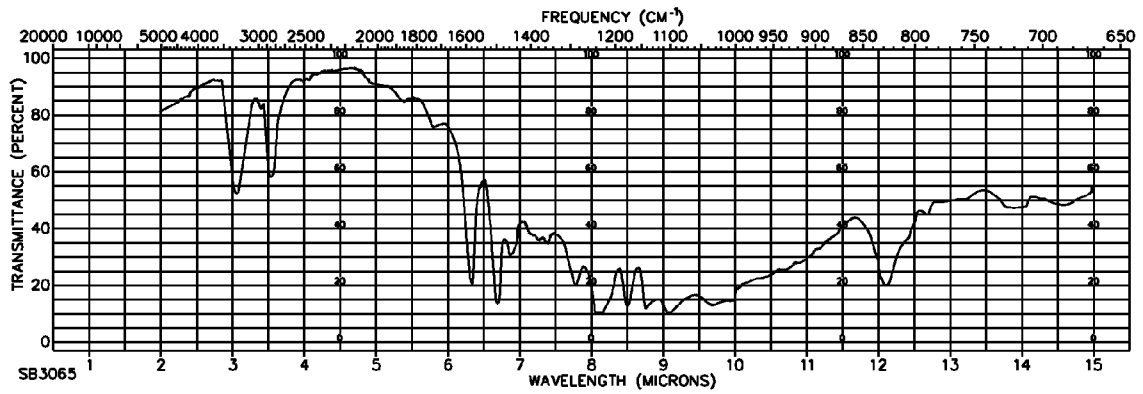


Figure 6.23
Typical IR spectrum for industrial laminates UL/ANSI Type FR-2

Added Figure 6.23 relocated from 6.9 effective February 7, 2004

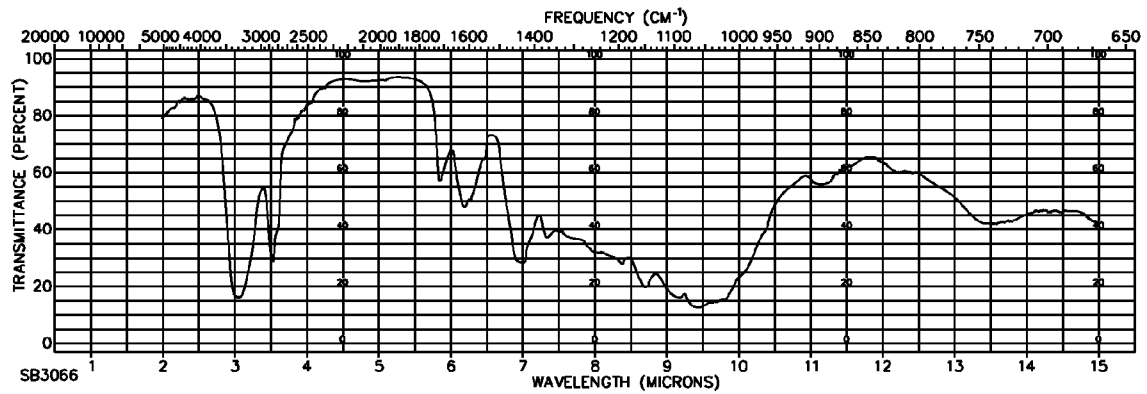


Figure 6.24
Typical IR spectrum for industrial laminates UL/ANSI Type FR-3

Added Figure 6.24 relocated from 6.10 effective February 7, 2004

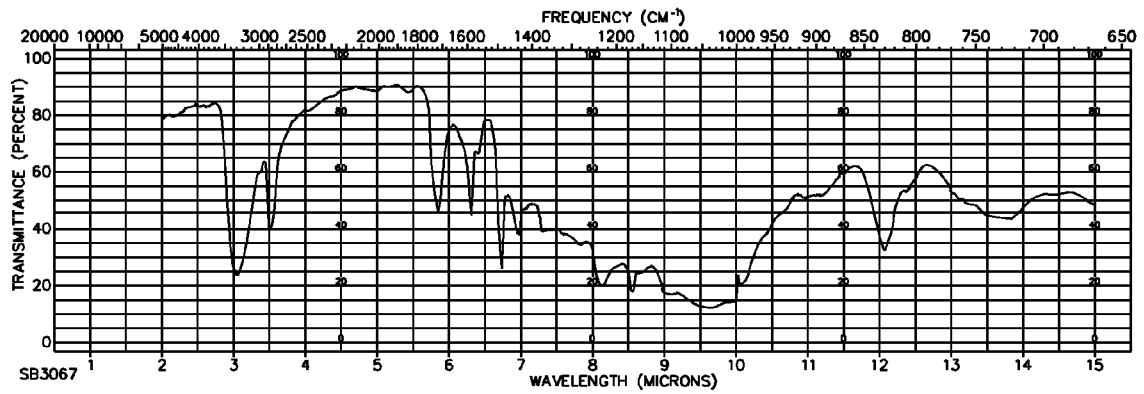


Figure 6.25
Typical IR spectrum for industrial laminates UL/ANSI Type G-3

Added Figure 6.25 relocated from 6.11 effective February 7, 2004

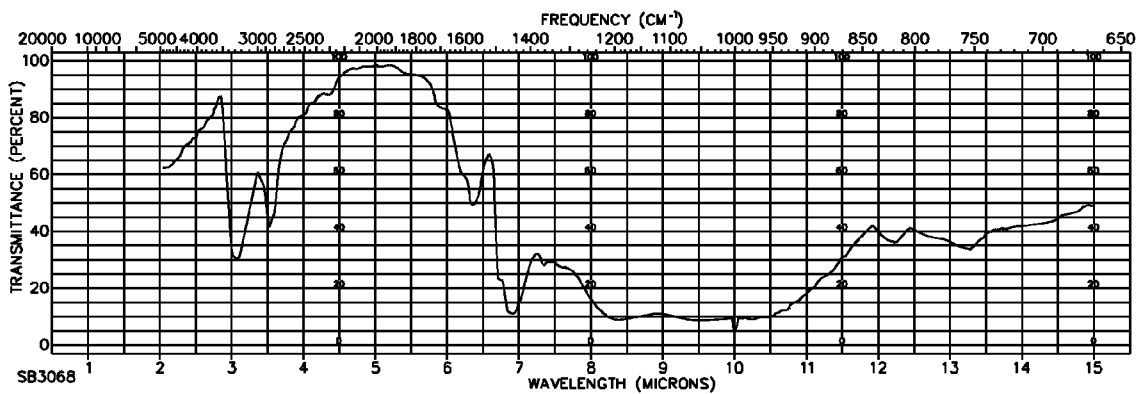


Figure 6.26
Typical IR spectrum for industrial laminates UL/ANSI Type CEM-1

Added Figure 6.26 relocated from 6.12 effective February 7, 2004

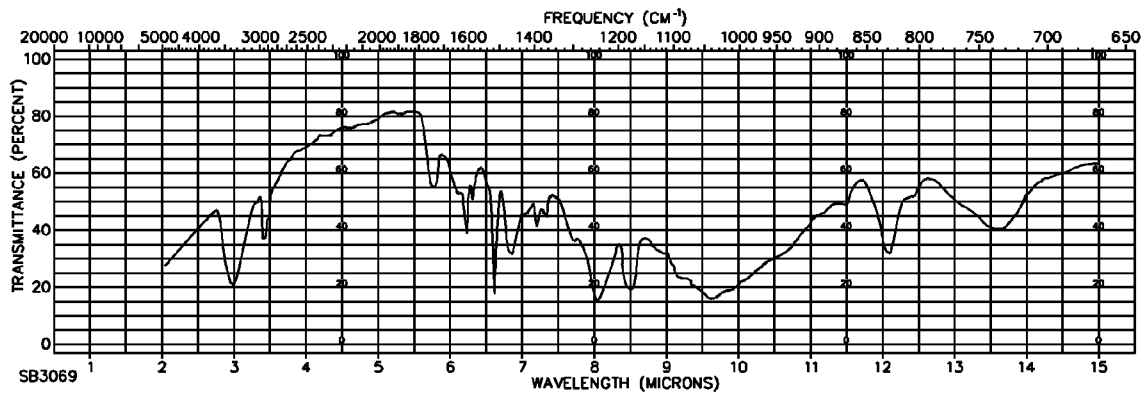


Figure 6.27
Typical IR spectrum for industrial laminates UL/ANSI Type CEM-3

Added Figure 6.27 relocated from 6.13 effective February 7, 2004

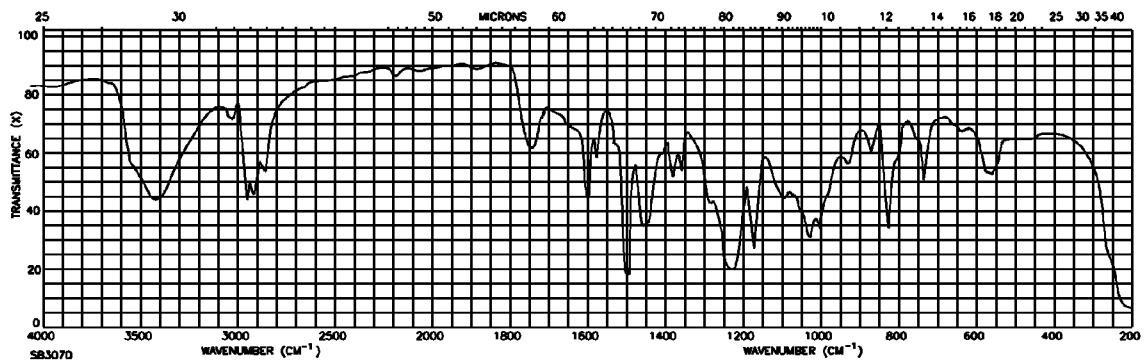


Figure 6.28
Typical IR spectrum for industrial laminates UL/ANSI Type GPO-2

Added Figure 6.28 relocated from 6.14 effective February 7, 2004

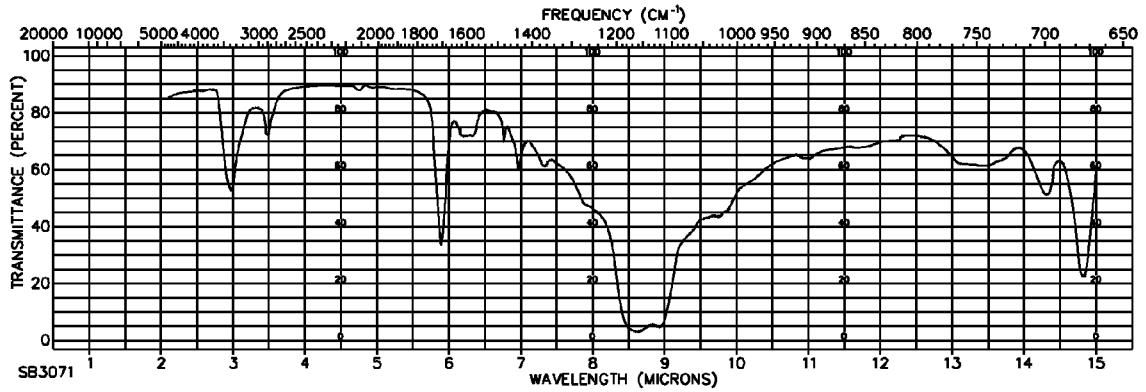


Figure 6.29
Typical IR spectrum for industrial laminates UL/ANSI Type GPO-3

Added Figure 6.29 relocated from 6.15 effective February 7, 2004

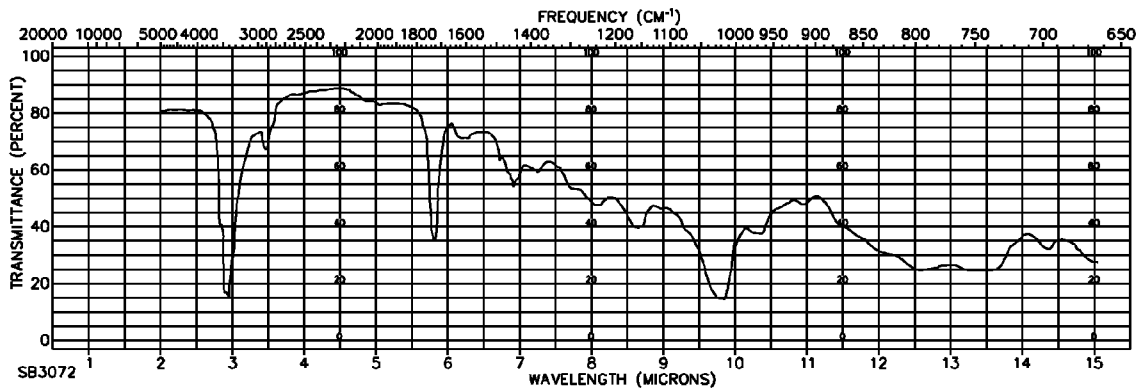


Figure 6.30
Typical IR spectrum for industrial laminates UL/ANSI Type GPY

Added Figure 6.30 relocated from 6.16 effective February 7, 2004

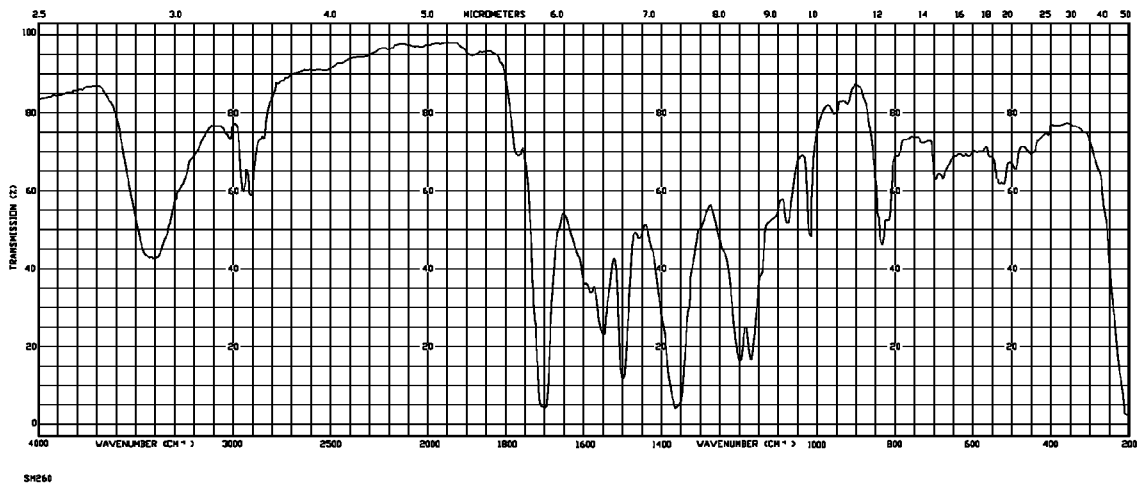
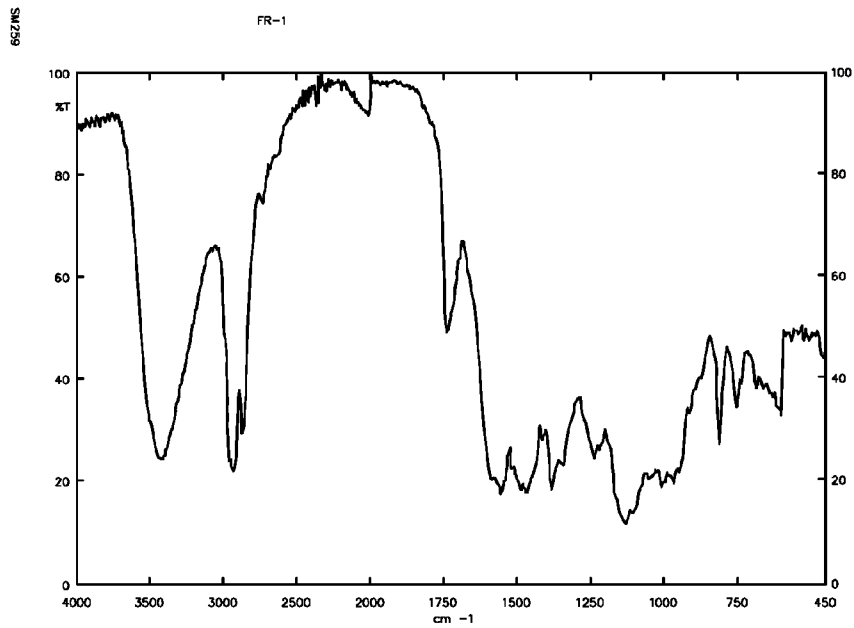


Figure 6.31
Typical IR spectrum for industrial laminates UL/ANSI Type FR-1

Added Figure 6.31 relocated from 6.17 effective February 7, 2004



7 Full Test Program

7.1 The full test program consists of determining all of the performance characteristics of the laminate material shown in Table 5.1 in conjunction with a 1, 2, or 4 point thermal aging program. The 1 or 2 point thermal aging program shall not result in the assignment of a UL/ANSI type designation if the infrared analysis or flammability classification of the material does not compare favorably with the UL/ANSI type data shown in Table 6.2 or the UL/ANSI reference spectra. Typical infrared analysis spectra of each UL/ANSI type are shown in Figures 6.1 – 6.15. The four point thermal aging program may result in the assignment of a UL/ANSI type designation when the test data, determined by the methods described in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, warrants no less than the relative thermal index of the UL/ANSI type. Additional tests are required for evaluating industrial laminates at ultrathin thicknesses, see Section 8.

7.1 revised November 28, 2001

7.2 The required profile of performance tests are shown in Table 7.1, together with the samples required for the test. Test methods shall be in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, and the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A.

Table 7.1
Rigid industrial laminate full test program and specimen requirements

Table 7.1 revised November 28, 2001

The specimens are to be in the machine (grain) direction. They are to be prepared by completely etching a metal clad sheet, where applicable.	
I Tests	
1. Short term (UL 746A)	
a) Infrared analysis ^a	
b) Flexural strength ^a	
c) Ash content (if applicable) ^a	
d) Flammability tests ^a	
e) High current arcing ignition (HAI)	
f) Hot wire ignition (HWI)	
g) Deleted	
h) High voltage arc tracking (HVTR)	
i) Dielectric strength	
j) Arc resistance in accordance with ASTM D495 (1994) ^d	
k) Comparative track index (CTI)	
l) Volume resistivity	
m) Thermogravimetric analysis (TGA) ^a	
n) Water absorption and immersion	
2. Long term thermal aging (UL 746B)	
a) 1- or 2-point thermal aging of the industrial laminate to 50 percent retention of initial flexural strength property level. (Dielectric Strength for G-7, GPO-2, and GPO-3 materials). See Table 7.2 for temperature/ time. If a control is to be used in accordance with 7.3, an industrial laminate of the same general UL/ANSI grade is to be aged and tested concurrently with the laminate.	
b) The temperature, times, and samples required for a 4-point thermal aging shall be determined in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.	
II Specimens (Does not include samples needed for a 4-point thermal aging program)	

Table 7.1 Continued on Next Page

Table 7.1 Continued

Quantity			Dimensions, mm (inch)
All grades except G-7, GPO-2, GPO-3	G-7, GPO-2, GPO-3		
35	35		100 by 100 by 3.2 (4 by 4 by 0.125) ^e
60	60		125 by 13 by 1.6 (5 by 0.5 by 0.062)
40 ^{a,b}			100 by 25 by 1.6 (4 by 1 by 0.062)
10	60 ^c		100 by 100 by 0.8 (4 by 4 by 0.031)
10	40 ^b		100 by 100 by 1.6 (4 by 4 by 0.062)
60 ^c			100 by 25 by 1.6 (4 by 1 by 0.062)
60	60		125 by 13 by 0.8 (5 by 0.5 by 0.031)

^a Not required if previously determined under the abbreviated program described in Section 5, General.
^b Includes 1- point thermal aging program samples.
^c Includes 2- point thermal aging program samples.
^d Standard Test Method For High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation.
^e Samples provided in the 1.6 mm (0.062 inch) thickness may be built up to a thickness of 3.2 mm (0.125 inch).

Table 7.2
1 and 2 temperature point thermal aging program

Table 7.2 revised February 7, 2001

UL/ANSI type	Aging temperature, °C	Aging time (hours)			
X, XP, XPC	180	480	640	800	960
	170	870	1160	1450	1740
XX, XXP, XXX	180	585	780	975	1170
	170	1200	1600	2000	2400
XXXP, XXXPC	180	465	620	775	930
	170	720	960	1200	1440
C, CE, L, LE	170	420	560	700	840
	160	720	960	1200	1440
G-3	230	390	520	650	780
	210	1050	1400	1750	2100
G-5, G-9	170	250	335	420	505
	160	960	1280	1600	1920
G-7	230	300	400	500	600
	210	900	1200	1500	1800
FR-1	180	480	640	800	960
	170	900	1200	1500	1800
FR-2	180	370	495	620	745
	160	765	1020	1275	1530
FR-3	160	480	640	800	960
	150	780	1040	1300	1560
FR-4, G10	180	300	400	500	600
	170	630	840	1050	1260
FR-5, G11	210	450	600	750	900
	200	1080	1440	1800	2160
CEM-1	190	800	1040	1300	1560
	180	1500	2000	2500	3000
CEM-3	180	660	800	1100	1320

Table 7.2 Continued on Next Page

Table 7.2 Continued

UL/ANSI type	Aging temperature, °C	Aging time (hours)			
GPO-2	170	1260	1680	2100	2520
	170	300	400	500	600
	160	600	800	1000	1200
GPO-3	145	210	280	350	420
	135	900	1200	1500	1800
GPY	225	1230	1640	2050	2460
	210	2040	2720	3400	4080

7.3 Thermal aging tests for the 1 or 2 point thermal aging procedure are to be conducted at the elevated temperatures and times shown in Table 7.2. The dielectric strength property shall be used as the test characteristic for material UL/ANSI grades G-7, GPO-2, and GPO-3. The flexural strength property shall be used as the tested characteristic for all UL/ANSI grades. Test procedures are described in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B. A control (an industrial laminate of the same generic UL/ANSI grade) may be provided for comparison purposes of the 1 or 2 point thermal aging procedure.

7.3 revised November 28, 2001

7.3.1 The last column of Table 7.2 indicates the times at which samples should be tested throughout a 1- or 2- point thermal aging investigation. If degradation is $\geq 50\%$ at the third time indicated in the last column of Table 7.2 (in bold print style), aging at the applicable temperature can be stopped. The candidate material can then be considered equivalent to the control material at that temperature and shall be assigned the same relative thermal indices of the control material. If degradation is $< 50\%$ at this time, aging shall continue to the last time indicated in the table and then stopped. The methods of comparison described in 7.4 - 7.8 shall be applied in order to determine the relative thermal indices for the candidate material.

7.3.1 revised November 28, 2001

7.4 A comparison of the results of aging of the candidate material and control material at one point thermal aging procedure is to be conducted. Both the candidate material and the control material are assumed to have the same activation energy of degradation as the desired UL/ANSI type, i.e., the lifelines generated for both the candidate and control materials are assumed to have the same slope as the lifeline of the requested UL/ANSI type. If the extrapolated relative thermal index of the candidate material is more than 5°C (9°F) below the relative thermal index of the UL/ANSI type, the material shall not be assigned a relative thermal index unless aging tests are conducted at one additional temperature. See 7.5 for the 2 point thermal aging data evaluation procedure.

7.4 revised November 28, 2001

7.5 If the extrapolated relative thermal index of the candidate material is less than 5°C (9°F) below the relative thermal index of the requested UL/ANSI type, the candidate material shall be assigned the same relative thermal index as that determined for the UL/ANSI type. If the extrapolation results in a relative thermal index that is more than 5°C (9°F) below the UL/ANSI type's relative thermal index, the candidate material shall be assigned the relative thermal index determined by the comparison. This relative thermal index shall be assigned for both mechanical and electrical characteristics although only one was tested. Temperatures are assigned discrete 5°C (9°F) steps to the next lowest value in accordance with the requirements for Assignment of Temperature Classifications in the Standard for Polymeric Materials - Long Term Property Evaluations, UL 746B. See 7.7 for an example.

7.5 revised November 28, 2001

7.6 Example No. 1: One point thermal aging data compared with the life curve data on a UL/ANSI type material.

Temperature (C)	UL/ANSI ^a XXXPC laminate	Hours to reach 50% flexural property retention
		Tested laminate
180	650	500
160	2200	—
150	2700	—
130	9000	—

^a Data used is obtained from Figure 7.6.
 $A = 1/1.34738 \times 10^6$ $\log A = 6.12949$
 $B = 9363.64$ $B(\log e) = 4066.573$

Using the procedure in UL 746B for Analysis and Evaluation, linear regression analysis on the base materials data, results in the relationship: $\log(\text{life}) = [4066.573/(C + 273.16)] + (-6.12949)$. A relative thermal index of 125°C is assigned to the UL/ANSI type XXXPC material, that corresponds to a 12,132 hour correlation time (life) and a value of $\log A = -6.12949$.

It is to be assumed that the slope of the tested material's life curve is identical to the curve slope of the UL/ANSI type materials, and that the equations differ only in the value of the ordinate intercept. The equation for the material can be found by substituting the known temperature data and the time as follows: $\log(500) = [4066.573/(180 + 273.16)] + \log A$, thus $\log A = -6.27484$.

Hence, the relationship between time and temperature for the material is given by: $\log(\text{life}) = [4066.573/(C + 273.16)] - 6.27484$.

At the UL/ANSI type's correlation time, the tested material's relative thermal index is given by: $\log(12132) = [4066.573/(C + 273.16)] - 6.27484$, which can be calculated as 119.4°C (246.9°F). This value is not within the 5°C differential indicated in 7.8 and the material is not eligible for a relative thermal index rating of the same value as the UL/ANSI type material, unless acceptable results are obtained from additional temperature point tests.

7.6 revised November 28, 2001

7.7 Example No. 2: Two point thermal aging data compared with the life curve on a UL/ANSI type material.

Assume that additional data at 170°C results in a material life of 800 hours, that is:

$$T_1 = 180^\circ\text{C}, \text{Life}_1 = 500 \text{ hours}, T_2 = 170^\circ\text{C}, \text{Life}_2 = 800 \text{ hours}$$

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

$$\bar{X} = \frac{(X_1 + X_2)}{2}$$

$$\bar{Y} = \frac{(Y_1 + Y_2)}{2}$$

$$\bar{X} = \frac{(1/T_1 + 1/T_2)}{2}$$

$$\bar{Y} = \frac{\log(\text{life}_1) + \log(\text{life}_2)}{2}$$

$$\bar{X} = \frac{[(180 + 273.16) + (170 + 273.16)]}{2(180 + 273.16)(170 + 273.16)}$$

$$\bar{Y} = \frac{\log [(500)(800)]}{2}$$

$$\bar{X} = 1/448.1042$$

$$\bar{Y} = 2.80103$$

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

$$2.80103 = [4066.573/448.1042] + \log A_1$$

$$\log A_1 = -6.27403$$

Hence, the time and temperature relationship for the material is given by: $\log(\text{life}) = [4066.573/(C + 273.16)] - 6.27403$.

At the UL/ANSI type's correlation time, the material's relative thermal index is given by:

$$\log(12132) = [4066.573/(C + 273.16)] - 6.27403$$

which can be calculated as 119.4°C (246.9°F). Using the procedure in 7.5, the material is to be assigned a 10°C (18°F) reduced relative thermal index of 115°C (239°F) from 125°C (257°F) for the property tested (Mechanical-Flexural Strength) and a corresponding 10°C reduced index of the property (Electrical-Dielectric Strength) not tested to 115°C based upon the electrical/mechanical values shown in Table 5.2.

7.7 revised November 28, 2001

7.8 If the evaluation of thermal aging test data for the material requires assignment of a lower temperature than those values shown in Table 5.2 for the UL/ANSI type, the material shall not be assigned a UL/ANSI type designation.

7.9 When a 4 point thermal aging is performed on a material similar to an existing UL/ANSI grade, the test program, samples, methods, data analysis, and evaluation shall be as described in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B. The primary property to be tested shall be dielectric strength for UL/ANSI grades G7, GPO-2, and GPO-3. Flexural strength and dielectric strength shall be the primary test property for all other UL/ANSI grades. Secondary properties would be comprised of dielectric strength (where not used as a primary property) and flammability. If the resulting thermal index permits assignment of the same values as shown in Table 5.2 then the material shall be assigned the appropriate UL/ANSI grade designation.

7.10 If the composition of the material as determined by Infrared Analysis does not compare favorably with any existing UL/ANSI type, then both dielectric strength and flexural strength shall be used as primary properties for testing, plus other secondary properties mentioned in 7.9.

Exception: If the comparison of the material to a generic PTFE resin as determined by IR analysis compares favorably, then the thermal aging program may be waived and an electrical and mechanical thermal index of 105°C may be granted. The PTFE resin can contain inert fillers (i.e., the filler is not chemically reactive with the PTFE resin and does not contribute to the overall flammability) and/or glass reinforcement. The appropriate indexing tests as described in Table 7.1 must be performed at the minimum and maximum laminate thickness. If an electrical and mechanical thermal index higher than 105°C is required, then a 4-point thermal aging program must be performed as described 7.10.

Revised 7.10 effective February 7, 2004

7.11 An industrial laminate having an established electrical thermal index and acceptable performance profile characteristics as described in Table 7.3 meets the Direct Support Requirements and may provide direct support of current carrying parts at 120V rms or less and 15A or less.

7.11 revised November 28, 2001

Table 7.3
Performance level categories (PLC) of industrial laminates used as the base material of printed-wiring boards that provide direct support of current-carrying parts

Table 7.3 revised November 28, 2001

Test ^c	Units or PLC	V-0, V-1, V-2, HB, VTM-0 ^f , VTM-1 ^f , VTM-2 ^f	Thickness mm (inch) ^d
High current arc ignition	Max PLC	3	Actual ^a
Hot wire ignition	Max PLC	4	Actual ^a
Volume resistivity— dry	Min ohm-cm	50	1.6 ^e (0.062)
Volume resistivity – wet	x10 ⁶	10	1.6 ^e (0.062)
Dielectric strength – dry	Min k Volts	6.89	1.6 ^e (0.062)
Dielectric strength— wet	per mm	6.89	1.6 ^e (0.062)
Comparative tracking index	Max PLC	4	3.2 ^e (0.125)
Heat deflection	Degrees C	b	3.2 ^e (0.125)

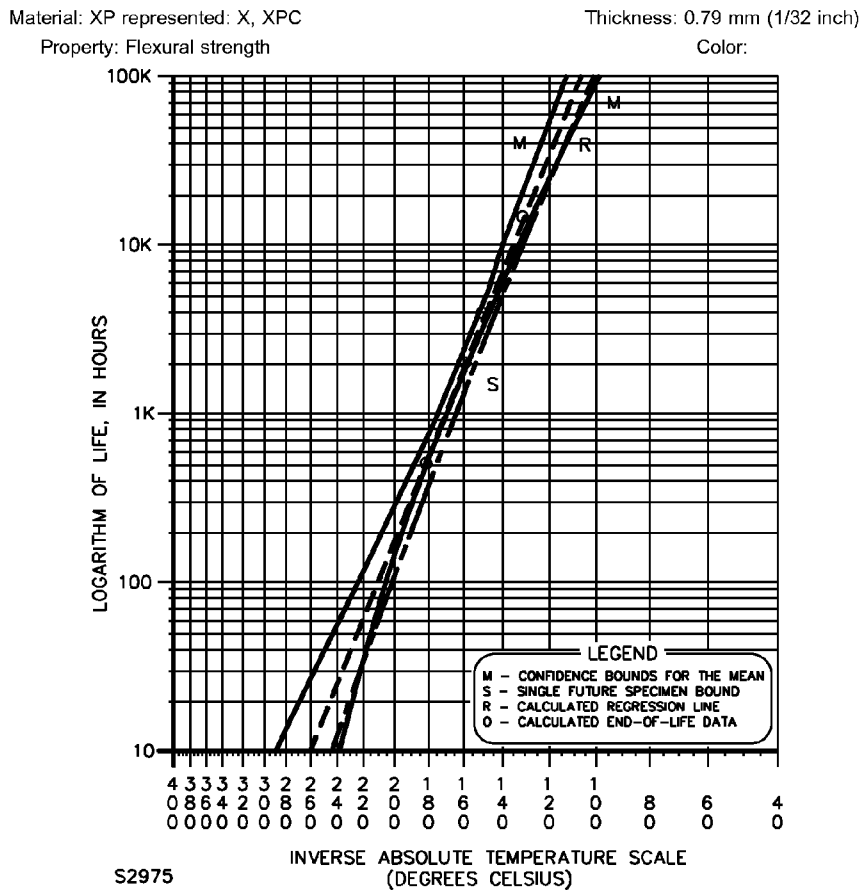
^a Actual thickness or minimum thickness of group being considered.
^b Not required for thermosets and films; for thermoplastics, at least 10°C above rated operating temperature with 90°C minimum value.
^c Testing is to be as described in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A.
^d Test sample thickness on which the index value is based.

Table 7.3 Continued on Next Page

Table 7.3 Continued

Test ^e	Units or PLC	V-0, V-1, V-2, HB, VTM-0 ^f , VTM-1 ^f , VTM-2 ^f	Thickness mm (inch) ^d
^e Test sample representative of all thicknesses. ^f VTM-0, VTM-1, VTM-2 ratings apply only to etched films.			

Figure 7.1
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
130	14000
150	3600
160	2000
180	500

Correlation coefficient K = 0.9988
 The arrehenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.743299 \times 10^0;$$

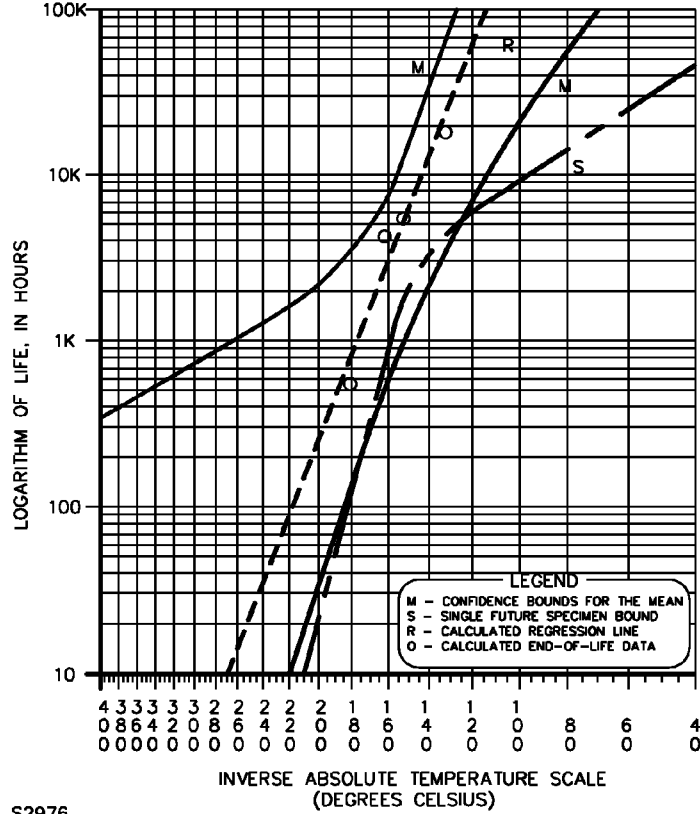
$$B = 12101.4$$

Where L is in hours and T is in degrees celsius

Figure 7.2
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: XP represented: X, XPC
 Property: Flexural strength

Thickness: 1.59 mm (1/16 inch)
 Color:



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
130	17000
150	5000
160	4000
180	520

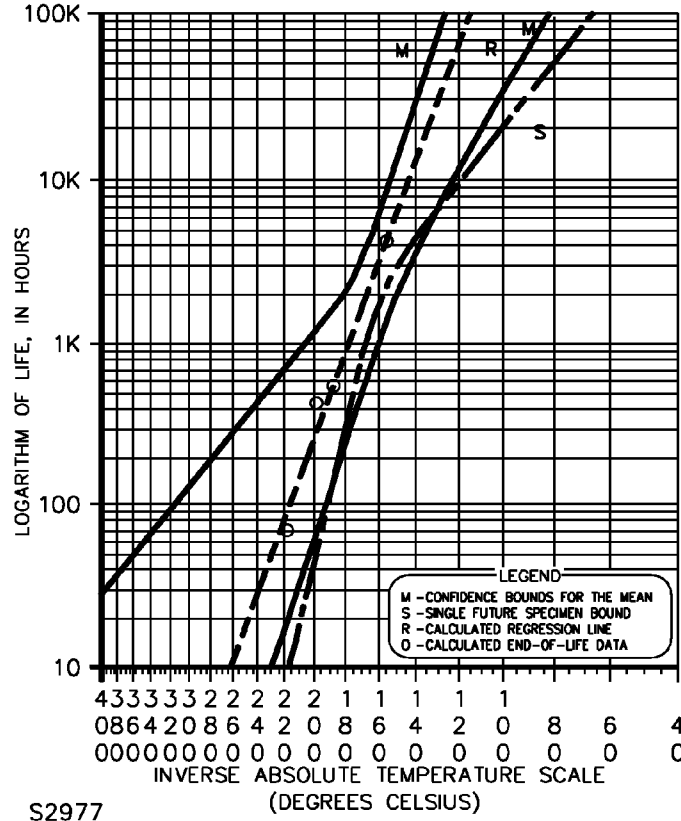
Correlation coefficient K = 0.9709
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.88902 \times 10^9;$
 $B = 12312.5$

Where L is in hours and T is in degrees celsius

Figure 7.3
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: XX Represented: XXX, XXP Thickness: 0.79 mm (1/32 inch)
 Property: Flexural strength Color:



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
130	17000
150	4200
160	3300
180	560

Correlation coefficient K = 0.9853
 The arrehenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

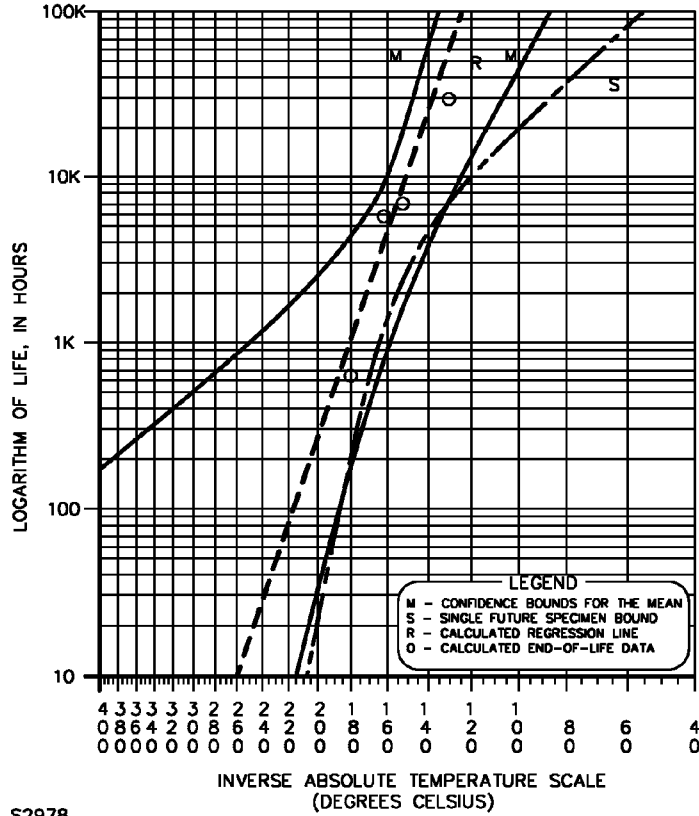
$$A = 1/0.593717 \times 10^9;$$

$$B = 12108.2$$

Where L is in hours and T is in degrees celsius

Figure 7.4
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: XX represented: XXX, XXP
 Property: Flexural strength
 Thickness: 1.59 mm (1/16 inch)
 Color:



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
130	33000
150	6800
160	6000
180	640

Correlation coefficient K = 0.9743
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.222833 \times 10^{11};$

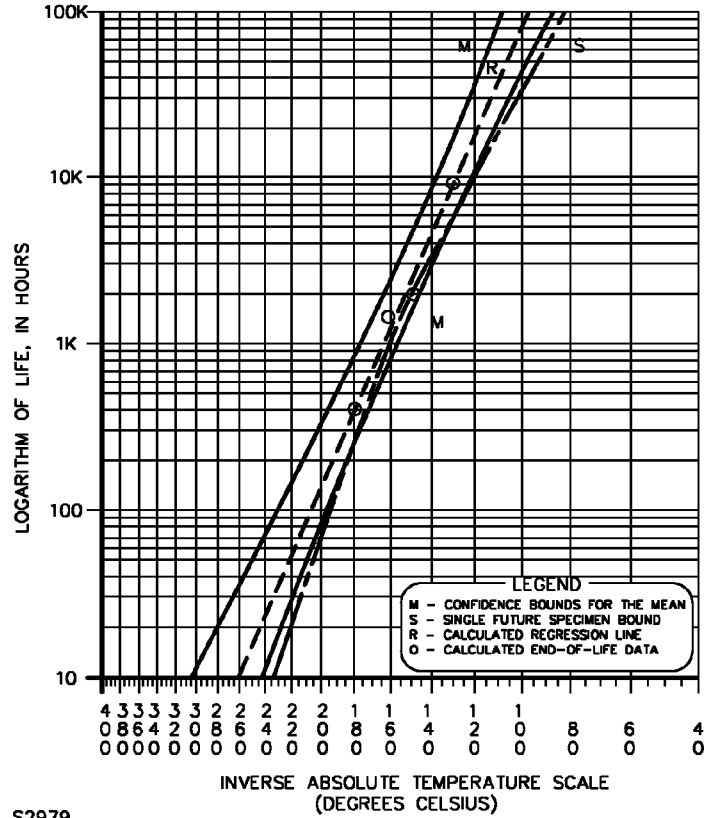
$B = 13858.3$

Where L is in hours and T is in degrees celsius

Figure 7.5
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: XXXPC represented: XXXP
 Property: Flexural strength

Thickness: 0.79 mm (1/32 inch)
 Color:



S2979

End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
130	8500
150	1900
160	1300
180	380

Correlation coefficient K = 0.9970

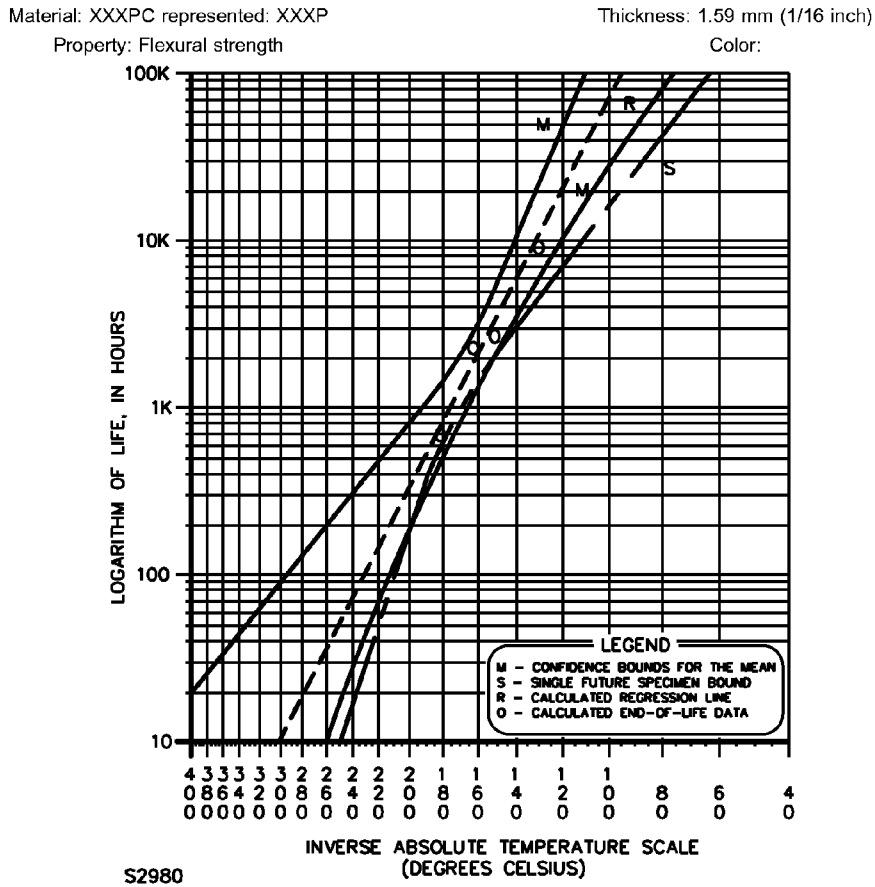
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.141989 \times 10^9;$$

$$B = 11197$$

Where L is in hours and T is in degrees celsius

Figure 7.6
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	650
160	2200
150	2700
130	9000

