UL 746E

STANDARD FOR SAFETY

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

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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Summary of Topics:

This revision of ANSI/UL 746E dated June 26, 2025 includes clarification of the UL 94 VTM test method, 19.11.1, 19.11.2, 19.11.2A, 19.11.2B, 19.11.2C, 19.11.3, 19.11.6, and 23.5

Text that has been changed in any manner or impacted by ULSE's electronic publishing system is marked with a vertical line in the margin.

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated April 18, 2025.

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

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The most recent designation of ANSI/UL 746E as an American National Standard (ANSI) occurred on June 26, 2025. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page. Any other portions of this ANSI/UL standard that were not processed in accordance with ANSI/UL requirements are noted at the beginning of the impacted sections.

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

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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 For constructions and materials not specifically addressed in this Standard:

- The printed wiring board should provide safeguards not less than that generally afforded by this document and the principles of safety contained herein. This includes printed wiring boards with technologies, materials, or methods of construction, including the manufacturing process, not specifically addressed in this document.

- Propose for discussion with the Technical Committee the need for additional detailed requirements to address a new situation in a timely manner.

2 Glossary

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

2.2 ADHESIVE – A gelatinous substance such as glue or cement used to join, bond, or fasten materials or objects together.

2.3 ANISOTROPIC – A material having different values for properties, such as conductivity, depending on the direction or dimension within the material.

2.4 AS RECEIVED – Samples in an unconditioned state, prior to being subject to conditioning, or without a history of conditioning.

2.5 ASSEMBLY SOLDERING PROCESS – The process used for soldering components to a printed wiring board during the assembly process. The soldering process may include, but is not limited to, reflow, wave, selective soldering, or other equivalent soldering techniques.

2.6 BASE MATERIAL – An organic or inorganic insulating material used to support a pattern of conductor material. The base material may be rigid or flexible.

2.7 BASE MATERIAL THICKNESS – The thickness of the base dielectric material excluding conductive foil or material deposited on the surface of the base material. If an adhesive is used to adhere the conductor material to the base material, the adhesive thickness and application surfaces (base material sides) are indicated separately.

2.8 BIAS CUT – Samples cut crosswise to the surface of the material. See Figure 7.1.

2.9 BONDING LAYER – An adhesive layer used to bond discrete layers of multilayer laminate constructions. Also known as prepreg.

2.10 BUILD-UP THICKNESS – Overall thickness of a combination of materials. Unless otherwise indicated, the build-up thickness will refer to the overall thickness of a laminate construction where no internal or external conductor material resides.

2.11 CAP LAYER – A single sided copper clad laminate bonded to the external surface of the multilayer board with bonding layer material (prepreg or b-stage material).

2.12 CIRCUIT – Electrical devices and elements interconnected to perform a desired electrical function.

2.13 CIRCUITRY LAYER – Conductor layer or plane in or on a printed wiring board.

2.14 CLAD MATERIAL – See Metal Clad Base Material.

2.15 COATING – A non-metallic substance applied by some process, such as dipping, curtain coating, film laminating, screening, spraying, or melt-flow.

2.16 CONDITIONING – Exposure of test samples to an environment for a period of time, prior to or after testing and prior to evaluation.

2.17 CONDUCTIVE (ELECTRICAL) – The ability of a substance or material to conduct electricity.

2.18 CONDUCTIVE FOIL – A thin metal sheet intended for forming a conductor pattern on a base material.

2.19 CONDUCTOR – A trace or path for electricity to transmit in a conductor pattern.

2.20 CONDUCTOR ADHESIVE – Adhesive material used to attach conductor material to a base material.

2.21 CONDUCTOR AVERAGE TRACE WIDTH – The average width of a length of conductor trace.

2.22 CONDUCTOR BASE WIDTH – The width of a conductor at the interface of the conductor material as determined by microsection analysis. This width is used to determine bond strength/peel strength values.

2.23 CONDUCTOR LAYER – A single plane of a conductor material or pattern on a base material.

2.24 CONDUCTOR MATERIAL – An organic or inorganic substance capable of transmitting electricity, used for circuit conductors, including but not limited to copper, tin, nickel, gold, carbon paste, copper paste, silver paste, ruthenium oxide paste, etc.

2.25 CONDUCTOR PATTERN – The path, design, or configuration of conductor material on the base material, including but not limited to conductor traces, lands, through-holes, and vias.

2.26 CONDUCTOR THICKNESS – The thickness of the conductor and additional metallic platings or coatings, excluding non-conductive coatings.

2.27 CONDUCTOR TRACE – A linear conductor path of a conductor circuit.

2.28 CONDUCTOR WEIGHT – See Conductor Thickness.

2.29 CONDUCTOR WIDTH – The width of the conductor as viewed from a top view or at the plane of the surface of a base material, whichever is less. See Conductor Base Width.

2.30 CONFORMAL COATING – A protective covering applied on a printed wiring board capable of conforming to the configuration of objects coated, used to increase the dielectric voltage-withstand capability between conductors and/or to protect against environmental conditions.

2.31 CONTINUITY – An uninterrupted path for the flow of electrical current in a circuit.

2.32 CONSTRUCTION – A variation in laminate materials, including but not limited to base material, laminate, prepreg, dielectric materials, or other insulation materials. Variations include singlelayer, multilayer, and composite constructions.

2.33 CORE MATERIAL – The innermost material or base material which may be used to support a subsequent layer or layers of dielectric material and conductor pattern. Core material may be an organic or inorganic material, with or without integral dielectric material. Core material may be referred to as substrate material.

2.34 COUPON – A test vehicle constructed to represent a production material to be used for testing. See Sample.

2.34A CURING AGENT – A component added at the A-Stage to facilitate or increase the rate of curing of a thermosetting resin. Commonly known as a crosslinking agent.

2.35 CURRENT – The flow or movement of electrons in a conductor as a result of voltage difference between the ends of the conductive path.

2.36 DECLAD – A dielectric material from which the foil or conductive material has been removed by etching or other means.

2.37 DELAMINATION – A planar separation of materials (i.e., separation between conductor and base material, prepreg, dielectric material, etc.).

2.38 DESICCATOR – A sealable vessel containing anhydrous calcium chloride, or other drying agent, maintained at a relative humidity not exceeding 20 percent at 23 ±2°C (73.4 ±3.6°F).

2.39 DIELECTRIC – A material capable of high resistance to the flow of electrical current and capable of being polarized by electric field.

2.40 DOUBLESIDED – A singlelayer board construction with conductor pattern on the two external sides of the base material only. Sometimes referred to as di-clad.

2.41 END PRODUCT – An individual part or assembly in its final completed state. See End-Use Product.

2.42 END-USE PRODUCT – A device or appliance in which a printed wiring board is installed as a component.

2.42A EPOXY – A class of thermosetting polymers derived from an epoxide resin.

2.43 ETCHANT – A chemically reactive solution used to remove portions or all material from a base material construction.

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

2.45 ETCHING – The action of chemical, or chemical and electrolytic, removal of conductive or resistive material.

2.46 EXTERNAL LAYER – The conductor pattern on the external surface of the board construction.

2.47 FAMILY – Multiple grades of materials that have identical IR spectra and performance characteristics are UL Recognized for the manufacturer as a material family (alternate grades separated by a comma) of which one grade is representative of others in the family.

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

2.48A FILLER, INORGANIC – An inorganic material added at the A-Stage which does not react chemically to form part of the polymer.

2.48B FILLER, ORGANIC – An organic material added at the A-Stage which does not react chemically to form part of the polymer.

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

2.49A FLAME RETARDANTS – Substances that inhibit or suppress the combustion process when added to combustible materials. Flame retardants can be Reactive (i.e. chemically bound to the combustible material) or Additive (i.e. not chemically bound or reacted with the combustible material but are dispersed evenly throughout).

2.50 FLAMMABILITY ONLY RECOGNITION – A material intended for use where the construction shall be evaluated for a flammability classification only, and the thermal, mechanical, and electrical capacity of the material is not of concern and only the flammability classification of the resulting printed wiring board is of concern in the end-use product.