Correlation coefficient K = 0.9920
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.134738 \times 10^7;$

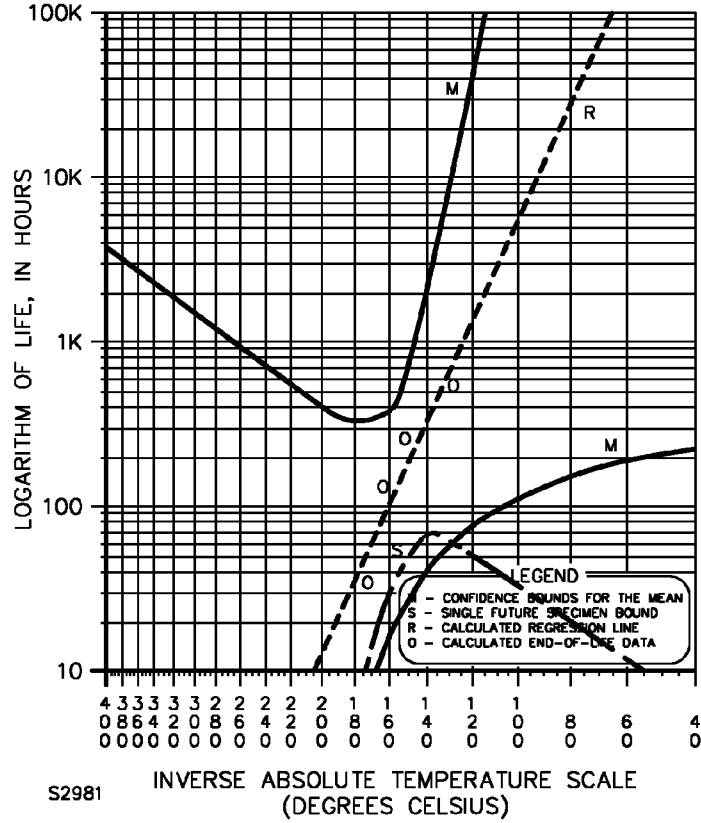
$B = 9363.64$

Where L is in hours and T is in degrees celsius

Figure 7.7
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: CE represented: C, L, LE
 Property: Flexural strength

Thickness: 0.79 mm (1/32 inch)
 Color:



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
130	390
150	260
160	110
170	33

Correlation coefficient K = 0.9128

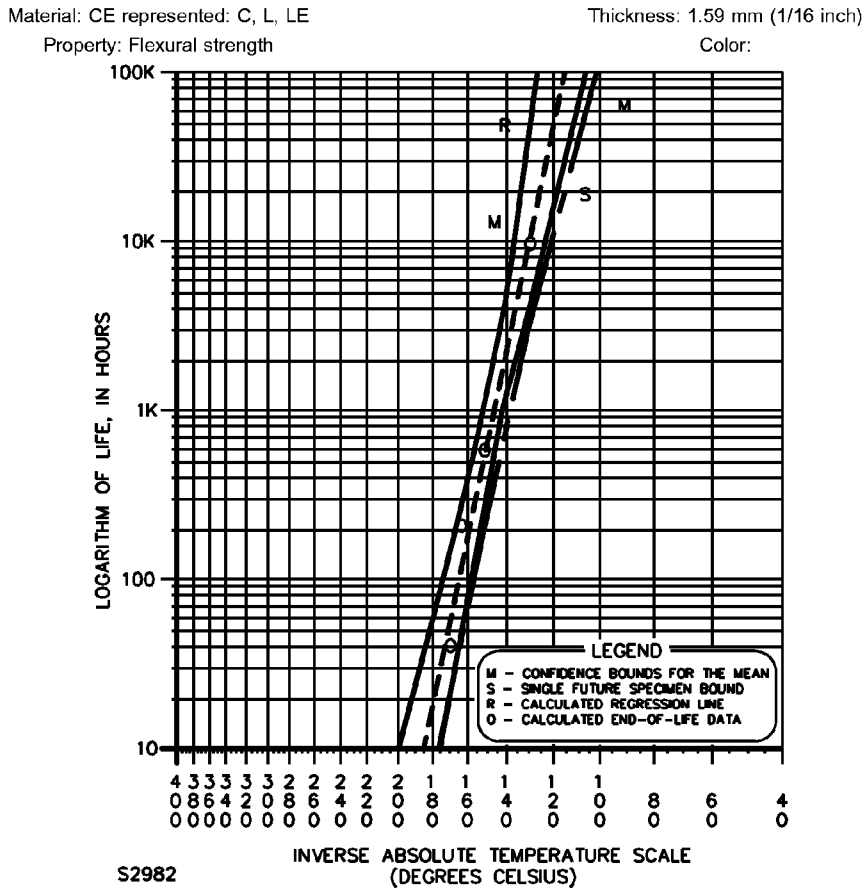
The Arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.298287 \times 10^9;$$

$$B = 10392.4$$

Where L is in hours and T is in degrees celsius

Figure 7.8
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
130	9000
150	510
160	200
170	33

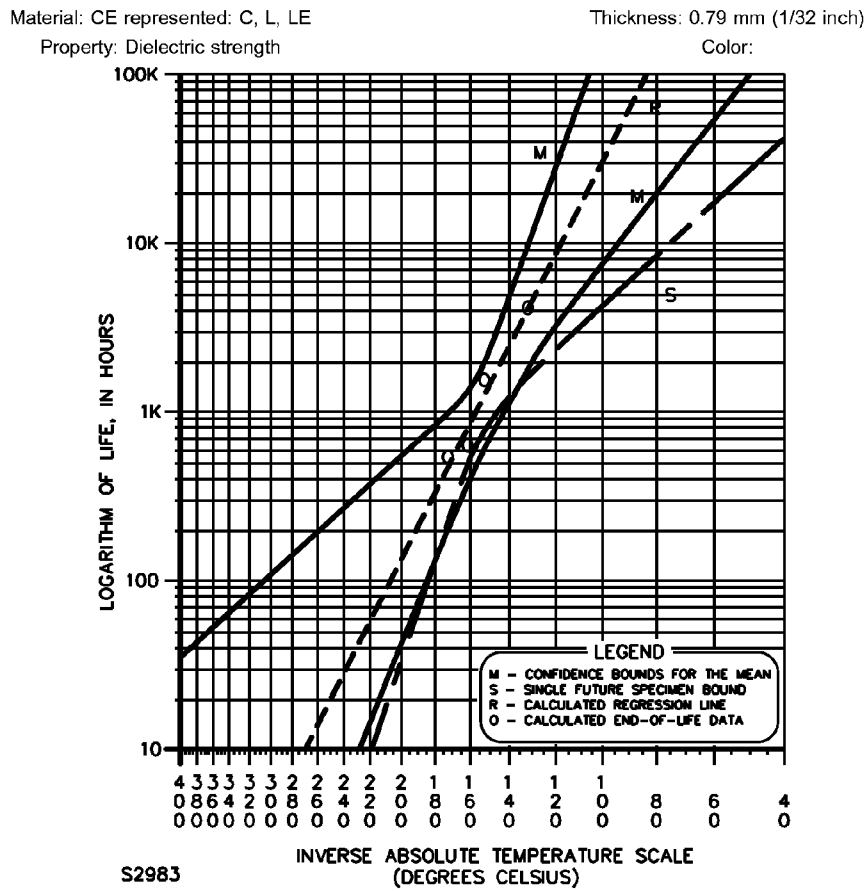
Correlation coefficient K = 0.9953
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.157827 \times 10^{23};$$

$$B = 24295.4$$

Where L is in hours and T is in degrees celsius

Figure 7.9
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
130	3900
150	1530
160	600
170	500

Correlation coefficient K = 0.9825

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.69715 \times 10^7;$$

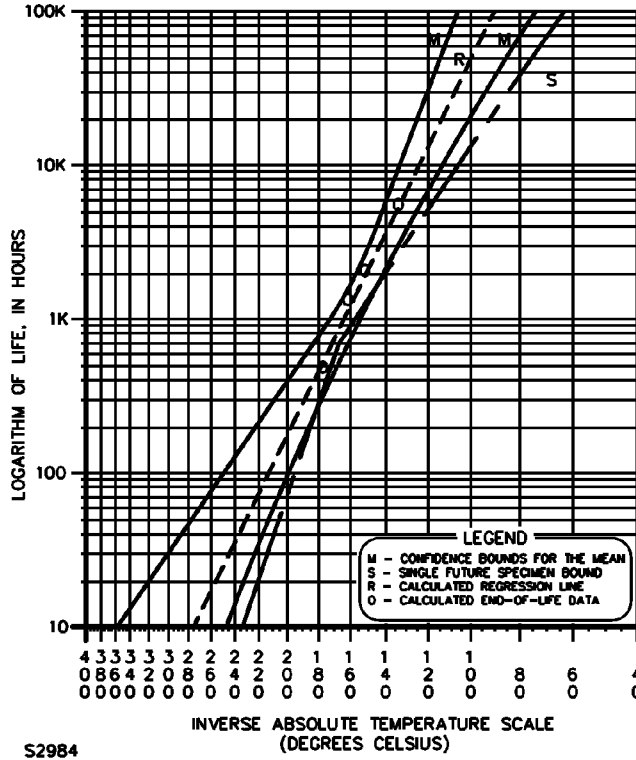
$$B = 9697.96$$

Where L is in hours and T is in degrees celsius

Figure 7.10
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: CE represented: C, L, LE Thickness: 1.59 mm (1/16 inch)
 Property: Dielectric strength Color:

MATERIAL: CE REPRESENTED: C, L, LE THICKNESS: 1/16
PROPERTY: DIELECTRIC STRENGTH



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
130	5500
150	1900
160	1200
170	570

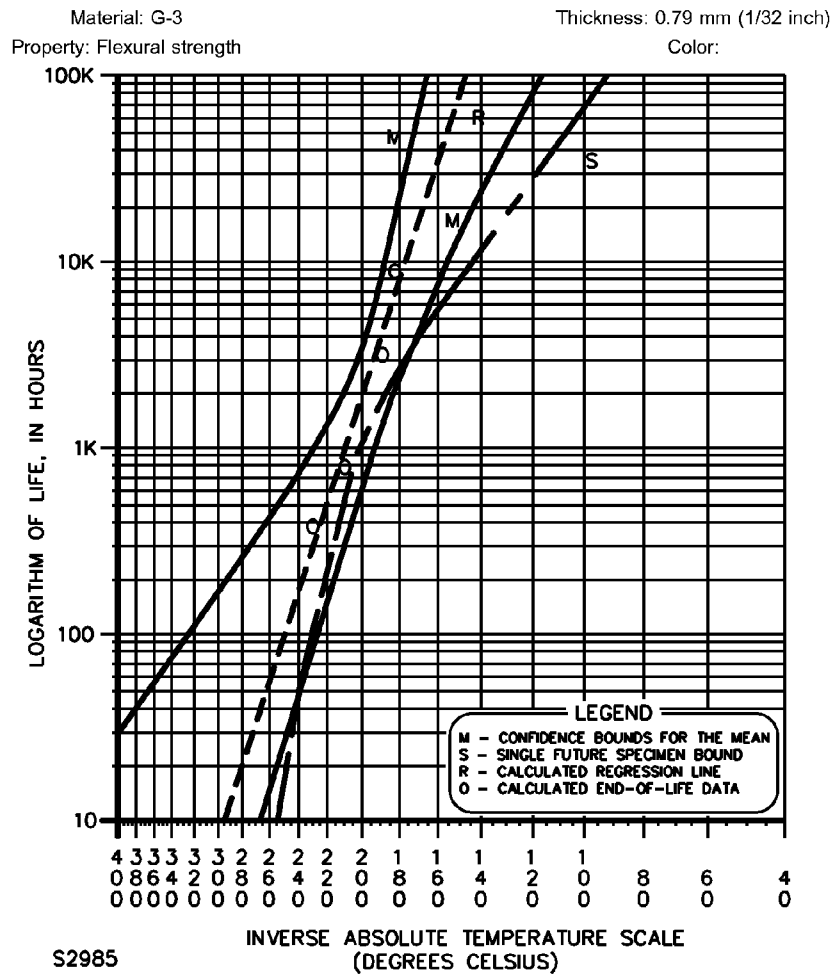
Correlation coefficient $K = 0.9943$
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.677959 \times 10^7;$$

$$B = 9832.96$$

Where L is in hours and T is in degrees celsius

Figure 7.11
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
180	9000
190	2600
210	760
230	320

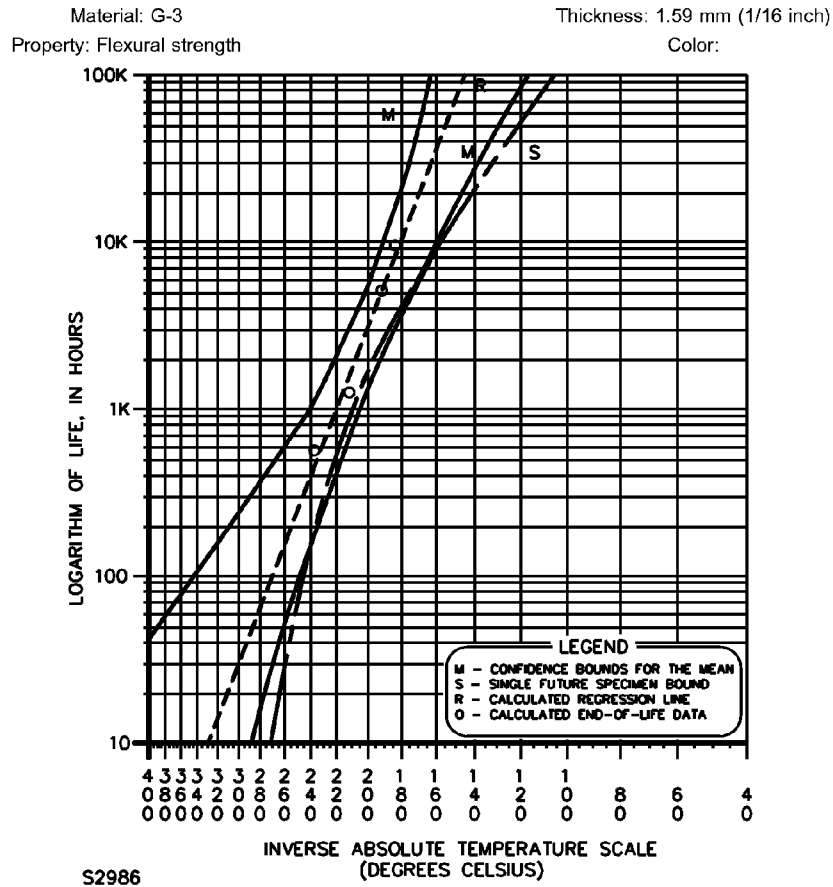
Correlation coefficient K = 0.9837

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.193911 \times 10^{11}; B = 14736.2$

Where L is in hours and T is in degrees celsius

Figure 7.12
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	9000
190	4300
210	1100
230	600

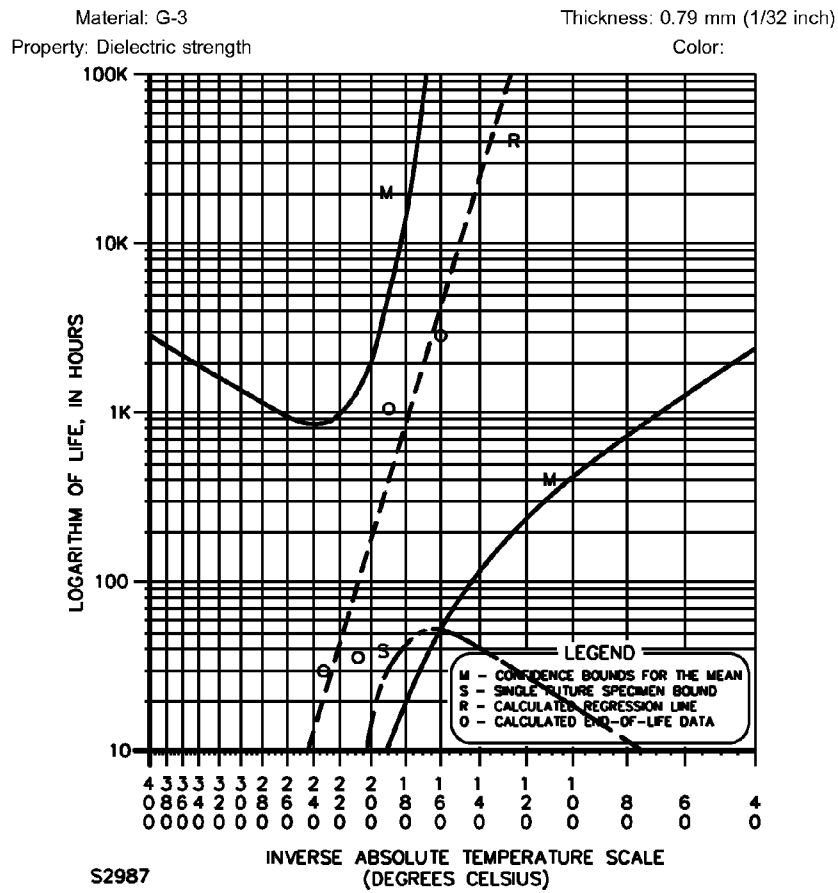
Correlation coefficient $K = 0.9879$
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.144708 \times 10^9;$$

$$B = 12588.5$$

Where L is in hours and T is in degrees celsius

Figure 7.13
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
160	2800
190	950
210	27
230	26

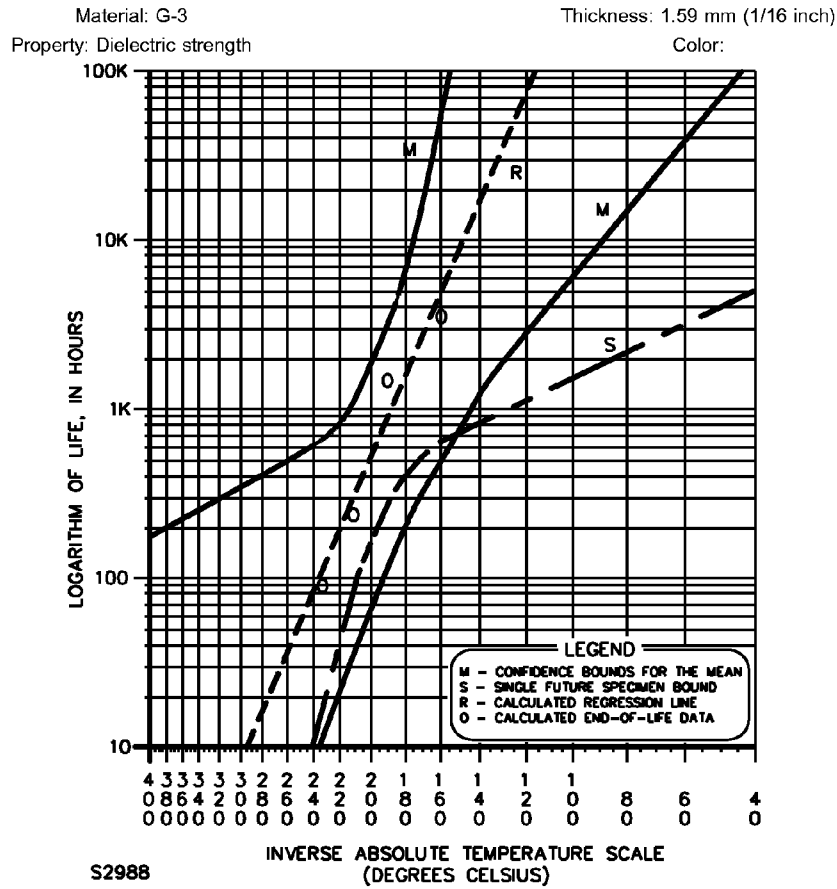
Correlation coefficient K = 0.9271
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.422055 \times 10^{13};$

$B = 16136.1$

Where L is in hours and T is in degrees celsius

Figure 7.14
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
160	3300
190	1500
210	260
230	85

Correlation coefficient K = 0.9651
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.104686 \times 10^9;$

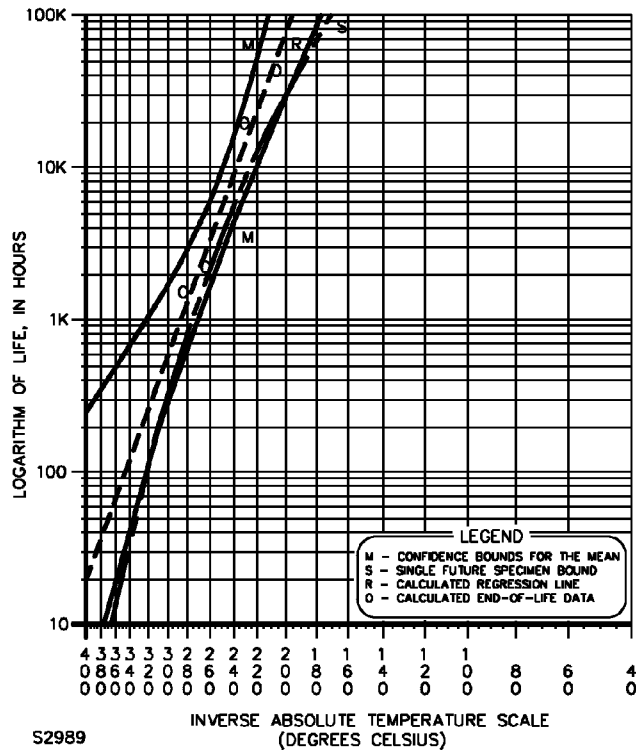
$B = 11646.4$

Where L is in hours and T is in degrees celsius

Figure 7.15
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: G-7
 Property: Flexural strength
MATERIAL: G-7
PROPERTY: FLEXURAL STRENGTH

Thickness: 0.79 mm (1/32 inch)
 Color:
THICKNESS: 1/32



End-of-life criterion: 50% retention of property level
 Laboratory data:

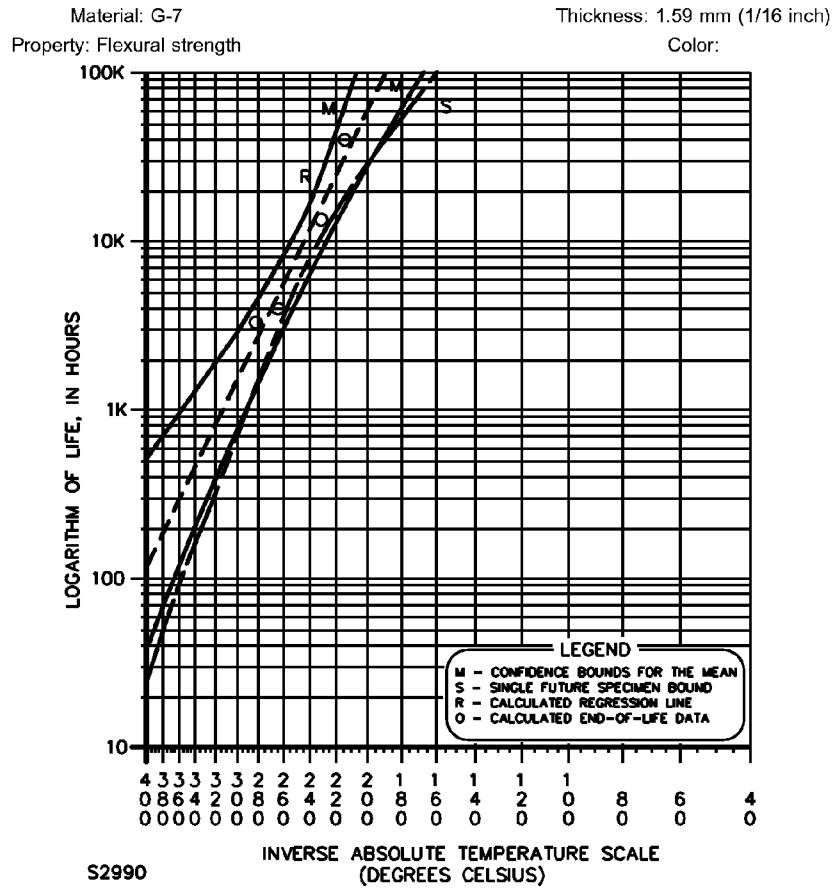
Temperature (C)	Hours to end-of-life
210	40000
230	17000
270	1600
280	1500

Correlation coefficient K = 0.9933
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.272091 \times 10^8;$
 $B = 13431.8$

Where L is in hours and T is in degrees celsius

Figure 7.16
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
210	40000
230	14000
270	3300
280	3000

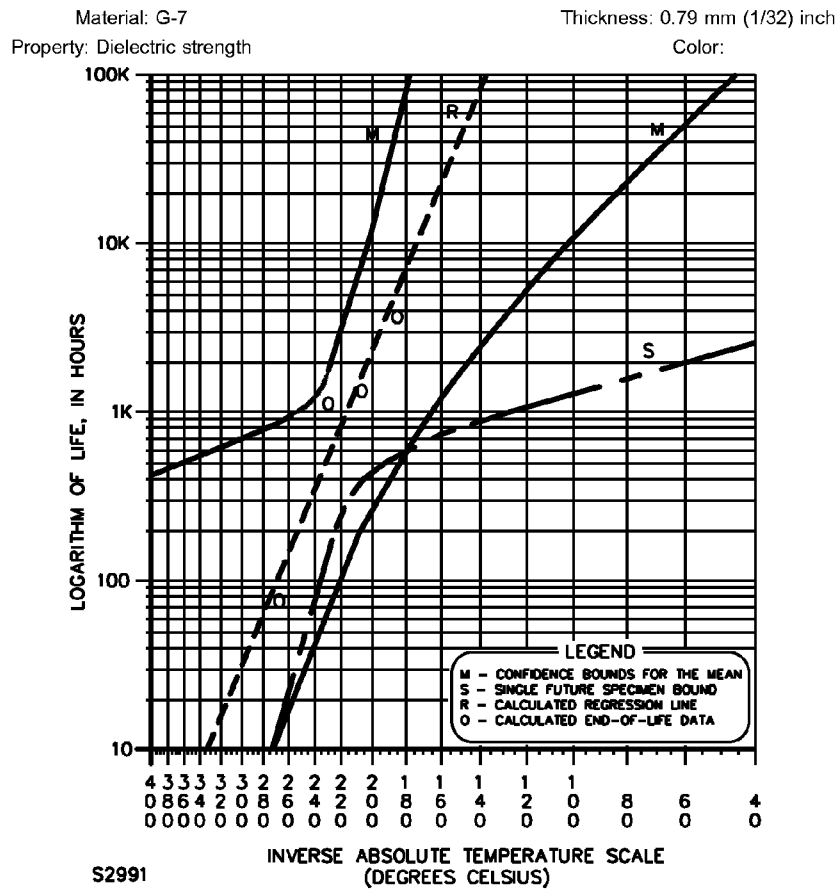
Correlation coefficient K = 0.9941
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/27611.8;

B = 10012.3

Where L is in hours and T is in degrees celsius

Figure 7.17
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
190	3000
210	1100
230	1000
270	67

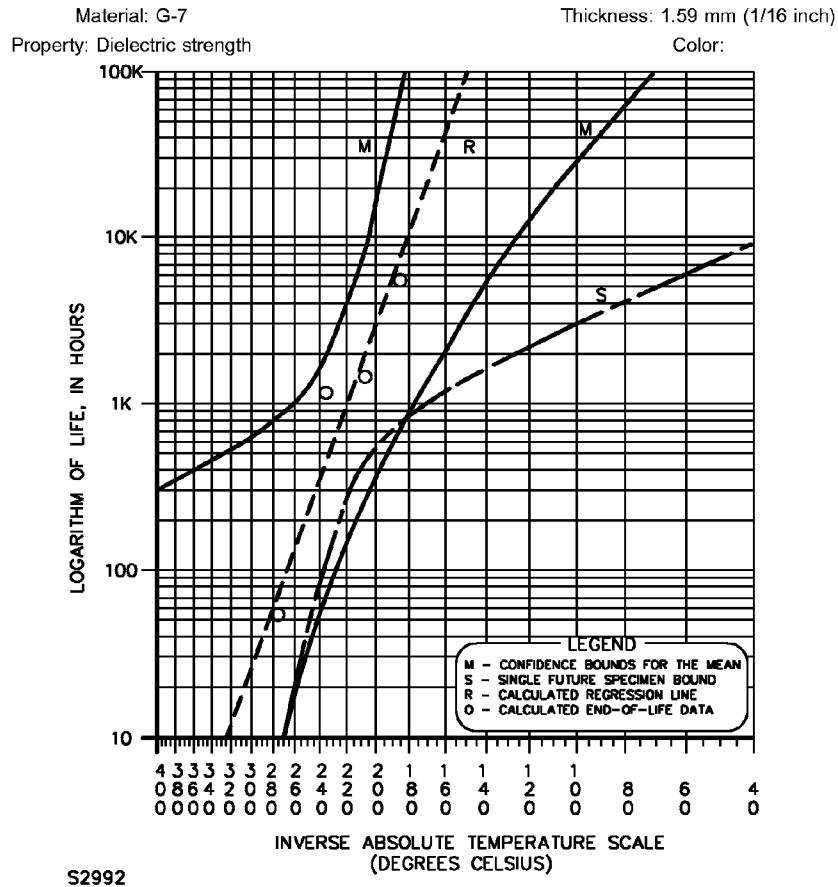
Correlation coefficient K = 0.9586
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.186425 \times 10^8;$$

$$B = 11553$$

Where L is in hours and T is in degrees celsius

Figure 7.18
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
190	4200
210	1300
230	1100
270	55

Correlation coefficient K = 0.9643

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.455205 \times 10^9;$$

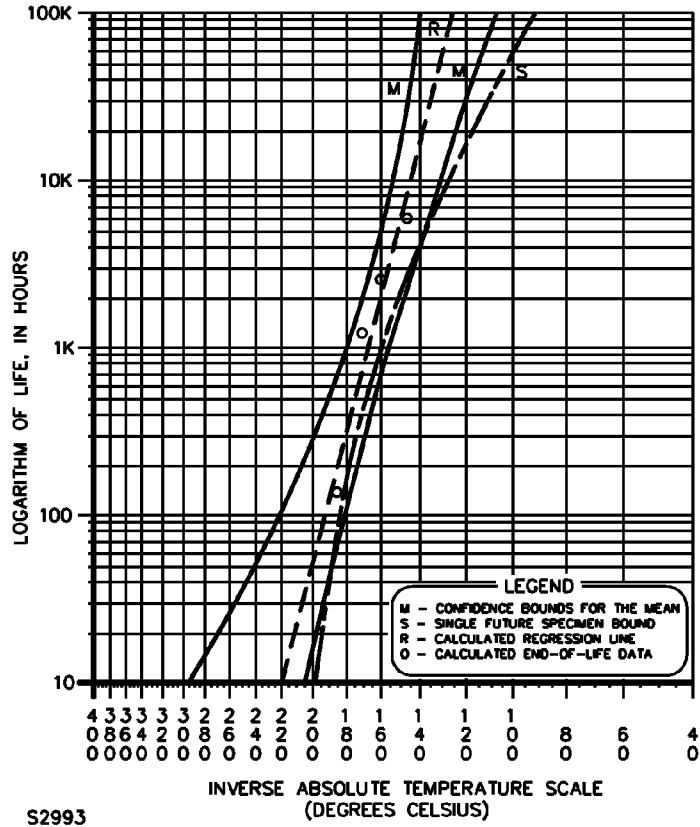
$$B = 13189.1$$

Where L is in hours and T is in degrees celsius

Figure 7.19
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: G-9 represented: G-5
 Property: Flexural strength

Thickness: 0.79 (1/32 inch)
 Color:



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
150	5000
160	2200
170	1200
190	120

Correlation coefficient K = 0.9882

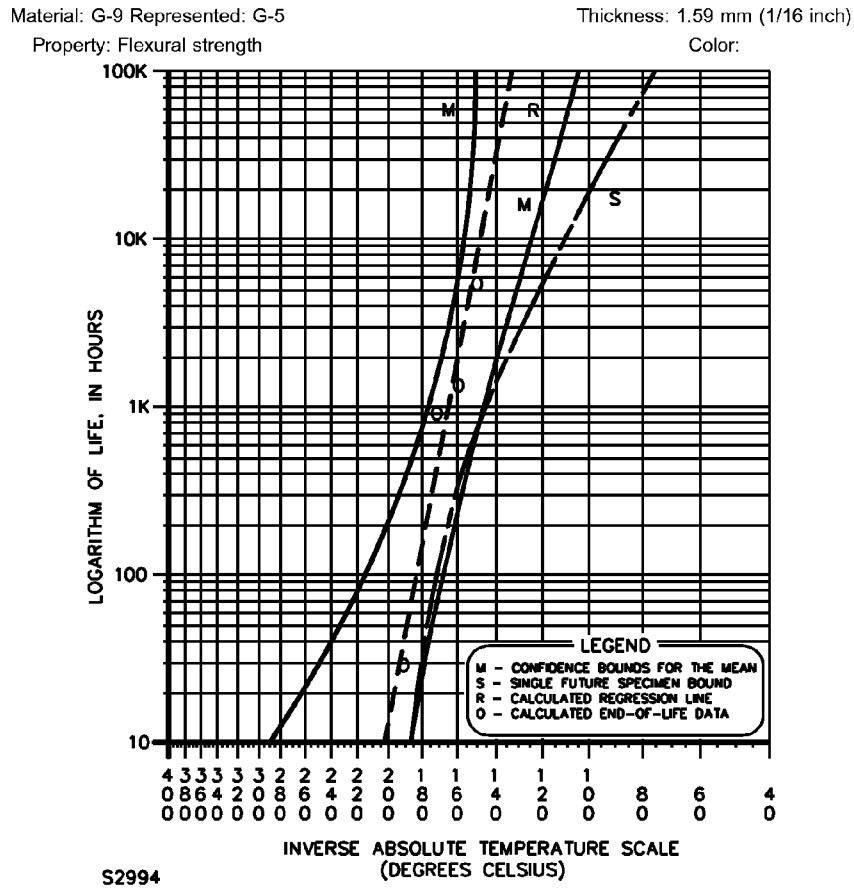
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.82422 \times 10^{15},$$

$$B = 18208.9$$

Where L is in hours and T is in degrees celsius

Figure 7.20
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
150	5000
160	1200
170	800
190	22

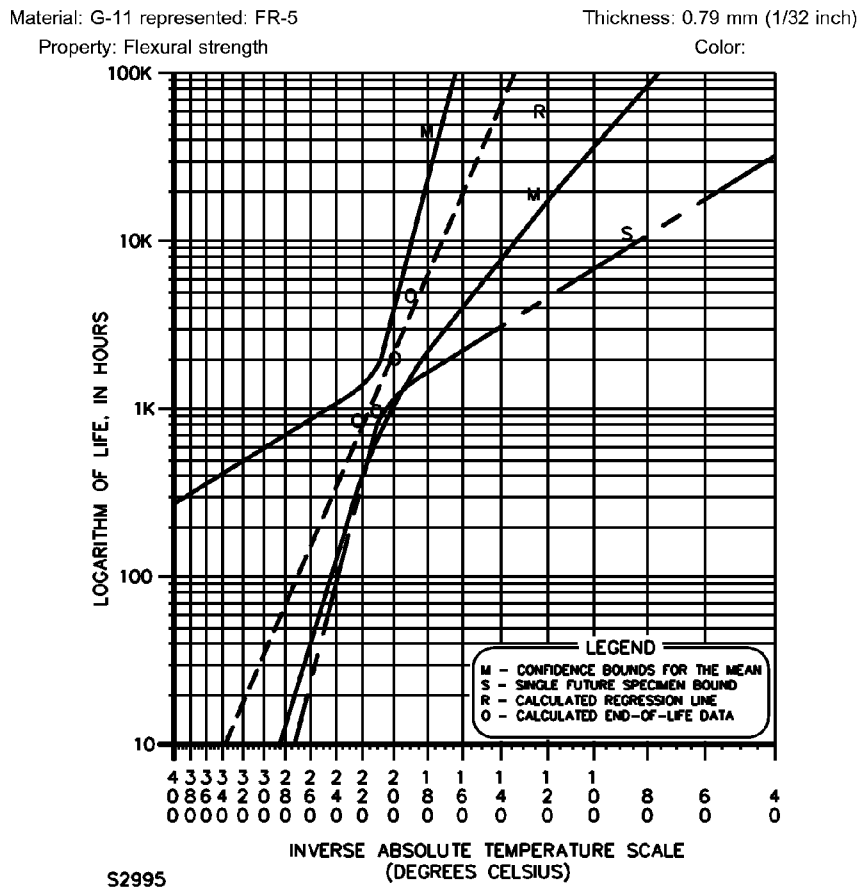
Correlation coefficient K = 0.9768
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.70143 \times 10^{22};$$

$$B = 25948.4$$

Where L is in hours and T is in degrees celsius

Figure 7.21
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
190	3100
200	1600
210	850
220	750

Correlation coefficient K = 0.9712

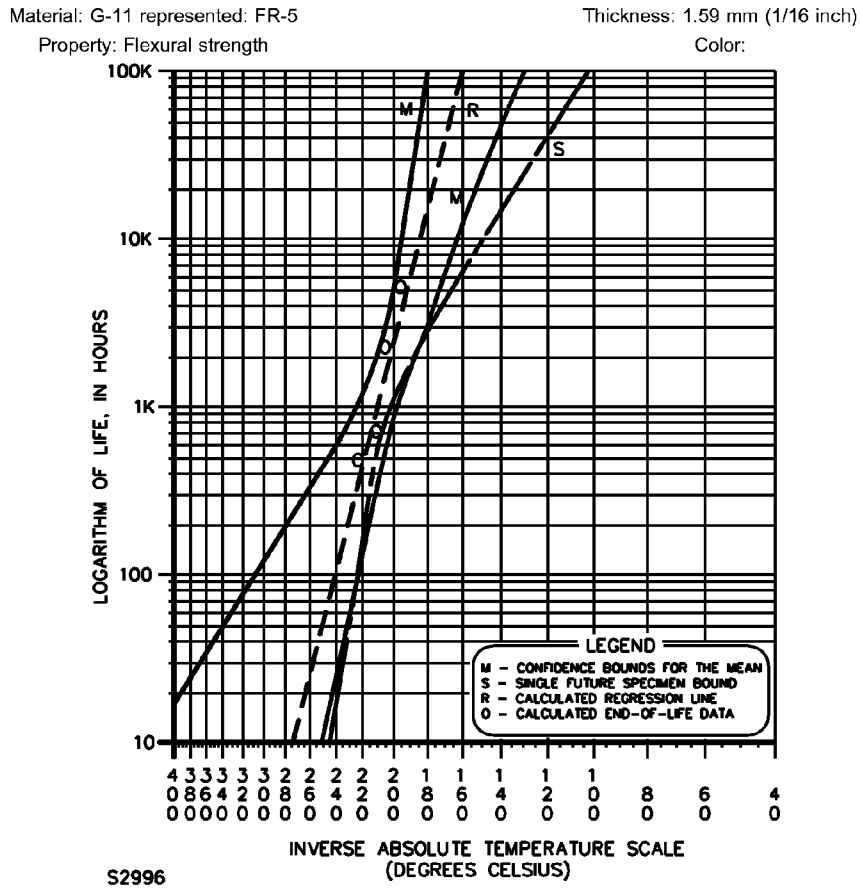
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.117396 \times 10^8$$

$$B = 11218.2$$

Where L is in hours and T is in degrees celsius

Figure 7.22
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
190	4900
200	2100
210	620
220	460

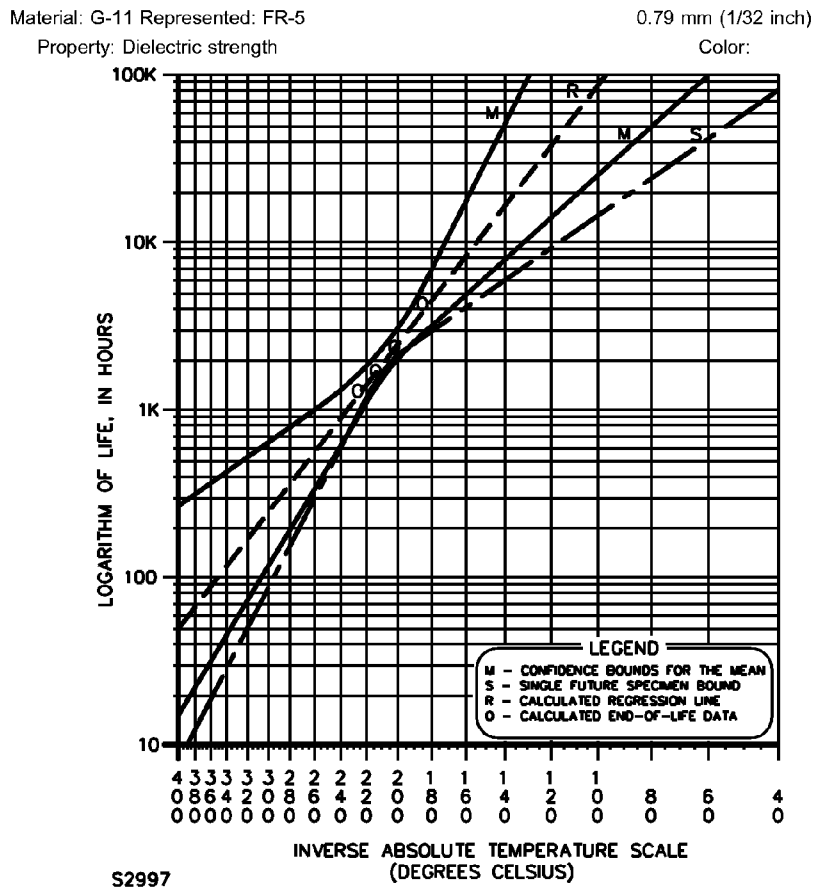
Correlation coefficient K = 0.9803
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.155348 \times 10^{15};$

$B = 19046.3$

Where L is in hours and T is in degrees celsius

Figure 7.23
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
190	3000
200	2000
210	1600
220	1300

Correlation coefficient $K = 0.9883$
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/258.81;$