2.51 FOIL LAMINATION – A process for bonding a conductive foil to a dielectric base material.

2.52 GRADE – A designation arbitrarily assigned to a material by the fabricator.

2.53 INDUSTRIAL LAMINATE – Insulating material consisting of reinforcement impregnated or coated with resin and laminated under pressure and high temperature with or without vacuum assist. The resin may contain filler and additives. The reinforcement may be fibrous material such as cellulose paper, cotton, woven aramid, nonwoven aramid, woven glass, random laid glass mat or other fibers and films. The insulating material may or may not contain reinforcement material. See Base Material.

2.54 INTERNAL LAYER – A conductor pattern contained entirely within a multilayer board construction.

2.55 LAMINATE – The product of bonding two or more layers of material.

2.56 LAMINATE THICKNESS – The thickness of the dielectric material in a singlesided or doublesided singlelayer metal-clad base material.

2.57 LAYER-TO-LAYER SPACING – The thickness of dielectric material between adjacent conductor planes (i.e., the physical distance between adjacent conductor planes).

2.58 MACHINE CUT – Samples cut lengthwise to the surface of the material. See Figure 7.1. Also known as warp direction cut.

2.59 MASS LAMINATE – An assembly of base material layers (laminate) and bonding layers (prepreg) laminated together, and which is performed by a base material manufacturer or any other source outside the printed wiring board fabricator's facility. Mass laminating is performed in several ways. Two examples are:

a) The manufacturer of the base material receives the inner layers etched by the printed wiring board fabricator and, with a bonding layer supplied by the printed wiring board fabricator or from his own stock, laminates the boards with a solid metal sheet on the external surfaces.

b) The manufacturer of the base material receives art work from the printed wiring board fabricator or generates his own art work to prepare the inner layers, etches the inner layers of his own in-house base material, and with a bonding layer laminates the boards with a solid metal sheet on the external surfaces.

After either of the above procedures, the laminator returns to the printed wiring board fabricator a composite of internal layers and solid metal external layers for final etching of external surfaces and/or plating operations.

2.60 MAXIMUM OPERATING TEMPERATURE (MOT) – The maximum operating temperature is the maximum continuous use temperature that the laminate in a board construction may be exposed to under normal operating conditions.

2.60A MELAMINE – A class of melamine–formaldehyde thermosetting polymers which are the product of the reaction of melamine, which is a trimer of cyanamide, and formaldehyde.

2.61 METAL BASE LAMINATE – A metal core used as the support for a dielectric insulating material or base material applied to one or both sides of the metal core surface.

2.62 METAL CLAD BASE MATERIAL – Base material with metal conductor material on one or both sides, with or without adhesive.

2.63 METAL CLAD LAMINATE – See Metal Clad Base Laminate.

2.64 METAL CORE LAMINATE – See Metal Base Laminate.

2.65 METAL WEIGHT – See Conductor Weight.

2.66 MINIMUM CONDUCTOR WIDTH – The minimum width conductor present on the sample or production printed wiring board. See Conductor Base Width.

2.67 MULTILAYER – Consists of alternate layers of conductors and base materials laminated or bonded together, including at least one internal conductive layer.

2.68 PATTERN – The configuration of conductive and nonconductive materials on a base dielectric material.

2.69 PERFORMANCE LEVEL CATEGORIES (PLC) – An integer defining a range of test values for a given electrical or mechanical property test.

2.70 PERMANENT COATING – See Permanent Materials.

2.71 PERMANENT MATERIALS – Materials intended to be a part of the board, for the life of the product.

2.72 PERMANENT RESIST – A solder resist or mask material intended to be a part of the board, for the life of the product.

2.72A PHENOLIC – A class of phenol–formaldehyde thermosetting polymers which are the product of the reaction of phenol and formaldehyde. The earliest synthetic polymers to be manufactured.

2.72B PIGMENT – A material added at the A-Stage for the purpose of changing the color from natural in the C-Stage product.

2.72C POLYESTER – A class of thermosetting polymers typically prepared by the esterification of a polyfunctional alcohol with a difunctional organic acid.

2.72D POLYIMIDE – A class of thermosetting polymers formed of imide monomers.

2.73 PREPREG – Fibrous reinforcement material impregnated or coated with a thermosetting resin binder, and consolidated and cured to an intermediate stage semi-solid product (B-stage resin).

2.74 PRINTED BOARD – See printed circuit board and printed wiring board.

2.75 PRINTED (CIRCUIT) BOARD – A printed board produced from rigid industrial laminate material that provides point-to-point connections and printed components in a predetermined arrangement. See printed wiring board and printed board.

2.76 PRINTED WIRING BOARD – A completely processed combination of a printed wiring pattern, including printed components, and the base material. See printed circuit board and printed board.

2.77 REINFORCEMENT MATERIAL – Any material (i.e. fibrous, continuous, sheet, etc.) capable of enhancing the base material mechanical or physical performance.

2.78 RELATIVE THERMAL INDEX (RTI) – Maximum service temperature for a material, where a class of critical properties will not be unacceptably compromised through chemical thermal degradation, over the reasonable life of an electrical product, relative to a reference material having a confirmed, acceptable corresponding performance-defined RTI.

2.78A RESIN, A-STAGE – The first stage in the production of a thermosetting polymer in which a soluble and fusible prepolymer is formed. Commonly known as a varnish.

2.78B RESIN, B-STAGE – The second stage in the production of a thermosetting polymer where it is partially branched and crosslinked. However, network formation is not so advanced that the material is completely insoluble and infusible. Commonly known as prepreg when combined with a reinforcement.

2.78C RESIN, C-STAGE – The final stage in the production of a thermosetting polymer so that it has a sufficiently high crosslinking density to render it completely insoluble and infusible. Commonly known as a laminate when combined with a reinforcement.

2.79 RESIN COATED COPPER FOIL (RCF) – Metal foil coated with unreinforced resin using a single- (one pass) or double- (two pass) coated system. Single-coated foils are usually coated with one layer of B-stage resin. Double-coated foils are usually coated with two layers of resin; C-stage resin adjacent to the foil and B-stage resin on the surface of the C-stage resin.

2.79A RESIN, EPOXIDE – A resin formed from a prepolymer present in the A-Stage which incorporates the characteristic oxirane three-membered heterocycle of two carbon atoms and one oxygen atom.

2.79B RESIN, PRIMARY – The original resin type in the A-Stage before it was crosslinked into a polymer network that represented the greatest weight percent of resins in the A-Stage.

2.79C RESIN, SECONDARY – A resin added at the A-Stage of greater than 3 weight percent which may or may not chemically react with the primary resin and which does not form part of the curing or flame-retardant system.

2.79D RESIN SYSTEM – The resin system of a composite material comprises the resin matrix that binds and transfers mechanical load through the reinforcement to the rest of the structure.

2.79E RESIN, THERMOSETTING – A polymer that may be crosslinked by the application of heat and/or a suitable curing agent to form a thermoset polymer. Once crosslinked a thermosetting resin cannot be significantly re-softened or re-shaped by reheating. Thermoset polymers are commonly produced by lamination, compression or transfer molding.

2.79F RESIN, THERMOPLASTIC –A plastic material that significantly softens on heating and hardens on cooling in a process that may be repeated many times. Thermoplastic materials are commonly produced and distributed in the form of pellets or powder, and shaped into the final product form by melting, pressing, or injection molding.

2.80 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.

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

2.82 RIGID PRINTED WIRING BOARD – A printed wiring board produced using rigid base dielectric materials.

2.83 SAMPLE – A test vehicle which may be a production material, or a portion there of, or a coupon.

2.83A SILICONE – A class of three-dimensional polymerized siloxane thermosetting polymers formed by the crosslinking of highly branched silicone precursors.

2.84 SINGLELAYER – Singlelayer board constructions are doublesided constructions with one layer of dielectric materials(s) separating the conductor planes, and singlesided constructions with a single conductor plane on one side of a dielectric materials(s).