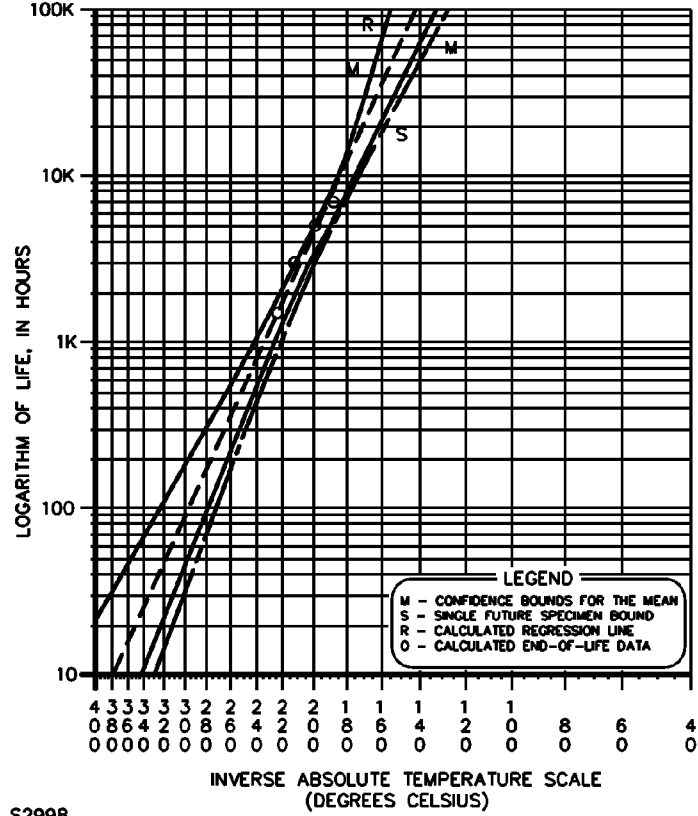
$B = 6258.21$

Where L is in hours and T is in degrees celsius

Figure 7.24
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: G-11 represented: FR-5
 Property: Dielectric strength

Thickness: 1.59 mm (1/16 inch)
 Color:



S2998

End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
190	6000
200	4000
210	2500
220	1500

Correlation coefficient K = 0.9976

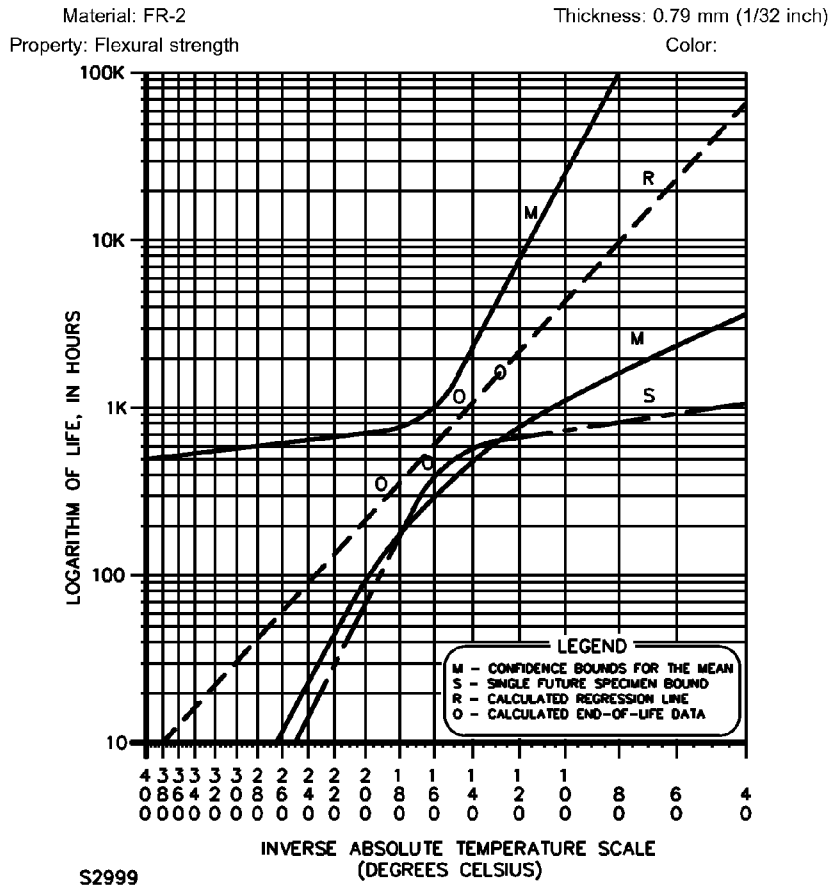
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.128511 \times 10^7$$

$$;B = 10561.3$$

Where L is in hours and T is in degrees celsius

Figure 7.25
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
Laboratory data:

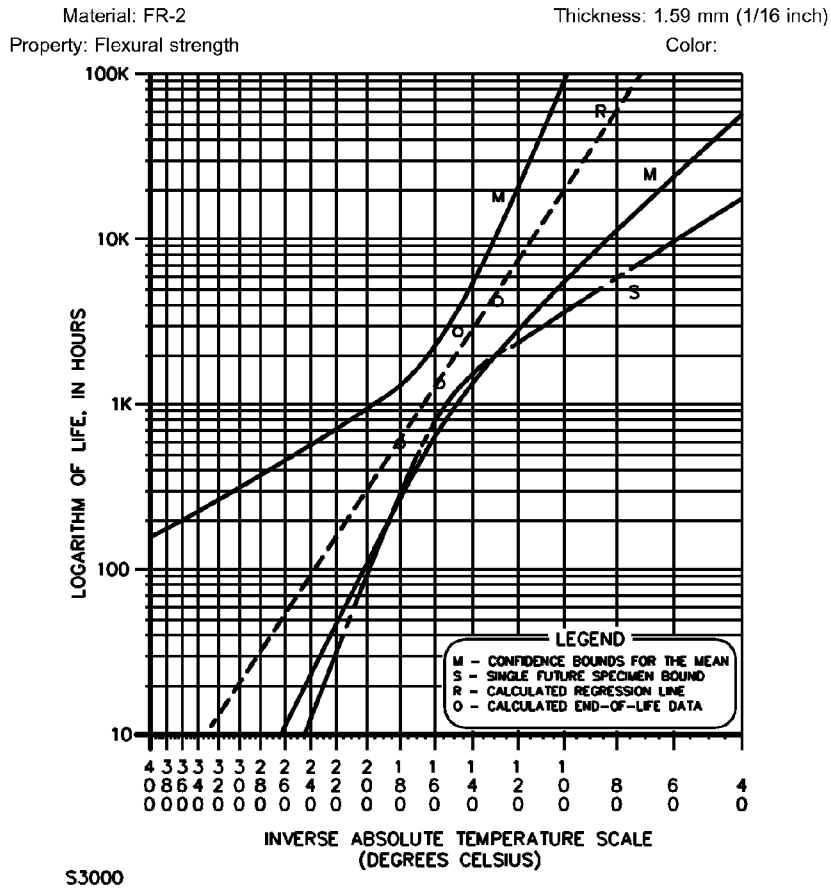
Temperature (C)	Hours to end-of-life
130	1400
150	1000
160	490
180	360

Correlation coefficient K = 0.9589
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/319.402;
B = 5267.49

Where L is in hours and T is in degrees celsius

Figure 7.26
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
130	3800
150	2300
160	1100
180	570

Correlation coefficient K = 0.9806

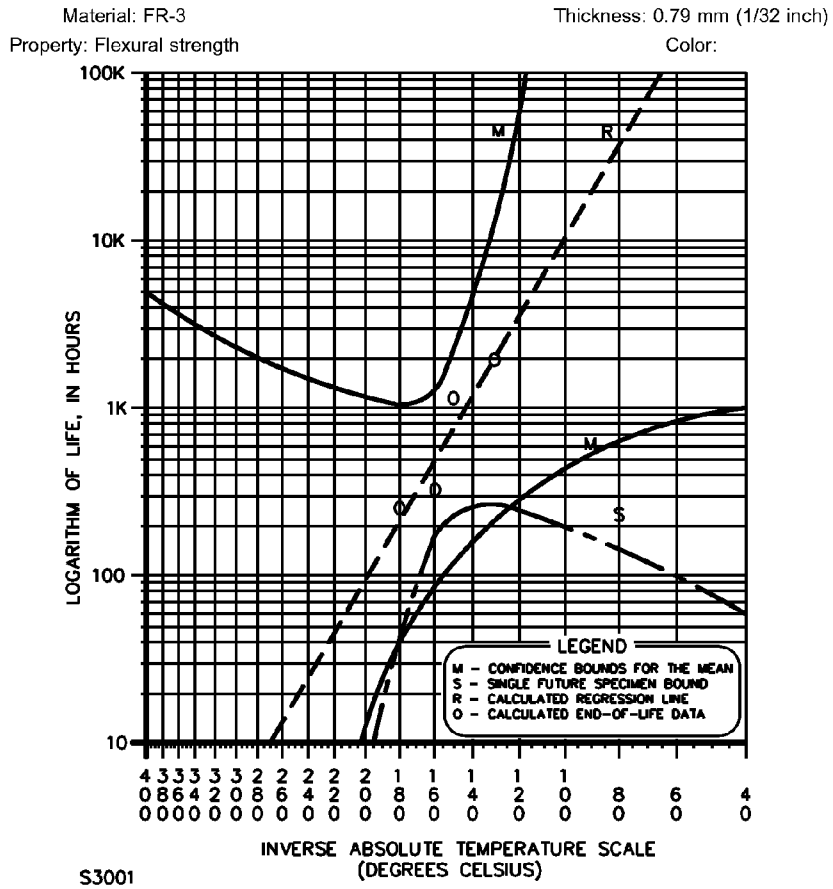
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/12263.9;

B = 7157.79

Where L is in hours and T is in degrees celsius

Figure 7.27
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
130	1600
150	950
160	240
180	210

Correlation coefficient K = 0.9195

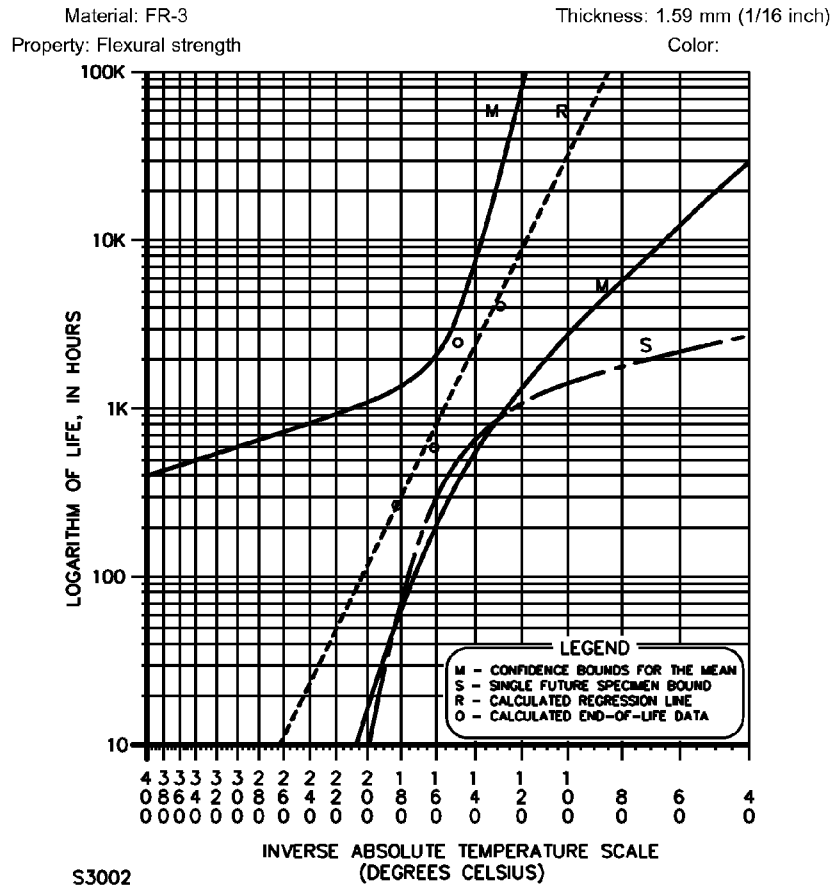
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/343751;

B = 8126.2

Where L is in hours and T is in degrees celsius

Figure 7.28
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

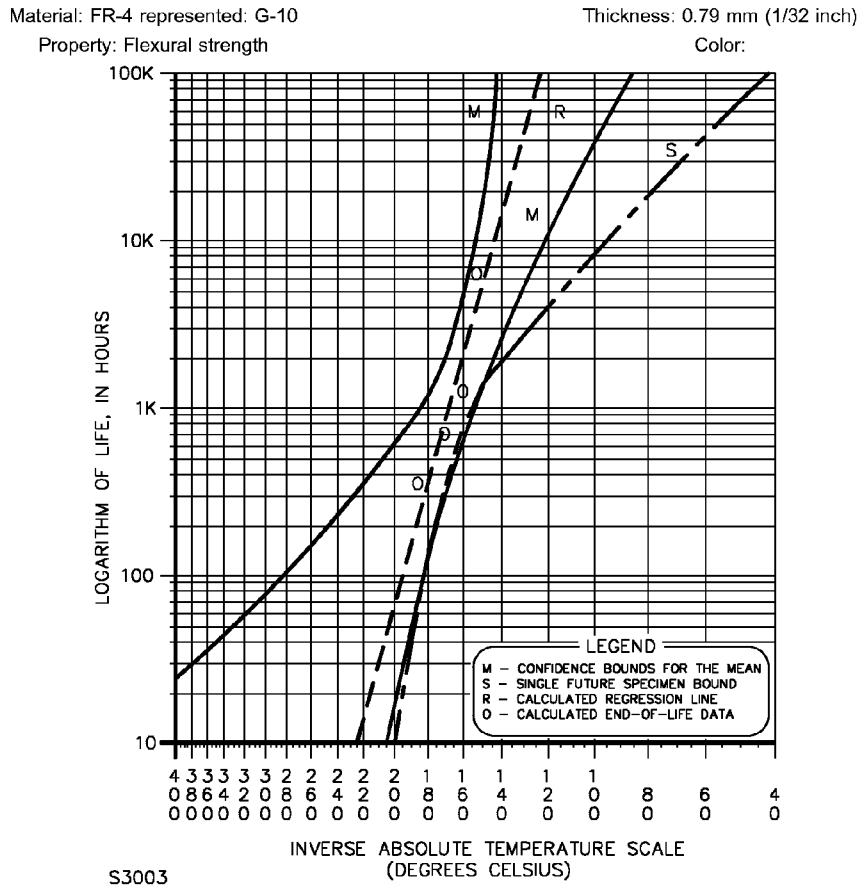
Temperature (C)	Hours to end-of-life
130	3300
150	2000
160	570
180	250

Correlation coefficient K = 0.9605
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.116652 \times 10^8;$
 $B = 9900.47$

Where L is in hours and T is in degrees celsius

Figure 7.29
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
150	5600
160	1200
170	620
180	350

Correlation coefficient K = 0.9732
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.130488 \times 10^{15};$$

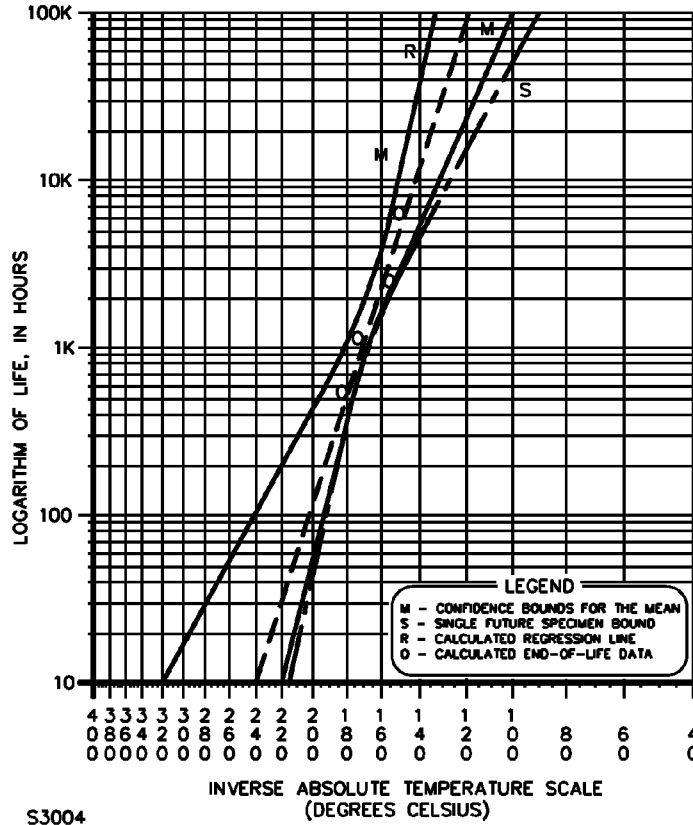
$$B = 17297.8$$

Where L is in hours and T is in degrees celsius

Figure 7.30
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: FR-4 represented: G-10
 Property: Flexural strength

Thickness: 1.59 mm (1/16 inch)
 Color:



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
150	5700
160	1800
170	1100
180	480

Correlation coefficient K = 0.9898
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.788381 \times 10^{12};$

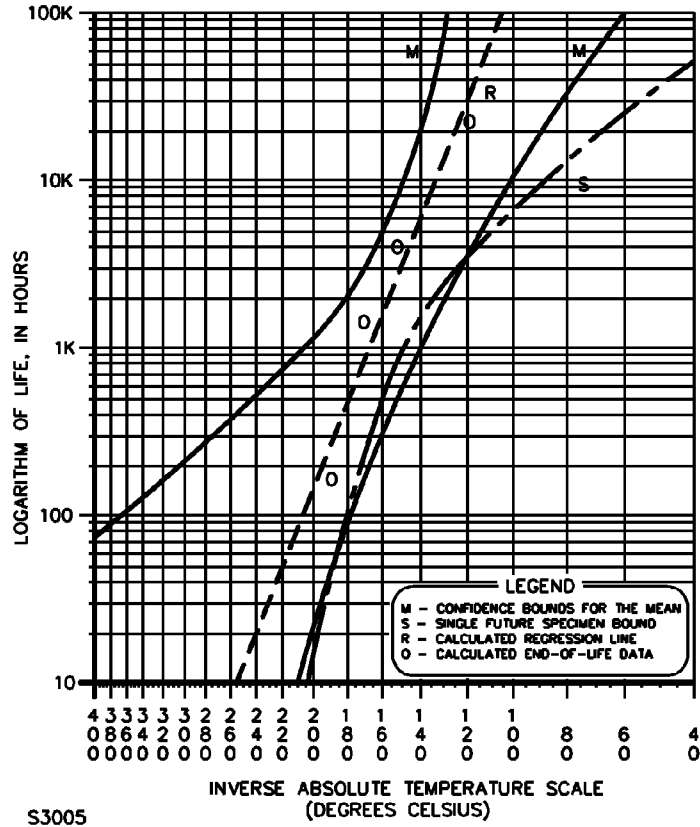
$B = 15204.9$

Where L is in hours and T is in degrees celsius

Figure 7.31
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: FR-4 represented: G-10
 Property: Flexural strength

Thickness: 0.79 mm (1/32 inch)
 Color:



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
120	20000
150	3500
170	1300
190	150

Correlation coefficient K = 0.9766

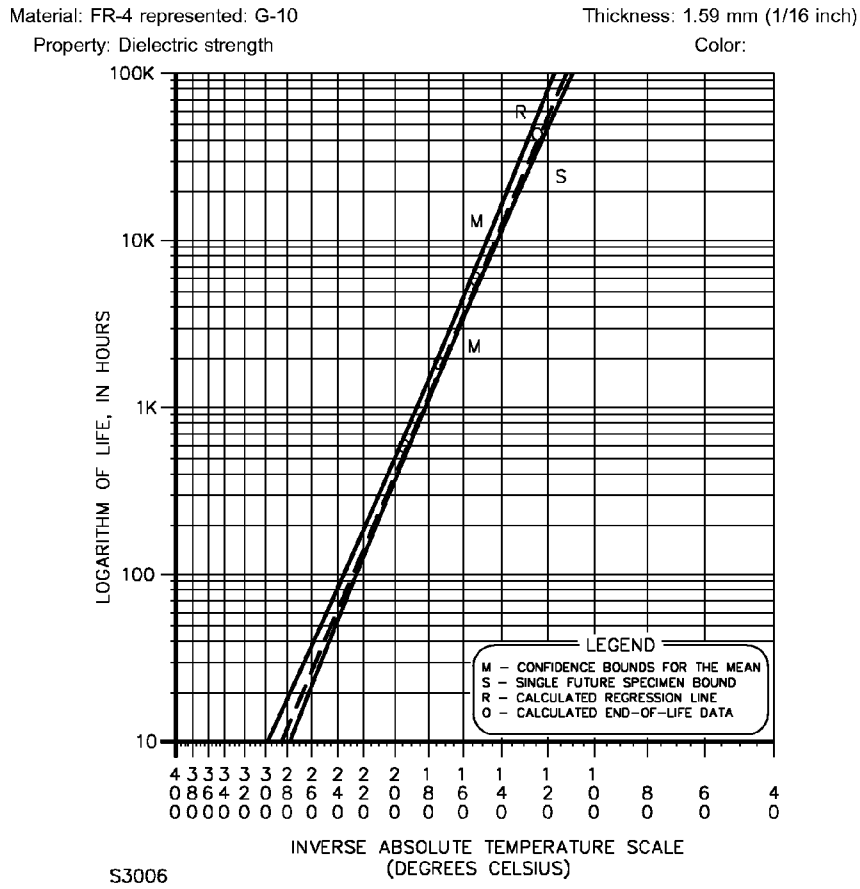
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.94621 \times 10^9;$$

$$B = 12112.6$$

Where L is in hours and T is in degrees celsius

Figure 7.32
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
120	40000
150	5700
170	1600
190	560

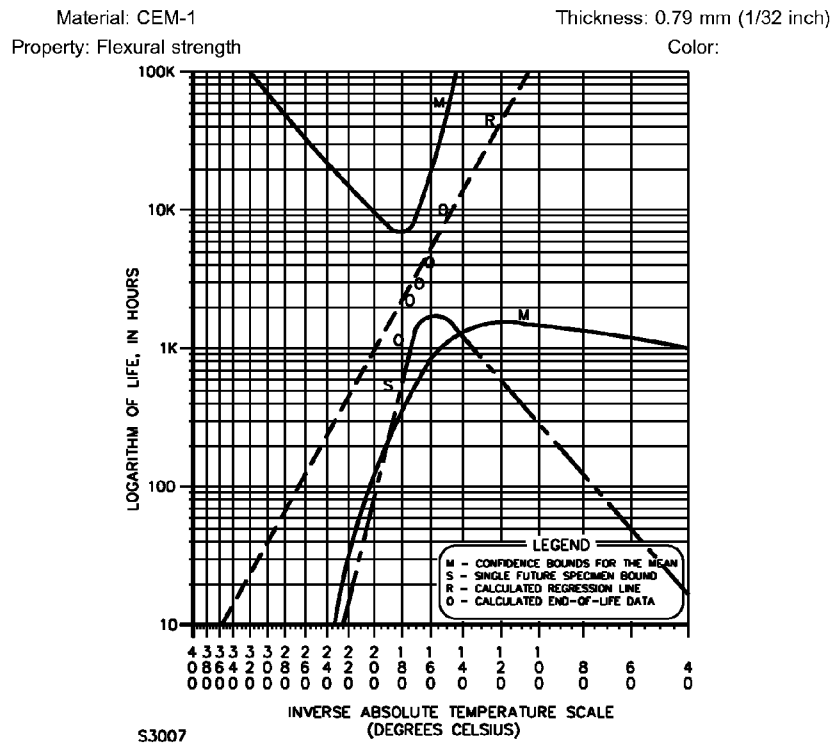
Correlation coefficient K = 0.9998
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.5172098 \times 10^8;$

$B = 11155.7$

Where L is in hours and T is in degrees celsius

Figure 7.33
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
180	6354
180	1087
180	1093
170	4358
170	2322
160	3949
165	2865
150	7210
150	8913

Correlation coefficient K = 0.6978

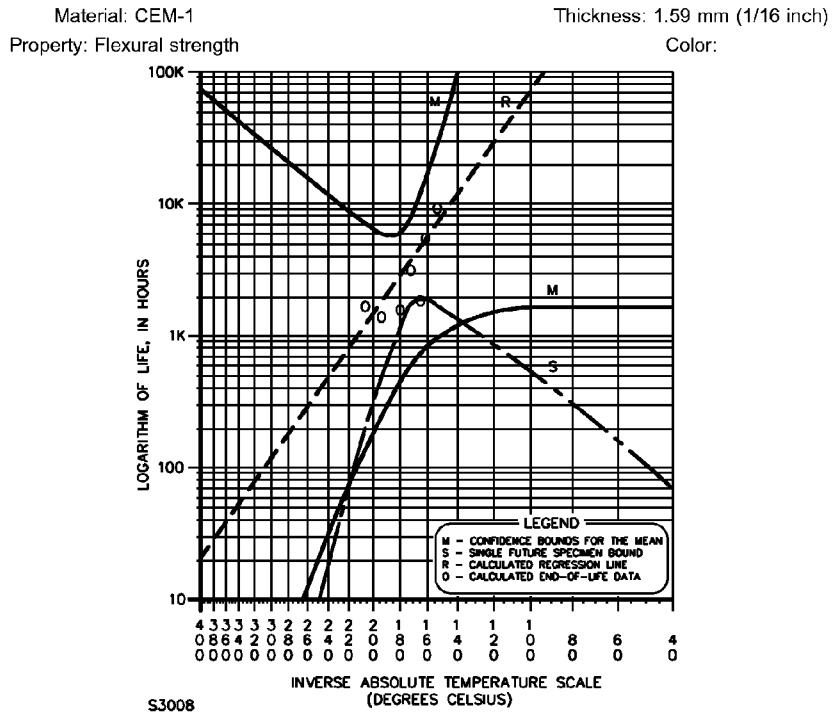
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.89749.1;$

$B = 8595.54$

Where L is in hours and T is in degrees celsius

Figure 7.34
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
200	1685
190	1384
180	2910
180	5361
180	1513
170	2554
160	11137
160	4781
165	1644
150	8142

Correlation coefficient K = 0.6931

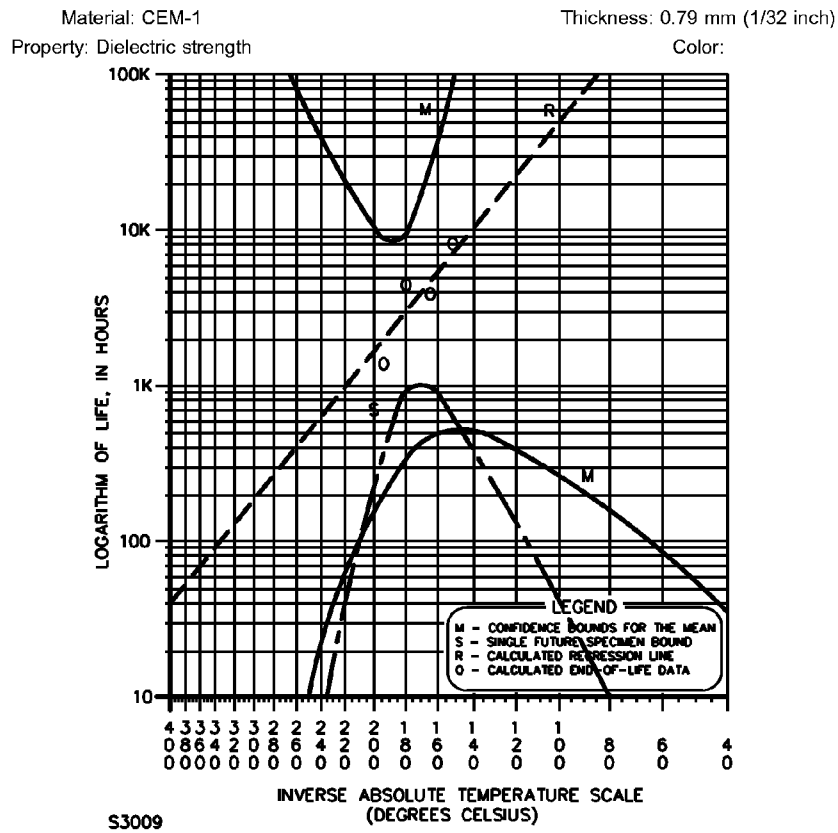
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/1269.18;

B = 6784.76

Where L is in hours and T is in degrees celsius

Figure 7.35
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
190	1063
190	5343
190	1217
180	3793
165	3463
150	7078

Correlation coefficient K = 0.6443

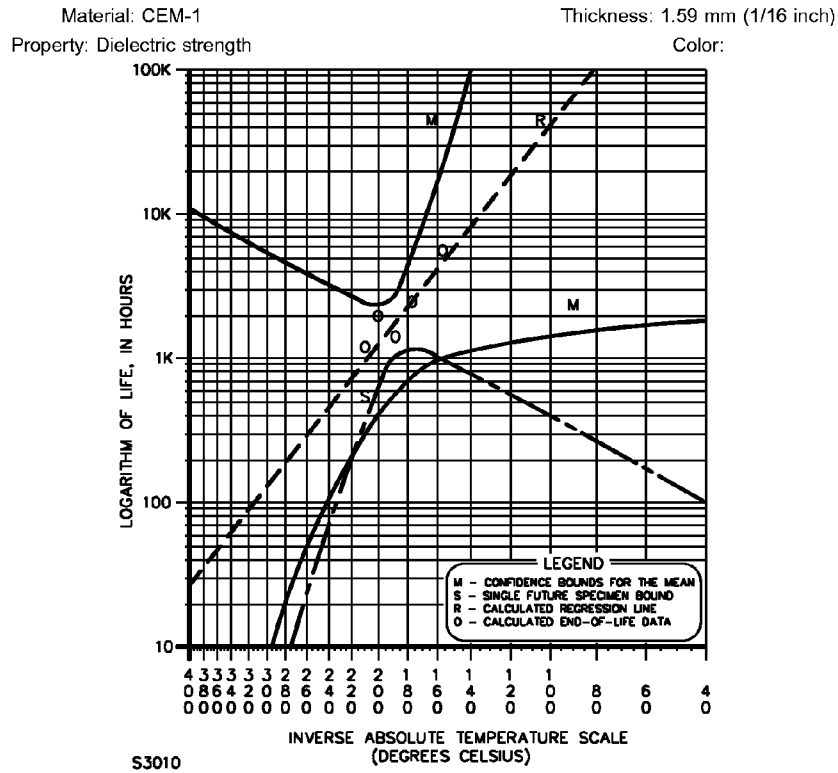
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/183.75;

B = 5941.19

Where L is in hours and T is in degrees celsius

Figure 7.36
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
210	1078
200	1109
200	1752
190	885
190	1273
180	3427
180	2117
165	3493

Correlation coefficient K = 0.7717

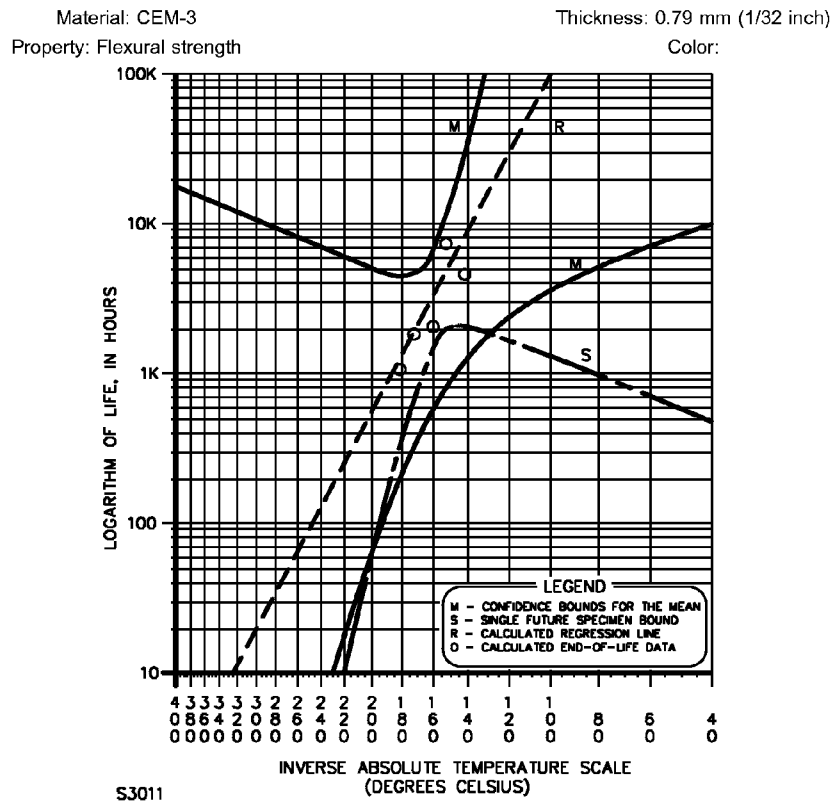
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/298.755;

B = 6062.73

Where L is in hours and T is in degrees celsius

Figure 7.37
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
180	972
170	1584
160	3754
160	1688
150	6446
150	6932
140	4220

Correlation coefficient K = 0.8424

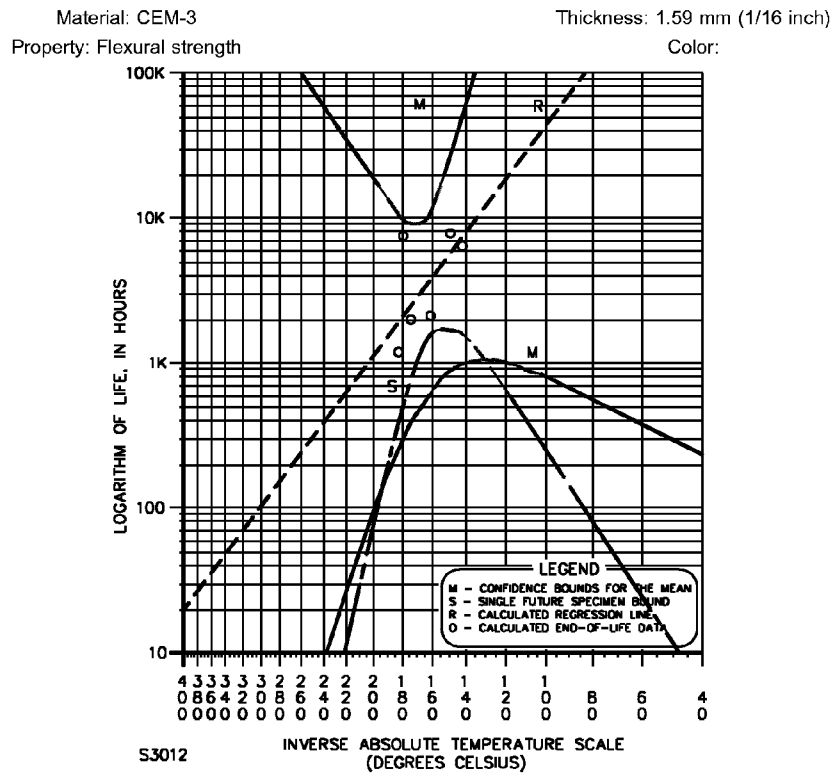
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/319726;

B = 8911.02

Where L is in hours and T is in degrees celsius

Figure 7.38
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
180	1056
175	7143
170	2016
160	4225
160	2125
150	7368
150	7118
140	6416

Correlation coefficient $K = 0.6377$

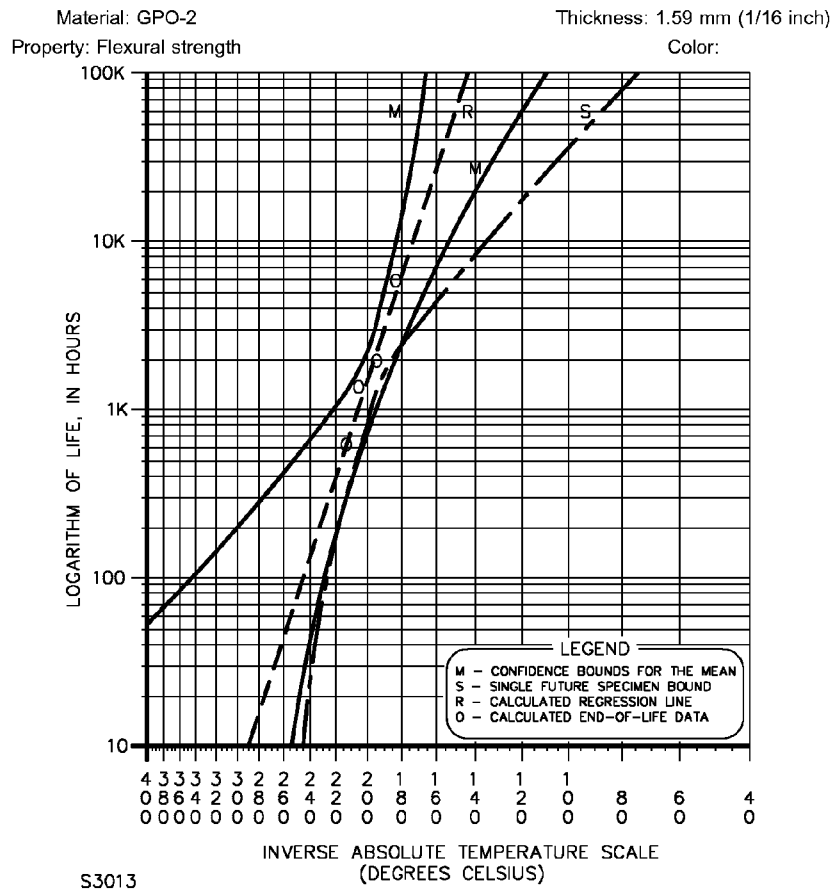
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/852.55;$$

$$B = 6500.21$$

Where L is in hours and T is in degrees celsius

Figure 7.39
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
210	560
200	1400
190	1800
180	5000

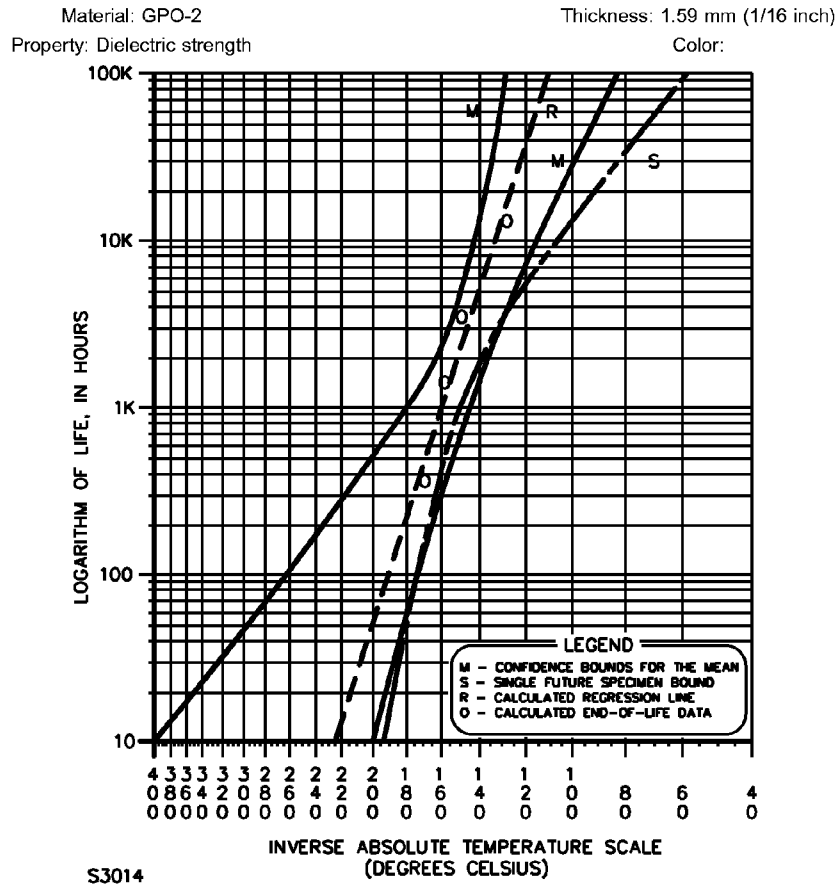
Correlation coefficient K = 0.9786
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.451173 \times 10^{11};$$

$$B = 14939.1$$

Where L is in hours and T is in degrees celsius

Figure 7.40
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
170	320
160	1300
150	2900
130	12000

Correlation coefficient K = 0.9811

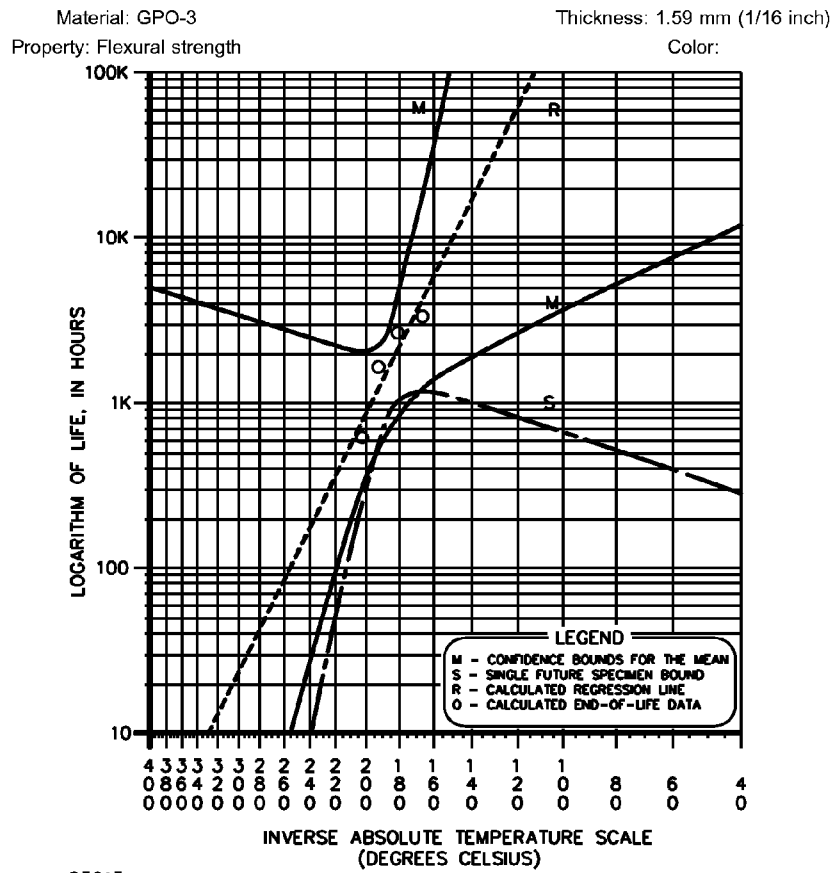
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.347756 \times 10^{13};$$

$$B = 15497.7$$

Where L is in hours and T is in degrees celsius

Figure 7.41
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
200	580
190	1400
180	2100
170	2400

Correlation coefficient K = 0.9338

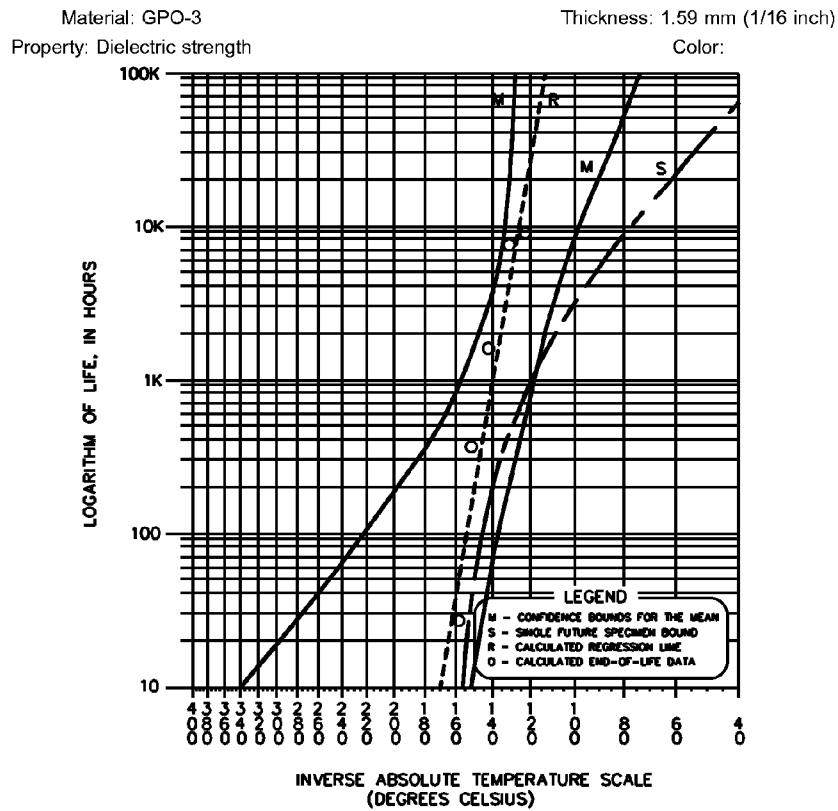
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.114597 \times 10^7;$$

$$B = 9712.69$$

Where L is in hours and T is in degrees celsius

Figure 7.42
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



S3016

End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
160	20
150	240
140	1400
130	6700
120	7500