2.85 SINGLE-SIDED – A board with conductor pattern on one side of the dielectric material(s).

2.86 SOLDER MASK – See Solder Resist.

2.87 SOLDER RESIST – A coating material intended to prevent deposition of solder upon selected areas during solder operations.

2.88 SPUTTERING – The ejection of atoms caused by ion bombardment of a target material in a plasma environment and the subsequent deposition of ejected atoms onto the surface of the substrate.

2.89 SUBSTRATE – See Core Material.

2.90 TEMPERATURE PROFILE – The temperatures a select point traverses as it passes through a process involving multiple temperatures and dwell times.

2.91 TEST PATTERN – The conductor pattern intended for test and inspection purposes.

2.92 TRANSVERSE CUT – Samples cut normal to the surface of the material. See Figure 7.1. Also known as fill direction cut.

2.93 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.

2.94 UNCLAD – A dielectric or laminate material without foil or conductive material (never copper clad).

2.95 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.

2.96 X-AXIS – A reference axis, usually horizontal or left-to-right direction in a two dimension coordinate system.

2.97 Y-AXIS – A reference axis, usually vertical or bottom-to-top direction in a two dimension coordinate system. The x and y axis are usually perpendicular to one another, in a two or three dimension coordinate system.

2.98 Z-AXIS – The axis perpendicular to the plane created by the x and y reference axis. This axis usually refers to the thickness of a laminate construction.

3 Units of Measurement

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

4 Measurement Accuracy and Testing Conditions

4.1 A measuring device used to perform the tests required by this Standard, shall be capable of measuring the specified parameter with an accuracy within 10 percent of the measured parameter.

4.2 Prior to all tests, subject all samples to a stabilization period in accordance with the Standard Practice for Conditioning Plastics for Testing, ASTM D618, and the Standard for Plastics – Standard Atmospheres for Conditioning and Testing, ISO 291, for a minimum of 40 hours at 23 ±2°C (73.4 ±3.6°F) and 50 ±10 percent RH, unless specified otherwise in the individual test method.

4.3 During the test, the standard atmospheric conditions surrounding the sample shall be 25°C ±10°C (77°F ±18°F) and 50 ±10 percent relative humidity, unless otherwise specified in the individual test method.

4.4 Flammability samples shall be preconditioned as described in the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. As an alternative to the 70°C for 168 hours preconditioning, industrial laminate and solder resist materials shall be preconditioned using the alternate conditions of 125 ±2°C for 24 ±1 hours, unless otherwise specified.

4.5 Once samples are removed from the thermal or humidity pre-conditioning environment, samples shall be tested within 30 minutes or the specified time period.

5 Supplementary Test Procedures

5.1 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, the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, and the Standard for

Polymeric Materials – Flexible Dielectric Film Materials for use in Printed Wiring Boards and Flexible Materials Interconnect Constructions, UL 746F, 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 for Flexible Materials Interconnect Constructions, UL 796F, contains the minimum performance requirements for flexible printed wiring boards and interconnect constructions.

6 References

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

6.2 The following publications are referenced in this standard:

ASTM D 149 – Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies.

ASTM D 257 – Standard Methods of Test for DC Resistance or Conductance of Insulating Materials.

ASTM D 348 – Standard Test Methods for Rigid Tubes Used for Electrical Insulation.

ASTM D 374 – Standard Test Methods for Thickness of Solid Electrical Insulation..

ASTM D 495 – Standard Test Method for High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation.

ASTM D 570 – Standard Test Method of Test for Water Absorption of Plastics.

ASTM D 618 – Standard Practice for Conditioning Plastics for Testing.

ASTM D 619 – Standard Test Methods for Vulcanized Fibre Used for Electrical Insulation.

ASTM D 790 – Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials..

ASTM D 882 – Standard Test Methods for Tensile Properties of Thin Plastic Sheeting.

ASTM D 1000 – Standard Test Method for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications.

ASTM D 3850 – Standard Test Method for Rapid Thermal Degradation of Solid Electrical Insulating Materials by Thermogravimetric Method (TGA).

ASTM D 5423 – Standard Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation.

ASTM E 3 – Standard Guide for Preparation of Metallographic Specimens.

IEC 61189-2 – Test methods for electrical materials, printed boards and other interconnection structures as assemblies – Part 2: Test methods for materials for interconnection structures.

IEC 62321-3-2 – Determination of certain substances in electrotechnical products – Part 3-2: Screening – Flourine, chlorine and bromine in polymers and electronics by Combustion – Ion Chromatography (C-IC).

IPC-4101 – Specification for Base Materials for Rigid and Multilayer Printed Boards

IPC TM-650 2.1.1 – Microsectioning Manual and Semi or Automatic Method.

ISO 291 – Plastics – Standard Atmospheres for Conditioning and Testing.

INDUSTRIAL LAMINATES

7 General

7.1 The dielectric material test programs are divided into parts, as shown in Table 7.1 to determine the physical, electrical, flammability, thermal and other performance property characteristics based on the material construction and specific application.

Table 7.1
Description of Application-Specific Test Programs in UL 746E

Section	Program	Description
8	UL/ANSI abbreviated evaluation	Test program for laminates with comparable characteristics to the UL/ANSI type materials qualify for reduced testing
9	UL/ANSI or Non-ANSI full evaluation	Test program for full characterization of the material performance
10	UL/ANSI or Non-ANSI ultrathin materials and Prepreg Test Program	Test program for characterization of thin material.
11	Non-reinforced materials and other materials requiring mechanical support	Test program for characterization of non-reinforced materials requiring mechanical support
12	Metal base laminates	Test program for characterization of metal base laminate / composite material
13	Flexible film constructions	See UL 746F for Flexible Material investigations
19	Metal clad laminates	Test program for characterization of metal clad material
20	Metal clad mass laminated multilayer laminates	Test program for characterization of prefabricated multilayer laminate

7.1A The material constituent component details shall be provided by the supplier. The constituent details shall include, but are not limited to: Curing Agent, Flame Retardant, Inorganic Filler, Organic Filler, Pigment, Primary Resin, Reinforcement and Secondary Resin.

7.2 Profiles of minimum performance, relative thermal indices, and major constituents of industrial laminates are given in Table 7.2 – Table 7.4. These profiles are minimum characteristics required for an industrial laminate to be assigned a UL/ANSI type designation.

Table 7.2
Rigid Industrial Laminate Profiles of Performance

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc)		Min HWI (Sec)	Max HVAR (Sec)	Max HVTR (in/min)	D 495 Sec	Min DS	Min FS	CTI (V)	VR ohm-cm x10[a]	WA %Chg
	mm	inch		OS	AS	PLC	PLC	PLC		kV/mm	MPa (psi)	PLC		
X	0.71	0.028	HB	(24)	(200)	(6)	(300)	(11.7)	–	–	151.7	–	–	–
				3	0	5	0	4			(22,000)			
	1.45	0.057	HB	(24)	(200)	(8)	(300)	(9.6)	5	9.6/–	172.4	–	–	–
				3	0	4	0	4			(25,000)			
XP	0.71	0.028	–	(10)	(200)	(7)	(300)	(8.4)	–	26.9/–	82.7	–	–	–
				4	0	4	0	4			(12,000)			
	1.45	0.57	HB	(19)	(145)	(7)	(300)	(8.0)	–	19.4/–	89.6	–	–	–
				3	0	4	0	4			(13,000)			
XPC	0.71	0.028	HB	(10)	(200)	(7)	(15)	(10.0)	–	–	–	–	–	–
				4	0	4	3	4						
	1.45	0.057	HB	(16)	(200)	(8)	(300)	(10.8)	6	21.8/–	68.9	–	–	–
				3	0	4	0	4			(10,000)			
XX	0.71	0.028	HB	(8)	(200)	(6)	(300)	(11.0)	–	29.9/–	103.4	–	–	–
				4	0	5	0	4			(15,000)			
	1.45	0.057	HB	(12)	(200)	(7)	(300)	(15.4)	–	19.5/–	103.4	–	–	–
				4	0	4	0	4			(15,000)			
XXP	0.71	0.028	HB	(11)	(200)	(5)	(300)	(12.1)	–	–	96.5	–	–	–
				4	0	5	0	4			(14,000)			
	1.45	0.057	HB	(15)	(200)	(7)	(300)	(22.0)	5	15.7/–	96.5	–	–	–
				3	0	4	0	4			(14,000)			