Correlation coefficient $K = 0.9543$

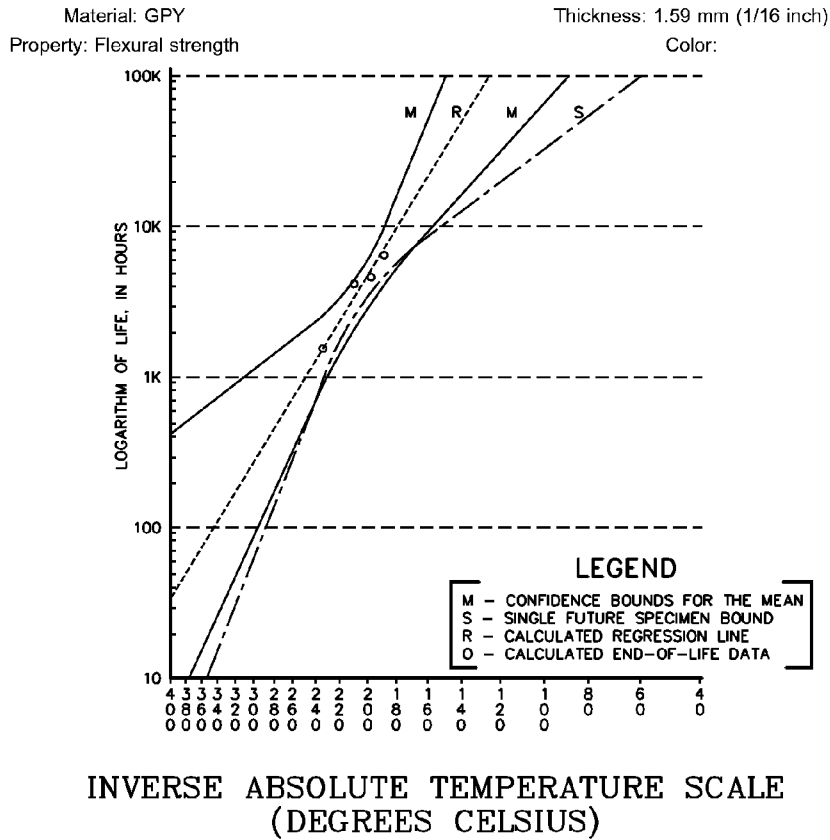
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.119904 \times 10^{25};$$

$$B = 25641.4$$

Where L is in hours and T is in degrees celsius

Figure 7.44
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



SM248

End-of-life criterion: 50% retention of property level
 Laboratory data:

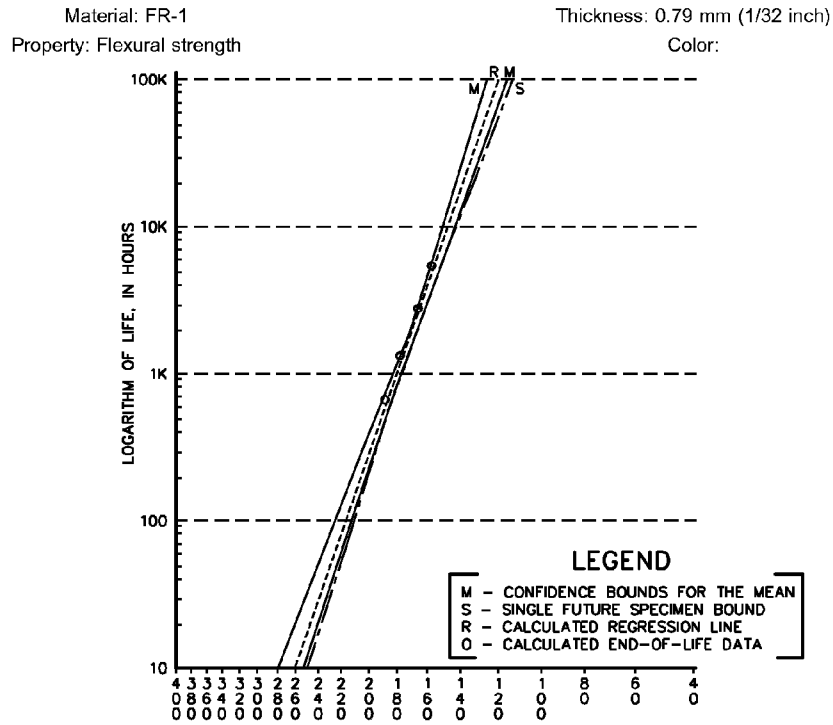
Temperature (C)	Hours to end-of-life
235	1413
210	3978
200	4531
190	6428

Correlation coefficient K = 0.9851
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/3423.89;
 B = 7855.99

Where L is in hours and T is in degrees celsius

Figure 7.46
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



**INVERSE ABSOLUTE TEMPERATURE SCALE
 (DEGREES CELSIUS)**

SM250

End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	673
170	1308
160	2895
150	5615

Correlation coefficient K = 0.9992

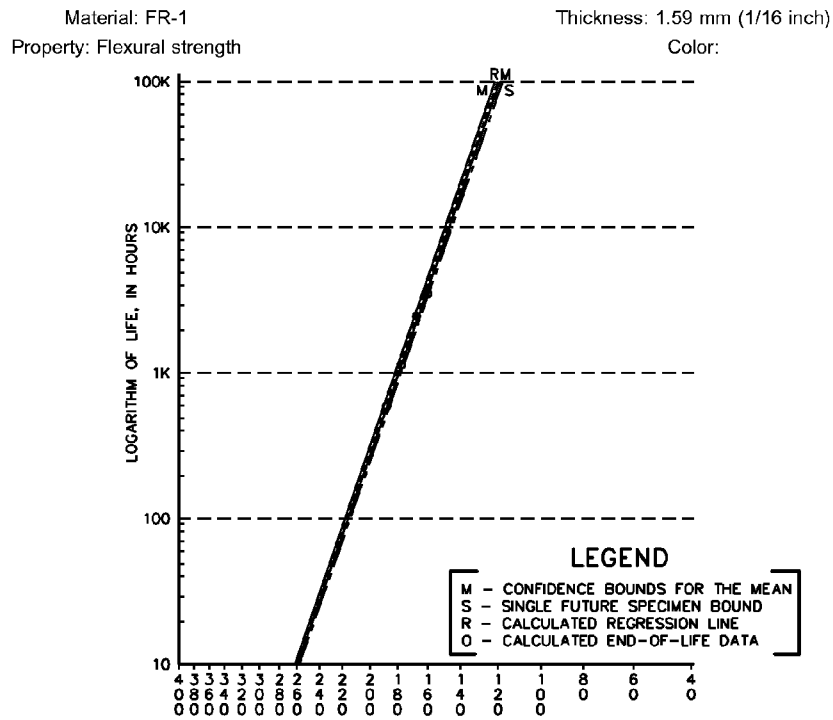
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/2.11129E + 11;$

$B = 13726$

Where L is in hours and T is in degrees celsius

Figure 7.47
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



**INVERSE ABSOLUTE TEMPERATURE SCALE
 (DEGREES CELSIUS)**

SM251

End-of-life criterion: 50% retention of property level
 Laboratory data:

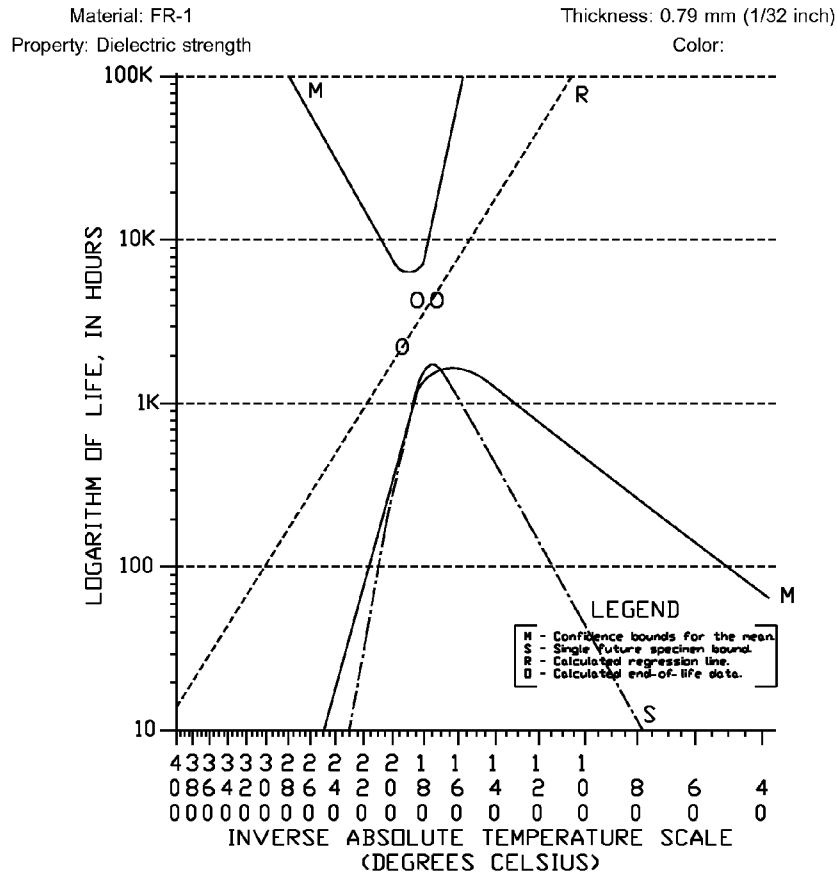
Temperature (C)	Hours to end-of-life
180	738
170	1381
160	2794
150	5742

Correlation coefficient K = 1
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 11.561434E + 10;$
 $B = 13160.7$

Where L is in hours and T is in degrees celsius

Figure 7.48
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



SM252

End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
190	1999
180	4016
170	4212

Correlation coefficient K = .8874

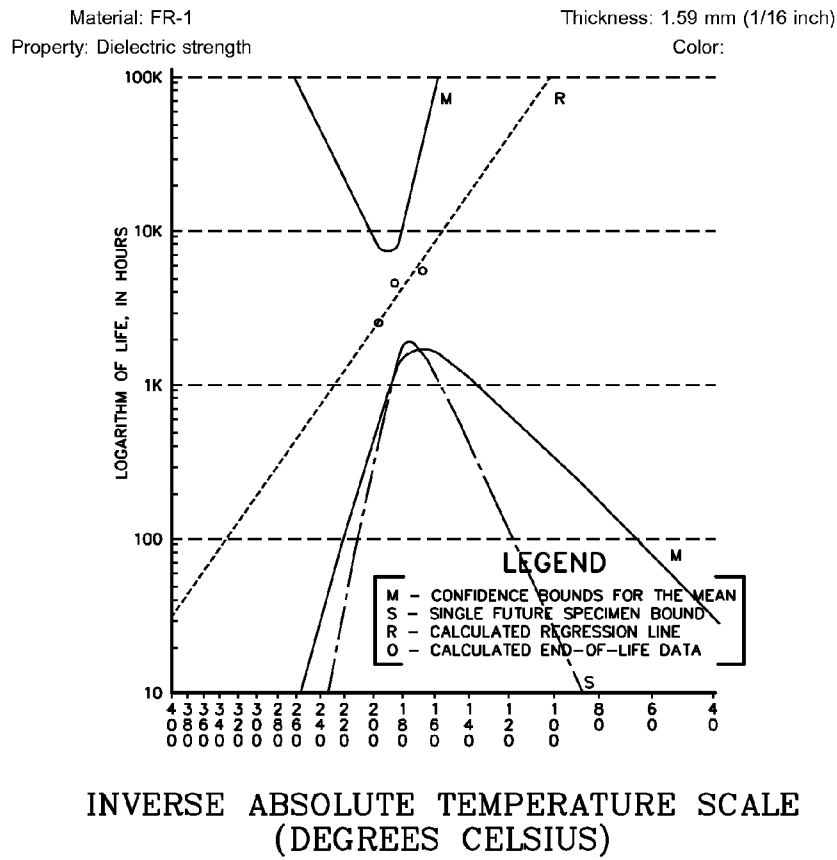
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/5987.01;

B = 7600.05

Where L is in hours and T is in degrees celsius

Figure 7.49
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



SM253

End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
190	2263
180	4467
170	4503

Correlation coefficient K = 08647

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/1472.7;$

$B = 7010.89$

Where L is in hours and T is in degrees celsius

8 Ultrathin Laminate and Prepreg Test Program

8.1 Ultrathin laminates and prepregs shall be of the same UL/ANSI type and resin system that was previously investigated under the industrial laminate test program. Thickness and relative thermal indices are shown in Table 8.1 for FR-4, G-10, GPY, FR-5, and CEM-3 material. All UL/ANSI type materials must comply with the minimum electrical and mechanical RTI's listed in Table 8.1 and may not exceed the electrical and mechanical RTI's listed in Table 5.2.

8.1 revised November 28, 2001

8.2 Where ultrathin materials are built up to a thickness of 0.8 mm (0.031 inch) or greater using the laminate and prepreg thicknesses per Tables 8.1 and 8.2, no testing shall be required, provided they contain the same resin system as the previously evaluated FR-4, G-10, GPY, CEM-3, or FR-5 laminate. Intermixing of materials that are not generically identical shall not be employed unless an evaluation is conducted in accordance with 8.10 – 8.12 to determine the compatibility of the dissimilar materials. The assigned relative thermal indices shall be 130°C electrical and 140°C mechanical for FR-4, CEM-3, and G-10, and 140°C electrical and 160°C mechanical for GPY and FR-5. The use of sheet thicknesses that are less than those referenced in Tables 8.1 and 8.2 requires a two temperature aging. Aging is to be conducted at 170°C and 180°C for FR-4, G-10, and CEM-3 material, 210°C and 225°C for GPY material, and 200°C and 210°C for FR-5 material.

8.2 revised November 28, 2001

8.3 Tests to be performed and test samples required of ultrathin laminates and prepregs, built up to a thickness of 0.38 mm (0.015 inch) to 0.61 mm (0.024 inch) are shown in Table 8.3. At the conclusion of the performance indexing tests, the UL/ANSI material shall be assigned the relative thermal index shown in Table 8.1. In addition to the required performance indexing tests shown in Table 8.3, if the composition of the material, as determined by Infrared Analysis, does not compare favorably with an existing UL/ANSI type, then a 4 point thermal aging program shall be required of ultrathin materials built up to a thickness of 0.38 mm (0.015 inch) to determine the electrical and mechanical thermal index. Both dielectric strength and tensile strength shall be used as primary properties for testing, plus other secondary properties mentioned in 7.9. The test program, samples, method, data analysis, and evaluation shall be as described in the Standard for Safety for Polymeric Materials – Long Term Property Evaluations, UL 746B. If a 4 point dielectric strength thermal aging program has been conducted at 1.6 mm (0.062 inch) and/or 0.80 mm (0.031 inch) on the subject material, a 2 point dielectric strength thermal aging program may be conducted at 0.38 mm (0.015 inch).

Exception: For CEM-3 material, the test sample is to be built up to a thickness of 0.48 mm (0.019 inch) to 0.61 mm (0.024 inch).

8.3 revised November 28, 2001

8.4 A two temperature aging program conducted at 170°C and 180°C for FR-4, G-10, and CEM-3 material, 210°C and 225°C for GPY material, and 200°C and 210°C for FR-5 material shall be required on samples of ultrathin laminates built up to less than 0.38 mm (0.015 inch). Samples are to be fabricated to the minimum built up thickness for which evaluation is desired from individual sheets as specified in Tables 8.1 and 8.2. The mechanical property to be investigated shall be tensile strength. Test results of the materials shall be compared with those of 0.38 mm (0.015 inch) thick control samples to determine the mechanical temperatures index using the methods described in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

8.5 The profile of performance index tests shown in Table 8.3 shall be performed using samples as shown in Table 8.3 built up to the same evaluation thickness used for the 2 temperature aging, as indicated in 8.4.

8.6 Upon completion of the tests in 8.4 and 8.5, the UL/ANSI material may be assigned the appropriate electrical temperature index in Table 8.1. If the Infrared Analysis does not compare favorably with an existing UL/ANSI type, the material shall be assigned the appropriate electrical and mechanical temperature index determined in the thermal aging program.

8.6 revised November 28, 2001

8.7 When a higher electrical index temperature than shown in Table 8.1 is desired for the material, the measurement of electrical characteristics (dielectric strength) shall also be required as a primary property and shall be performed at the same two temperature points, using samples as described in 8.4. Sample requirements are shown in Table 8.4. The electrical temperature index which may be assigned is determined as described in 7.5.

8.8 Ultrathin laminates and prepregs using a resin system not previously investigated shall be tested under a full rigid industrial laminate profile or performance indexing, 4 point thermal aging as described in 7.1, and the ultrathin laminate and prepreg test program as described in 8.3, 8.4, and 8.5.

8.8 revised November 28, 2001

8.9 The evaluation of thermal aging data shall be conducted as described in 7.9.

8.10 In reference to 8.2 regarding materials which are not generically identical, the combination of materials shall be subjected to a minimum of a 2 point thermal aging program in accordance with the procedure defined in UL 746B, the Standard for Polymeric Materials— Long Term Property Evaluations, and each individual material shall have been previously evaluated for performance profile indexing values and RTI's. The mechanical strength property, flexural strength, is to be used as the test characteristic. Test results of the material are to be compared with those of a 0.8 mm (0.031 inch) thick control sample of the standard construction to determine whether the relative thermal index would remain unchanged.

Exception: With regard to materials which are not generically identical, the two point aging program may be waived on the combination of materials if one of the materials is shown to be inert (that material will not cause the relative thermal index characteristics of surrounding materials to degrade). The combination of the materials is to be assigned the mechanical and electrical RTI's and the performance profile indexing values based on the values of the lowest rated material within the combination. Higher values shall not be assigned unless the performance profile indexing tests are conducted.

8.10 revised November 28, 2001

8.11 In reference to 8.2 regarding materials which are not generically identical, the mechanical RTI of the combination as determined by 8.10 shall be at least as high as the lowest rated material. The combination of the materials is then to be assigned the mechanical and electrical RTI's of the lowest rated material.

8.12 In reference to 8.2 regarding materials which are not generically identical, if the performance profile indexing tests are not conducted on the combination of materials, the performance profile indexing values shall be assigned based on the values of the lowest rated material within the combination. Higher values shall not be assigned unless the performance profile indexing tests are conducted. These values shall be limited to the constructions tested by defining the outer surface material.

Table 8.1
Ultrathin laminates generic thermal index

Table 8.1 revised November 28, 2001

UL/ANSI grade	Individual sheets nominal thickness ^a		Relative thermal index	
	mm	(Mils)	Electrical	Mechanical
G-10	0.05 – 0.15	(2 – 6)	110	–
G-10	0.17 – 0.35	(7 – 14)	120	–
G-10	0.38 – 0.61	(15 – 24)	130	130
FR-4	0.10 – 0.35	(4 – 14)	120	–
FR-4	0.38 – 0.61	(15 – 24)	130	130
FR-5	0.38 – 0.61	(15 – 24)	140	140
GPY	0.10 – 0.35	(4 – 14)	140	–
GPY	0.38 – 0.76	(15 – 30)	140	160
CEM-3	0.25 – 0.45	(10 – 18)	120	–
CEM-3	0.48 – 0.62	(19 – 24)	130	130
CEM-3	0.63 – 0.96	(25 – 38)	130	140

^a The pressed, cured thickness.

Table 8.2
Ultrathin prepregs generic thermal index

Table 8.2 revised November 28, 2001

UL/ANSI grade	Individual sheets nominal thickness ^a		Individual sheets relative thermal index	
	mm	(Mils)	Electrical	Mechanical ^b (°C)
G-10	0.05	(2)	110	–
FR-4	0.05 – 0.07	(2 – 3)	90	–
FR-4	0.10	(4)	120	–
GPY	0.05	(2)	140	–
FR-5	0.38	(15)	140	–
CEM-3	0.10	(4)	120	–

^a The unpressed, semi-cured thickness.
^b The mechanical rating shall be that of the final buildup thickness.

Table 8.3
Samples for indexing ultrathin industrial laminates

Table 8.3 revised November 28, 2001

Indexing tests	Method	Section
Mechanical property: Tensile strength	UL 746A	9
Electrical properties: Dielectric strength	UL 746A	19
High current arc ignition (HAI)	UL 746A	31
Hot wire ignition (HWI)	UL 746A	30
Flammability properties: Horizontal burning	UL 94	7
Vertical burning	UL 94	8
<p>SAMPLES SHALL NOT BE METAL CLAD – They are to be prepared by etching the copper off a copper clad sheet of the ultrathin laminate.</p> <p>Thickness: All samples are to be built up to the minimum thickness to be evaluated using the minimum sheet thickness shown in Tables 8.1 and 8.2.</p> <p>A) 10 bars – Tensile Strength Test, per UL 746A, and per ASTM D882 (Method A), Standard Test Methods for Tensile Properties of Thin Plastic Sheeting (cut in a bias direction - see Figure 8.1).</p> <p>B) 10 bars – Tensile Strength Test, per UL 746A, and per ASTM D882 (Method A), Standard Test Methods Tensile Properties of Thin Plastic Sheeting (cut in machine direction - see Figure 8.1).</p> <p>C) 70 bars – 125 mm (5 inches) long, 13 mm (0.5 inch) wide.</p> <p>D) 20 plaques – 100 mm (4 inches) square.</p>		

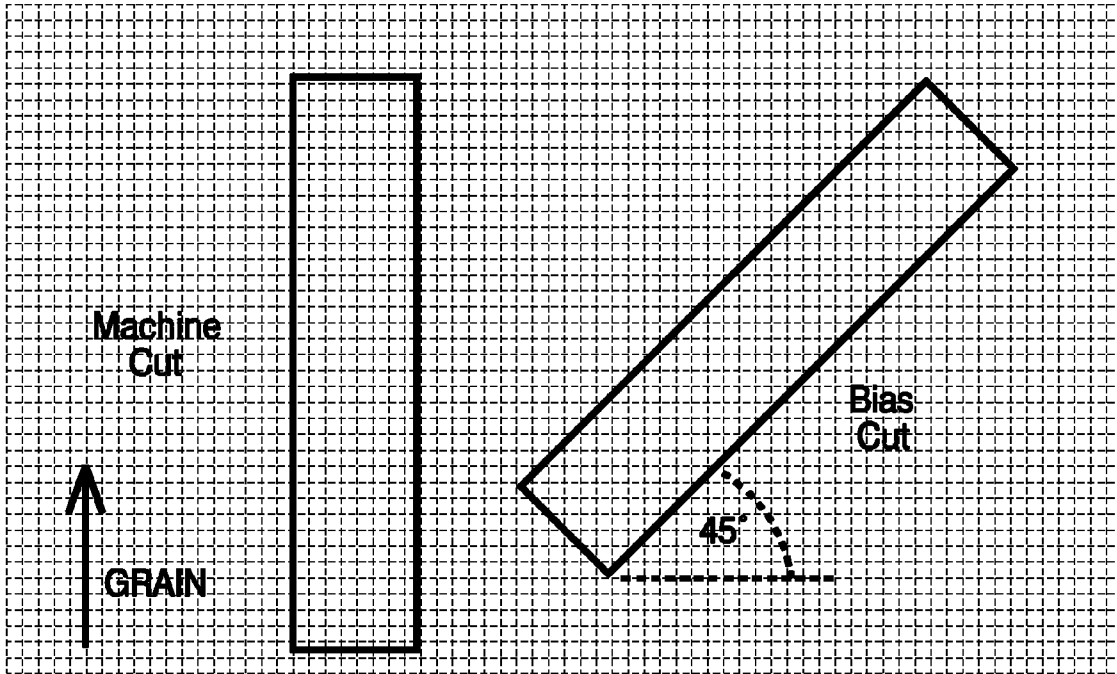
Table 8.4
Samples for two point thermal aging

Table 8.4 revised November 28, 2001

Thickness: Material in minimum built up thickness to be evaluated.	
Control– same material built up to 0.38 mm (0.015 inch) thickness.	
A)	For Mechanical Relative Thermal Index (see 8.4) 100 – bars – Tensile Strength Test, per UL 746A and per ASTM D882 (Method A), Standard Test Methods for Tensile Properties of Thin Plastic Sheeting (cut in a bias direction - see Figure 8.1), 100 bars – Tensile Strength Test, per UL 746A and per ASTM D882 (Method A), Standard Test Methods for Tensile Properties of Thin Plastic Sheeting (cut in a machine direction - Figure 8.1).
B)	For Optional Electrical Temperature Index (see 8.7) 100 samples, 100 mm (4 inches) square.
NOTE: The control material is to be made from the same thickness of individual sheets as limited by Tables 8.1 and 8.2.	

Figure 8.1
Example of bias and machine cuts for tensile strength samples – Laminate sheet incorporating woven fibers

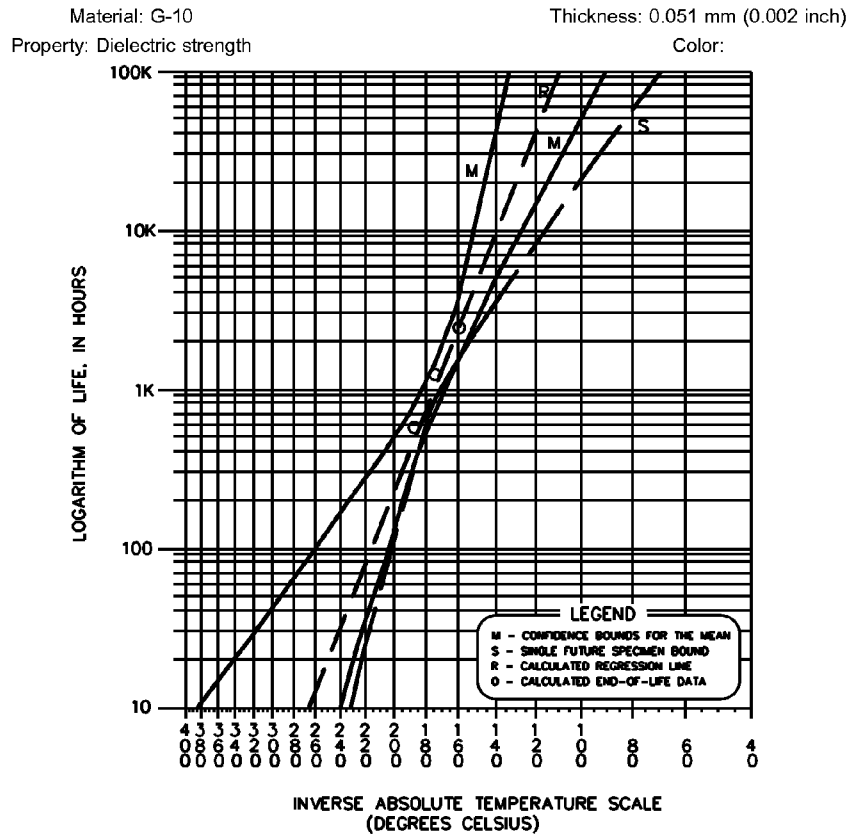
Figure 8.1 added November 28, 2001



S4341A

Figure 8.2
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.2 revised November 28, 2001



S3017

End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
180	610
170	1250
160	2100

Correlation coefficient K = 0.9945

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.651655 \times 10^9;$

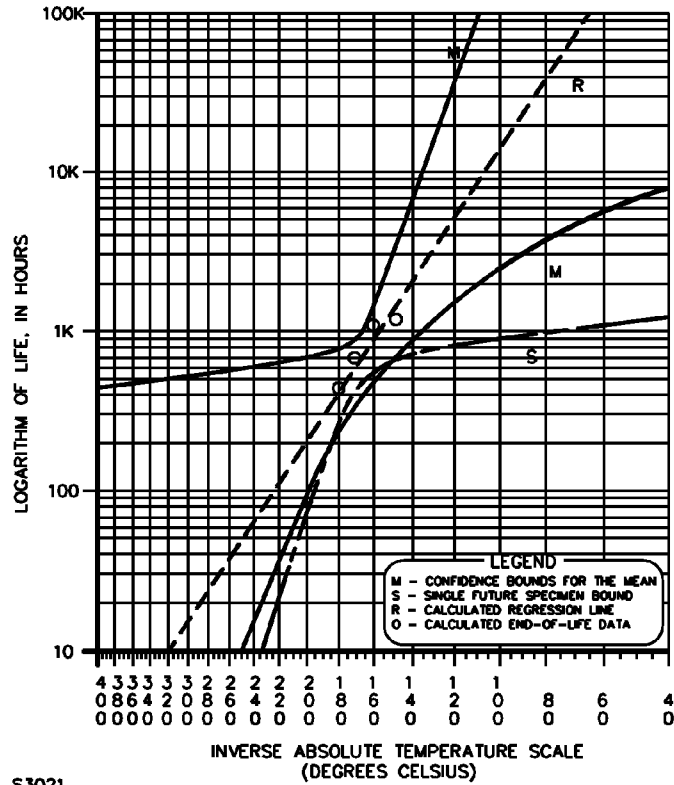
$B = 12119.2$

Where L is in hours and T is in degrees celsius

Figure 8.6
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.6 revised November 28, 2001

Material: G-10 UT lam Thickness: 0.10 mm (0.004 inch)
 Property: Dielectric strength Color:



S3021

End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
150	1035
160	970
170	560
180	350

Correlation coefficient K = 0.9579

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

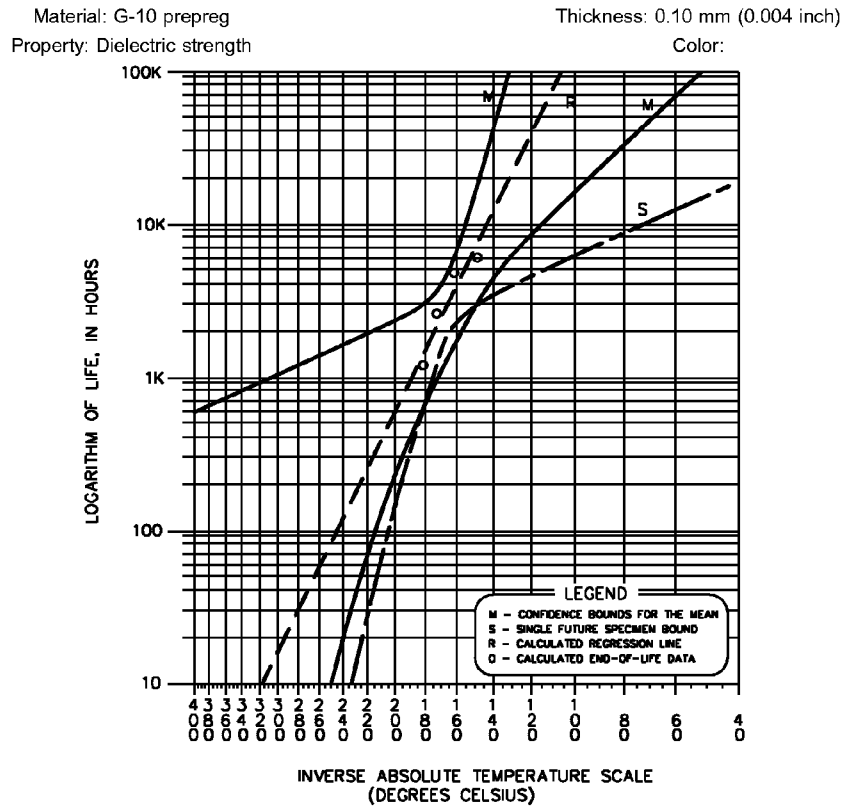
A = 1/23455.9;

B = 7253.31

Where L is in hours and T is in degrees celsius

Figure 8.8
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.8 revised November 28, 2001



S3023

End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
150	5000
160	4000
170	2350
180	1100

Correlation coefficient K = 0.9682

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.148874 \times 10^7;$$

$$B = 9680.55$$

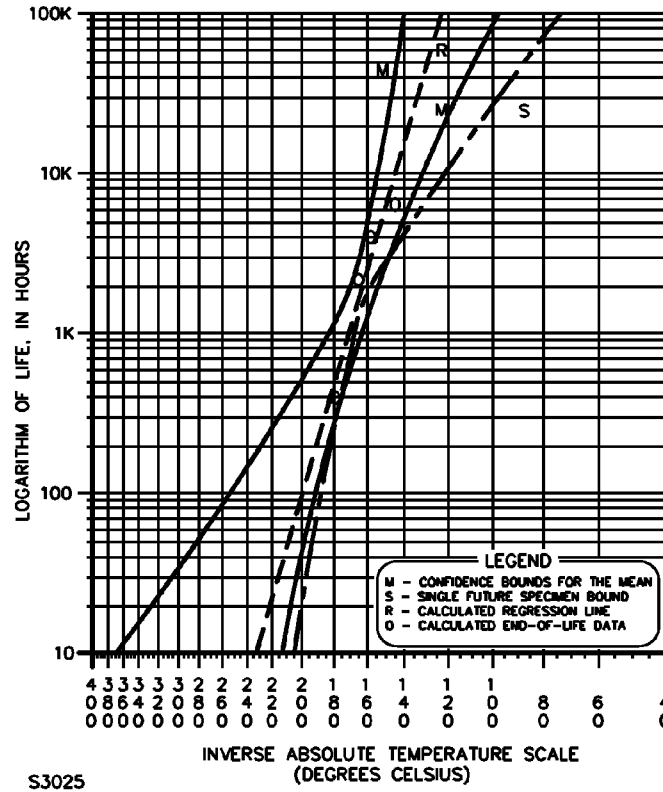
Where L is in hours and T is in degrees celsius

Figure 8.10
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.10 revised November 28, 2001

Material: FR-4 UT laminate
 Property: Dielectric strength

Thickness: 0.38 mm (0.015 inch)
 Color:



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
150	4050
160	2400
170	980
180	300

Correlation coefficient K = 0.9823

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.239228 \times 10^{14}$;

$B = 16628.9$

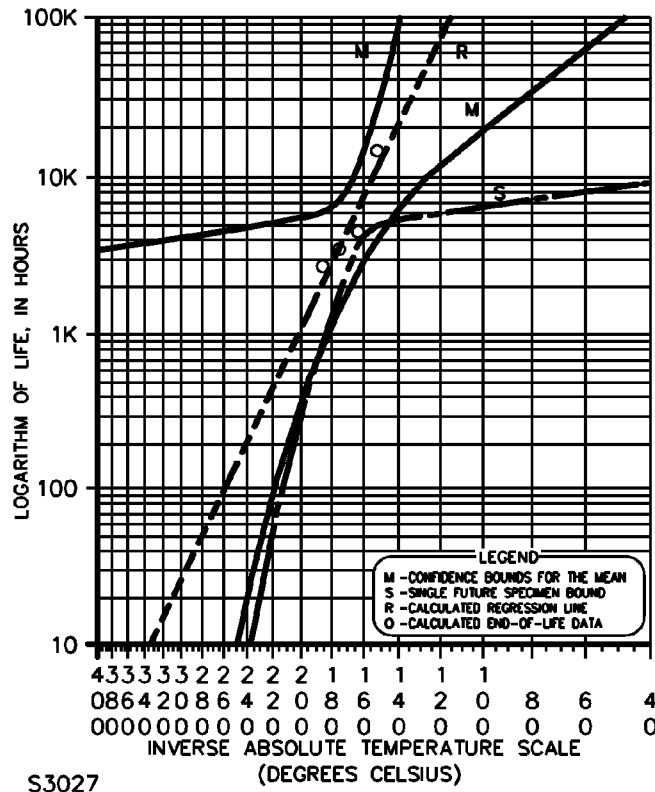
Where L is in hours and T is in degrees celsius

Figure 8.12
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.12 revised November 28, 2001

Material: FR-4 UT prepreg
 Property: Dielectric strength

Thickness: 0.10 mm (0.004 inch)
 Color:



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
150	13000
160	4800
170	3500
180	2600

Correlation coefficient K = 0.9554

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.142591 \times 10^7;$

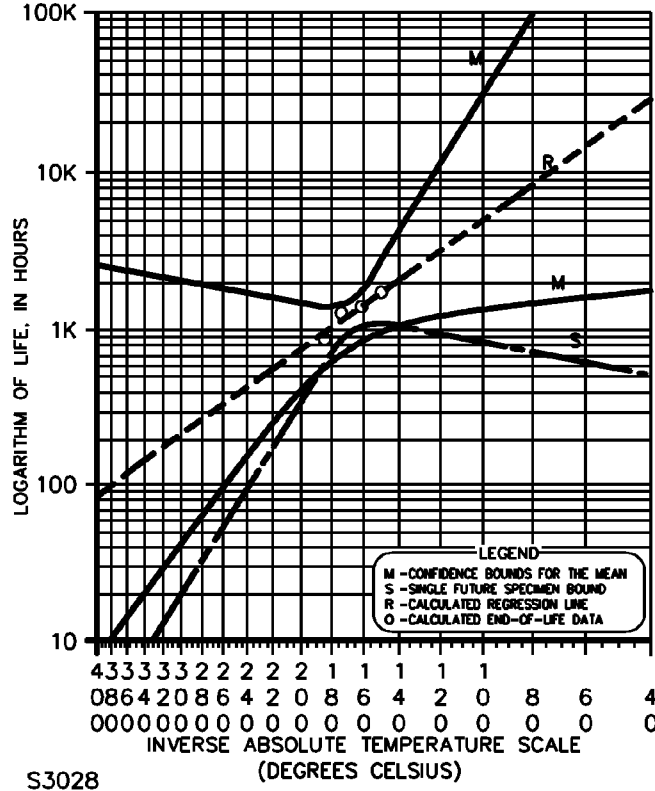
$B = 9924.03$

Where L is in hours and T is in degrees celsius

Figure 8.13
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.13 revised November 28, 2001

Material: FR-4 UT prepreg Thickness: 0.051 mm (0.002 inch)
 Property: Dielectric strength Color:



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
150	1450
160	1270
170	1200
180	810

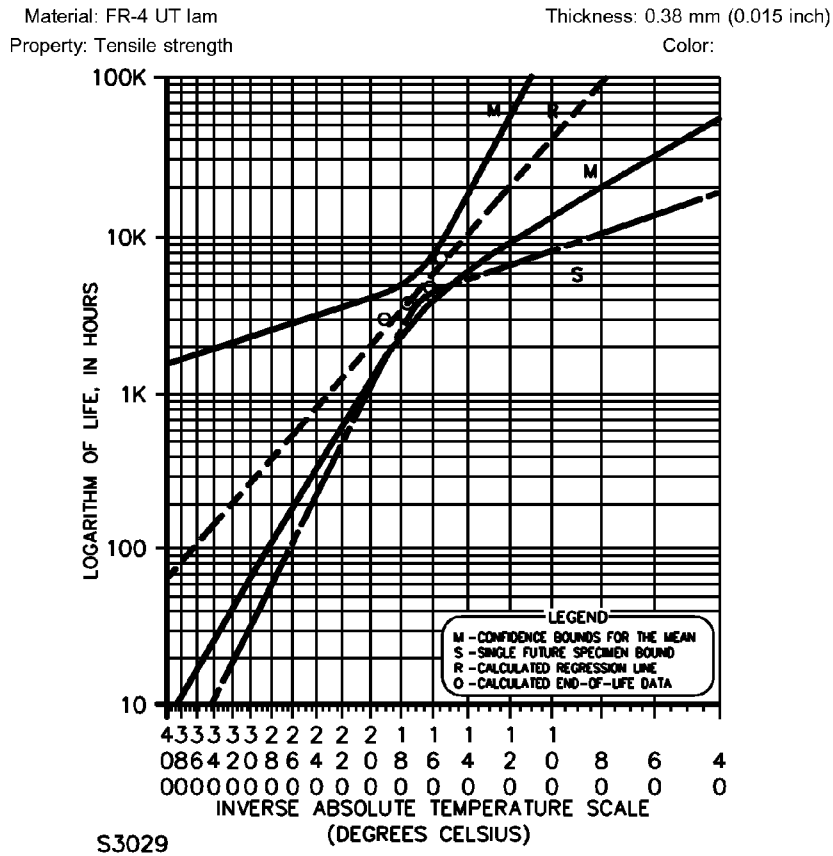
Correlation coefficient K = 0.9235
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/2.20274;
 B = 3434.58

Where L is in hours and T is in degrees celsius

Figure 8.14
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.14 revised November 28, 2001



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
150	7200
160	4400
170	3700
180	3000

Correlation coefficient K = 0.9724
 The Arrhenius equation: $L = A(2.718282)^{B/(T + 273.16)}$

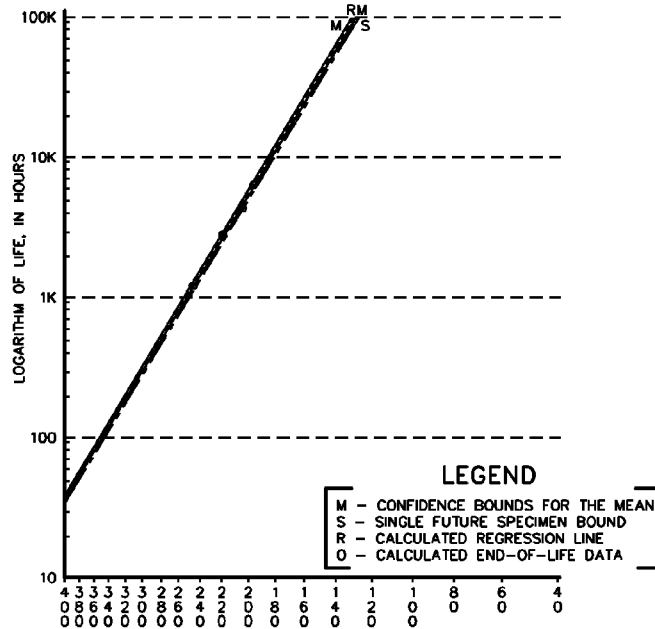
$A = 1/51.4767;$
 $B = 5392.52$

Where L is in hours and T is in degrees Celsius

Figure 8.16
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.16 revised November 28, 2001

Material: GPY UT lam Thickness: 0.10 mm (0.004 inch)
 Property: Tensile strength Color:



**INVERSE ABSOLUTE TEMPERATURE SCALE
 (DEGREES CELSIUS)**

SM255

End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
235	544
210	1186
200	1657
190	2350

Correlation coefficient K = 1.00001

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/6378.05;

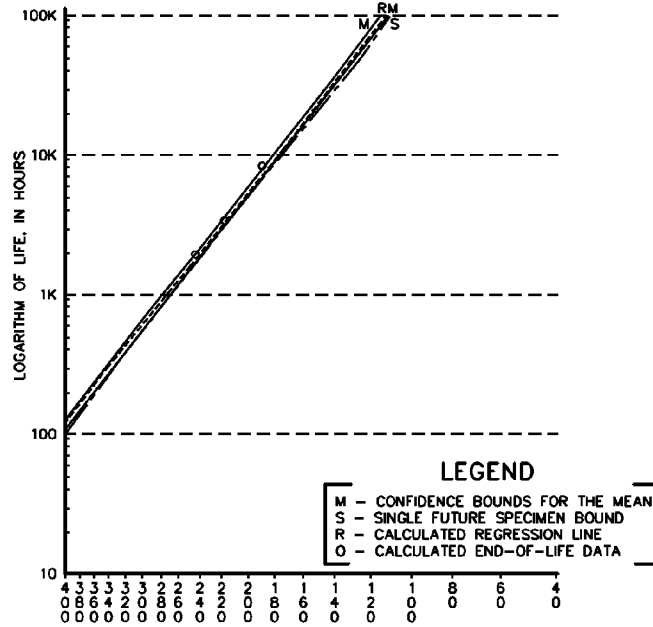
B = 7652.72

Where L is in hours and T is in degrees celsius

Figure 8.17
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.17 revised November 28, 2001

Material: GPY UT lam Thickness: 0.38 mm (0.015 inch)
 Property: Tensile strength Color:



**INVERSE ABSOLUTE TEMPERATURE SCALE
 (DEGREES CELSIUS)**

SM256

End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
235	1336
210	2911
200	4067
190	5766

Correlation coefficient K = 0.999989

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.15)}$

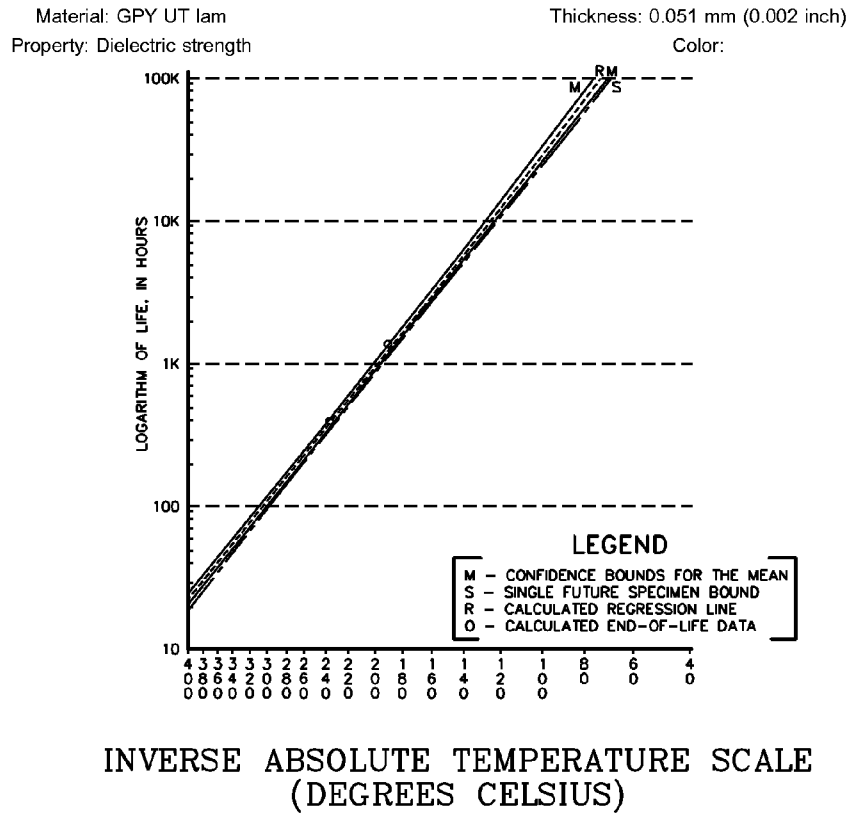
A = 1/2574.01;

B = 7648.01

Where L is in hours and T is in degrees celsius

Figure 8.18
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Figure 8.18 revised November 28, 2001



SM257

End-of-life criterion: 50% retention of property level

Laboratory data:

Temperature (C)	Hours to end-of-life
225	2382
210	4549
180	8036

Correlation coefficient K = 0.999987

The arrhenius equation: $L = A (2.718282)^{B/(T + 273.15)}$

A = 1/87.2966;

B = 6099.99

Where L is in hours and T is in degrees celsius

8A INSULATING MATERIALS INTENDED FOR USE IN FABRICATING HIGH DENSITY INTERCONNECT (HDI) TYPE CONSTRUCTIONS

Added Section 8A effective February 7, 2004

8A.1 General

8A.1.1 The test program for dielectric materials, Multilayer Build-Up Materials (BUM), and similar insulating materials for use in fabricating High Density Interconnect (HDI) Type Constructions outlines the testing of dielectric materials for use in fabricating multilayer printed wiring boards where the dielectric material requires mechanical support from a separate core material. The test program consists of two parts in which the first part covers the evaluation of the electrical thermal index of the dielectric material, and the second part covers the evaluation of the performance profile characteristics. This test program is not intended to establish a mechanical thermal index for the dielectric material. The mechanical thermal index is established for the dielectric and core material construction based on the mechanical thermal index of the core material.

8A.1.2 High Density Interconnect (HDI) materials and/or Multilayer Build-Up Materials (BUM) are defined as very thin insulating materials used to support conductor materials, intended for the production of microvias using sequential build up and related multilayer interconnect technologies.

8A.1.3 Dielectric materials (i.e., HDI and BUM materials) shall include, but not be limited to very thin thickness insulating materials supporting conductor materials requiring mechanical strength from a separate core material. Materials such as resin-coated copper (RCC), liquid photoimageable (LPI) insulating coating materials, photoimageable film insulating coating materials, and other very thin thickness insulating material, when used to support conductor material, shall be considered dielectric materials.

8A.1.4 The core material used to support the dielectric material must have an established electrical and mechanical relative thermal index (RTI) based on testing to the appropriate criteria outlined in this standard.

8A.1.5 The dielectric and core material constructions are evaluated as Non-ANSI type materials.

8A.1.6 The dielectric material is to be applied to the core material by the curing and production processes used to fabricate the dielectric and core material multilayer construction.

8A.2 Thermal Aging

8A.2.1 Thermal aging samples are to be constructed as described in either Figure 8A.3, or Figure 8A.2, or Figures 8A.3 and 8A.4 incorporating traces insulated by a dielectric material.

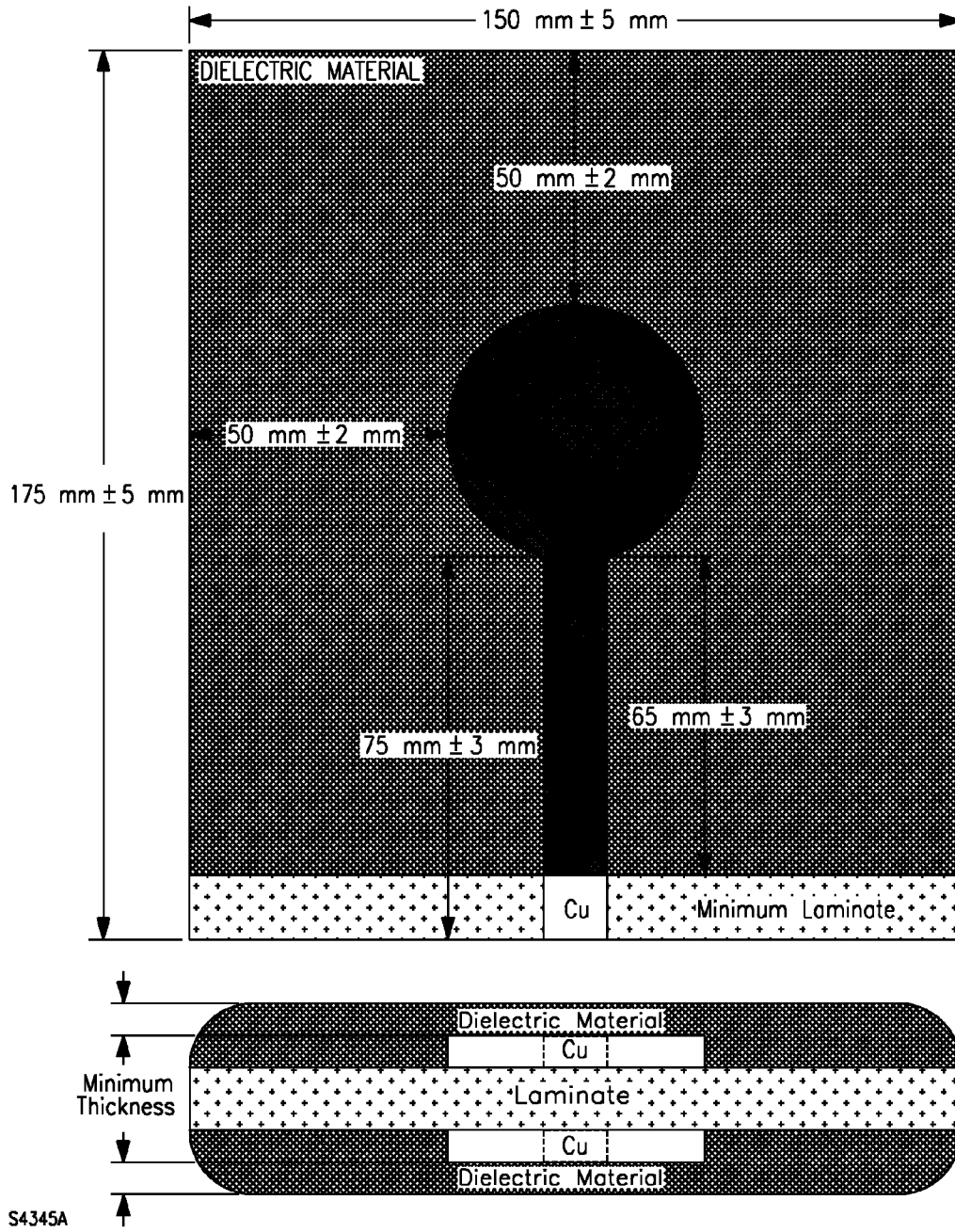
8A.2.2 The thermal aging samples shown in Figures 8A.1 and 8A.2 shall be prepared with the minimum dielectric material thickness on both surfaces of the minimum thickness core material. The minimum copper weight shall be used on the core material and etched in the key hole pattern shown in Figure 8A.1. The resin shall be removed from one edge of the sample to expose 13 mm (0.5 inch) of the underlying copper. All copper shall be completely etched off the external dielectric material surfaces.

8A.2.3 The thermal aging samples shown in Figures 8A.3 and 8A.4 shall be prepared with the minimum dielectric material thickness on both surfaces of the minimum thickness core material. The minimum copper weight shall be used on the core and dielectric materials and etched in the crossover pattern shown in Figures 8A.3 and 8A.4. The resin shall be removed from two edges of the sample to expose 13 mm (0.5 inch) of the underlying copper.

8A.2.4 The conductor pattern shall be included on both sides of the samples and the conductor patterns shall be positioned directly opposite each other, as mirror images, if double sided constructions are intended for production; or, the conductor pattern shall be included on one side of the samples if only single sided constructions are intended for production. A double sided construction may be considered representative of constructions of identical materials with only single sided construction; however, a single sided construction is not considered representative of a double sided construction.

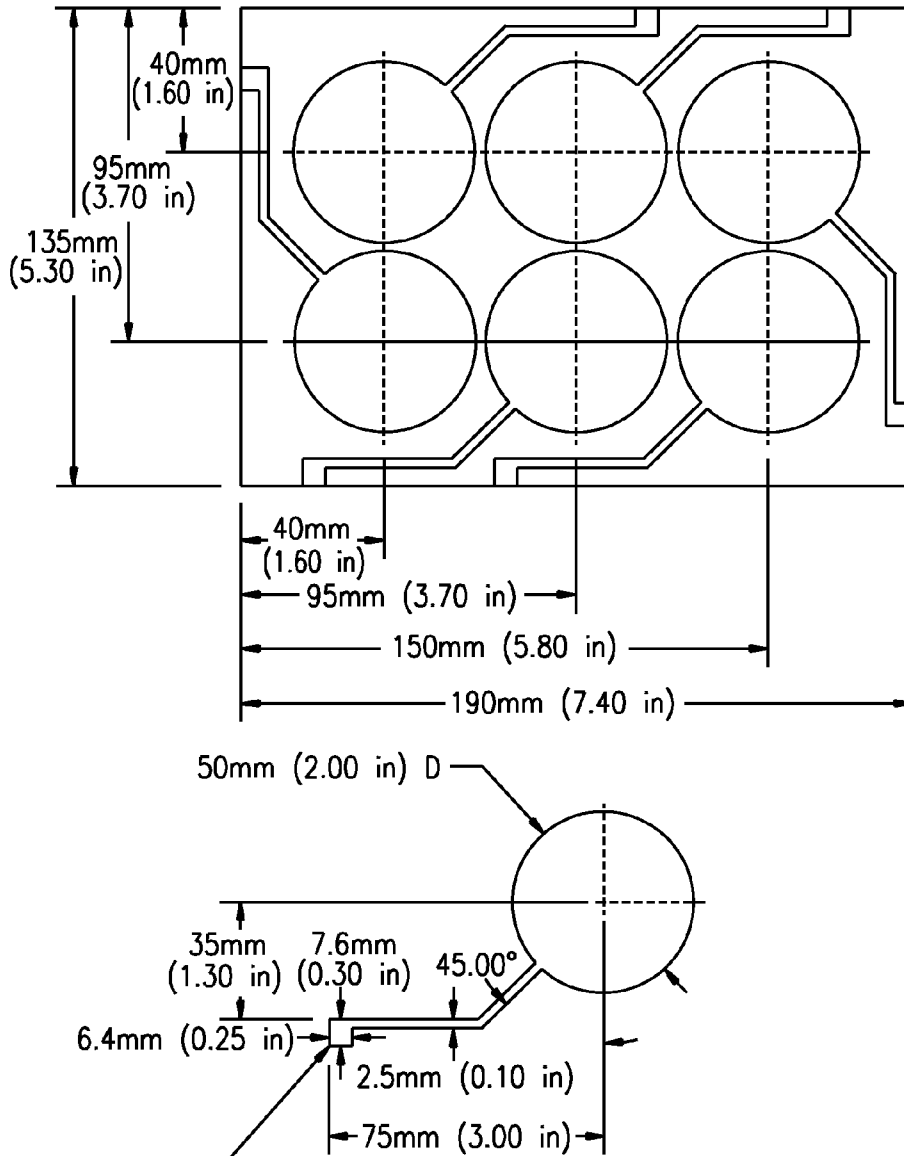
8A.2.5 The electrical thermal index shall be determined for the minimum core material thickness and minimum dielectric material (HDI/BUM) thickness by conducting a four-point thermal aging in accordance with UL 746B, the Standard for Polymeric Materials – Long Term Property Evaluations. The samples are to be evaluated in accordance with the criteria outlined in UL 746B, Section 20 (fixed temperature aging method) or Section 20A (fixed time aging method). Dielectric strength shall be the primary property tested in the aging program in accordance with ASTM D149, Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies. Flammability shall be the secondary property tested. The Secondary Property flame samples are to be constructed as per 8A.3.1A and 8A.3.1B and evaluated only after the primary property has reached end of life in the fixed temperature aging program at the highest aging temperature or when the 500 hours end-point (50 percent) temperature has been determined if the fixed time aging method is used. If using the key hole pattern aging sample, a 6 mm (0.25 inch) diameter electrode per ASTM D149(1995), Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies, is to be used. If using the crossover pattern aging sample, only Test Points (TP) 1 – 6 as shown in Table 18.2 shall be tested unless warping occurs. If the sample experiences warping, Test Points (TP) 7 – 12 shall be tested. The sides will be determined as indicated in Figure 8A.5. The dielectric material shall not show evidence of wrinkling, cracking, blistering, or delamination when subjected to the thermal aging described above.

Figure 8A.1
Key hole dielectric aging sample



Note: All dimensions are minimum.

Figure 8A.2
Alternate dielectric aging sample



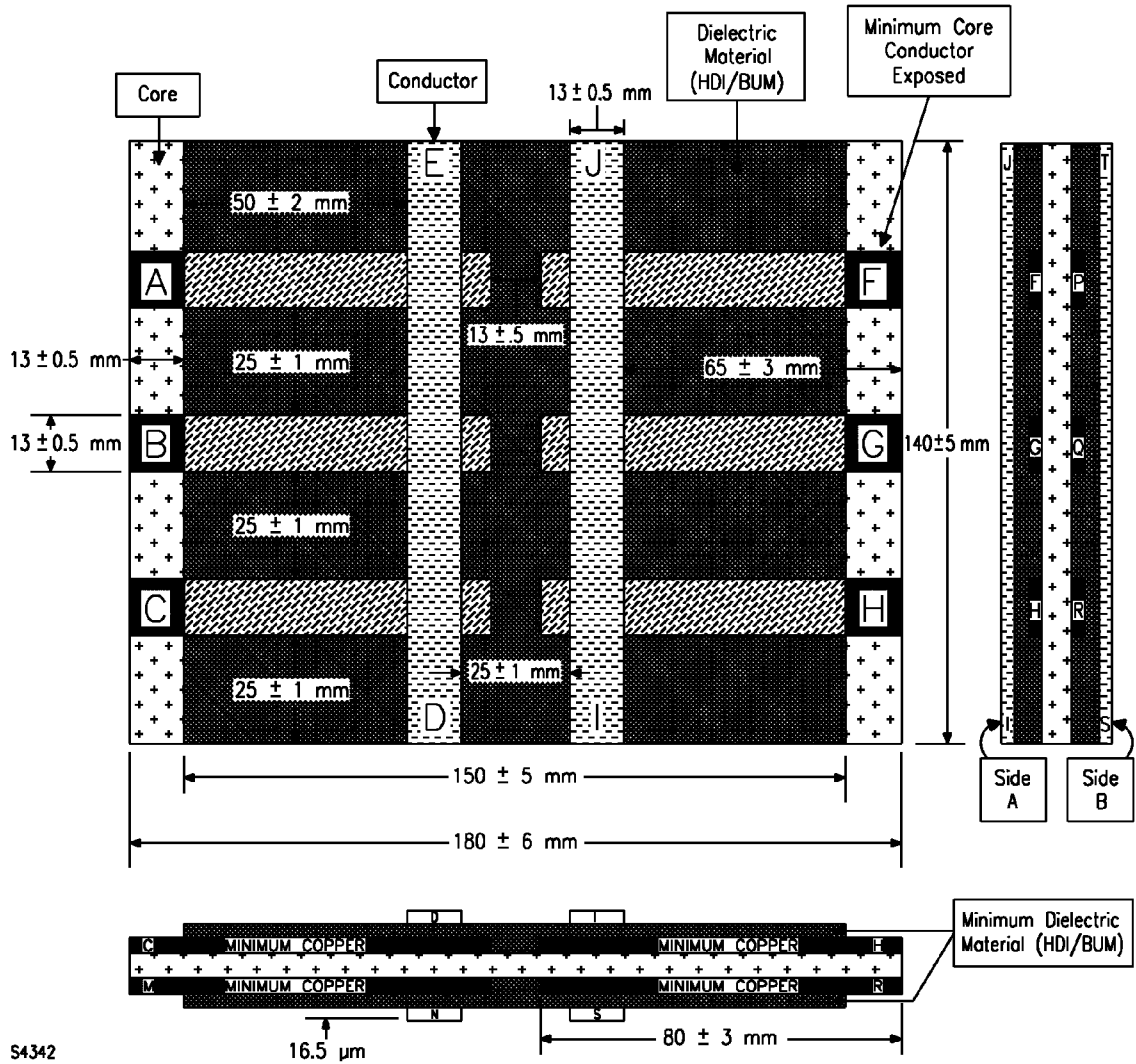
This pad is to be left exposed, remainder of sample is coated with HDI Material.

S4358A

Note: All six test sites are identical dimensionally and are rotated 90 degrees as shown in the diagram above.

Test samples are to be double sided for a total of twelve sites per sample.

Figure 8A.3
Crossover aging sample side A



S4342

Note: All dielectric dimensions are minimum.

Figure 8A.4
Crossover aging sample side B

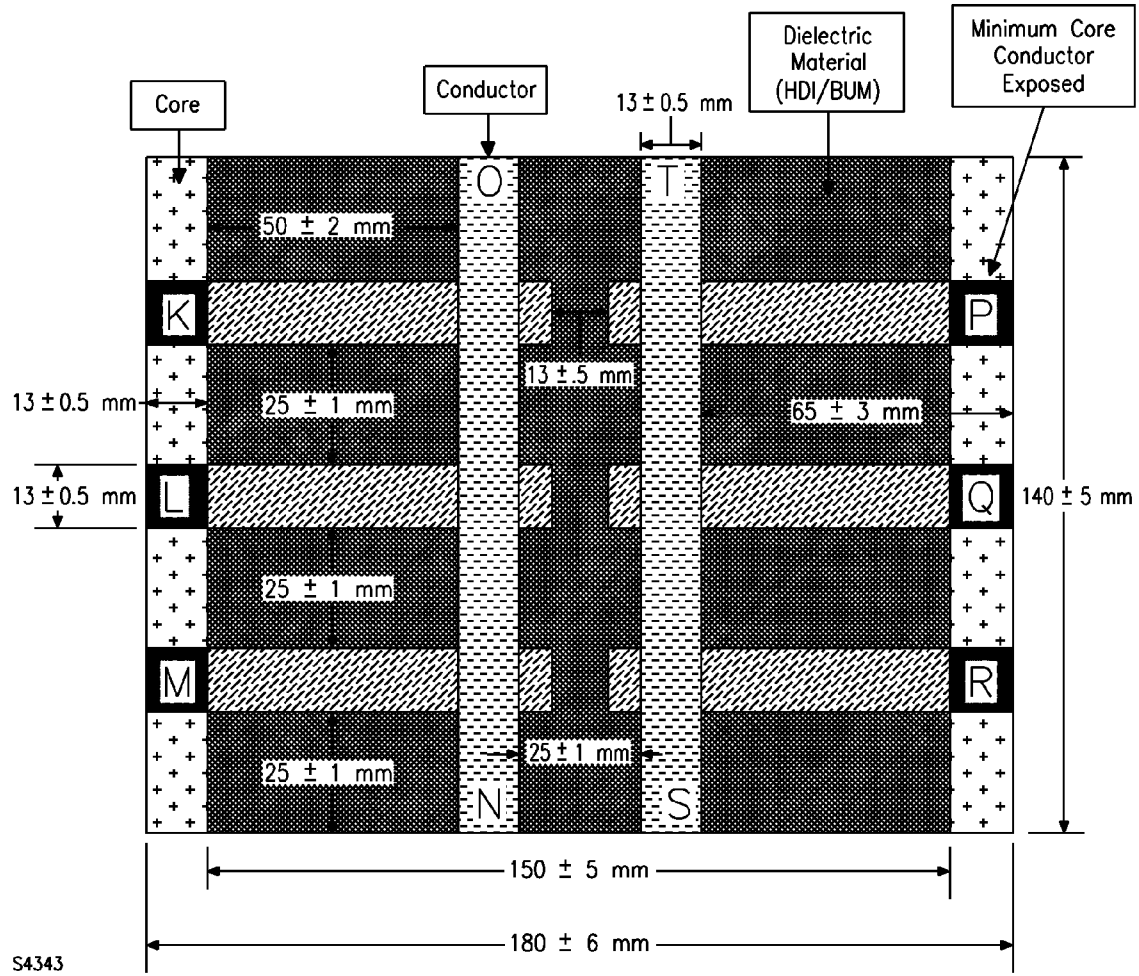
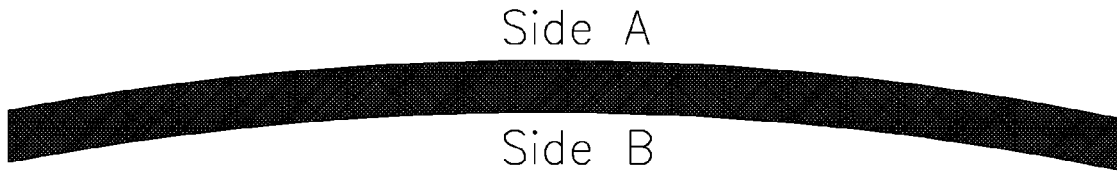


Figure 8A.5
Side determination



S4344

Table 8A.2
Crossover pattern aging sample dielectric test points

	Test Points	From	To
SIDE A	1	A	D
	2	B	D
	3	C	E
	4	F	I
	5	G	I
	6	H	J
SIDE B	7	K	N
	8	L	N
	9	M	O
	10	P	S
	11	Q	S
	12	R	T

The rate of rise shall be maintained at a constant rate throughout the Dielectric Strength aging program and shall give an average time to breakdown between 10 and 20 sec per ASTM D149. The rate of rise may be determined by dividing the "as received" dielectric strength value by 20 sec.

Exception: If the HDI material has been previously evaluated per UL 746E with a recognized electrical RTI, generically similar HDI and core materials shall not be subjected to thermal aging, but shall be subjected to the Performance Indexing tests. Generically dissimilar HDI and core materials shall be subjected to a two-point aging program using dielectric strength as the aging test characteristic and the performance indexing tests.

8A.3 Performance Profile Indexing

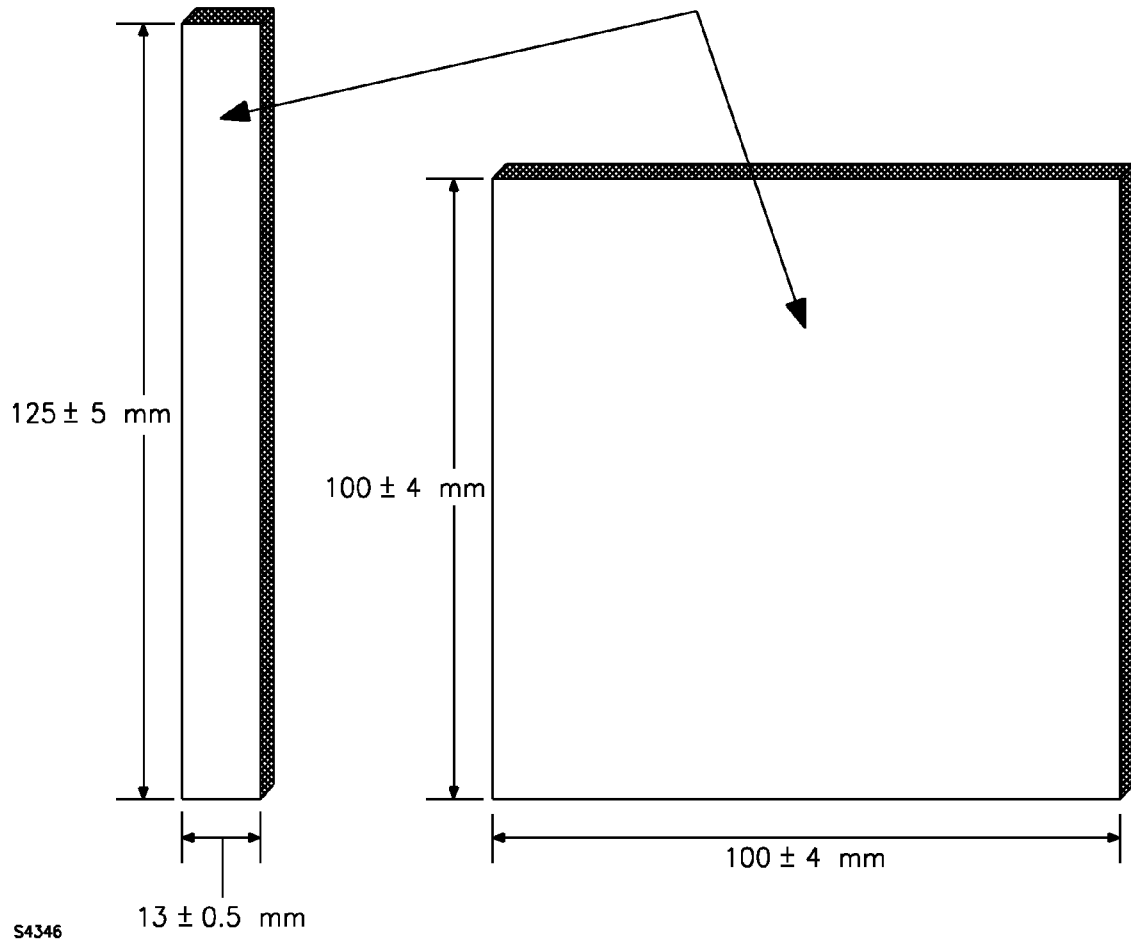
8A.3.1 Samples constructed as described in Figure 8A.6 are to be subjected to the test outlined in Table 8A.3 in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A and the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.

Table 8A.3
Indexing test samples

Test	Sample Size (mm)	Number of Samples	Sample Code
Volume and Surface Resistivity	100 by 100	12	C
CTI	100 by 100	30	C
Dielectric Strength	100 by 100	10	D
HAI	125 by 13	10, 10	A, B
HWI	125 by 13	10, 10	A, B
Flammability	125 by 13	20, 20	A, B
IR, TGA	125 by 13	–	E
Sample Codes			
<p>A) bars - 125 mm (5 inch) long, 13 mm (0.5 inch) wide Samples should be provided with one layer of the minimum resin thickness coating on both surfaces of a minimum thickness core material. All copper shall be completely etched off all layers.</p> <p>B) bars - 125 mm (5 inch) long, 13 mm (0.5 inch) wide Samples should be provided with one layer of the maximum resin thickness coated on both surfaces of a minimum thickness core material. All copper shall be completely etched off all layers.</p> <p>C) plaques - 100 mm (4 inch) square Samples shall be provided with twice the minimum resin thickness on both surfaces of the minimum thickness core material. The minimum copper weight shall be provided, only between the resin layer and the core material. The resin shall be removed from one edge of the sample to expose 13 mm (0.5 inch) of the underlying minimum copper weight. Copper shall not be provided on external resin surfaces.</p> <p>D) plaques - 100 mm (4 inch) square Samples shall be provided with minimum resin thickness on both surfaces of the minimum thickness core material. The minimum copper weight shall be provided, only between the resin layer and the core material. The resin shall be removed from one edge of the sample to expose 13 mm (0.5 inch) of the underlying minimum copper weight. Copper shall not be provided on external resin surfaces.</p> <p>E) Approximately 60 g (2 oz) of the dielectric material in any shape. Samples shall be provided of fully cured dielectric material.</p>			

Figure 8A.6
Indexing samples

See Table 8A.3 for Details of Sample Construction



8A.4 Metal Clad Test Program

8A.4.1 The Metal Clad test program is an optional evaluation for the dielectric material manufacturer. The Metal Clad test program shall be performed to determine bond strength, delamination, and flammability characteristics of the dielectric material.

8A.4.2 The Bond Strength/Delamination tests shall be performed on minimum and maximum constructions with 2 layers of dielectric material on each side of the minimum thickness core material.

Exception: The Metal Clad test program may be performed on only 1 layer of dielectric material on each side of the minimum thickness core material for both the Bond Strength/Delamination and Flammability tests. If only 1 layer of dielectric material is tested, the Metal Clad parameter values will be limited to 1 layer of dielectric material.

8A.4.3 The Flammability testing shall be performed where 1 layer is the minimum and 2 layers is the maximum number of dielectric material layers.

Exception: The Metal Clad test program may be performed on only 1 layer of dielectric material on each side of the minimum thickness core material for both the Bond Strength/Delamination and Flammability tests. If only 1 layer of dielectric material is tested, the Metal Clad parameter values will be limited to 1 layer of dielectric material.

8A.5 Vertical Flammability Evaluation

8A.5.1 Twenty samples each constructed in accordance with Figure 8A.7 a - d are to be subjected to the Flammability evaluation as described in 14.6.

Note: The example in Figure 8A.7 would represent the Flammability Test Samples required for an application using minimum and maximum dielectric material thicknesses of 2 mil and 3 mils respectively and minimum and maximum number of dielectric material layers of 1 and 3 respectively.

8A.6 Bond Strength Evaluation

8A.6.1 Six samples containing foil-type or clad conductors and constructed as described in Figures 14.1 and 8A.8, are to be subjected to Bond Strength evaluation as described in 14.5.

8A.6.2 Three samples containing foil-type or clad conductors and constructed as described in Figure 14.1 and 8A.8, are to be conditioned as specified in 8A.6.4. Following thermal cycling conditioning, the boards are to be subjected to the bond strength evaluation outlined in 14.5.

8A.6.3 Thermal Cycling

- a) Thermal shock at the manufacturer's specified maximum temperature and time;
- b) Thermal conditioning for three cycles of the following using the scheduling described in Table 8A.2:
 - 1) 48 hours at 10°C (18°F) above the maximum operating temperature specified by the manufacturer;
 - 2) 64 hours at 35°C ±2°C (95°F ±3.6°F) at 90 ±5 percent humidity;
 - 3) 8 hours at 0°C (32°F); and

- 4) 64 hours at 35°C ±2°C (95°F ±3.6°F) at 90 ±5 percent humidity.

8A.7 Test Programs for Revising Dielectric Material Parameters

8A.7.1 The established core thickness may be reduced in the dielectric and core material construction by performing the following Test Program. The samples shall be constructed as described in 8A.2 and 8A.3 using the thinnest core thickness:

- a) 2-point thermal aging using dielectric strength as the primary property and the original construction as the control in accordance with 8A.2, and
- b) Thickness Dependent Indexing – HAI, HWI and Flame.

8A.7.2 The dielectric material maximum thickness may be increased by performing the following test program. The samples shall be constructed as described in 8A.2 and 8A.3 using the dielectric material requested maximum thickness:

- a) Aging Flammability as a Secondary Property, and
- b) Thickness Dependent Indexing – HAI, HWI and Flame.

8A.7.3 The relative thermal index and performance profile characteristics can be established for a combination of dielectric materials by performing the following test program. The electrical thermal index of the combination of dielectric materials shall be at least as high as the lowest rated material. The combination of the materials is then to be assigned the electrical RTI of the lowest rated material. The samples shall be constructed as described in 8A.2 and 8A.3 using the combination of the dielectric materials:

- a) 2-point thermal aging using dielectric strength as the primary property and the original construction as the control in accordance with 8A.2, and
- b) HAI, HWI, CTI, Dielectric Strength, and Flame.

8A.7.4 A range of colors can be established for dielectric material by performing the following test program. The samples shall be constructed as described in 8A.3 using samples representing the range of colors:

- a) Perform IR and TGA on the natural color, and
- b) Flame tests on representative colors described in the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.

8A.7.5 An RTI can be established on a dielectric material with High Tg and Low Tg by performing the following test program. The samples shall be constructed as described in 8A.2 and 8A.3 using samples representing the High Tg and Low Tg:

- a) If the IR and TGA of each dielectric material compare, perform 4-point thermal aging on the Low Tg dielectric material and 2-point thermal aging on the High Tg dielectric material using the Low Tg material as the control. The aging shall be performed in accordance with 8A.2. The performance profile indexing tests in 8A.3 shall be performed on each material, or
- b) If IR and TGA of both dielectric materials does not compare, perform a 4-point thermal aging program and the performance profile indexing tests on each material.

8A.7.6 An RTI can be established for a dielectric material containing two or more components/layers, not comparable by IR, by performing the following test program:

- a) IR and TGA on each component
- b) Performance profile indexing on the dielectric material with each component at its corresponding minimum/maximum thickness,
- c) 4-point thermal aging on the dielectric material using the minimum component thicknesses, and
- d) Flame tests on the minimum and maximum component thicknesses

8A.7.7 Additional manufacturers of the dielectric material may be established by performing the following test program:

- a) IR, TGA, and Flame on the dielectric material produced by each manufacturer
- b) Verification of the same curing conditions and production processes as tested by the original manufacturer.

8A.7.8 Modifications to the chemical composition of the established dielectric material require testing as follows:

- a) IR, TGA, Flame, and Indexing tests per 8A.3
- b) Determine 4-point or 2-point thermal aging test program per UL 746B, Table 19.1.

8A.7.9 Additional forms of the same dielectric material (i.e., RCC and BUM) may be established by the following test program:

- a) IR, TGA, Flame, and Indexing per 8A.3 on each form of the dielectric material.
 - 1) If the IR scans compare between each form, perform a 4-point thermal aging on one form and a 2-point thermal aging program on second form per 8A.2, or
 - 2) If the IR scans do not compare between each form, perform 4-point thermal aging on each per 8A.2.

Figure 8A.7
Flammability sample constructions example

minimum layer thickness
and minimum number of layers

2 mil
minimum core
2 mil

a

maximum layer thickness
and minimum number of layers

3 mil
minimum core
3 mil

b

maximum layer thickness
and maximum number of layers

3 mil
3 mil
3 mil
minimum core
3 mil
3 mil
3 mil

c

minimum layer thickness
and maximum number of layers

2 mil
2 mil
2 mil
minimum core
2 mil
2 mil
2 mil

d

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Notes:

Each Solder Mask shall be tested. All combinations (coated and uncoated) are requested at the start of the test program.

All four uncoated constructions shall be tested at the start of the program.

Each Figure 8A.7 coated constructions (a) and (c) shall be tested.

Figure 8A.7 coated constructions (b) and (d) may be tested depending on the performance of the Figure 8A.7 (a) and (c) constructions.

Figure 8A.8
Bond strength constructions

A	Layer	B
Minimum Cu	1	Minimum Cu
Minimum HDI Material	2	Least Amount of HDI Material needed for the Maximum Cu
Most Amount of Cu Used w/Minimum HDI material	3	Maximum Cu
Any HDI Material Thickness	4	Any HDI Material Thickness
Any Cu thickness*	5	Any Cu thickness*
Minimum HDI Material	6	Least Amount of HDI Material needed for the Maximum Cu
Most Amount of Cu Used w/Minimum HDI material	7	Maximum Cu
Minimum core	8	Minimum core
Any Cu thickness*	9	Any Cu thickness*
Any HDI Material Thickness	10	Any HDI Material Thickness
Any Cu thickness*	11	Any Cu thickness*
Any HDI Material Thickness	12	Any HDI Material Thickness
Any Cu thickness*	13	Any Cu thickness*
Any HDI Material Thickness	14	Any HDI Material Thickness
Minimum Cu	15	Minimum Cu

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* Not to exceed Maximum Copper Thickness, and

Layers 4 & 5 and 11 & 12 shall be repeated as many times as necessary to achieve maximum number of layers. This example represents a maximum of 3 layers of HDI Material.

Note: Figure 8A.8 constructions A and B shall be constructed with the Maximum number of layers on each side.

8A.7.10 An alternate core material can be established for the dielectric material by performing the following test program. The samples shall be constructed as described in 8A.2 and 8A.3.

- a) Performance profile indexing on the dielectric and alternate core material combination in accordance with 8A.3.
- b) If the RTI of the dielectric and alternate core material combination is to be increased greater than 10°C above the RTI of the current combination, then perform 4-point thermal aging using dielectric strength as the primary property and the original construction as the control in accordance with 8A.2, or
- c) If the assigned RTI of the dielectric and alternate core material combination will not increase more than 10°C above the current rating, then perform 2-point thermal aging using dielectric strength as the primary property and the original construction as the control in accordance with 8A.2.

VULCANIZED FIBRE

9 General

9.1 Profiles of performance and relative thermal indices for vulcanized fibre are given in Tables 9.1 and 9.2. These profiles are the minimum characteristics required for vulcanized fibre to be considered acceptable. Vulcanized fibre shall be evaluated by comparison of its profile of performance with the data given in Tables 9.1 and 9.2.

Table 9.1
Vulcanized fibre generic temperature index

Table 9.1 revised November 28, 2001

Designation	Nominal thickness		Tolerance		Relative thermal index	
	mm	(inch)	mm	(inch)	Electrical (°C)	Mechanical (°C)
Vulcanized fibre	0.8	(0.031)	±0.076	(±0.003)	115	110
	1.6	(0.062)	±0.102	(±0.004)	115	110

Table 9.2
Summary of performance indexing data on vulcanized fibre

Table 9.2 revised November 28, 2001

Thickness		Hot wire ignition (PLC)	High voltage arc resistance (ASTM 495) (PLC)	Volume resistivity (ohm-cm)	Dielectric strength volt/mm (volt/mil)	Flexural strength		Dimensional stability percent change
mm	(inches)					MPa	(psi)	
0.8	(0.031)	—	—	—	—	103.4	(15,000)	—
1.6	(0.062)	4	6	7.09×10^{11}	27.913 (709)	103.4	(15,000)	0.43

10 Vulcanized Fibre Test Program

10.1 Vulcanized fibre is to be evaluated on the basis of unaged property tests. See Table 10.1 for the required tests and specimens.

10.2 Vulcanized fibre test data which compares favorably with the requirements of 10.3 shall be considered acceptable, and be assigned the same relative thermal index and profiles of performance values shown in Tables 9.1 and 9.2.

Table 10.1
Vulcanized fibre test program testing and sample requirements

Table 10.1 revised November 28, 2001

Tests	Test method
1) Infrared analysis comparison	UL 746A
2) Flexural strength	UL 746A
3) Zinc chloride analysis	ASTM D 691 for extraction, ASTM D 1224 for measurement by atomic absorption
4) Dielectric strength	UL 746A
5) Flammability	UL 94
Samples a) 20 specimens: each 100 mm (4 inches) long, 25 mm (1 inch) wide, and 1.6 mm (0.062 inch) thick. b) 20 specimens: each 100 mm (4 inches) in length and width, and 1.6 mm (0.062 inch) thick. For the following two types of specimens, the edges are to be smooth and the radius on the corners is not to exceed 1.3 mm (0.05 inch). c) 30 specimens: 125 mm (5 inches) long, 13 mm (0.5 inch) wide, and 1.6 mm (0.062 inch) thick. d) 30 specimens: same as c except 0.8 mm (0.031 inch) thick.	

10.3 The following criteria shall be used in determining whether or not the material compares favorably with this data.

- a) The infrared spectrum shall be of the same basic composition as is given in Figure 10.3. A fundamental variation in composition from this spectrum is not acceptable. Examples of the unacceptable fundamental variations are given in 6.6 (a) – (d).
- b) The flexural strength values in the 1.6 mm (0.062 inch) thickness shall be not less than 103.4 MPa (15,000 psi) lengthwise.

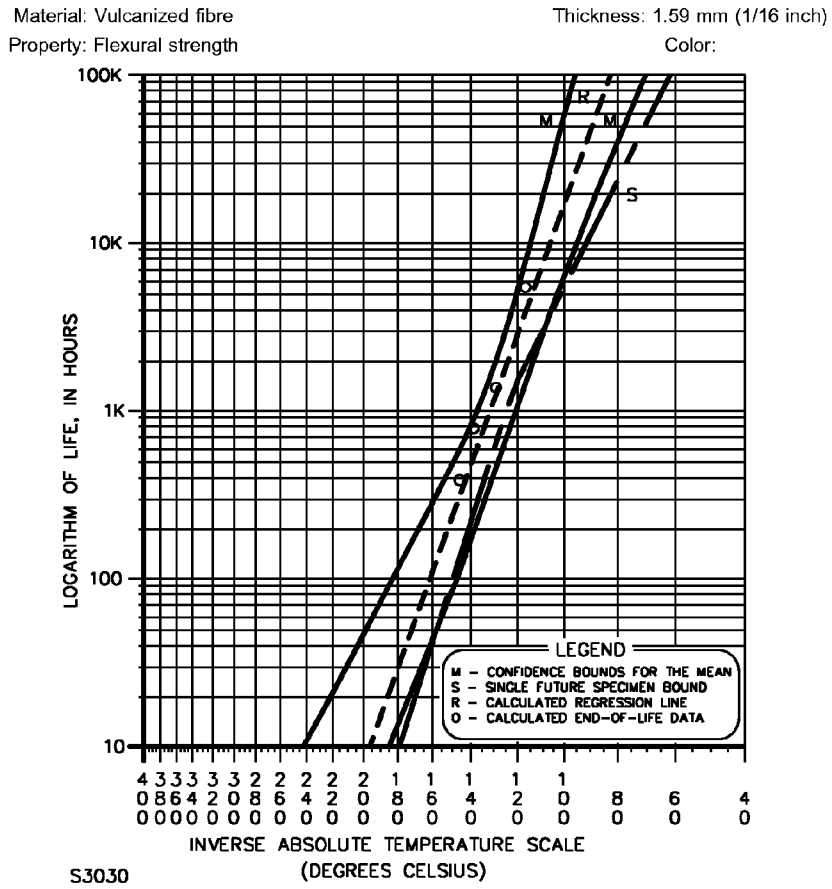
- c) The dielectric strength average value shall not be less than 175 volts/mil on the 0.8 mm (0.031 inch) thick material.
- d) Zinc chloride analysis values shall be less than 0.1 percent by volume, but a trace should be present.