Table 7.2 Continued on Next Page

Table 7.2 Continued

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc)		Min HWI (Sec)	Max HVAR (Sec)	Max HVTR (in/min)	D 495 Sec	Min DS	Min FS	CTI (V)	VR ohm-cm x10[a]	WA %Chg
	mm	inch		OS	AS	PLC	PLC	PLC		kV/mm	MPa (psi)	PLC		
XXX	0.71	0.028	–	(10)	(200)	(8)	(300)	(13.3)	–	–	93.1	–	–	–
				4	0	4	0	4			(13,500)			
	1.45	0.057	HB	(11)	(200)	(10)	(300)	(12.1)	4	–	93.1	–	–	–
				4	0	4	0	4			(13,500)			
XXXP	0.71	0.028	HB	(18)	(200)	(6)	(300)	(7.5)	–	38.4/18.6	82.7	–	–	–
				3	0	5	0	4			(12,000)			
	1.45	0.057	HB	(17)	(200)	(8)	(300)	(11.3)	6	–	82.7	(100)	–	–
				3	0	4	0	4			(12,000)	4		
XXXPC	0.71	0.028	HB	(11)	(128)	(5)	(300)	(13.0)	–	–	82.7	–	–	–
				4	0	5	0	4			(12,000)			
	1.45	0.057	HB	(19)	(200)	(6)	(300)	(11.6)	–	–	82.7	(100)	7,5	–
				3	0	5	0	4			(12,000)	4		
C	0.63	0.025	–	(7)	(200)	(8)	(300)	(11.7)	–	–	117.2	–	–	–
				4	0	4	0	4			(17,000)			
	1.40	0.055	HB	(7)	(200)	(9)	(300)	(10.6)	4	8.9/–	117.2	–	–	–
				4	0	4	0	4			(17,000)			
CE	0.63	0.025	–	(7)	(200)	(9)	(300)	(15.0)	–	18.3/–	113.8	–	–	–
				4	0	4	0	4			(16,500)			
	1.40	0.055	HB	(6)	(200)	(9)	(300)	(14.3)	6	15.9/–	113.8	–	–	–
				4	0	4	0	4			(16,500)			
L	0.63	0.025	–	(10)	(200)	(5)	(300)	(14.0)	–	–	113.8	–	–	–

Table 7.2 Continued on Next Page

Table 7.2 Continued

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc)		Min HWI (Sec)	Max HVAR (Sec)	Max HVTR (in/min)	D 495 Sec	Min DS	Min FS	CTI (V)	VR ohm-cm x10[a]	WA %Chg
	mm	inch		OS	AS	PLC	PLC	PLC		kV/mm	MPa (psi)	PLC		
				4	0	5	0	4			(16,500)			
	1.45	0.057	HB	(11)	(200)	(6)	(300)	(15.0)	4	7.3/–	113.8	–	–	–
				4	0	5	0	4			(16,500)			
LE	0.63	0.025	–	(10)	(200)	(7)	(300)	(15.7)	–	–	110.3	–	–	–
				4	0	4	0	4			(16,000)			
	1.45	0.057	HB	(6)	(200)	(9)	(300)	(17.2)	4	11.0/–	110.3	–	–	–
				4	0	4	0	4			(16,000)			
G-3	0.63	0.025	HB	(6)	(200)	(9)	(300)	(12.0)	–	30.6/–	124.1	–	–	–
				4	0	4	0	4			(18,000)			
	1.40	0.055	HB	(6)	(200)	(17)	(300)	(24.0)	–	16.3/–	137.9	–	–	–
				4	0	3	0	4			(20,000)			
G-5	0.63	0.025	V-0	(24)	(200)	(11)	(300)	(0.2)	–	–	379.1	–	–	–
				3	0	4	0	0			(55,000)			
	1.40	0.055	V-0	(57)	(200)	(18)	(300)	(0.2)	6	28.0/–	344.7	–	–	–
				2	0	3	0	0			(50,000)			
G-7	0.63	0.025	V-0	(6)	(200)	(15)	(300)	(0.1)	–	14.8/–	68.9	–	–	–
				4	0	3	0	0			(10,000)			
	1.40	0.055	V-0	(6)	(200)	(11)	(300)	(0.1)	–	7.7/–	137.9	–	–	–
				4	0	4	0	0			(20,000)			
G-9	0.63	0.025	V-0	(53)	(200)	(6)	(300)	(11.7)	–	23.2/–	–	–	–	–
				2	0	5	0	4						

Table 7.2 Continued on Next Page

Table 7.2 Continued

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc)		Min HWI (Sec)	Max HVAR (Sec)	Max HVTR (in/min)	D 495 Sec	Min DS	Min FS	CTI (V)	VR ohm-cm x10[a]	WA %Chg
	mm	inch		OS	AS	PLC	PLC	PLC		kV/mm	MPa (psi)	PLC		
	1.40	0.055	V-0	(83) 1	(200) 0	(20) 3	(300) 0	(0.2) 0	–	25.2/–	413.7 (60,000)	–	–	–
G-10	0.63	0.025	HB	(39) 2	(200) 0	(9) 4	(300) 0	(0.8) 0	–	32.0/29.8	413.7 (60,000)	–	–	–
	1.40	0.055	HB	(42) 2	(200) 0	(12) 4	(300) 0	(0.8) 0	3	–	413.7 (60,000)	(100) 4	9,9	0.20
G-11	0.63	0.025	HB	(5) 4	(114) 1	(9) 4	(300) 0	(19.0) 4	–	39.0/–	413.7 (60,000)	–	–	–
	1.40	0.055	HB	(7) 4	(200) 0	(17) 3	(300) 0	(12.0) 4	–	34.1/–	413.7 (60,000)	–	–	–
FR-1	0.71	0.028	V-1, V-0	(17) 3	(200) 0	(15) 3	(300) 0	(7.0) 4	–	–	–	–	–	–
	1.45	0.057	V-1, V-0	(18) 3	(200) 0	(15) 3	(300) 0	(7.0) 4	126	19.7/15.7	68.9 (10,000)	(100) 4	9,7	–
FR-2	0.71	0.028	V-1, V-0	(17) 3	(200) 0	(8) 4	(300) 0	(14.5) 4	–	32.6/23.0	82.7 (12,000)	–	–	–
	1.45	0.057	V-1, V-0	(18) 3	(200) 0	(9) 4	(300) 0	(10.5) 4	93	–	82.7 (12,000)	4	7,6	–
FR-3	0.71	0.028	V-1, V-0	(124) 0	(200) 0	(59) 2	(300) 0	(17.5) 4	–	31.2/26.1	137.9 (20,000)	–	–	–
	1.45	0.057	V-1, V-0	(200)	(200)	(133)	(300)	(35.0)	–	–	137.9	(100)	8,8	–

Table 7.2 Continued on Next Page

Table 7.2 Continued

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc)		Min HWI (Sec)	Max HVAR (Sec)	Max HVTR (in/min)	D 495 Sec	Min DS	Min FS	CTI (V)	VR ohm-cm x10^a	WA %Chg
	mm	inch		OS	AS	PLC	PLC	PLC		kV/mm	MPa (psi)	PLC		
				0	0	0	0	4			(20,000)	4		
FR-4.0	0.63	0.025	V-0	(16)	(200)	(300)	(300)	(10.4)	–	31.8/30.7	413.7	–	–	–
				3	0	0	0	4			(60,000)			
	1.40	0.055	V-0	(48)	(200)	(300)	(300)	(13.7)	14	–	413.7	(100)	9,9	0.20
				2	0	0	0	4			(60,000)	4		
FR-4.1	0.63	0.025	V-0	(16)	(200)	(300)	(300)	(10.4)	–	31.8/30.7	413.7	–	–	–
				3	0	0	0	4			(60,000)			
	1.40	0.055	V-0	(48)	(200)	(300)	(300)	(13.7)	14	–	413.7	(100)	9,9	0.20
				2	0	0	0	4			(60,000)	4		
FR-5	0.63	0.025	V-1, V-0	(16)	(200)	(18)	(300)	(16.6)	–	31.2/29.6	413.7	–	–	–
				3	0	3	0	4			(60,000)			
	1.40	0.055	V-1, V-0	(48)	(200)	(44)	(300)	(16.5)	4	–	413.7	(100)	9,9	0.20
				2	0	2	0	4			(60,000)	4		
FR-15.0	0.63	0.025	V-0	(16)	(200)	(300)	(300)	(10.4)	–	31.8/30.7	413.7	–	–	–
				3	0	0	0	4			(60,000)			
	1.40	0.055	V-0	(48)	(200)	(300)	(300)	(13.7)	(14)	–	413.7	(100)	9,9	0.20
				2	0	0	0	4	3		(60,000)	4		
FR-15.1	0.63	0.025	V-0	(16)	(200)	(300)	(300)	(10.4)	–	31.8/30.7	413.7	–	–	–
				3	0	0	0	4			(60,000)			
	1.40	0.055	V-0	(48)	(200)	(300)	(300)	(13.7)	(14)	–	413.7	(100)	9,9	0.20
				2	0	0	0	4	3		(60,000)	4		

Table 7.2 Continued on Next Page

Table 7.2 Continued

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc)		Min HWI (Sec)	Max HVAR (Sec)	Max HVTR (in/min)	D 495 Sec	Min DS	Min FS	CTI (V)	VR ohm-cm x10^a	WA %Chg
	mm	inch		OS	AS	PLC	PLC	PLC		kV/mm	MPa (psi)	PLC		
CEM-1	0.63	0.025	V-0	(33) 2	(200) 0	(25) 3	(120) 1	(24.0) 4	–	38.6/35.9	344.7 (50,000)	–	–	–
	1.57	0.062	V-0	(42) 2	(200) 0	(79) 1	(120) 1	(14.7) 4	109	30.3/28.1	241.3 (35,000)	(200) 3	8,8	0.14
CEM-3.0	0.63	0.025	V-0	(44) 2	(200) 0	(120) 0	(120) 1	(11.4) 4	–	29.5/28.4	344.7 (50,000)	–	–	–
	1.40	0.055	V-0	(47) 2	(200) 0	(120) 0	(120) 1	(11.3) 4	–	–	275.6 (40,000)	(225) 3	8, 12	0.21
CEM-3.1	0.63	0.025	V-0	(44) 2	(200) 0	(120) 0	(120) 1	(11.4) 4	–	29.5/28.4	344.7 (50,000)	–	–	–
	1.40	0.055	V-0	(47) 2	(200) 0	(120) 0	(120) 1	(11.3) 4	–	–	275.6 (40,000)	(225) 3	8, 12	0.21
GPO-2	0.63	0.025	HB	(168) 0	(200) 0	(51) 2	(300) 0	(1.0) 1	–	14.4/8.8	–	–	–	–
	1.40	0.055	V-0	(181) 0	(200) 0	(84) 1	(300) 0	(0.3) 0	111	–	124.1 (18,000)	(600) 0	7,6	0.20
GPO-3	0.63	0.025	HB	(200) 0	(200) 0	(67) 1	(300) 0	(0.1) 0	–	17.2/–	–	–	–	–
	1.40	0.055	V-0	(200) 0	(200) 0	(130) 0	(300) 0	(0.13) 0	151	–	124.1 (18,000)	(500) 1	–	0.28

Table 7.2 Continued on Next Page

Table 7.2 Continued

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc)		Min HWI (Sec)	Max HVAR (Sec)	Max HVTR (in/min)	D 495 Sec	Min DS	Min FS	CTI (V)	VR ohm-cm x10[a]	WA %Chg
	mm	inch		OS	AS	PLC	PLC	PLC		kV/mm	MPa (psi)	PLC		
GPY	0.63	0.025	HB, V-1, V-0	3	(200) 0	(300) 0	(15) 3	0	–	38.9/37.8	448.2 (65,000)	–	8,14	–
	1.40	0.055	HB, V-1, V-0	3	(200) 0	(300) 0	(300) 0	0	183	–	368.9 (53,500)	(100) 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 CTI – comparative tracking index (All samples for the CTI are to be 3.2 mm or 0.125 inch thick)

8 VR – volume resistivity

9 WA – water absorption

10 The exponent "a" in the "VR" column header corresponds to the pairs of numbers shown in the column. The first number in the pair corresponds to the dry condition and the second number corresponds to the wet condition as described in Note 1.

11 DS – Dielectric Strength

12 FS – Flexural Strength

13 D495 – Arc Resistance, Standard Test Method for High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation, ASTM D495

Table 7.3
Rigid Industrial Laminate and Relative Thermal Index

UL/ANSI Type	Minimum thickness		Nominal thickness		Relative thermal index	
	mm	(inch)	mm	(inch)	Electrical	Mechanical
X	0.71	(0.028)	0.8	(0.031)	130	130
XP	0.71	(0.028)	0.8	(0.031)	130	130
XPC	0.71	(0.028)	0.8	(0.031)	130	130
XX	0.71	(0.028)	0.8	(0.031)	130	130
	1.45	(0.057)	1.6	(0.062)	140	140
XXP	0.71	(0.028)	0.8	(0.031)	130	130
	1.45	(0.057)	1.6	(0.062)	140	140
XXX	0.71	(0.028)	0.8	(0.031)	130	130
	1.45	(0.057)	1.6	(0.062)	140	140
XXXP	0.71	(0.028)	0.8	(0.031)	125	125
XXXPC	0.71	(0.028)	0.8	(0.031)	125	125
C	0.63	(0.025)	0.8	(0.031)	85	115
	1.40	(0.055)	1.6	(0.062)	115	125
CE	0.63	(0.025)	0.8	(0.031)	85	115
	1.40	(0.055)	1.6	(0.062)	115	125
L	0.63	(0.025)	0.8	(0.031)	85	115
	1.45	(0.057)	1.6	(0.062)	115	125
LE	0.63	(0.025)	0.8	(0.031)	115	85
	1.45	(0.057)	1.6	(0.062)	115	125
G-3	0.63	(0.025)	0.8	(0.031)	140	170
G-5	0.63	(0.025)	0.8	(0.031)	50	140
G-7	0.63	(0.025)	0.8	(0.031)	170	220
G-9	0.63	(0.025)	0.8	(0.031)	50	140
G-10	0.63	(0.025)	0.8	(0.031)	130	140
G-11	0.63	(0.025)	0.8	(0.031)	140	160
	1.40	(0.055)	1.6	(0.062)	170	180
FR-1	0.71	(0.028)	0.8	(0.031)	130	130
FR-2	0.71	(0.028)	0.8	(0.031)	75	75
	1.45	(0.057)	1.6	(0.062)	105	105
FR-3	0.71	(0.028)	0.8	(0.031)	90	90
	1.45	(0.057)	1.6	(0.062)	110	110
FR-4.0	0.63	(0.025)	0.8	(0.031)	130	140
FR-4.1	0.63	(0.025)	0.8	(0.031)	130	140
FR-5	0.63	(0.025)	0.8	(0.031)	140	160
	1.40	(0.055)	1.6	(0.062)	170	180
FR-15.0	0.63	(0.025)	0.8	(0.031)	150	150
FR-15.1	0.63	(0.025)	0.8	(0.031)	150	150
CEM-1	0.63	(0.025)	0.8	(0.031)	130	140

Table 7.3 Continued on Next Page

Table 7.3 Continued

UL/ANSI Type	Minimum thickness		Nominal thickness		Relative thermal index	
	mm	(inch)	mm	(inch)	Electrical	Mechanical
CEM-3.0	0.63	(0.025)	0.8	(0.031)	130	140
	1.40	(0.055)	1.6	(0.062)	130	140
CEM-3.1	0.63	(0.025)	0.8	(0.031)	130	140
	1.40	(0.055)	1.6	(0.062)	130	140
GPO-2	0.63	(0.025)	0.8	(0.031)	c	c
	1.40	(0.055)	1.6	(0.062)	105[a]	160
GPO-3	0.63	(0.025)	0.8	(0.031)	c	c
	1.40	(0.055)	1.6	(0.062)	105[b]	140
GPY	0.63	(0.025)	0.8	(0.031)	140	160
	1.40	(0.055)	1.6	(0.062)	170	180

[a] A maximum relative thermal index of 130°C may be assigned on successful completion of 2-point thermal aging program.