10.3 revised November 28, 2001

10.4 When the material does not compare favorably with the criteria in 10.3, a full set of unaged property tests and a four temperature thermal aging shall be required.

10.5 When unaged property criteria other than those found in Table 9.2, or a temperature index higher than shown in Table 9.1 is desired, applicable indexing tests in UL 746A, Polymeric Materials-Short Term Property Evaluations or aging tests in UL 746B, Polymeric Materials-Long Term Property Evaluations, shall be performed to determine those properties.

Figure 10.1
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
145	285
135	780
125	1350
115	3600

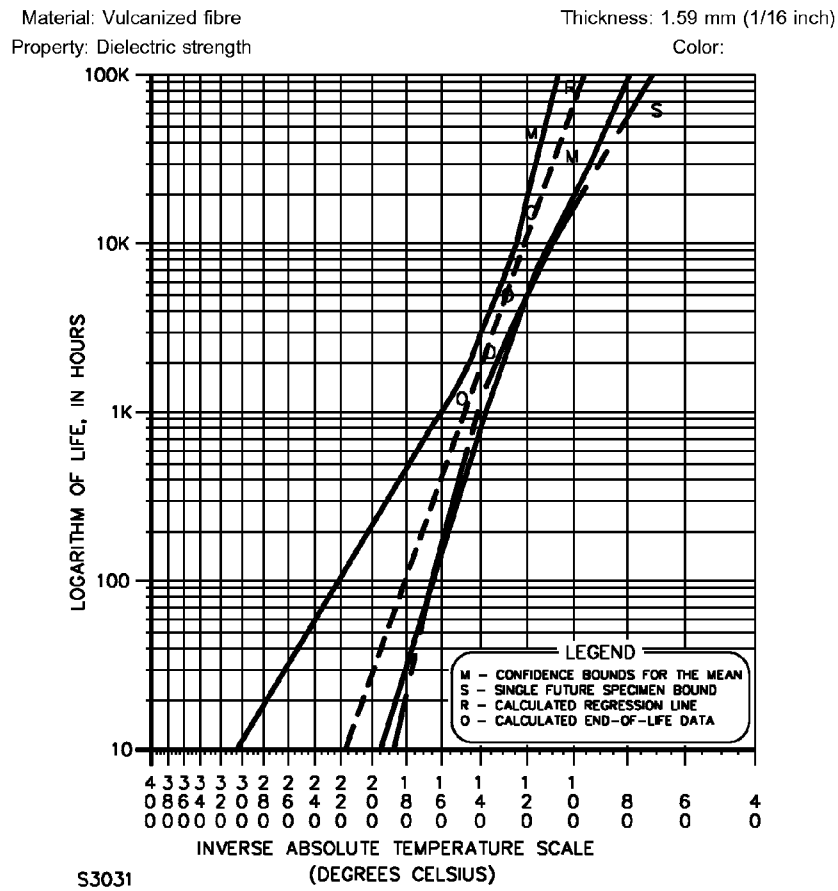
Correlation coefficient K = 0.9937
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.181274 \times 10^{12};$

$B = 13233.6$

Where L is in hours and T is in degrees celsius

Figure 10.2
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
145	1100
135	1800
125	4400
115	13000

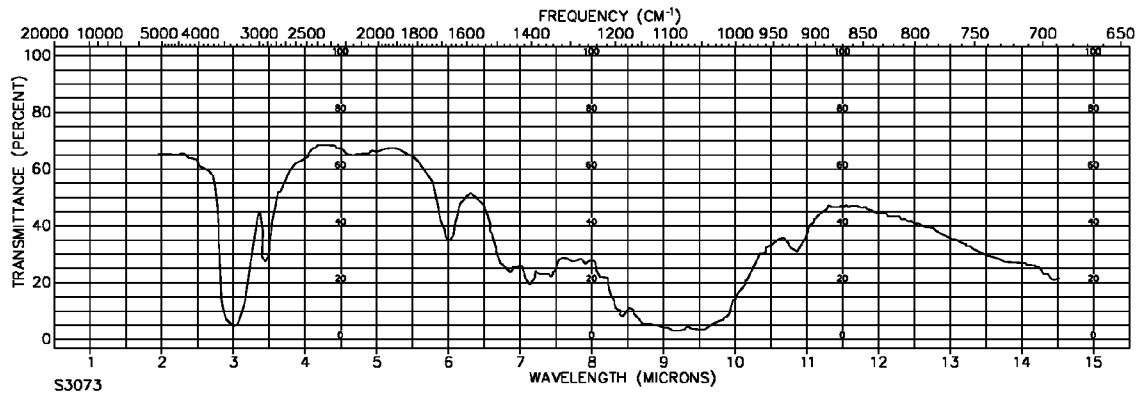
Correlation coefficient K = 0.9905
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/0.114862 \times 10^{12};$

$B = 13518.5$

Where L is in hours and T is in degrees celsius

Figure 10.3
Typical infrared spectrum-vulcanized fibre



FILAMENT WOUND TUBING

11 General

11.1 Profiles of performance and relative thermal indices for filament wound tubing are given in Tables 11.1 and 11.2. These are the minimum characteristics needed for a material to be assigned a UL/ANSI type designation.

11.2 Filament wound tubing is to be evaluated for designation as a UL/ANSI material type by comparing its profile of performance with that of the selected UL/ANSI material type.

Table 11.1
Generic temperature index for filament wound tubing

Table 11.1 revised November 28, 2001

UL/ANSI designation	Nominal wall thickness		Minimum tolerance		Temperature index	
	mm	(inch)	mm	(mils)	Electrical (°C)	Mechanical (°C)
FW-G-10	0.8	(0.031)	±0.051	(±2)	180	180
	1.6	(0.062)	±0.127	(±5)	180	190
FW-G-11	0.8	(0.031)	±0.051	(±2)	170	170
	1.6	(0.062)	±0.127	(±5)	180	170

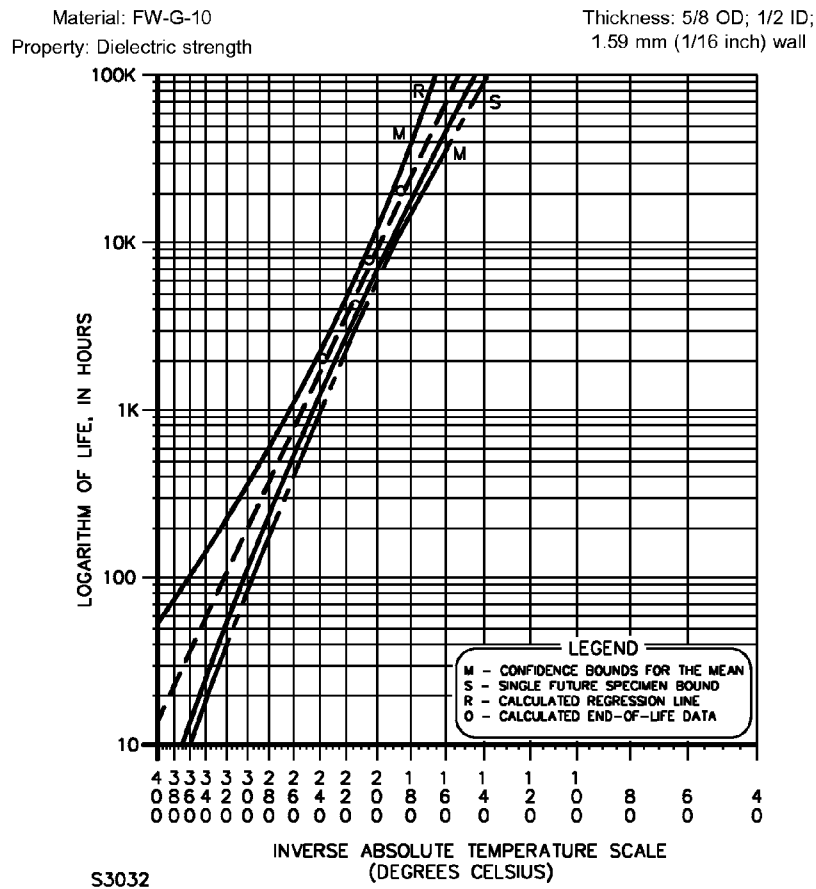
Table 11.2
Summary of performance profile indexing data on filament wound tubing

Table 11.2 revised November 28, 2001

UL/ANSI designation	Normal wall thickness		Flammability class	High-current arcing ignition (PLC)		Hot-wire ignition (PLC)	High volt arc resistance (PLC)	High-volt-arc tracking (PLC)	High-volt-arc resist. per ASTM D495 (PLC)	Axial compressive strength per ASTM D348		Dielectric strength perpendicular to longitudinal axis V/mil
	mm	(inch)		O.S.	1.59 mm A.S.					MPa	(psi)	
FW-G-10	0.8	(0.031)	HB	4	0	0	1	0	5	—	—	510
FW-G-10	1.6	(0.062)	HB	4	0	0	1	0	5	89.6 (13,000)	—	440
FW-G-11	0.8	(0.031)	HB	4	0	0	1	0	5	—	—	410
FW-G-11	1.6	(0.062)	HB	4	0	0	1	0	5	89.6 (13,000)	—	360

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Figure 11.1
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	19000
200	7300
210	4100
230	2050

Correlation coefficient K = 0.9974

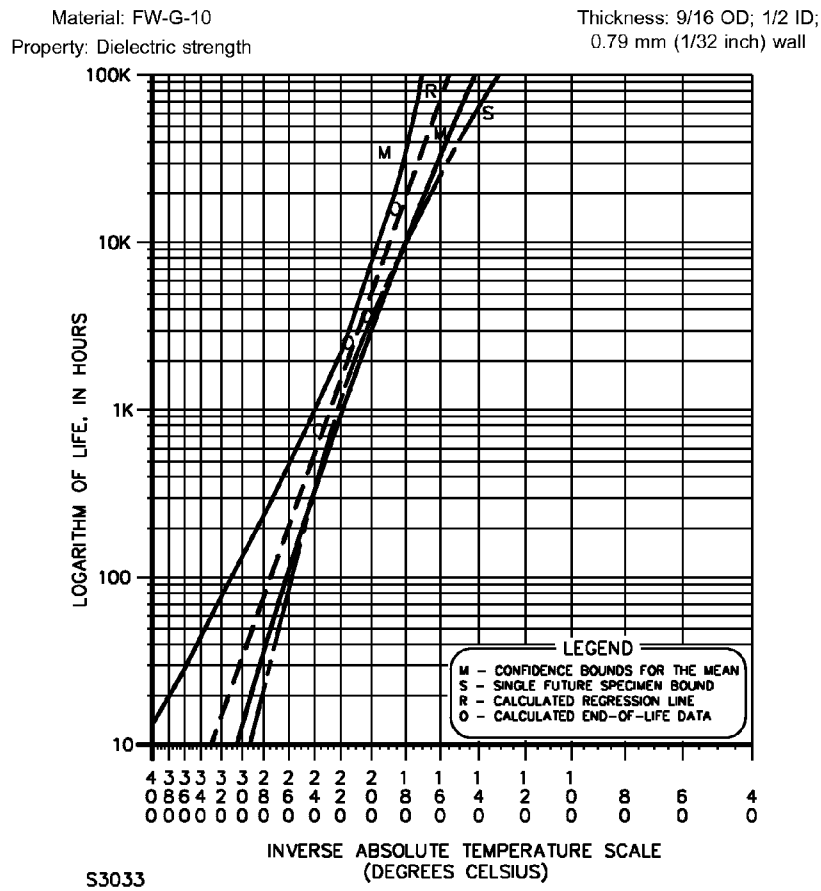
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/388992 \times 10^{11};$$

$$B = 10287.2$$

Where L is in hours and T is in degrees celsius

Figure 11.2
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	14000
200	3300
210	2500
230	700

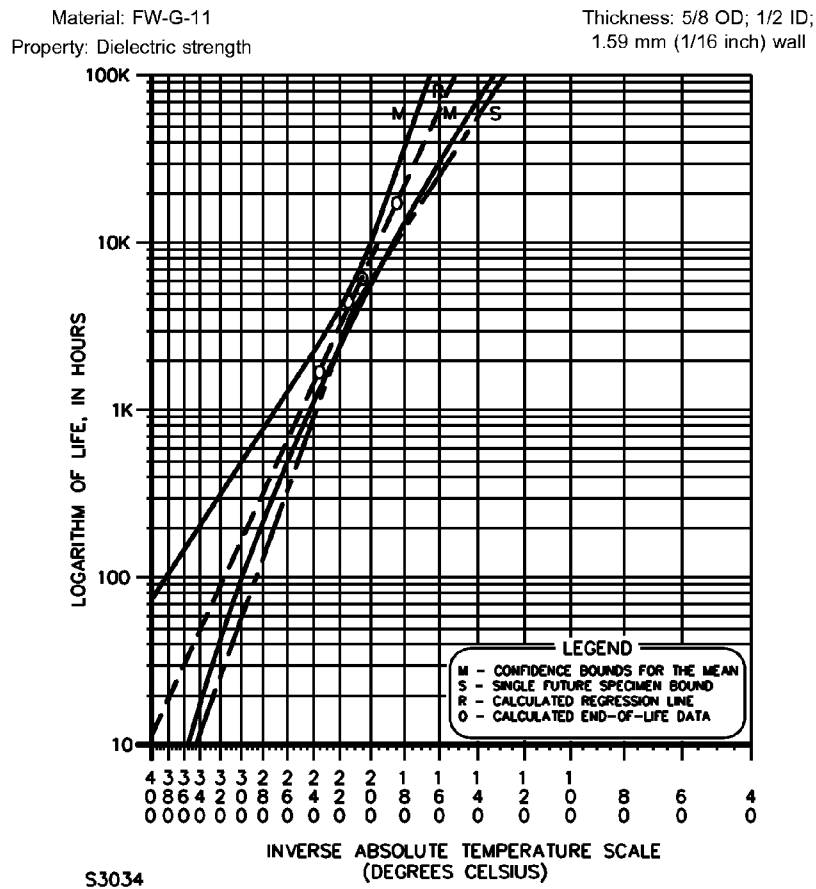
Correlation coefficient K = 0.9946
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.498903 \times 10^9;$$

$$B = 13385.4$$

Where L is in hours and T is in degrees celsius

Figure 11.3
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	16000
200	5500
210	4400
230	1600

Correlation coefficient K = 0.9949

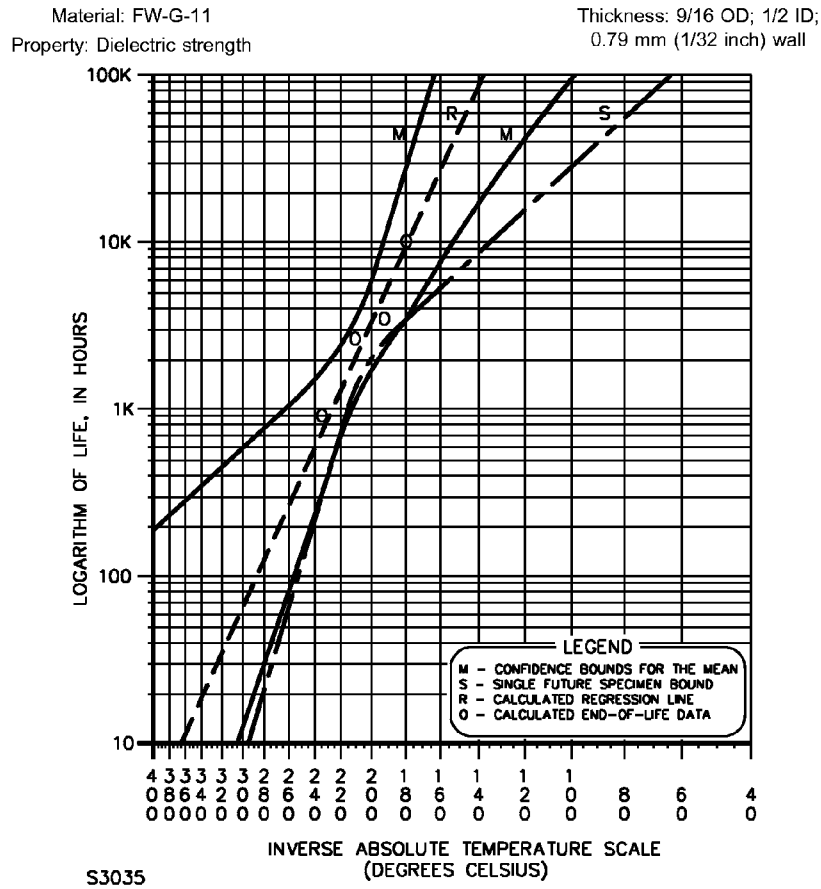
The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/457093;

B = 10288.7

Where L is in hours and T is in degrees celsius

Figure 11.4
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	9000
200	2200
210	2000
230	820

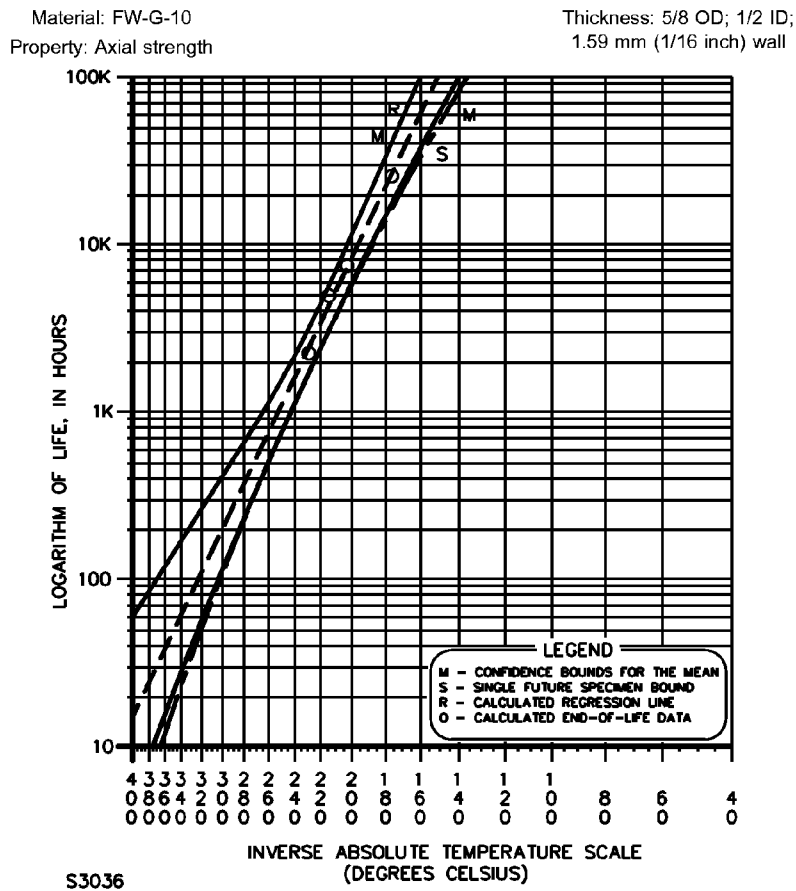
Correlation coefficient K = 0.9811
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.197411 \times 10^7;$$

$$B = 10635.2$$

Where L is in hours and T is in degrees celsius

Figure 11.5
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	18000
200	6700
210	5100
230	2000

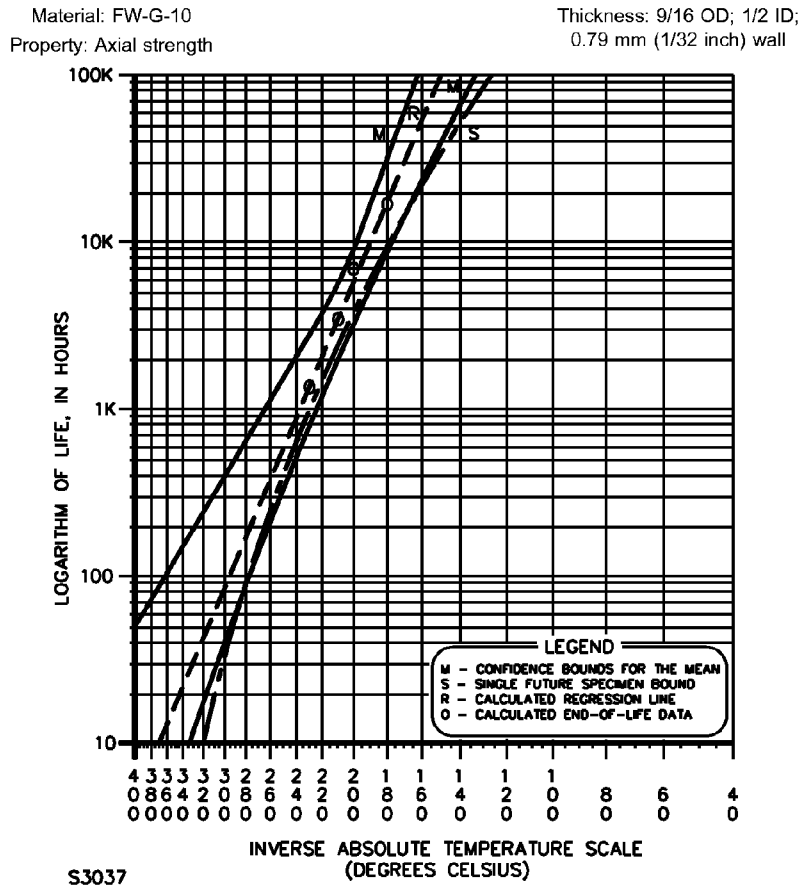
Correlation coefficient K = 0.9972
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

A = 1/160121;

B = 9869.75

Where L is in hours and T is in degrees celsius

Figure 11.6
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	14000
200	6200
210	3100
230	1200

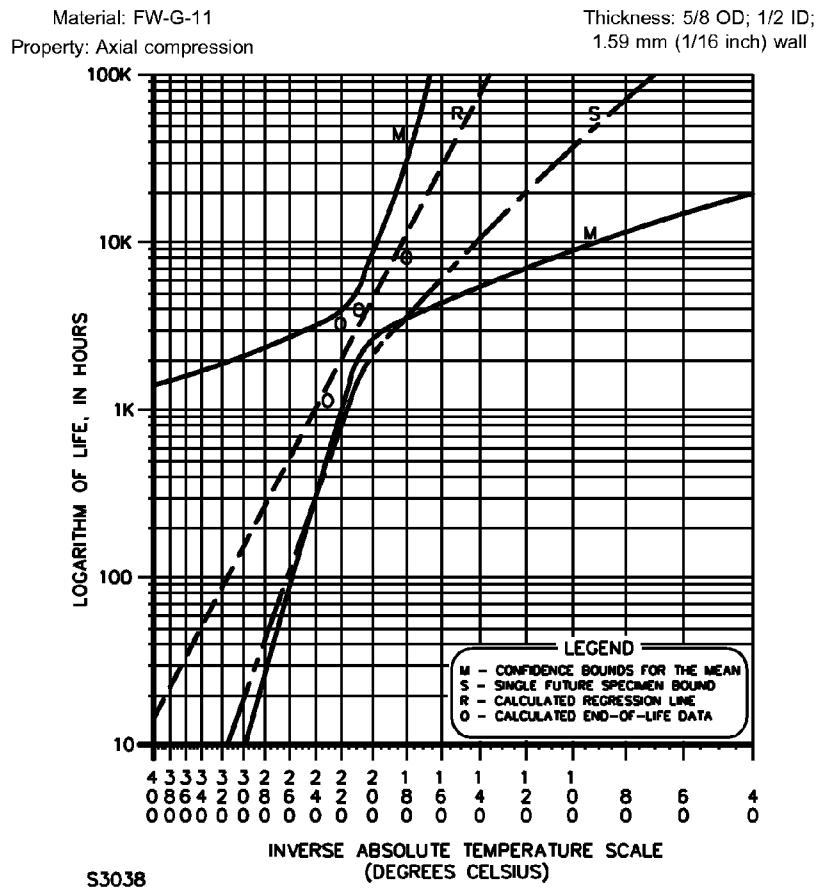
Correlation coefficient K = 0.9944
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$$A = 1/0.500073 \times 10^7;$$

$$B = 11353.3$$

Where L is in hours and T is in degrees celsius

Figure 11.7
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	7900
200	4100
210	3500
230	1000

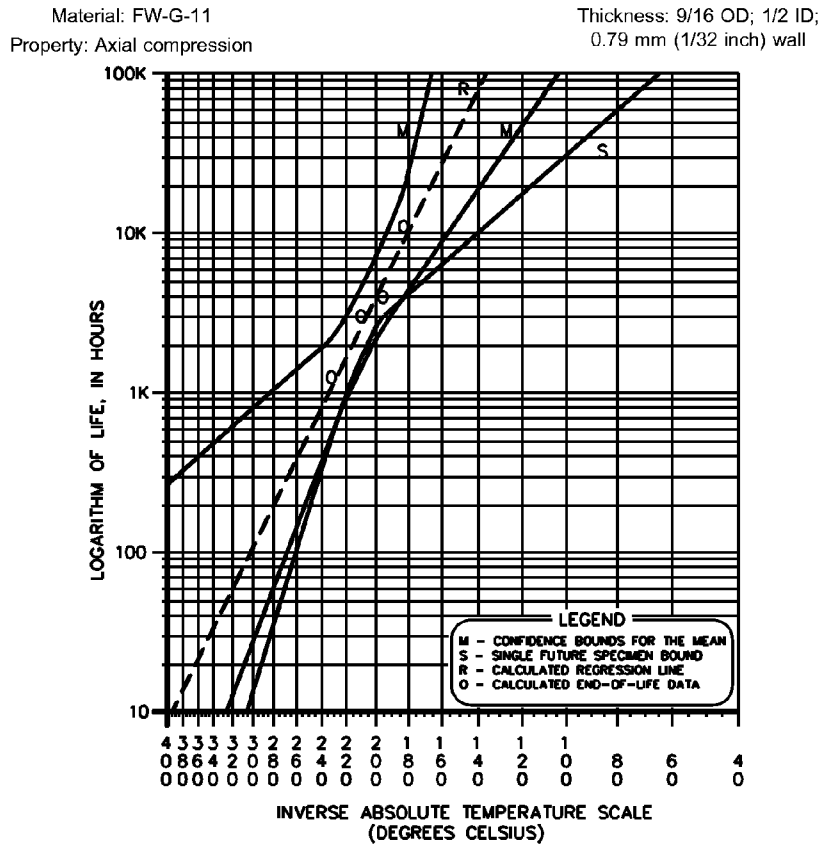
Correlation coefficient $K = 0.9653$
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/61354.7;$

$B = 9127.21$

Where L is in hours and T is in degrees celsius

Figure 11.8
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature



S3039

End-of-life criterion: 50% retention of property level
 Laboratory data:

Temperature (C)	Hours to end-of-life
180	9800
200	2700
210	2300
230	1100

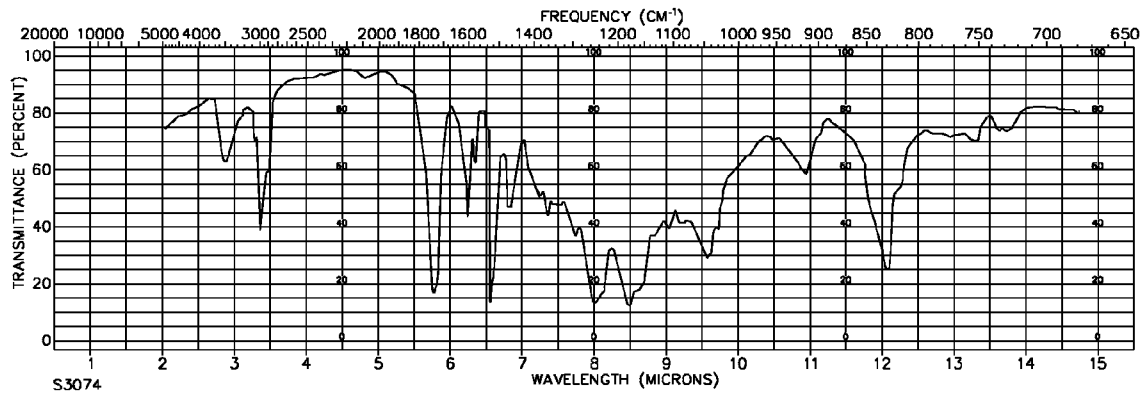
Correlation coefficient K = 0.9825
 The arrhenius equation: $L = A (2.718282)^{B/(T + 273.16)}$

$A = 1/275748;$

$B = 9781.66$

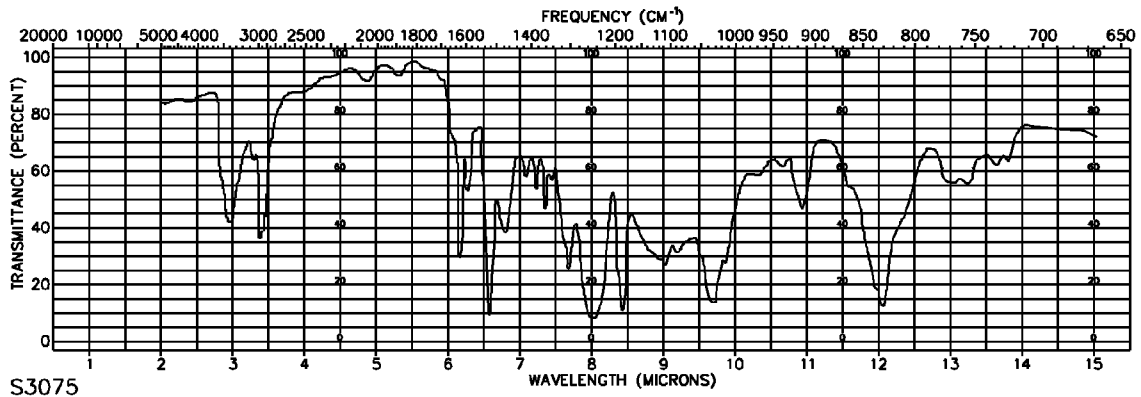
Where L is in hours and T is in degrees celsius

Figure 11.9
Typical infrared spectrum of FW-G-10 filament wound tubing



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Figure 11.10
Typical infrared spectrum of FW-G-11 filament wound tubing



12 Filament Wound Tubing Test Program

12.1 Filament wound tubing is to be evaluated on the basis of unaged property tests. See Table 12.1 for the required tests and specimens.

Table 12.1
Filament wound tubing abbreviated test program and sample requirements

Table 12.1 revised November 28, 2001

Samples: 40 specimens – each 16 mm (0.625 inch) O.D., 13 mm (0.5 inch) I.D., 25 mm (1 inch) long with 1.6 mm (0.062 inch) thick wall, of each grade.	
Tests: 1. Infrared analysis comparison 2. Axial compressive strength 3. Ash content 4. Horizontal flammability	Test method UL 746A UL 746A UL 746A UL 94

12.2 A material which compares favorably with the UL/ANSI values given in Filament Wound Tubing, Section 11 for the properties tested in Table 12.1 may be assigned the same file of performance values shown in Table 11.1 and 11.2.

12.3 The following criteria shall be used in determining if the material compares favorably with the UL/ANSI type.

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- a) The infrared spectrum shall be of the same basic composition as is shown in Figures 11.9 or 11.10. A fundamental variation in composition from the typical spectrum is not acceptable. Examples of unacceptable fundamental variations are given in 6.6 (a) – (d).
- b) The minimum axial compression strength values shall not be less than 89.6 MPa (13,000 psi) for 1.59 mm (1/16 inch) thickness for both FW-G-10 and FW-G-11 materials.
- c) The ash content shall be within the range of values of 66.5 – 86.1 percent.
- d) The flammability class shall be HB.

12.4 If the material does not compare favorably with the above four criteria, a full set of unaged property tests and two temperature agings shall be required. The required tests and samples are given in Table 12.2.

12.5 When unaged property criteria other than those given in Table 11.2, or a temperature index higher than shown in Table 11.1 is desired, a four point thermal aging test as described in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, or performance indexing as described in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, shall be performed to determine those properties.

Table 12.2
Filament wound tubing full test program and sample requirements

Table 12.2 revised November 28, 2001

Samples:	
1.6 mm (0.062 inch) thick wall:	
35 Specimens –	125 mm (5 inches) long and 13 mm (0.5 inch) I.D., 16 mm (0.625 inch) O.D., to be cut in half along the longitudinal axis to obtain a total of 70 pieces.
50 Specimens –	25 mm (1 inch) long and 13 mm (0.5 inch) I.D., 16 mm (0.625 inch) O.D.
0.8 mm (0.062 inch) thick wall:	
35 Specimens–	125 mm (5 inches) long and 13 mm (0.5 inch) I.D., 14.3 mm (0.56 inch) O.D., to be cut in half along the longitudinal axis to obtain a total of 70 pieces.
20 Specimens–	450 mm (18 inches) long and 13 mm (0.5 inch) I.D., 14.3 mm (0.56 inch) O.D.
Performance indexing tests (Per UL 746A):	
1. Axial compressive strength	
2. Dielectric strength	
3. Arc resistance (ASTM D495)	
4. Arc tracking (HVTR)	
5. Horizontal flammability	
6. Deleted	
7. High current arc ignition (HAI)	
8. Hot wire ignition (HWI)	
9. Infrared analysis	
10. Ash content	
Two point thermal aging test (Per UL 746B):	
Axial compressive strength	

METAL CLAD LAMINATES, METAL CLAD FLEXIBLE FILM, AND PREFABRICATED MULTILAYERED LAMINATES

13 General

13.1 Any additional processing of industrial laminates performed by the manufacturer shall be tested according to Sections 14 – 16.

13.2 The tests in these sections are intended to reduce testing required for users of these products.

14 Metal Clad Laminates

14.1 General

14.1.1 The metal clad laminate test program in 14.2 – 14.7 shall be performed in addition to the programs of investigation for industrial laminates (see Sections 5– 8) to determine if a new surface treatment or material on the laminate would provide the same results as given previously without the new surface.

14.1.1 revised November 28, 2001

14.1.2 The Bond Strength for the single or multilayer metal clad industrial laminate shall not be less than:

- a) 0.525 N/mm (3 lbf/inch) for each individual conductor trace, for the minimum bond strength determined in accordance with 14.5, after being subjected to thermal shock, 14.4; and
- b) 0.525 N/mm (3lbf/inch) for each individual conductor trace, for the minimum bond strength determined in accordance with 14.5, after being subject to thermal shock and 240 hours (10 day) oven conditioning; or
- c) 0.350 N/mm (2 lbf/inch) for each individual conductor trace, for the minimum bond strength determined in accordance with 14.5, after being subject to thermal shock and 1344 hours (56 day) oven conditioning.

14.1.2 revised November 28, 2001

14.1.3 If the metal cladding is bonded by means of a separate adhesive to the laminate, additional testing is required per 14.7.

14.1.3 added November 28, 2001

14.2 Single layer sample construction

14.2.1 Four specimens are to be prepared from a metal-clad laminate. The metal foil shall consist of the lightest and heaviest weights to be investigated. If the samples contain metal foil weights up to and including 102μ ($3\text{oz}/\text{ft}^2$), the minimum weight to be used in production is to be used in the samples and be considered representative of metal from the minimum up to and including 102μ ($3\text{oz}/\text{ft}^2$) maximum. [Minimum metal weight of less than 34μ ($1\text{oz}/\text{ft}^2$) will require samples to be plated up to the equivalent of 34μ ($1\text{oz}/\text{ft}^2$) to permit bond strength testing to be performed.] For metal foil weights heavier than 102μ ($3\text{oz}/\text{ft}^2$), the samples shall contain the heaviest weight of metal, either on the opposite side of the laminate containing the minimum metal weight, or in a separate set of samples containing the heaviest weight. The specimens are to be labeled to indicate the initial minimum metal weight used in their production.

14.2.1 revised November 28, 2001

14.2.2 Specimens of metal clad laminate to be investigated are to contain a metal pattern on both sides of the material with the pattern so positioned that the unbroken areas are directly opposite each other on the surface of the material. Investigation of double-sided construction covers single sided construction. However, a single-sided construction is not considered representative of double-sided construction. The pattern is to consist of 0.8 mm (0.031 inch) and 1.6 mm (0.062 inch) wide conductors, together with unbroken circles of 13, 25, 38, and 50 mm (0.5, 1, 1.5, and 2 inch) diameters. A drawing of the pattern is shown in Figure 14.1.

14.2.2 revised November 28, 2001

14.2.3 Chromic/sulfuric etchant shall be considered representative of all etchants. Any other acidic or alkaline etchant shall be considered representative of all etchants except chromic/sulfuric.

14.3 Multi-layer sample construction

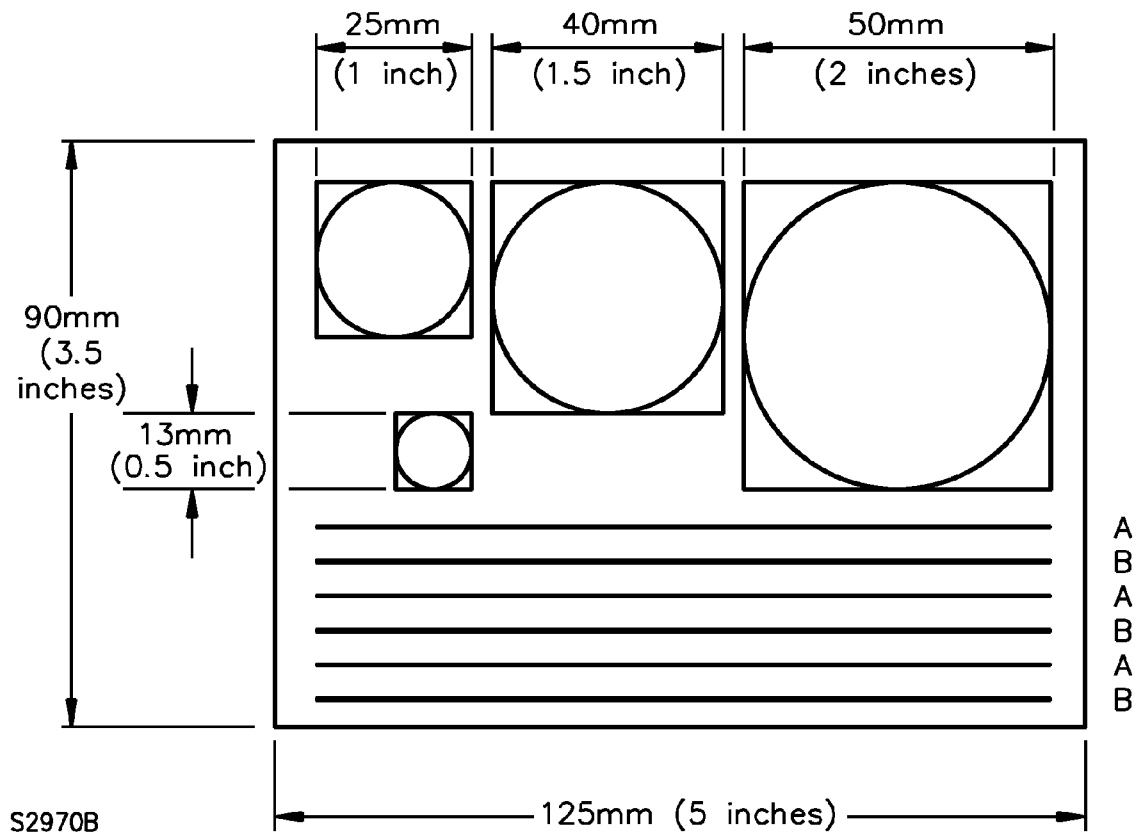
14.3.1 Four specimens are to be prepared as described in 14.3.2 and 14.3.3.

14.3.2 A representative multilayer laminate construction shall include but not be limited to the thinnest individual insulation sheets and bonding sheets, the minimum external conductor weight, the minimum total build up construction, and shall not exceed the minimum production thickness including two or the minimum number of internal conductor layers, whichever is greater. At least one internal conductor layer of the maximum metal weight shall be included in the construction. Each combination of materials or construction shall be provided for investigation. See 14.3.3 and Figure 14.2.

14.3.2 revised November 28, 2001

Figure 14.1
Metal clad industrial laminate

Figure 14.1 revised November 28, 2001



A – Metal Line 0.8 ± 0.13 mm (0.031 ± 0.005 inch) wide.

B – Metal Line 1.6 ± 0.13 mm (0.062 ± 0.005 inch) wide.

C – Large Areas – Shall be either square or circular. When Recognition for double-sided laminate cladding is desired, test specimens shall contain large areas on directly opposite positions on each side.

14.3.3 The construction of multilayer Bond Strength and Delamination samples shall be as follows:

- a) The thinnest individual sheets of laminate shall be included. The thinnest bonding layer shall be included in contact with internal conductors that may not be the maximum metal weight. The internal conductor of maximum metal weight shall be in contact with the necessary thickness of bonding sheet to have good layer registration without inside delamination or air entrapment.
- b) The Bond Strength and Delamination conductor test pattern shown in Figure 14.1 shall be included in the internal patterned conductor layers, and on both the external patterned conductor layers of the sample with good registration.
- c) The largest unpierced conductor area to be used in production, with a maximum diameter of 50 mm (2.0 inch), shall be included on the external and internal conductor layers. The 50 mm (2.0 inch) maximum diameter conductor is considered representative of larger areas for the printed wiring board fabricators.
- d) At least one internal patterned conductor layer shall contain the maximum metal weight used in production. If the maximum internal metal weight cannot be accommodated by the minimum multilayer construction build up described in 14.3, an additional set of Bond Strength and Delamination test samples shall be provided. The first set of samples shall contain the maximum internal metal weight that can be accommodated by the minimum multilayer build-up described in 14.3. The second set of Bond Strength and Delamination test samples shall contain minimum multilayer construction build up to accommodate the maximum internal metal weight to be used in production.
- e) The external conductor layers shall be comprised of the minimum metal weight used in production. If the initial minimum external metal weight is less than 34μ ($1\text{oz}/\text{ft}^2$), the conductor shall be plated up to 34μ ($1\text{oz}/\text{ft}^2$) to aid the bond strength pull. When external metal weights heavier than 102μ ($3\text{oz}/\text{ft}^2$) are required, an additional set of samples fabricated with the maximum external metal weight to be used in production shall be provided.
- f) Each generic insulation base material layer shall be in contact with each generic bonding material layer. The total build up of the multilayer laminate Bond Strength and Delamination samples shall not exceed the minimum production thickness plus two or the minimum number of internal patterned conductor layers, whichever is greater. If the multilayer is constructed per Figure 14.3, example (c), each generic bonding layer shall be subjected to Bond Strength testing per 14.5.
- g) Chromic/sulfuric etchant shall be considered representative of all etchants. Any other acidic or alkaline etchant shall be considered representative of all etchants except chromic/sulfuric.

If additional internal layers are included, the pattern may be the same, as the exterior pattern or may be a series of circles, prepared by the use of any etchant chosen by the preparer of the specimens.

14.3.3 revised November 28, 2001

14.3.4 The construction of multilayer flammability samples shall be as follows:

- a) The buildup shall include the thinnest individual insulation and bonding sheets. The build-up thickness shall be the minimum total thickness that would result from two or the minimum number of etched conductive layers of the minimum internal metal weight.
- b) Each generic base material layer shall be in contact with each generic bonding layer and be an external surface layer. Each bonding layer that will be used as an external layer shall be in contact with each generic insulation layer.
- c) All metal shall be etched from internal and external surfaces.