[b] A maximum relative thermal index of 120°C may be assigned on successful completion of 2-point thermal aging program.

[c] For 0.63 mm (0.025 inch) thick material, a 2-point thermal aging program is required before a temperature rating is assigned. See Section 9, especially 9.4, for additional information regarding 2-point thermal aging programs.

Table 7.4
Industrial Laminate Constituents

UL/ANSI type	Resin	Reinforcement 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

Table 7.4 Continued on Next Page

Table 7.4 Continued

UL/ANSI type	Resin	Reinforcement material
FR-4.0[a]	Brominated Epoxy	Continuous filament woven glass fabric
FR-4.1[a, b]	Non-Halogenated 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
FR-15.0[a]	Brominated Epoxy	Continuous filament woven glass fabric
FR-15.1[a, b]	Non-Halogenated Epoxy	Continuous filament woven glass fabric
CEM-3.0[c]	Brominated Epoxy	Continuous filament woven glass fabric surfaces, nonwoven glass core
CEM-3.1[b,c]	Non-Halogenated 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
FR-6	Polyester	Random laid material of glass fibers
GPY	Polyimide	Continuous filament woven glass fabric

[a] Total inorganic filler content equal to 45 percent maximum by weight in accordance with 7.20.

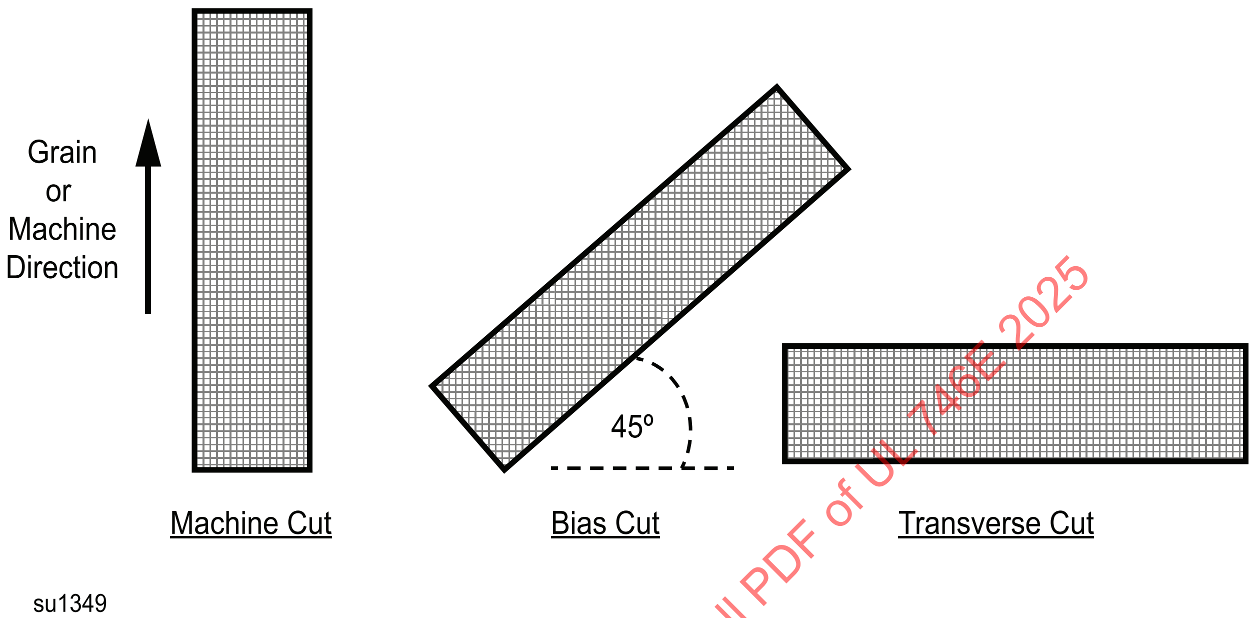
[b] Total halogen content equal to 900 ppm maximum Bromine or Chlorine and 1500 ppm combined Bromine and Chlorine tested in accordance with 7.13.

[c] Total inorganic filler content equal to 90 percent maximum by weight excluding the reinforcement.

7.3 The properties of materials may vary with thickness and orientation. Therefore, when preparing samples, consideration is to be given to testing samples representative of both the thickest and the thinnest end product applications, and where mechanical tests are involved, testing samples that are machine cut, bias cut, and transverse cut to the surface of the material based on orientation of reinforcement. See Figure 7.1 for examples of machine, bias and transverse cut samples.

Figure 7.1

Example of Machine, Bias and Transverse Cut Samples – Used for Materials with Orientation Dependent Properties, such as Seen with Woven Fibers



7.4 The industrial laminate sample thickness shall be measured and tested in accordance with ASTM D 374, Method A or C. The deviation from the sample minimum thickness shall be within the allowable range specified in Table 7.6 for UL/ANSI laminates and Table 7.5 for Non-ANSI laminates and other UL/ANSI laminate thicknesses not represented in Table 7.6.

7.5 Flammability tests shall be conducted in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.

7.6 Qualitative infrared (IR) testing is performed for the characterization of dielectric material. IR shall be conducted by surface scraping of the glossy side of the industrial laminate or based on the appropriate test procedure in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. The infrared spectrum for each type of material is unique and can be considered characteristic of that material. UL 746A, Appendix A contains the infrared analysis conformance criteria. IR shall be performed on each unique layer contained in the material construction to appropriately characterize variations in the material if the construction is non-homogenous.

7.7 Thermogravimetric Analysis (TGA) testing is performed for determination of the rapid thermal decomposition of a solid polymeric material to characterize the material and shall be conducted in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. Appendix B of UL 746A contains the thermogravimetric analysis conformance criteria.

7.8 Differential Scanning Calorimetry (DSC) testing is performed for determining transition temperatures of a solid polymeric material to characterize the material and shall be conducted in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. Appendix C of UL 746A contains the differential scanning calorimetry conformance criteria.

7.9 Ash content testing shall be conducted in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, on materials that contain noncombustible reinforcement, such as fiberglass.

7.10 Flexural strength testing shall be conducted in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, on samples cut in the machine (grain) direction. Ten samples shall be tested with dimensions and thicknesses specified in the appropriate application section. Samples with a 1.6 mm nominal thickness, the support span shall be 25 mm (1 inch) and the rate of crosshead motion shall be 0.8 mm/min (0.03 in/min). Samples with a 0.8 mm nominal thickness, the support span shall be 16 mm (0.63 inch) and the rate of crosshead motion shall be 0.5 mm/min (0.02 in/min).

7.11 Thermal aging programs shall be conducted in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

7.12 The performance tests shall be conducted in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A.

Table 7.5
Industrial Laminate Sample Build-Up Thickness Tolerance

Laminate nominal thickness,		Thickness tolerance,	
mm	(in)	mm	(in)
Less than 0.020	Less than 0.0008	± 0.003	± 0.0001
0.020 – 0.074	0.0007 – 0.003	± 0.010	± 0.0004
0.075 – 0.099	0.003 – 0.004	± 0.013	± 0.0005
0.10 – 0.19	0.004 – 0.007	±0.02	±0.0008
0.20 – 0.37	0.008 – 0.014	±0.03	±0.0012
0.38 – 0.49	0.015 – 0.019	±0.04	±0.0016
0.50 – 0.62	0.020 – 0.024	±0.05	±0.0019
0.63 – 1.59	0.025 – 0.061	±0.08	±0.0031
1.60 – 2.54	0.062 – 0.100	±0.10	±0.004
Greater than 2.55	Greater than 0.100	±0.13	±0.005

Table 7.6
UL/ANSI Industrial Laminate Sample Build Up Thickness Tolerance[a]

UL/ANSI Type	Minimum thickness		Nominal thickness	
	mm	(Inch)	mm	(Inch)
X, XP, XPC, XX, XXP, XXX, XXXP, XXXPC	0.71	(0.028)	0.8	(0.031)
	1.45	(0.057)	1.6	(0.062)
C, CE	0.63	(0.025)	0.8	(0.031)
	1.40	(0.055)	1.6	(0.062)
L, LE	0.63	(0.025)	0.8	(0.031)
	1.45	(0.057)	1.6	(0.062)

Table 7.6 Continued on Next Page

Table 7.6 Continued

UL/ANSI Type	Minimum thickness		Nominal thickness	
	mm	(Inch)	mm	(Inch)
G-3, G-5, G-7, G-9, G-11	0.63 1.40	(0.025) (0.055)	0.8 1.6	(0.031) (0.062)
FR-1, FR-2, FR-3	0.71 1.45	(0.028) (0.57)	0.8 1.6	(0.031) (0.062)
FR-5, CEM-1, CEM-3.0, CEM-3.1, GPO-2, GPO-3	0.63 1.40	(0.025) (0.055)	0.8 1.6	(0.031) (0.062)
G-10, FR-4.0, FR-4.1, FR-15.0, FR-15.1, GPY	0.38 0.63 1.40	(0.015) (0.025) (0.055)	0.43 0.8 1.6	(0.017) (0.031) (0.062)

[a] Samples submitted with a thickness between the minimum thickness and the nominal thickness are to receive a rating corresponding to the minimum thickness.

7.13 Total halogen content testing (i.e. the total amount of chlorine and bromine) in base materials shall be conducted in accordance with one of the following methods:

a) IEC 61189-2: Test methods for electrical materials, printed boards and other interconnection structures and assemblies – Part 2: Test methods for materials for interconnection structures, Test 2C12: Total halogen content in base materials; or

b) IEC 62321-3-2 – Determination of certain substances in electrotechnical products – Part 3-2: Screening – Flourine, chlorine and bromine in polymers and electronics by Combustion – Ion Chromatography (C-IC).

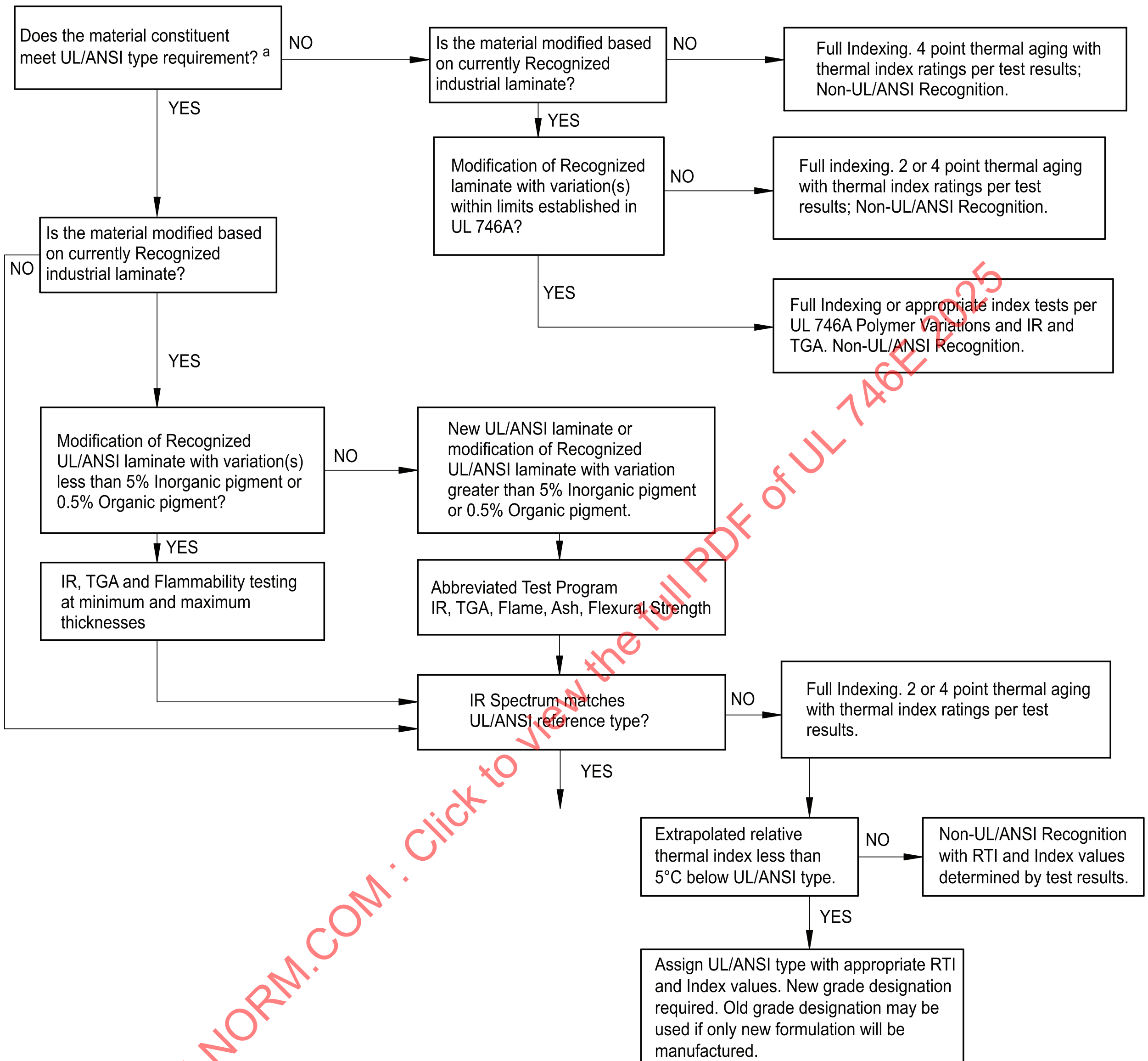
7.14 This total halogen test is performed on unclad base materials with a minimum thickness of 1.5 mm with a retained resin content of 40 – 45 percent in accordance with the Specification for Base Materials for Rigid and Multilayer Printed Boards, IPC 4101.

7.15 Base materials (resin system plus reinforcement matrix) found to have a maximum total halogen content of 1500 ppm with a maximum chlorine content of 900 ppm and maximum bromine content of 900 ppm are defined as "non-halogenated."

7.16 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 7.2 and Figure 7.3 shows the procedures to be followed in this evaluation.