(Note: The flammability samples shall be the same construction as the Bond Strength and Delamination samples minus the copper).

14.3.4 added November 28, 2001

14.4 Thermal shock

14.4.1 Both single and multilayer samples shall be conditioned at 121°C (250°F) for 1.5 hours prior to being subjected to the thermal shock described in 14.4.2 unless other time or temperature limits are specified by the manufacturer.

14.4.1 revised November 28, 2001

14.4.2 The samples shall be subjected to a thermal shock simulating a solder operation, in a fluidized bath of aluminum oxide powder, or equivalent. Each specimen is to be thermally shocked for the duration and temperature indicated by the manufacturer.

14.5 Bond strength delamination and blistering test

14.5 revised November 28, 2001

14.5.1 When the specimens have cooled to room temperature, after the thermal shock, the unbroken area circles and the entire specimen shall be examined and there shall be no wrinkling, cracking, blistering, or loosening of any conductor or any delamination of the insulation and bonding sheets, then a bond strength test, as described in the Standard for Printed Wiring Boards, UL 796, shall be performed on two of each of the conductor widths on the four test specimens. When the results do not conform with the criteria of 14.1.2, testing shall be discontinued.

14.5.1 revised November 28, 2001

14.5.2 Following the bond-strength testing, three test specimens are to be placed in an oven 10 days (240 hours) at an elevated temperature based on the operating temperature rating of the material under test (see 14.5.3). At the conclusion of the oven conditioning, the bond-strength testing is to be repeated. The specimens are to be examined visually, after oven conditioning and there shall be no wrinkling, cracking, blistering, or loosening of any conductor or any delamination of the insulation and bonding sheets. An alternate 56 days (1344 hour) oven conditioning temperature may be used if the laminate manufacturer anticipates that the higher test temperature and increased bond-strength test requirements of the 10 day oven conditioning program would be too severe for his product. See 14.5.3.

14.5.2 revised November 28, 2001

14.5.3 The following formulas are to be used to determine the oven temperature, for 10 days (240 hours) and 56 days (1344 hours) day of conditioning:

$$t_2 = 1.076(t_1 + 288) - 273 \text{ [for 10 days (240 hours) oven conditioning]}$$

$$t_2 = 1.02(t_1 + 288) - 273 \text{ [for 56 days (1344 hours) oven conditioning]}$$

in which:

t_2 is the oven temperature in °C, and

t_1 is the rated material operating temperature in °C.

t_1 is not to exceed the maximum rated operating temperature previously assigned to the laminate.

14.6 Flammability test

14.6.1 This testing shall be performed in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, on specimens that have been thermally shocked as described in 14.4.1.

Exception: If the de-clad laminate was previously investigated under the requirements in UL 94, and was assigned a HB flammability classification, flammability testing of the metal clad laminate is not required to assign this same HB classification to the metal-clad laminate material.

14.6.1 revised November 28, 2001

14.6.2 The total build-up of the flammability samples shall not exceed the minimum production thickness including two, or the minimum number of completely etched internal layers, whichever is greater.

14.6.2 added February 7, 2001

14.7 Additional tests

14.7.1 Bond Strength, Flammability, Infrared Analysis, Comparative Tracking Index (CTI), High Current Arc Ignition (HAI), and Hot Wire Ignition (HWI), tests shall be required where the cladding is bonded by means of a separate adhesive. Testing is to be performed in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A and the Standard for Tests for Flammability of Plastic Materials for Parts and Devices in Appliances, UL 94.

Exception: Where it is determined that a test has previously been conducted on a specimen that had the metal removed by etching, that test is not required to be conducted.

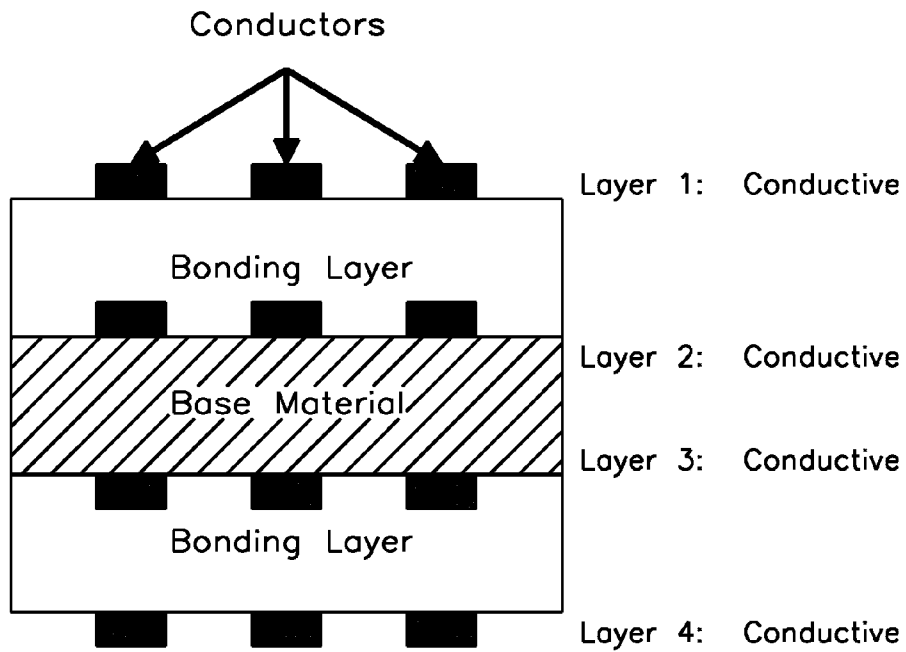
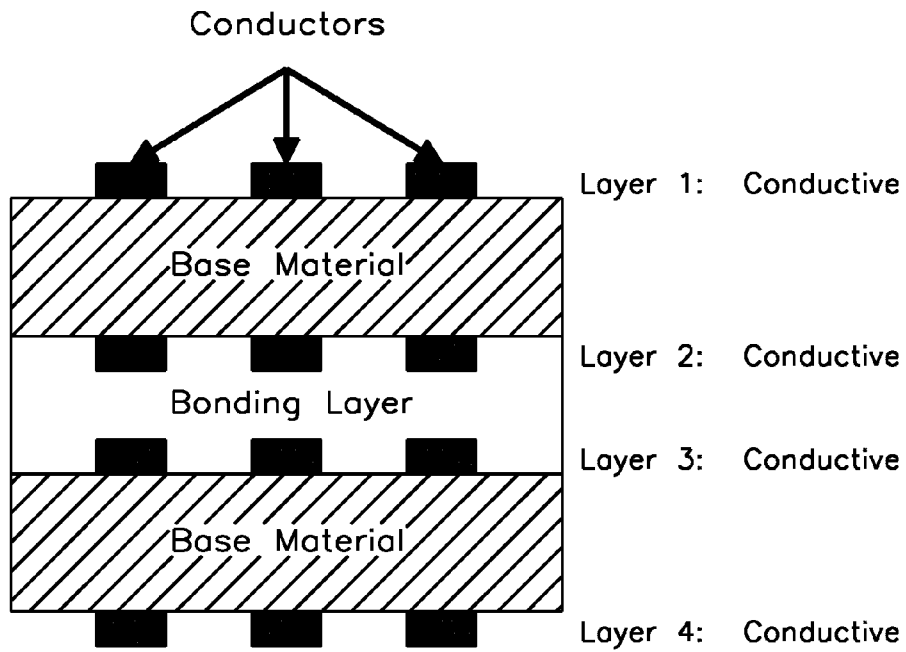
14.7.1 revised November 28, 2001

14.7.2 Test specimens for the Bond Strength test shall be constructed as indicated in Section 14.2 and/or Section 14.3 and shall include the minimum adhesive thickness that corresponds with the metal weights to be investigated. The Flammability, HAI and HWI test specimens shall be de-clad samples constructed with the minimum laminate thickness and the maximum adhesive thickness that corresponds with the metal weights to be investigated. The CTI test specimens shall be de-clad samples constructed with 3.2 mm (0.125 inch) laminate thickness and the maximum adhesive thickness that corresponds with the metal weights to be investigated.

14.7.2 revised November 28, 2001

Figure 14.2
Typical multilayer samples cross section

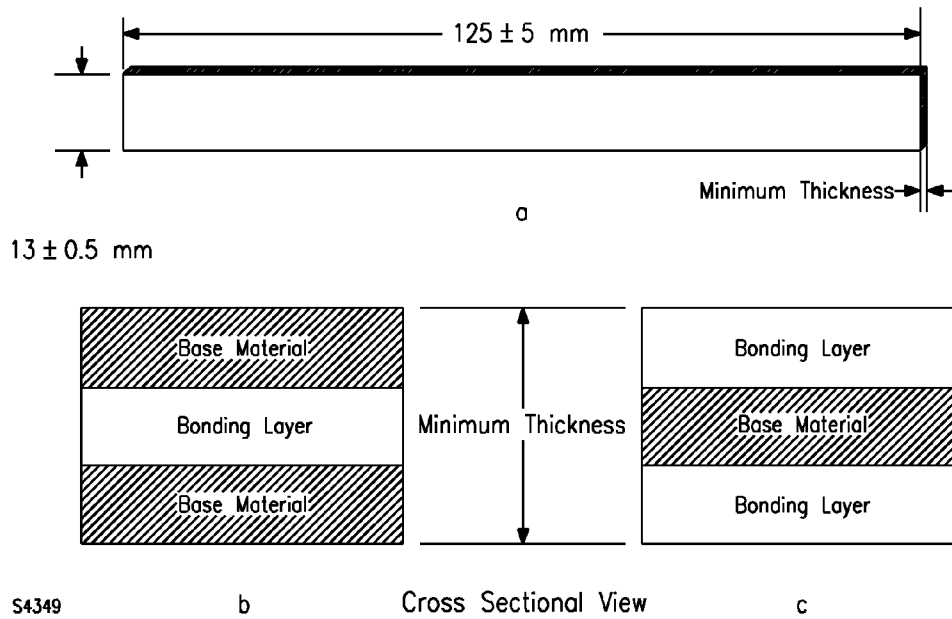
Figure 14.2 revised February 7, 2001



S4247

Figure 14.3
Typical multilayer flame sample (need graphic number)

Figure 14.3 added November 28, 2001



15 Prefabricated Multilayered Laminates – Mass Lamination

15.1 General

15.1.1 Where the prefabricated multilayered laminate (PML) construction was previously investigated for the industrial laminate Original Equipment Manufacturer (OEM) under the test program described in 14.6.1, no additional testing is required for the product.

15.1.2 Where the PML is fabricated from previously investigated ultra thin laminates and preregs by other than the OEM, the bond-strength and flammability tests are not required when the combination of laminate and prepreg without metal in the internal and external layers are of the same individual laminate material and preregs, in the same minimum build-up as that which was previously assigned a flammability classification, under the program described in 14.3 – 14.6.

15.2 Product limitations

15.2.1 A prefabricated multilayer laminate (PML) shall be limited to the range of metal-foil weights both external and internal, the maximum assigned individual thermal limits for the ultra thin laminate and prepreg thickness, the ultra thin laminate and prepreg combination, the minimum total build-up thickness, and the thermal shock limits that were tested.

15.3 Test samples

15.3.1 Test samples for the bond-strength test are to be prepared using previously investigated ultra thin laminates and bonding sheets. Samples are to include but not be limited to the thinnest individual ultra thin laminate and the thinnest individual prepreg to be investigated, and are to contain at least one internal plane layer of metal foil in the heaviest weight on the ultra thin laminate for internal planes. The etchant used for the preparation of the internal plane pattern is to be at the option of the manufacturer of the prefabricated multilayered laminate.

15.3.2 Bond strength and flammability testing shall follow the thermal shock test per 14.1.2 – 14.6.1.

16 Metal Clad Flexible Film

16.1 General

16.1.1 The acceptability of the bond between the conductor, its adhesive (if employed) and the base film, and performance characteristics of the combination shall be determined by this test program.

16.1.2 This program is divided into two parts where 16.2 – 16.8 cover the investigation to determine the acceptability of the metal clad film to be used in the construction of flexible printed wiring and 16.9 covers the investigation of an unclad film whose acceptability has not been determined previously.

Exception: The testing described in 16.8.1 and 16.8.2 is not required when the relative thermal index and profile of performance indexing tests have previously been performed.

16.2 Etched film property measurements

16.2.1 Table 16.1 indicates the tests and specimens to be used in this evaluation. Film thickness of samples is to be the minimum used in production. The flammability test samples are to consist of the minimum film thickness used in production with the minimum thickness of adhesive, and the minimum film thickness used in production with the maximum thickness of adhesive. Conductive material is to be removed from the film by means of an etchant.

16.3 Clad film property measurements

16.3.1 Where samples are clad on both sides, the conductive patterns shall be directly opposite each other.

Table 16.1
Etched flexible film test program and sample requirements

Table 16.1 revised November 28, 2001

Property	For method refer to	Specimens		
		Required number	Size (mm) length by width	Size (inches) length by width
Horizontal burning	UL 94 ^d	6 ^e	125 by 13	5 by 0.5
Vertical burning	UL 94 ^d	20 ^e	125 by 13	5 by 0.5
High-current-arc ignition	UL 746A ^a	10 ^g	125 by 13	5 by 0.5
Hot-wire ignition	UL 746A ^a	10 ^g	125 by 13	5 by 0.5
Infrared analysis (film with adhesive)		3 ^g	125 by 13	5 by 0.5
Moisture absorption	ASTM D 570 ^b	5 ^g	125 by 13	5 by 0.5
Volume and surface resistivities	ASTM D 247 ^c	10 ^g	100 by 100	4 by 4
Dielectric Strength	UL 746A ^c	f, g	100 by 100	4 by 4
Comparative tracking index	UL 746A ^a	f,g	50 by 50	2 by 2

^a The Standard for Polymeric Materials – Short-Term Property Evaluations, UL 746A.
^b The Standard Method of Test for Water Absorption of Plastics, ASTM D 570-1995.
^c The Standard Methods of Test for D-C Resistance or Conductance of Insulating Materials, ASTM D 257-1993.
^d The Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.
^e 20 samples are to consist of the minimum base film thickness with the minimum adhesive, and 20 samples are to consist of the minimum base film thickness with the maximum adhesive.
^f The required number varies depending on the thickness of the sample. Enough samples are needed to build up to twenty-five 3.2 mm (0.125 inch) samples for testing.
^g Samples are to consist of the minimum base film thickness with the minimum adhesive.

16.3A Ambient-bend test

16.3A added November 28, 2001

16.3A.1 There shall be no evidence of cracking, splitting, or delamination of the base film insulation, or separation of cladding from the film after the conditioning as described in 16.3A.2.

16.3A.1 is relocated from 16.7.1 and is unchanged November 28, 2001

16.3A.2 Five samples, fabricated as described in 16.4.2, are to be subjected to an oven conditioning for 10 consecutive days or the alternate 56 consecutive days. The oven temperatures for these specimens are to be the same as those used for the bond strength test (that is, based on the maximum utilization temperature), as described in 14.5.3. Following the oven conditioning, the samples are to be wrapped on a 6.4 mm (0.25 inch) diameter mandrel for 5 completely closed turns.

16.3A.2 is relocated from 16.7.2 and is unchanged November 28, 2001

16.4 Cold-bend test

16.4.1 The specimens shall have no cracking, splitting, or separation of cladding from film after the conditioning for the cold bend test in 16.4.2.

16.4.2 Two sets of five samples, each 229 mm (9 inches) long by 25 mm (1 inch) wide, are to be subjected to this test (see Figure 16.2). Double-sided samples are to be used where they exist. Five samples are to be built up to the minimum total thickness (that is, minimum film thickness, minimum cover-lay thickness, minimum metal thickness, and the like) and five samples are to be built up to the maximum built-up thickness to be used in production. The samples are to be conditioned for 1 hour at minus 20.0 \pm 2.0°C (minus 4.0 \pm 3.6°F). Specimens then are to be wrapped around a 6.4 mm (0.25 inch) diameter mandrel for five completely closed turns. Where the sample is single-sided, the copper is to be wrapped against the mandrel.

16.4.2 revised November 28, 2001

16.5 Repeated flexing test

16.5.1 The conductor shall not separate from the film, and the base film and cover-lay shall not crack, split, peel, or delaminate when a flexible base film is subjected to the repeated flexing test described in 16.5.2 and 16.5.3.

16.5.2 Four samples (two of the minimum built-up thickness and two of the maximum built-up thickness) are to be subjected to this test. The samples are to incorporate a continuous loop conductor 1.6 mm (0.062 inch) wide, back and forth to each end. See Figure 16.1. A continuity check through a measuring device is to be performed to verify a closed circuit condition.

16.5.2 revised November 28, 2001

16.5.3 Each sample is to be suspended between two parallel 12.7 mm (0.5 inch) diameter mandrels with a 0.8 mm (0.031 inch) clearance on each side of the test strip. A 227 g (0.5 lbf) weight (\pm 14 g or 0.5 oz) is to be hung on the bottom of the test strip. The part of the test strip above the flexure surface is to be bent back and forth to an angle of 180 degrees for 50 cycles or until either the conductor opens or the base insulation cracks, splits, or delaminates.

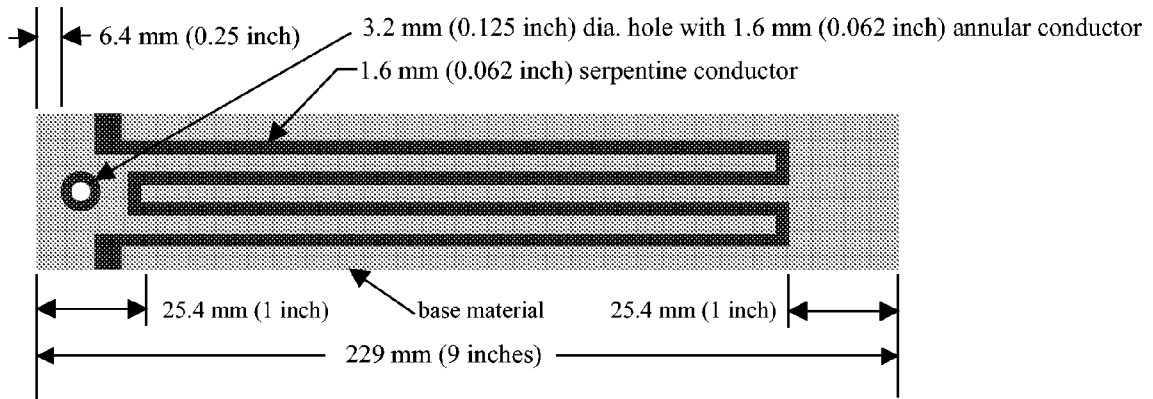
16.5.3 revised November 28, 2001

16.6 Bond strength test

16.6.1 The test program outlined in 14.1.2 – 14.5.3 shall be conducted, except as follows. The thermal shock test shall be performed in accordance with the film manufacturer's recommendation for time and temperature. For the bond strength test, five samples of the minimum film thickness and minimum metal weight to be used in production, are to be used, and the test fixture is not prohibited from employing a free wheeling rotary drum.

Figure 16.1
Repeated flexing specimen

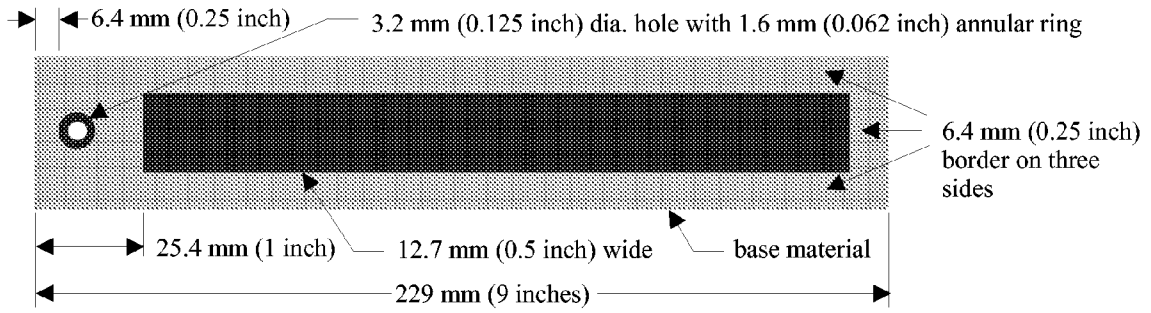
Figure 16.1 revised November 28, 2001



S5091A

Figure 16.2
Ambient-bend and cold-bend test sample

Figure 16.2 revised November 28, 2001



S5090A

16.7 Flexibility test

16.7.1 *Relocated as 16.3A.1 November 28, 2001*

16.7.2 *Relocated as 16.3A.2 November 28, 2001*

16.8 Cover-lay lamination test

16.8.1 Cover-lay construction shall not show evidence of delamination, cracking, splitting, or other deformation of the cover-lay or base insulation when subjected to the test in 16.8.2 and 16.8.3.

16.8.2 Five samples in accordance with Figure 14.1, incorporating cover-lay, copper, and base film in minimum build-up thicknesses and also maximum build-up thicknesses, are to be subjected to the following test conditions:

- a) Forty-eight hours at $71 \pm 2^{\circ}\text{C}$ ($159.8 \pm 3.6^{\circ}\text{F}$).
- b) Forty-eight hours at $25 \pm 2^{\circ}\text{C}$ ($77 \pm 3.6^{\circ}\text{F}$) immersed in water.
- c) Eight hours at minus $35 \pm 2^{\circ}\text{C}$ (minus $31 \pm 3.6^{\circ}\text{F}$).
- d) Sixty-four hours at $40 \pm 2^{\circ}\text{C}$ ($104 \pm 3.6^{\circ}\text{F}$) at 95 – 100 percent relative humidity.

16.8.3 All five of the samples mentioned in 16.8.2 are to be subjected to each of the four parts of the test mentioned in 16.8.2. After the test, each sample is to remain at $23 \pm 2^{\circ}\text{C}$ ($73.4 \pm 3.6^{\circ}\text{F}$) at 50 percent relative humidity for 1 hour.

16.9 Basic film investigation

16.9.1 A base film for which the profile of performance index values and the electrical and mechanical thermal characteristics have not been previously determined shall be investigated. Film property measurements shall be performed as described in 16.2.1. The procedures in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, shall be used to determine the thermal characteristics.

16.9.2 Thermal end-of-life of the primary property test samples (that is, 50 percent of the unaged values) shall be determined using tensile strength and elongation, and dielectric strength according to the test schedule in Table 16.2. Tensile strength samples shall be prepared in both the machine and bias direction for woven reinforced films and in the machine direction only for non-reinforced or non-woven reinforced films. All materials that require a secondary property to be determined as indicated in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, are to be removed from the oven and tested at the time the end-of-life has been reached for the primary property according to the test schedule in Table 16.3.

Table 16.2
Test schedule for primary properties

Film materials	Aging temperature (°C)				Cycle periods (days)			
	A	B	C	D	A	B	C	D
Polyester	90	105	120	130	28	14	7	3
Polyester/Polyimide	90	105	120	130	28	14	7	3
Polyimide	90	105	120	130	28	14	7	3
PVC	75	85	95	105	28	14	7	3

Note: The above test temperatures are tentative values. To determine the specific test values, a screening test at a temperature at least 10°C above the highest temperature shown should be performed before the program temperatures are assigned.

Table 16.3
Test schedule for secondary property

Materials	Secondary property	Aging temperature (°C)
All	Flammability	105, 120 except PVC: 85, 95

17 Metal-Based Laminates

17.1 General

17.1.1 The requirements in this Section outline the testing of metal-based laminates for use in fabricating printed-wiring boards. This test program consists of two parts in which the first part covers the investigation to determine performance profile characteristics, and the second part covers the investigation of the relative thermal indices of the insulation/bonding material.

17.1.2 An adhesive used to bond the conductor material to the metal base or dielectric insulation material shall not be water soluble.

17.1.3 Insulation/bonding material is to be applied to the base metal by the production processes used to fabricate the metal-based laminate including base metal, conductor material, dielectric insulation material, bonding material, epoxy coating, prepreg, bond-ply, adhesive, or any other material used to fabricate the metal-based laminate.

17.2 Performance profile characteristics

17.2.1 The performance profile test methods shall be in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, and the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. See Table 17.1 for sample requirements.

Table 17.1
Samples requirements for performance characteristics

Table 17.1 revised November 28, 2001

Property	For method refer to	Minimum number of samples	Sample size length by width		Base metal thickness	Insulation thickness
			mm	(inch)		
Horizontal burning	UL 94	6	125 by 13	(5 by 0.5)	minimum	maximum
Vertical burning	UL 94	20	125 by 13	(5 by 0.5)	minimum	maximum
Vertical burning	UL 94	20	125 by 13	(5 by 0.5)	minimum	minimum
High current arc ignition (HAI)	UL 746A	12	125 by 13	(5 by 0.5)	minimum	minimum
High current arc ignition (HAI)	UL 746A	12	125 by 13	(5 by 0.5)	minimum	maximum
Hot wire ignition (HWI)	UL 746A	6	125 by 13 ^a	(5 by 0.5)	minimum	minimum
Hot wire ignition (HWI)	UL 746A	6	125 by 13 ^a	(5 by 0.5)	minimum	maximum
Infrared analysis (IR)	—	3	125 by 13	(5 by 0.5)	minimum	maximum
Thermogravimetric analysis (TGA)	—	3	125 by 13	(5 by 0.5)	minimum	maximum
Volume and surface resistivity	UL 746A	12	100 by 100 ^b	(4 by 4)	minimum	minimum
Dielectric strength	UL 746A	10	100 by 100 ^b	(4 by 4)	minimum	minimum
Comparative tracking index (CTI)	UL 746A	20	100 by 100 ^b	(4 by 4)	minimum	maximum
Moisture absorption	UL 746A	3	75 by 25	(3 by 1)	minimum	maximum

Table 17.1 Continued on Next Page

Table 17.1 Continued

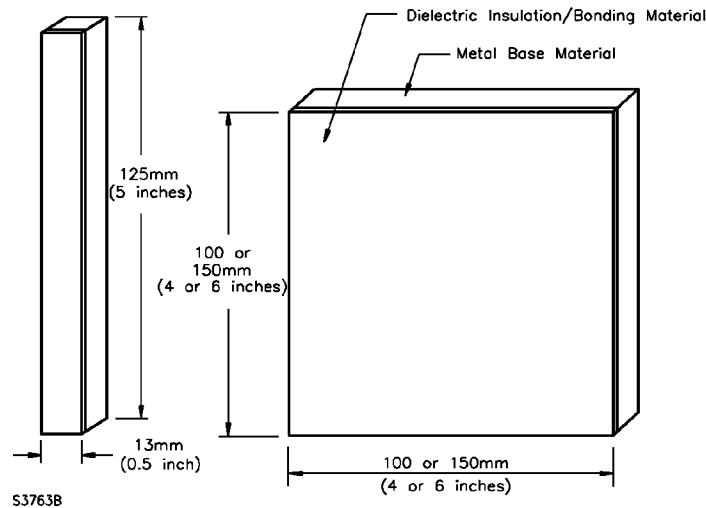
Property	For method refer to	Minimum number of samples	Sample size length by width		Base metal thickness	Insulation thickness
			mm	(inch)		
^a All side-edges of the sample are to be completely coated with the indicated thickness of dielectric insulation/bonding material for the purposes of conducting the Hot Wire Ignition Test.						
^b Where suitable, 150 by 150 mm (6 by 6 inch) square (or 150 mm round) samples may be used.						

17.2.2 Indexing samples are to be provided in accordance with Table 17.1 and are to be constructed as shown in Figure 17.1 by incorporating a metal base with dielectric insulation/bonding material on one or both sides of the sample.

17.2.3 Samples are to be prepared from clad metal-based laminate samples by completely etching the conductor material from the clad sample.

Figure 17.1
Indexing sample

Figure 17.1 revised November 28, 2001



Sample build-up thickness is to include the base metal and dielectric insulation/bonding material thicknesses indicated in Table 17.1.

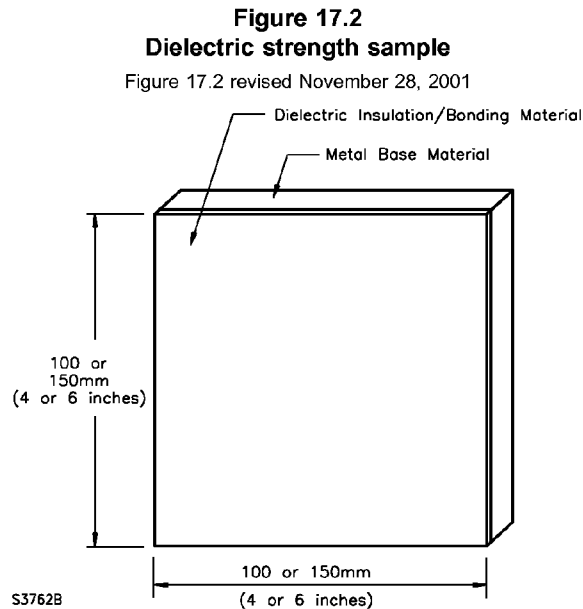
17.3 Thermal aging

17.3.1 Thermal aging samples are to be constructed in accordance with either of the following:

- a) As shown in Figure 17.2, dielectric strength sample, and Figure 17.3, bond strength sample; or
- b) As shown in Figure 17.4 for a combination dielectric strength and bond strength sample.

17.3.2 The samples shown in Figures 17.1 and 17.2 are to be prepared from clad metal-based laminate samples by completely etching the conductor material from the clad sample. Clad samples are to be etched leaving a pattern as shown in Figure 17.3 or Figure 17.4.

17.3.3 Clad samples are to be prepared with a conductor material weight of 1 ounce per square foot (305 grams per square meter).



Sample build-up thickness is to include the base metal and dielectric insulation/bonding material thicknesses indicated in Table 17.2.

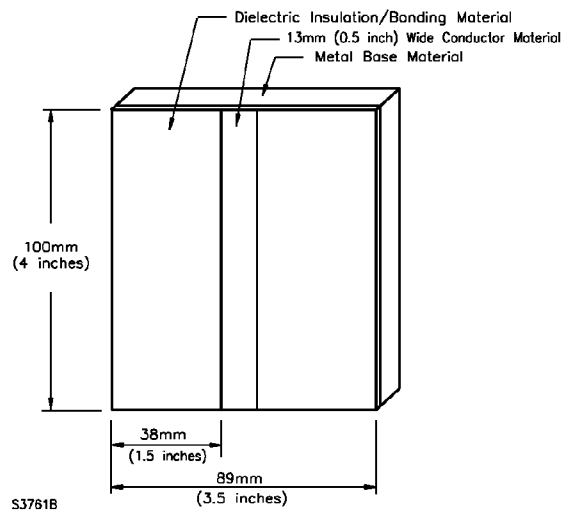
17.3.4 For metal-based laminate samples which are double-sided, the conductor material pattern is to be on both sides with the pattern positioned such that the unbroken areas are directly opposite each other on the surfaces of the sample. An investigation of a double-sided construction represents the investigation of a single-sided construction. However, a single-sided construction is not representative of a double-sided construction.

17.3.5 The relative thermal indices are to be determined for the minimum base metal thickness and minimum dielectric insulation/bonding material thickness by conducting a four point thermal aging of a primary property. Thermal aging shall be conducted on the metal-based laminate samples (see Figures 17.2 – 17.4) in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B. The primary property to be tested shall be dielectric strength in accordance with ASTM D149 (1995), Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies. Flammability shall be tested as a secondary property. The bond strength between the conductor and the insulation/bonding material shall also be tested as a primary property unless data indicates it is a secondary property. See Table 17.2 for sample requirements.

17.3.5 revised November 28, 2001

Figure 17.3
Bond strength sample

Figure 17.3 revised November 28, 2001



Sample build-up thickness is to include the base metal and dielectric insulation/bonding material thicknesses indicated in Table 17.2.

Table 17.2
Samples for thermal aging

Table 17.2 revised November 28, 2001

Property	Long term thermal aging program	Metal base thickness	Dielectric insulation/bonding material thickness	Sample	Minimum number of samples
Dielectric strength	four temperature ^a	Minimum	Minimum	Figure 17.2	170
Bond strength	one temperature ^b	Minimum	Minimum	Figure 17.3	50
Bond strength	four temperature ^c	Minimum	Minimum	Figure 17.3	170
Flammability	one temperature ^b	Minimum	Maximum	125 by 13 mm (5 by 0.5 inches)	50

^a Minimum required for evaluation to determine Relative Thermal Index for a metal-based laminate employing a dielectric insulation layer between the base metal and conductor material; conducted as a primary property.

^b Minimum required for evaluation to determine Relative Thermal Index for a metal-based laminate employing a dielectric insulation layer between the base metal and conductor material; conducted as a secondary property.

^c Optional four temperature long term thermal aging may be conducted as a primary property to establish Mechanical Relative Temperature Index differing from Electrical Relative Temperature Index.

17.3.6 Bond strength is to be evaluated by peeling a uniform 13 mm (0.5 inch) width of conductor material from the dielectric insulation/bonding material for a distance of 6.4 mm (0.25 inch) at a uniform rate of approximately 300 mm per minute (12 inches per minute). The angle between the conductor material and the dielectric insulation/bonding material is to be maintained at not less than 85 degrees. The force

required to separate the conductor material from the dielectric insulation/bonding material is to be measured. Three peels are to be conducted, and the average strength of the bond is to be determined on each sample.

17.3.6 revised November 28, 2001

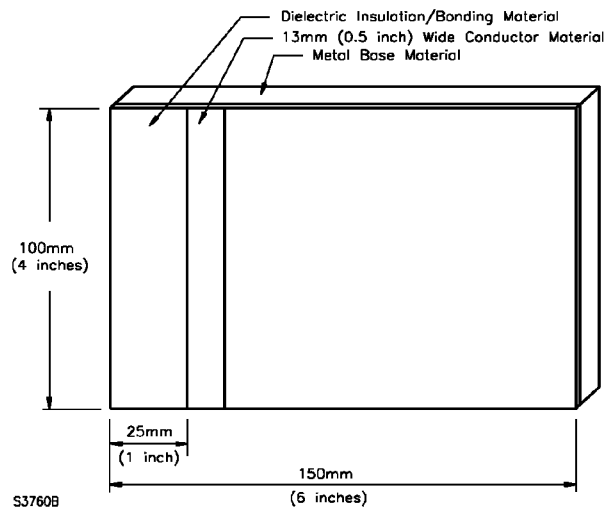
17.3.7 For a reduction in dielectric insulation thickness or conductor bonding material thickness, a two temperature thermal aging shall be conducted. For a change in base metal composition or base metal surface treatment, a two temperature thermal aging shall be conducted.

17.3.8 Where a comparison of the results of aging at two temperatures extrapolates to within 5°C (9°F) of the relative thermal index previously determined by thermal aging, the candidate base metal and dielectric insulation/bonding material shall be assigned the same relative thermal index as previously determined. Where the extrapolation results in a thermal index that is more than 5°C (9°F) below the relative thermal index, previously determined via thermal aging, the candidate base metal and dielectric insulation/bonding materials shall be assigned relative thermal indices of reduced value for both mechanical and electrical characteristics although only one was tested. Temperatures are assigned in discrete 5°C (9°F) steps to the next lowest value in accordance with the requirements for Assignment of Temperature Classifications in UL 746B, Standard For Safety For Polymeric Materials – Long Term Property Evaluations.

17.3.8 revised November 28, 2001

Figure 17.4
Combination sample – dielectric strength and bond strength sample

Figure 17.4 revised November 28, 2001



Sample build-up thickness is to include the base metal and dielectric insulation/bonding material thicknesses indicated in Table 17.3.

Table 17.3
Samples for thermal aging for the optional combination sample construction of Figure 17.4

Property	Long term thermal aging program	Metal base thickness	Dielectric insulation/bonding material thickness	Sample coupon	Minimum number of samples
Dielectric strength	four temperature ^a	Minimum	Minimum	Figure 17.4	170
Bond strength	one temperature ^b	Minimum	Minimum	Figure 17.4	50
Minimum	four temperature ^c	Minimum	Minimum	Figure 17.4	170

^a Minimum required for evaluation to determine Relative Thermal Index for a metal-based laminate employing a dielectric insulation layer between the base metal and conductor material; conducted as a primary property.

^b Minimum required for evaluation to determine Relative Thermal Index for a metal-based laminate employing a dielectric insulation layer between the base metal and conductor material; conducted as a secondary property.

^c Optional four temperature long term thermal aging which is conducted as a primary property to establish Mechanical Relative Temperature Index differing from Electrical Relative Temperature Index.

PERMANENT COATINGS

18 Permanent Coatings

18.1 General

18.1.1 The flammability rating of the combination of the permanent resist coating applied to a laminate material shall be determined as described in 18.2.1 – 18.4.1 after the combination has been subjected to thermal shock conditioning.

18.2 Test samples

18.2.1 Test samples are to be prepared:

- a) Using one of each generic grade of previously investigated UL/ANSI laminate material for which a flammability classification of the coating is requested. The curing process (temperature, time, and so forth) is to be specified by the coating manufacturer and shall be used when preparing samples.
- b) Using both 1.6 mm (0.062 inch) and 0.8 mm (0.031 inch) thicknesses of laminate material. When a request is made to cover material thinner than 0.8 mm (0.031 inch), samples are also to be prepared from the thinnest desired laminate provided that this thickness is not less than the thickness for which the laminate has previously been investigated.
- c) Using metal-clad material from which the metal has been completely removed by etching. Where the generic grade encompasses laminates with a V-0 rating, a laminate with this rating is to be selected for the coating. For all UL/ANSI grades, the laminate selected should be one that shows the best UL 94 flammability rating in its grade.
- d) Flammability test samples shall be constructed per the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. The sample shall be 125 mm \pm 5 mm (5 inch) long by 13 mm \pm 0.5 mm (0.5 inch) wide. All samples are to be cut from sheet material. Care is to be taken to remove all dust and any particles from the surface and for all edges to be smooth. The radius on the corners shall not exceed 1.3 mm (0.05 inch).

- e) Using 20 specimens per set (having the dimensions indicated above).

18.2.1 revised November 28, 2001

18.2.2 The following sets of samples are to be prepared according to 18.2.1:

- a) One set of uncoated samples provided in both the 1.6 mm (0.062 inch) and 0.8 mm (0.031 inch) thicknesses. When a coated laminate thinner than 0.8 mm (0.031 inch) is supplied, an additional uncoated set in that thickness is required.
- b) One set of samples is to be prepared by coating both sides of the 0.8 mm (0.031 inch) thick material with the minimum coating thickness anticipated to be applied by the printed wiring board manufacturer. When a thinner material is to be submitted, and extra set with that thickness is to be required.
- c) One set of samples is to be prepared by coating both sides of the 0.8 mm (0.031 inch) thickness of material using the maximum coating thickness anticipated to be applied by the printed wiring board manufacturer. When a thinner material is submitted, an extra set with that thickness is required.
- d) One set of samples is to be prepared by coating both sides of the 1.6 mm (0.062 inch) thickness of material using the minimum coating thickness anticipated to be supplied by the printed-wiring board manufacturer.
- e) One set of samples is to be prepared by coating both sides of the 1.6 mm (0.062 inch) thickness of material using the maximum coating thickness anticipated to be applied by the printed-wiring board manufacturer.

18.2.2 revised November 28, 2001

18.2.3 If a coating is to be considered in a range of colors, samples representing this range are also to be provided.

Added 18.2.3 effective February 7, 2003

18.2.4 The sample sets described in 18.2.2(b), 18.2.2(c), 18.2.2(d) and 18.2.2(e) employing that coating in the unpigmented color and in the most heavily pigmented light and dark colors are to be provided and considered representative of the color range, if the results are equivalent. In addition, the sample sets described in 18.2.2(b), 18.2.2(c), 18.2.2(d), and 18.2.2(e) employing the coating with the heaviest organic pigment loading are to be provided unless the most heavily pigmented light and dark colors include the highest organic pigment level.

Added 18.2.4 effective February 7, 2003

18.2.5 Infrared analysis testing is to be performed on each color tested for flammability. A cured sample is to be provided, if possible. As an alternative, a 4 oz liquid sample (with accompanying MSDS) is to be provided for this purpose. Infrared analysis testing is also to be performed on each component of a multi-component coating unless a cured sample employing all components is provided.

Added 18.2.5 effective February 7, 2003

18.3 Thermal shock

18.3.1 All samples shall be subjected to a thermal shock simulating a solder operation at a time/temperature value determined by the coating manufacturer.

18.4 Flammability test

18.4.1 The sample shall be subjected to the tests and classified according to the flammability tests described in the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.

18.4.1 revised November 28, 2001

19 Conformal Coatings

19.1 General

19.1.1 This Section covers requirements for conformal coatings used on printed-wiring boards in electrical equipment where electrical spacings are insufficient between uninsulated live parts of opposite polarity or between such parts and accessible dead metal parts. The coatings are used as a protective covering against environmental conditions and are also used instead of electrical spacings to increase the dielectric voltage withstand capability between lands (traces) on a printed-wiring board.

19.1.2 The printed-wiring board with conformal coating is to be evaluated in accordance with the Standard for Printed-Wiring Boards, UL 796, and is to comply with the requirements in this Section relative to temperature, solder conditions, conductor size, and adhesion to the base material under the conditions encountered in the end-use application.

19.1.3 Testing is to be conducted on each type of industrial laminate material that is to be considered. Flammability tests are to be conducted in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, for each type of industrial laminate to be considered. Specimens are to be prepared by completely etching a metal-clad sheet of laminate. The specimens shall contain the minimum and maximum conformal coating thickness, inks and solder resists if employed. The coating shall not degrade the flammability classification of the base material.

Exception No. 1: Testing of UL/ANSI FR-4 is representative of UL/ANSI FR-5, G-10, G-11, CEM-1, and CEM-3 materials.

Exception No. 2: Testing of UL/ANSI XXXPC is representative of UL/ANSI X, XP, XPC, XX, XXP, XXX, and XXXP materials.

Exception No. 3: Testing of UL/ANSI GPO-2 is representative of UL/ANSI GPO-3 material.

Exception No. 4: Flammability tests are not required where the base industrial laminate material is classed HB.

19.1.3 revised November 28, 2001

19.1.4 The coating will not be considered a conformal coating if only flammability tests are conducted.

19.1.4 added November 28, 2001

19.2 Conformal coating test

19.2.1 A minimum of twenty copper clad test specimens are to:

- a) Be supplied with minimum electrical spacing and coating thickness;
- b) Be prepared using the test pattern shown in Figure 19.1;
- c) Be prepared by normal production means employing any primer or cleaner recommended by the coating manufacturer where this feature is to be considered; and
- d) Employ lead wires that are routed through the blank side of the board and are soldered to the pattern.

See Table 19.1 for a description of the test program and all test specimens required.

19.2.2 Specimens are to be prepared for the voltage transient test (see 19.3.1) and the dielectric voltage-withstand and breakdown-voltage test (see 19.4.1) in accordance with Table 19.1. Immediately prior to voltage transient testing, the specimens are to be wrapped with a tight-fitting aluminum foil (representing an electrically conductive contaminate deposit along the surface of the coating) that covers the test pattern but does not cover the insulated test lead wire and solder points.

19.3 Voltage transient test

19.3.1 A 50 – 60 Hz voltage source is to be applied on the specimens between opposite legs of the test pattern, namely lead A and lead B in Figure 19.1. Each sample is to be subjected to ten randomly triggered (with respect to the 60 Hz supply waveform) applications of a 6 kilovolt surge impulse superimposed on the supply source at 60 second intervals. The surge generator is to have a source impedance of 50 ohms. With no load on the generator, the surge waveform is to have the following characteristics:

- a) Initial rise time of 0.5 microsecond between 10 percent and 90 percent of peak amplitude;
- b) The period of the ensuing oscillatory wave is to be 10 microseconds; and
- c) Each successive peak of alternating polarity is to be 60 percent of the preceding peak.

Refer to Figures 19.2 and 19.3 for a typical surge generation and control relay circuit. All specimens, unconditioned and conditioned, are to be subjected to the voltage transient test. There shall not be any ignition, dielectric breakdown through the coating, or evidence of a carbon path being created on the surface of the coating material.

Table 19.1
Test specimens

Table 19.1 revised November 28, 2001

Test	Quantity of each coating thickness	Dimensions mm (inch)	Coating thickness	
			Min	Max
Voltage transient, dielectric voltage-withstand and breakdown-voltage after:				
As received (unconditioned)	5	a	X	—
Environmental conditioning	5	a	X	—
Humidity conditioning	5	a	X	—
Thermal conditioning	5	a	X	—
Flammability	20	125x13x0.8 (5x0.5x0.031)	X	X
		125x13x1.6 (5x0.5x0.062)	X	X
Infrared Analysis	4 ounce liquid sample with MSDS or cured sample			
^a See 19.2.1.				

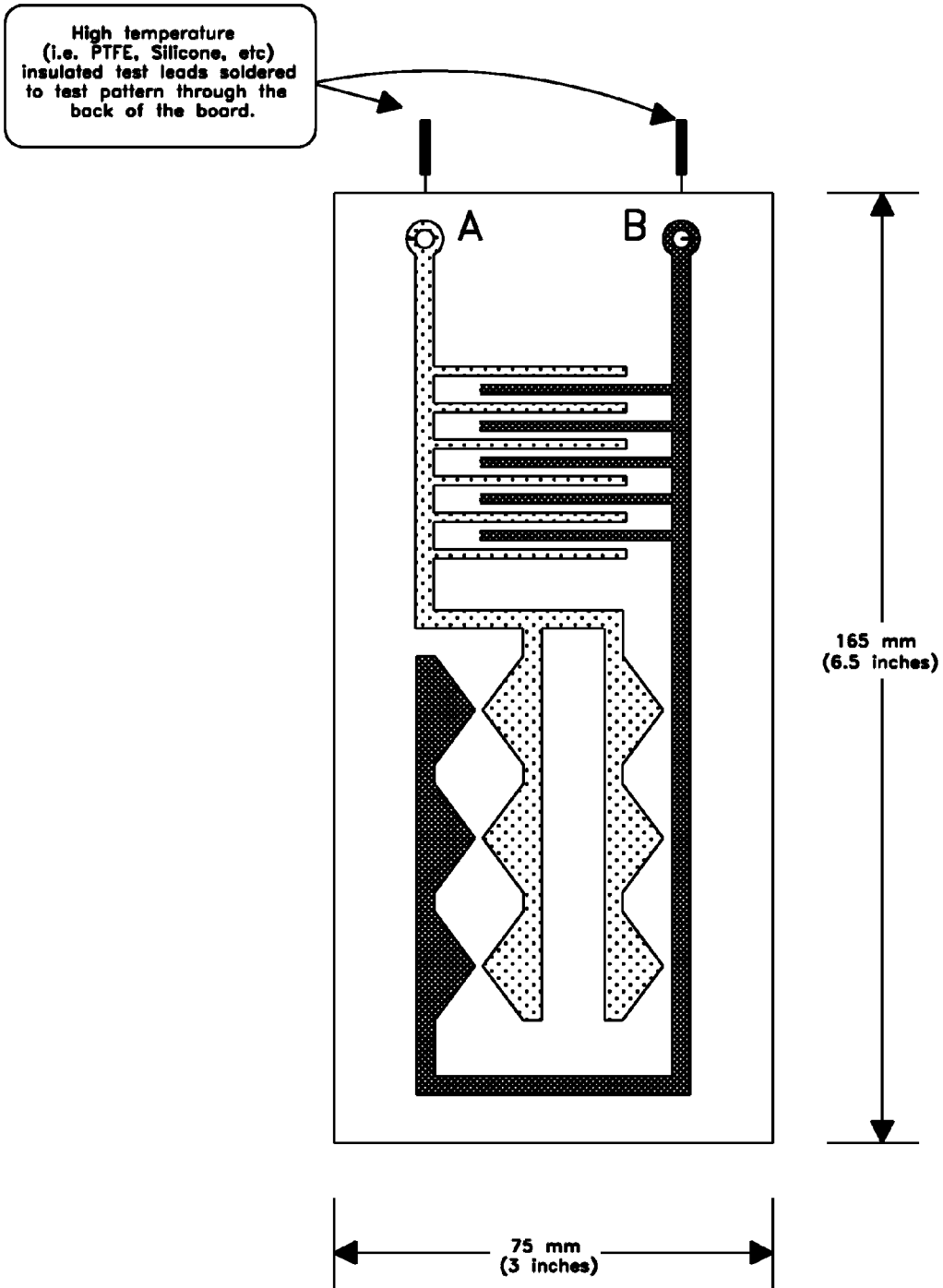
19.4 Dielectric voltage-withstand and breakdown-voltage test

19.4.1 The specimens subjected to the voltage transient test described in 19.3.1 are to withstand a 1000 V potential difference for one minute without breakdown. The voltage stress is to be applied between lead A and the foil covering connected to lead B. After one minute, the voltage stress is to be increased until breakdown occurs. Conditioned specimens (see 19.5.1 – 19.5.3) are to withstand the dielectric stress for one minute without breakdown and have a dielectric breakdown value at least fifty percent of the unconditioned samples.

19.5 Sample conditioning

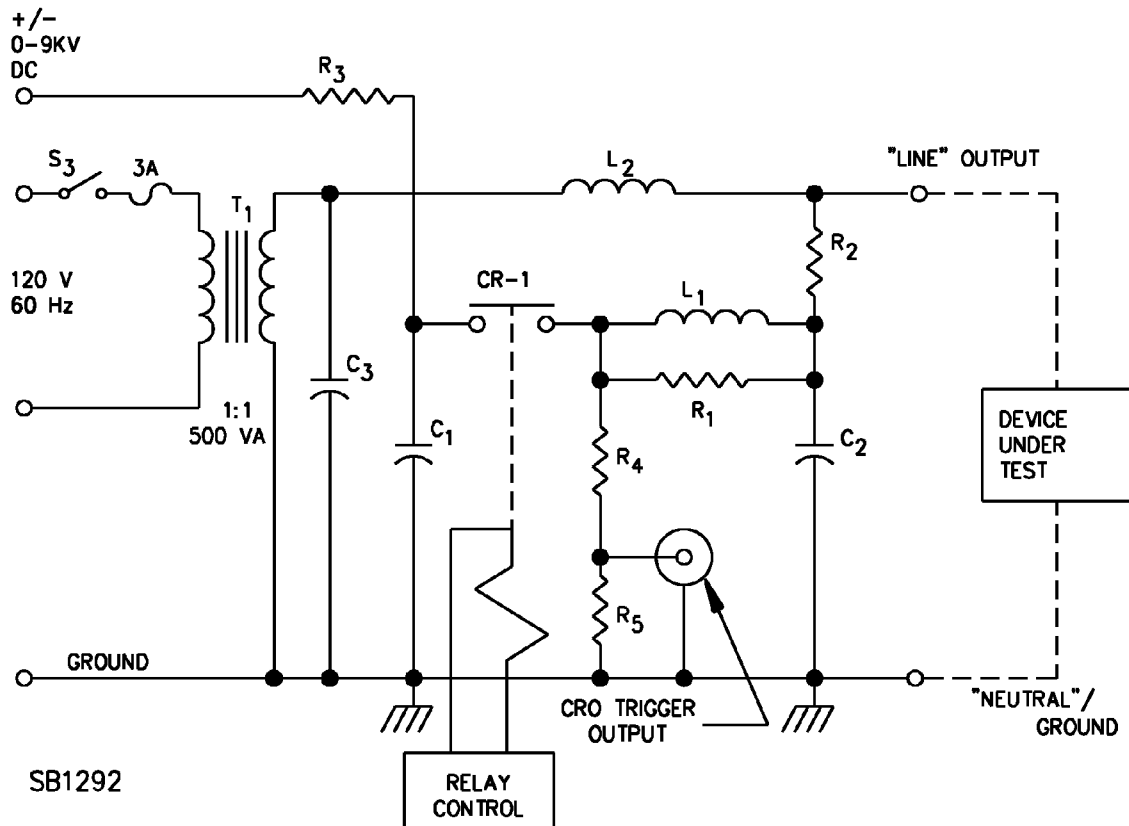
19.5.1 Specimens are to be subjected to three complete cycles of environmental conditioning as described in Table 19.2 and then subjected to the voltage transient test and the dielectric voltage-withstand and breakdown-voltage test.

Figure 19.1
Conformal coating dielectric test pattern



SM1235

Figure 19.2
Surge generator circuit



C1 = 0.025 μ F, 10kV
 C2 = 0.01 μ F, 10kV
 C3 = 4 μ F, 400V

R1 = 22 Ohms, 1W, composition
 R2 = 12 Ohms, 1W, composition
 R3 = 1.3M Ohms (12 x 110K Ohms, 1/2W)
 R4 = 47K Ohms (10 x 4.7K Ohms, 1/2W)

L1 = 14 μ H (33 turns, No. 23 AWG wire, 0.7 inch diameter air core)
 L2 = 70 μ H (44 turns, No. 14 AWG wire, 2.6 inch diameter air core)

CR - 1 = Relay (See Figure 19.3)

Table 19.3
Oven conditioning temperatures

Table 19.3 added February 7, 2001

Conformal coating operating temperature	Thermal oven aging temperature									
	1000 Hours					300 Hours				
	FR-4	XXXPC	FR-3	FR-2	GPO-2	FR-4	XXXPC	FR-3	FR-2	GPO-2
80°C	100°C	115	115	130	110	115°C	135	135	160	120
85°C	110°C	125	125	140	115	120°C	145	145	170	125
90°C	115°C	130	130	145	120	125°C	150	150	175	130
95°C	120°C	135	135	150	125	135°C	160	155	185	140
100°C	125°C	140	140	160	130	140°C	165	165	195	145
105°C	130°C	150	150	165	135	145°C	170	170	200	150
110°C	140°C	155	155	—	—	150°C	180	175	—	—
115°C	145°C	160	—	—	—	155°C	185	—	—	—
120°C	150°C	165	—	—	—	165°C	190	—	—	—
125°C	155°C	170	—	—	—	170°C	200	—	—	—
130°C	160°C	—	—	—	—	175°C	—	—	—	—
135°C	165°C	—	—	—	—	180°C	—	—	—	—
140°C	170°C	—	—	—	—	185°C	—	—	—	—

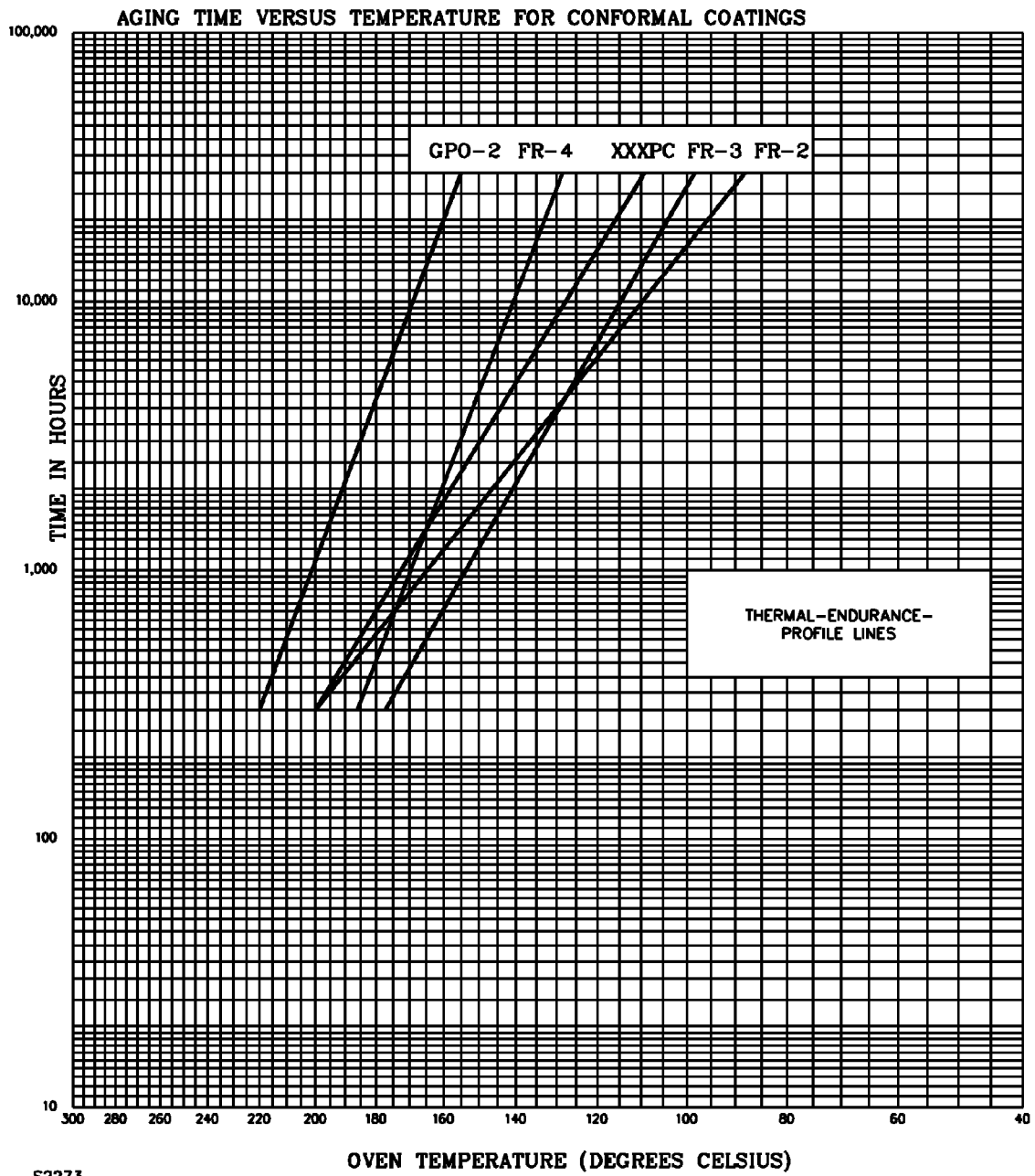
19.5.2 Specimens are to be humidity conditioned for 7 days at 90 – 95 percent relative humidity at 35.0 ±1.0°C (95.0 ±1.8°F). Within two minutes of removal from the test chamber or sealed transporting container, the specimens are to be subjected to the voltage transient test and dielectric voltage-withstand and breakdown-voltage test described in 19.3.1 and 19.4.1.

19.5.3 Specimens are to be thermal conditioned for 1000 hours in a full draft circulating air oven maintained at the oven temperature derived from the appropriate thermal endurance profile line in Figure 19.4. See Table 19.3 for common maximum operating temperatures and their corresponding oven aging temperatures. The thermal endurance profile lines for UL/ANSI grades FR2, FR3, FR4, XXXPC, and GPO-2 industrial laminates may be representative of other laminates. After conditioning, the specimens are to be cooled for a minimum of 40 hours at 23 ±2°C (73.4 ±3.6°F) and a 50 ±5 percent relative humidity and then be subjected to the voltage transient test and the dielectric voltage-withstand and breakdown-voltage test described in 19.3.1 and 19.4.1.

Exception: On the same thermal endurance profile line in Figure 19.4, a shorter or longer time at a higher or lower temperature, respectively, is not prohibited from being employed where agreeable to all concerned, and a period of not less than 300 hours is to be used.

19.5.3 revised February 7, 2001

Figure 19.4
Conditioning time versus oven temperature for normal operating temperature of conformal coatings



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MARKING

20 Details

20.1 An industrial laminate, vulcanized fibre, filament wound tubing or other material that complies with the requirements in this Standard shall be marked with a label containing:

- a) The manufacturer's name, trademark, or symbols by which the organization responsible for the product may be identified;
- b) The material designation; and
- c) A code to indicate the factory at which it is produced, when manufactured at more than one location, on the package or individual piece.

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SUPPLEMENT SA - FOLLOW-UP INSPECTION

INTRODUCTION

SA.1 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 Marking 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 product is being produced, stored or tested.

SA3.4 The Field Representative shall be permitted to select a sufficient quantity of material, as indicated in the Procedure, that is representative of current production 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 occur.

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 product 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.

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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 or 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 of material received from the Field Representative. For permanent coatings, only Qualitative Infrared Analysis is necessary. Upon completion of Follow-Up Testing, the Certification organization shall report the results to the manufacturer.

SA6.2 FLAMMABILITY TEST (for materials classified other than HB) – Test specimens are to be subjected to the appropriate burning tests, indicated in the Procedure, in accordance with the methods described in the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. The classifications obtained in the Follow-Up Tests are to be the same as those indicated in the Procedure.

SA6.3 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.

SA6.4 THERMOGRAVIMETRY (when indicated in the Procedure) – A thermogram of the material is to be obtained by means of a thermal analyzer with a thermogravimetric 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.

SA6.5 ASH CONTENT (for materials containing glass fibers or woven glass fabric) – The ash content of the material is to be obtained in accordance with the methods described in Determination of Ash Content, Section 44, of UL 746A, Polymeric Materials – Short Term Property Evaluations. The results obtained in the Follow-Up Tests are to satisfy the requirements specified in the Procedure.

SA6.6 FLEXURAL STRENGTH (for materials with a minimum thickness ≥ 0.64 mm (0.025 inch) – The flexural strength of the material is to be obtained in accordance with the methods described in Flexural Strength of Thermosetting Polymeric Materials, Section 14, of UL 746A, Polymeric Materials – Short Term Property Evaluations. The results obtained in the Follow-Up Tests are to satisfy the requirements specified in the Procedure.

SA6.7 TENSILE STRENGTH (for materials with a maximum thickness < 0.61 mm (0.024 inch) – The tensile strength of the material is to be obtained in accordance with the methods described in Tensile Properties of Thermoplastic Materials, Section 9, of UL 746A, Polymeric Materials– Short Term Property Evaluations. The results obtained in the Follow-Up Tests are to satisfy the requirements specified in the Procedure.

SA6.8 AXIAL COMPRESSIVE STRENGTH (for Filament Wound Tubing materials only) – The axial compressive strength of the material is to be obtained in accordance with the methods described in ASTM D348. The results obtained in the Follow-Up Tests are to satisfy the requirements specified in the Procedure.

SA6.9 ZINC CHLORIDE ANALYSIS (for Vulcanized Fibre materials only) – The zinc chloride analysis values shall be obtained in accordance with the methods described in ASTM D691 and ASTM D1224. The results obtained in the Follow-Up Tests are to satisfy the requirements specified in the Procedure.

ANNEX A

TGA Conformance Criteria

1) **Number of Degradations** – The current sample shall exhibit the same number of degradations (distinct areas of weight loss) as the reference sample. Generally, a distinct degradation is defined as an area of weight loss containing one inflection point which is bounded by an onset and offset of degradation (see definitions below, section 3) and which exhibits a gradual and continuous increase in the rate of weight loss (slope, as defined by the first derivative curve) to a maximum value (inflection point, maximum value of first derivative curve) followed by a gradual and continuous decrease in the rate of weight loss to a minimum value. There are instances in which one degradation is not distinct as defined above and will tend to merge with another. In these cases, it is the reviewer's judgement to determine the number of degradations. A degradation is not defined by its size; generally, only degradations of 1 percent weight loss or more will be evaluated using the stated criteria.

2) **Weight Loss Percent** – The weight loss percent of each degradation of the current sample shall correspond to that of the related degradation of the reference sample to within $\pm 5\%$. A related degradation is one occurring within the sample temperature range (see temperature criteria below). The values of weight percent at the beginning and end of a degradation are those taken at the extrapolated onset and offset of the degradation. Where two degradations overlap (the baseline between them does not return to zero slope) the midpoint value of the weight percent between the two degradations shall be used for comparison to the *current* TGA to the reference TGA. For purposes of defining the midpoint between two degradations that do overlap, it shall be the point at which the slope is at a local minimum as evidenced by the lowest point on the first derivative curve (percent weight loss with respect to time). *Note: It is common in overlapping degradations for the first derivative curve to exhibit more than one local minima between the degradations. In this case it is at the discretion of the reviewer to determine which minimum represents the appropriate point at which to measure the difference in weight loss percent.*

3) **Onset/Offset Temperature** – The extrapolated onset and offset temperatures and the inflection temperature of each degradation exhibited by the current sample shall correspond to a degradation on the reference sample TGA to within $\pm 15^\circ$ centigrade. The degradation of the current sample shall simultaneously conform to the second criterion as well. The extrapolated onset and offset of degradation are normally defined by the intersection of the corresponding extended baseline (onset, lower temperature; offset, higher temperature) with the tangent to the curve at the inflection point (peak of the first derivative curve). In the case of overlapping degradations the corresponding onset and offset temperature shall be derived by extending the baseline from the midpoint, as defined in section 2 above, to intersect the tangent to the inflection point.

4) **Residual Weight** – The residual weight of the current sample shall correspond to that of the reference sample TGA to within $\pm 5\%$. The residual weight is defined as the weight percent value at the endpoint of the TGA. It is a common point of reference to evaluate the amount of inorganic residue from fillers or additives.

(Note: The general criteria for weight percent difference between the reference and current sample at any temperature point on the TGA remains 5% as described in paragraph 2 above.)

The residual weight should represent a relatively constant and repeatable value to apply the criteria. It is the reviewer's judgement to determine if it sufficiently constant to evaluate. In some cases, such as with char formation, the application of the criteria may be adjusted.

5) **Curve Shape** – Overall curve shape of the current sample TGA shall conform to that of the reference sample TGA. This is a judgmental criteria based on experience. It is difficult to define in specific terms due to the numerous ways it can be manifested. It relates to definite changes in the TGA that are apparent to the reviewer and will be described in plain language as clearly as possible.

Some examples of curve shape differences include but are not limited to:

- a. If, for a specific degradation, the extrapolated onset and offset temperatures of the current sample were to vary from the reference values in opposite directions (onset, lower; offset, higher) then the rate of weight loss and curve shape could be judged to be significantly different even though the individual values were within limits.*
- b. If, for a specific degradation, the inflection point and the slope of the curve for the current sample varied from that of the reference TGA then the curve shape could be judged to be significantly different even though the individual values were within limits.*
- c. If, for successive degradations on the current sample TGA, the weight percent values of each were to vary from the references sample TGA the curve shape could be judged to be significantly different even though the individual values were within limits.*
- d. Combinations of differences described in a. and b. above may also cause a significant curve shape difference.*
- e. A current sample TGA may exhibit various other differences form the reference sample TGA:*
 - 1) gradual sloping onsets as opposed to sudden compact onsets of degradation,*
 - 2) flattened areas of a curve, especially at onsets, as opposed to rounded onsets,*
 - 3) unresolved degradations that are exhibited as slope changes (and as peaks or shoulders on the derivative curve) at the beginning or end of a major degradations.*

6) **Exception Consideration** – The criteria described above are intended as general guidelines to assist in the determination of conformance with respect to Thermogravimetric Analysis (TGA) data. Although these guidelines are based on empirical evidence, comparative evaluation of TGA data is subjective in nature and experience has shown that deviations are sometimes a function of certain material types and their associated instrument responses. Conformance evaluation consideration is therefore given to test result reproducibility and sample behavior on a case by case basis to allow for prudent guideline exceptions.

**Superseded requirements for
the Standard for**

**Polymeric Materials-Industrial Laminates, Filament Wound Tubing, Vulcanized Fibre, and Materials
Used in Printed-Wiring Boards**

UL 746E, Third Edition

The requirements shown are the current requirements that have been superseded by requirements in revisions issued for this Standard. To retain the current requirements, do not discard the following requirements until the future effective dates are reached.

6.6 (6.6) A qualitative infrared shall be made from resin obtained by surface scraping of the glossy side of the industrial laminates in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. The spectrum obtained shall indicate the same basic composition as that recorded in the spectrum of the UL/ANSI type. Typical infrared analysis spectra are shown in Figures 6.1 – 6.17 , for each UL/ANSI type. A fundamental variation in composition from the typical spectra is not acceptable. Examples of unacceptable fundamental variations are as follows:

- a) The absence of a significant absorption band which was present in the UL/ANSI type.
- b) The presence of a significant band which was not present in the UL/ANSI type.
- c) An indication of the presence of a different member of the same homologous series (a series of hydrocarbon compounds each differing by a carbon and two hydrogen atoms).
- d) A significant variation in the absorption coefficient (a value indicating the fraction of incident light absorbed) from the UL/ANSI type [“significant variation” cannot be defined by a specific numerical value because the extent of variation per unit (percent transmittance) is dependent upon the dipole moment of the particular chemical family].

Exception: A material that has unacceptable fundamental variations qualifies for additional testing of full indexing and two or four point thermal aging as described in the Full Test Program, Section 7. A relative thermal index equivalent to the UL/ANSI type shall be assigned to the material, if the test results so warrant. The material shall not be designated as a UL/ANSI type unless aging is done under the full test program, and the test results permit assignment to the material of the same relative thermal index as shown in Table 5.2.

6.6 effective until February 7, 2004

7.10 (7.10) If the composition of the material as determined by Infrared Analysis does not compare favorably with any existing UL/ANSI type, then both dielectric strength and flexural strength shall be used as primary properties for testing, plus other secondary properties mentioned in 7.9.

7.10 effective until February 7, 2004

Figure 6.7 (6.7)
Typical IR spectrum for industrial laminates UL/ANSI Types G-10 and FR-4

Figure 6.7 effective until February 7, 2004

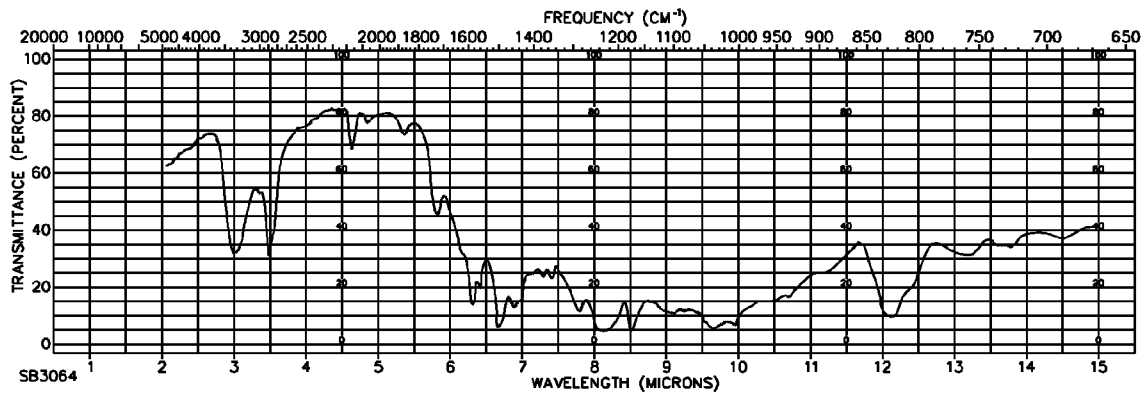


Figure 6.8 (6.22)
Typical IR spectrum for industrial laminates UL/ANSI Types G-11 and FR-5

Figure 6.8 effective until February 7, 2004

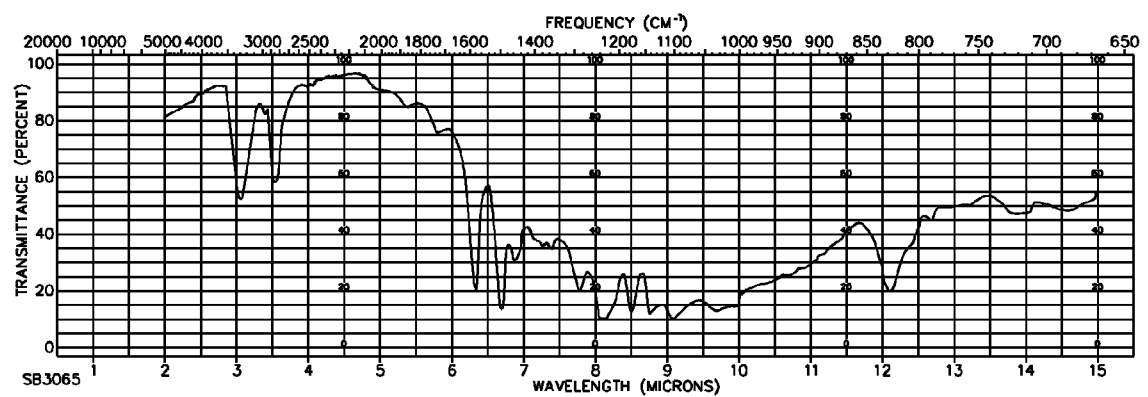


Figure 6.9 (6.23)
Typical IR spectrum for industrial laminates UL/ANSI Type FR-2

Figure 6.9 effective until February 7, 2004

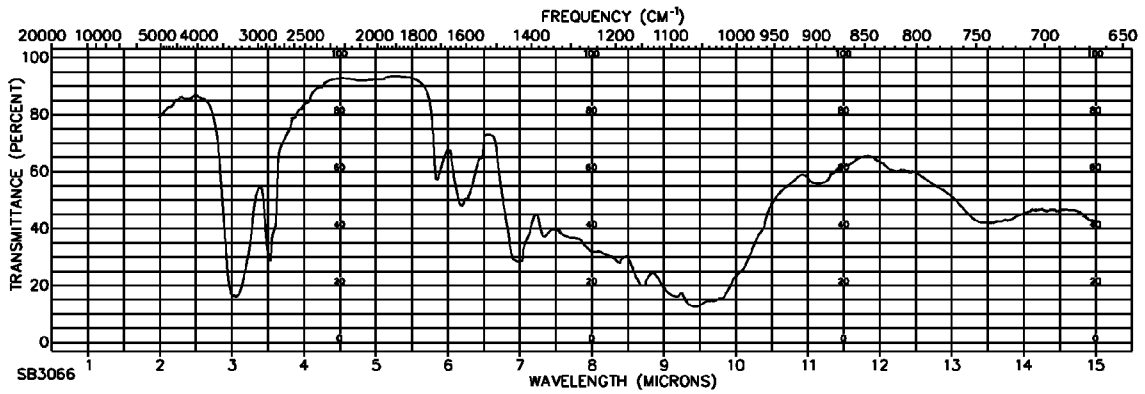


Figure 6.10 (6.24)
Typical IR spectrum for industrial laminates UL/ANSI Type FR-3

Figure 6.10 effective until February 7, 2004

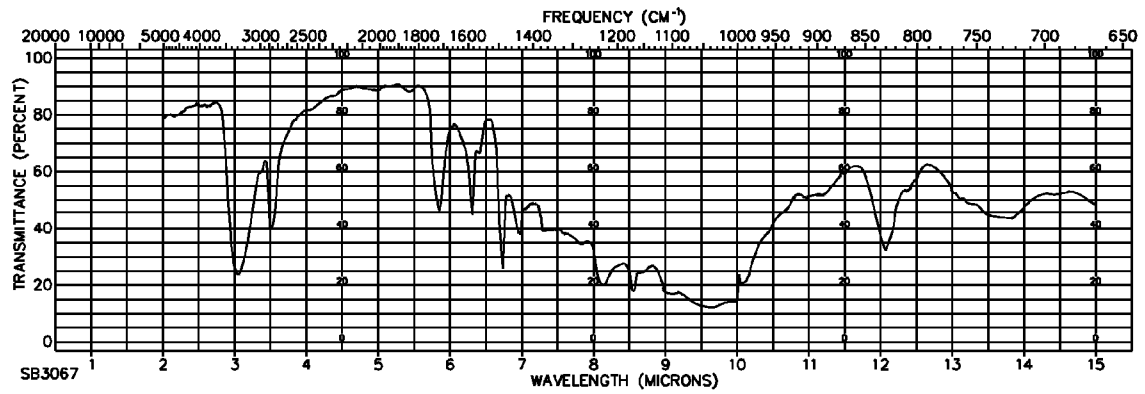


Figure 6.11 (6.25)
Typical IR spectrum for industrial laminates UL/ANSI Type G-3

Figure 6.11 effective until February 7, 2004

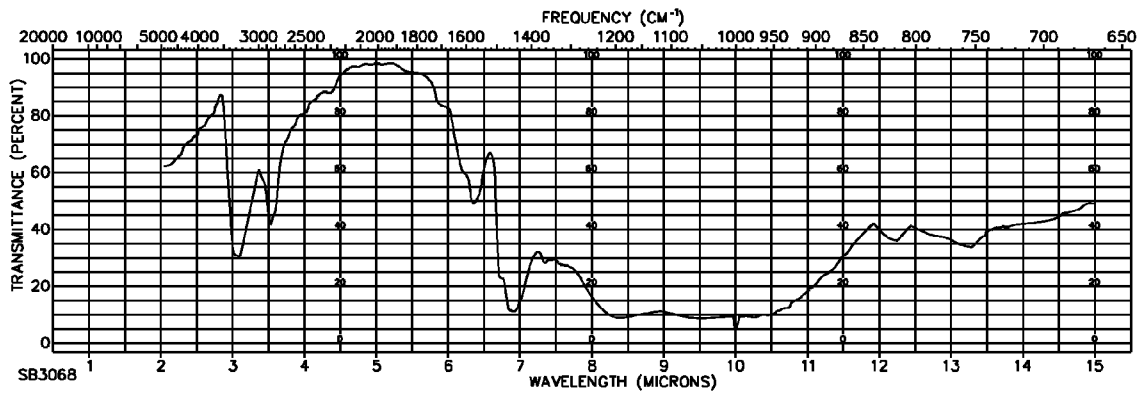


Figure 6.12 (6.26)
Typical IR spectrum for industrial laminates UL/ANSI Type CEM-1

Figure 6.12 effective until February 7, 2004

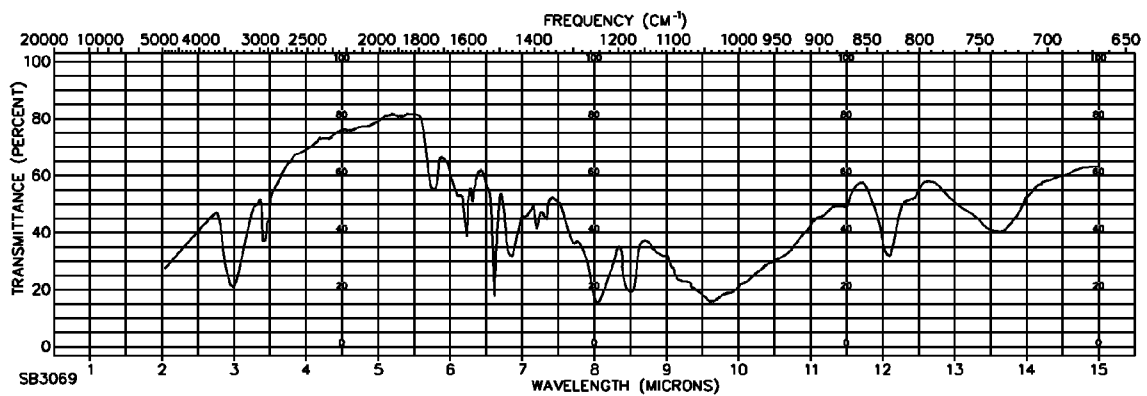


Figure 6.13 (6.27)
Typical IR spectrum for industrial laminates UL/ANSI Type CEM-3

Figure 6.13 effective until February 7, 2004

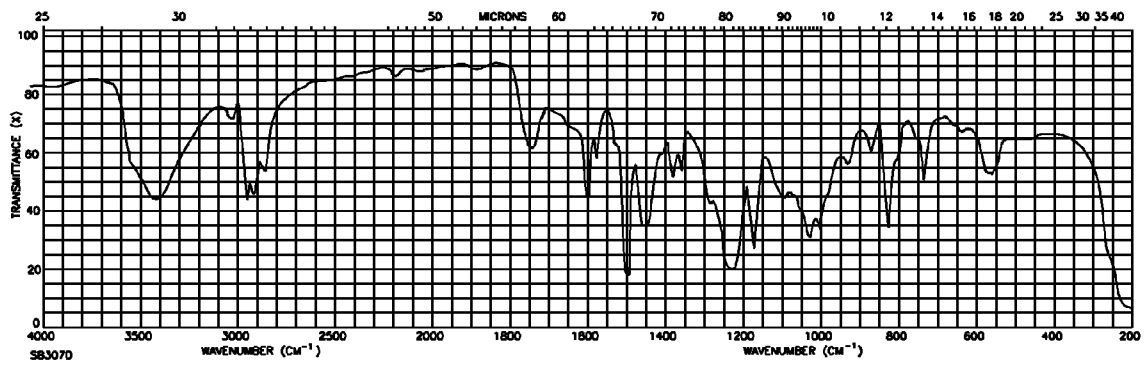


Figure 6.14 (6.28)
Typical IR spectrum for industrial laminates UL/ANSI Type GPO-2

Figure 6.14 effective until February 7, 2004

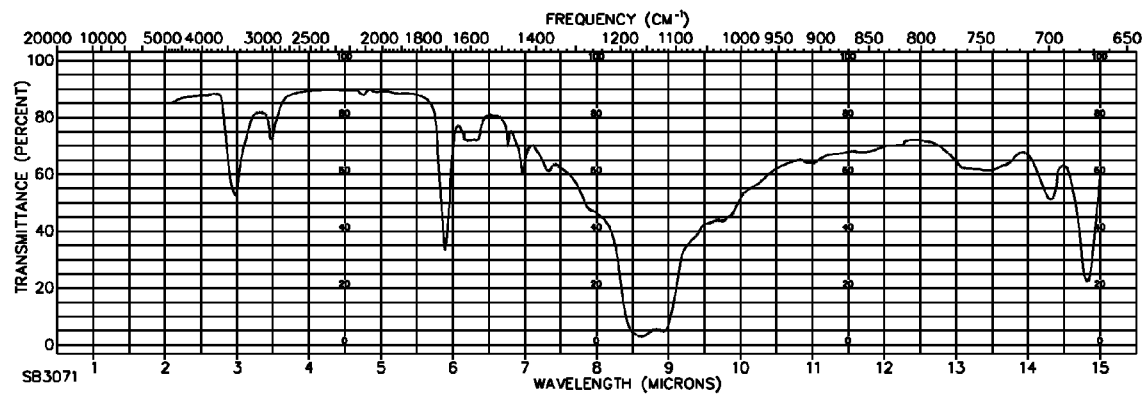


Figure 6.15 (6.29)
Typical IR spectrum for industrial laminates UL/ANSI Type GPO-3

Figure 6.15 effective until February 7, 2004

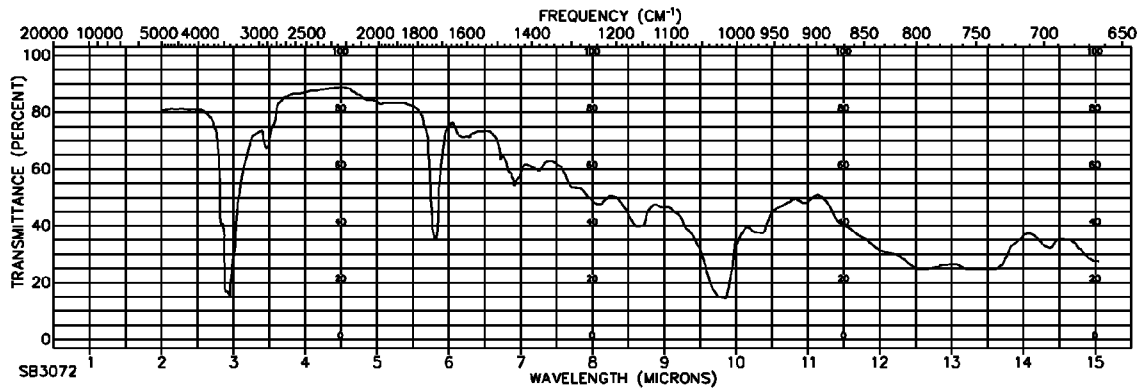


Figure 6.16 (6.30)
Typical IR spectrum for industrial laminates UL/ANSI Type GPY

Figure 6.16 effective until February 7, 2004

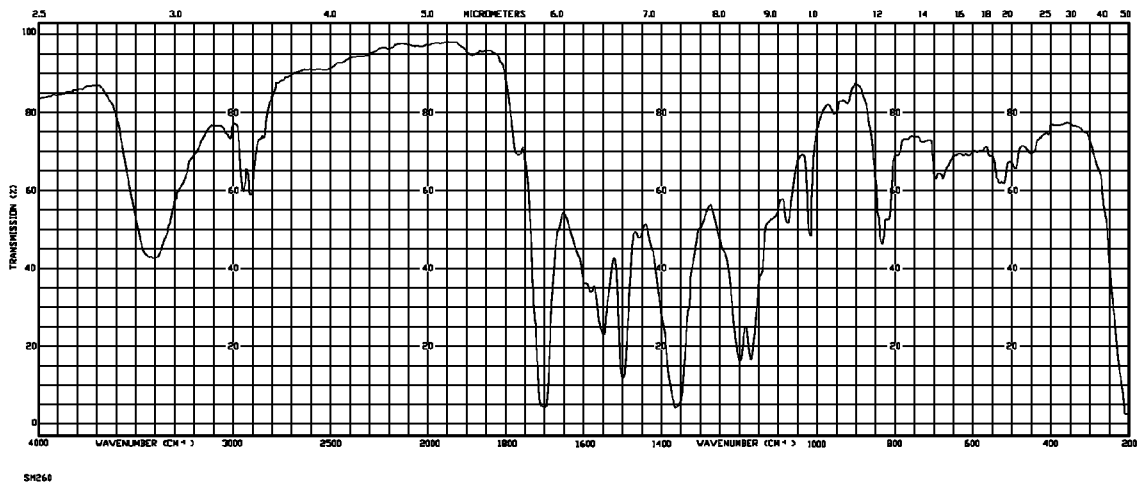
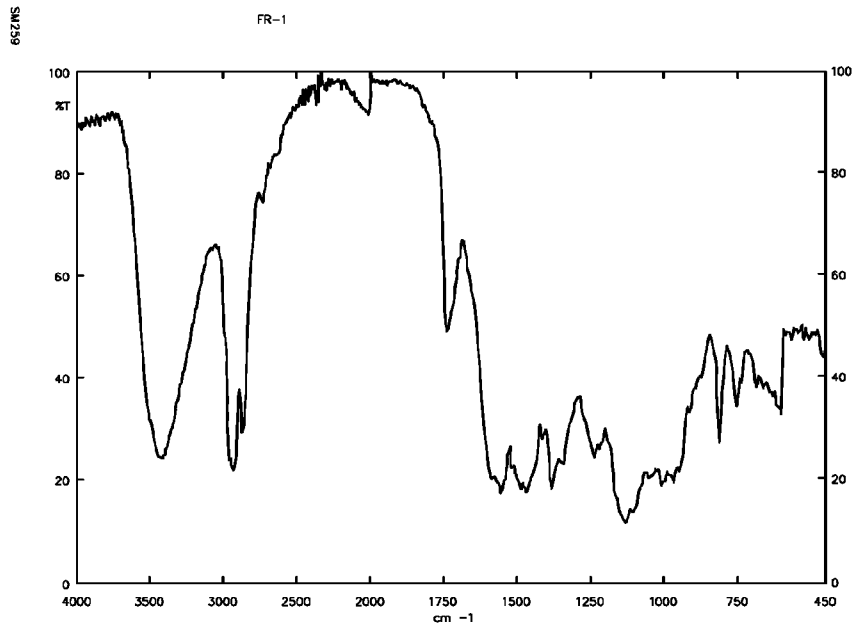


Figure 6.17 (6.31)
Typical IR spectrum for industrial laminates UL/ANSI Type FR-1

Figure 6.17 effective until February 7, 2004



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