Figure 7.2

Testing and Evaluation Program for Rigid Industrial Laminates

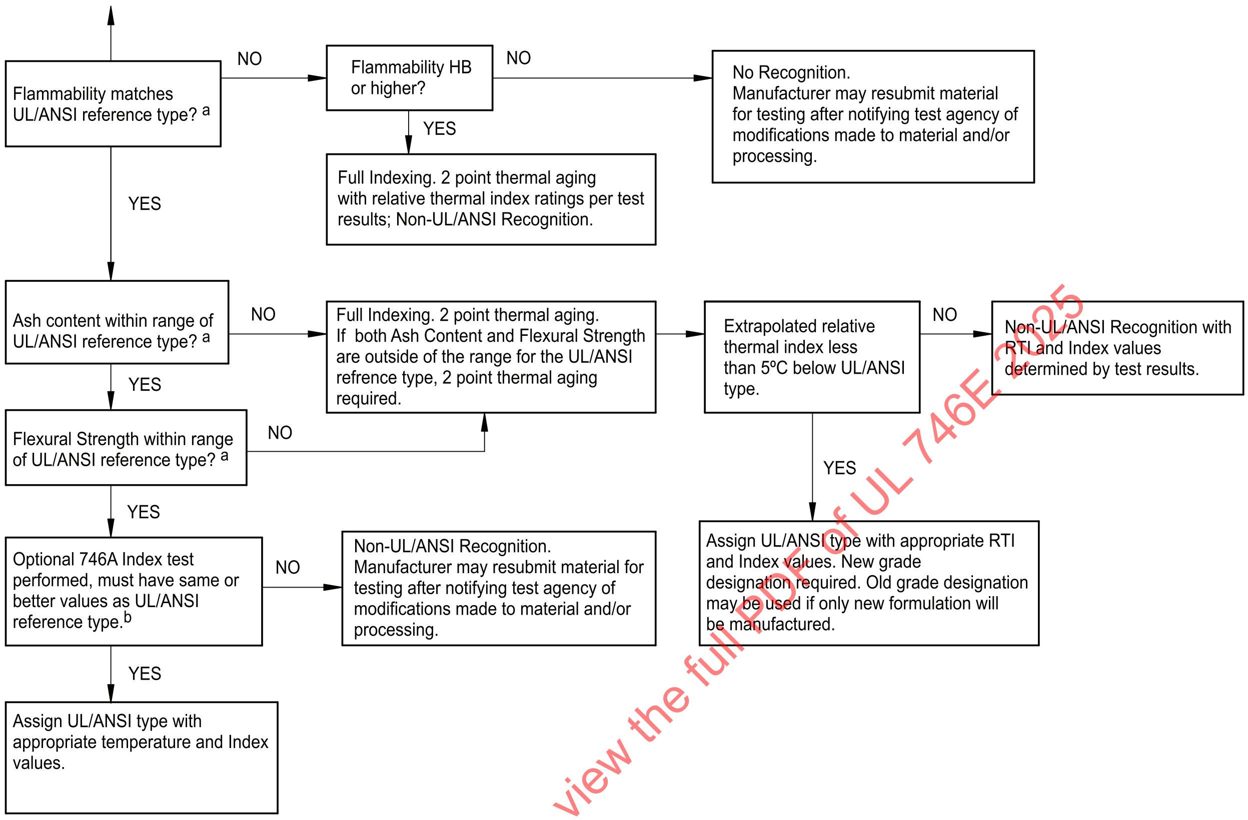


su0432c

[a] Refers to Table 7.4.

Figure 7.3

Testing and Evaluation Program for Rigid Industrial Laminates (continued)



[a] Refers to Table 8.2.
[b] Refers to Table 7.1.

7.17 An industrial laminate tested on the basis of the abbreviated test program in Section 8, and found to be in compliance with the criteria in Table 7.2, Table 7.3, Table 7.4, and Table 8.2, need not be tested to the full program in Section 9. An industrial laminate that is not in compliance shall additionally be subject to the test program in Section 9, with the number of aging points and rating assignments as indicated in Figure 7.2 and Figure 7.3.

7.18 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 9, to obtain profile of performance values when needed for end product use.

7.19 Variations in material composition include, but are not limited to, different molecular weights, colors, fillers, reinforcements, and additives, and the variation shall be evaluated in accordance with Polymer Variations, Standard for Polymeric Materials – Short-Term Evaluations, UL 746A. The additional tests specified in 7.23 – 7.26 shall also be performed based on the material variation required test program.

7.20 FR-4.0, FR-4.1, FR-15.0 and FR-15.1 UL/ANSI types must contain 50 percent epoxy resin minimum excluding inorganic fillers. The total inorganic filler content by weight is 45 percent maximum. This shall be determined from constituent components provided by the supplier when submitting products for evaluation. IR, TGA, ash content and/or identification type investigations may be used to verify the presence of indicated compounds.

7.21 CEM-3.0, CEM-3.1 UL/ANSI types shall contain 90 percent maximum total inorganic filler content by weight excluding the reinforcement. This shall be determined from constituent components provided by the supplier when submitting products for evaluation. IR, TGA, ash content and/or identification type investigations may be used to verify the presence of indicated compounds.

7.22 For the purpose of calculating filler content, inorganic fillers added to the resin shall be considered part of the resin weight percentage and not part of the reinforcement weight percentage.

7.23 For Test Program Code A in the Standard for Polymeric Materials – Short-Term Evaluations, UL 746A, Table 9.2, FS – Flexural Strength and Ash Content (where applicable) shall also be conducted.

7.24 For Test Program Code B in the Standard for Polymeric Materials – Short-Term Evaluations, UL 746A, Table 9.2, HAI – High Current Arc Ignition shall also be conducted.

7.25 For Test Program Code C in the Standard for Polymeric Materials – Short-Term Evaluations, UL 746A, Table 9.2, DS – Dielectric Strength and VR – Volume Resistivity shall also be conducted.

7.26 Variation of the original percentage of pigment of not more than 5 percent inorganic or 0.5 percent organic shall require infrared analysis and thermogravimetric analysis in accordance with the Standard for Polymeric Materials – Short-Term Evaluations, UL 746A, and flammability testing in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. Higher pigment loading requires additional long term thermal aging.

7.27 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.

8 Abbreviated Test Program

8.1 Industrial laminates may be evaluated on the basis of the abbreviated unaged property test program, shown in Table 8.1. Additional tests are required for evaluating industrial laminates at ultrathin thicknesses, see Section 10, Ultrathin Laminate and Prepreg Test Program.

Table 8.1
Industrial Laminate Abbreviated Unaged Property Test Program and Sample Requirements

Property	Sample dimensions length by width mm (inch)	Nominal thickness mm (inch)	Minimum number of samples	Applicable UL/ANSI Types	For method refer to
Infrared Analysis Comparison (IR)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	All	7.6, 8.6, UL 746A
	125 x 13 (5 x 0.5)	Minimum thickness	5	All	7.6, 8.6, UL 746A
Thermogravimetric Analysis (TGA)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	All	7.7, 8.8, UL 746A
	125 x 13 (5 x 0.5)	Minimum thickness	5	All	7.7, 8.8, UL 746A
Flexural Strength	100 x 25 (4 x 1)	1.6 (0.062)	5	All	8.10, UL 746A
	100 x 25 (4 x 1)	0.8 (0.031)	5	All except XPC, G-9, FR-1, GPO-2, GPO-3	8.10, UL 746A
Ash Content	125 x 13 (5 x 0.5)	1.6 (0.062)	10	All except X, XP, XPC, XX, XXP, XXX, XXXP, XXXPC, C, CE, L, LE, FR-1, FR-2, FR-3	8.9, UL 746A
	125 x 13 (5 x 0.5)	0.8 (0.031)	10	All except X, XP, XPC, XX, XXP, XXX, XXXP, XXXPC, C, CE, L, LE, FR-1, FR-2, FR-3	8.9, UL 746A
Flammability Vertical	125 x 13 (5 x 0.5)	1.6 (0.062)	20	All	8.4, 8.5, UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	20	All	8.4, 8.5, UL 94
Flammability Horizontal	125 x 13 (5 x 0.5)	1.6 (0.062)	6	All	8.4, 8.5, UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	6	All	8.4, 8.5, UL 94
GPO-2 or GPO-3 Thermal Aging (Optional – See 8.11)					
2-Point Thermal Aging Flexural Strength	100 x 25 (4 x 1)	0.8 (0.031)	200	GPO-2, GPO-3	8.11, UL 746B

Table 8.1 Continued on Next Page

Table 8.1 Continued

Property	Sample dimensions length by width mm (inch)	Nominal thickness mm (inch)	Minimum number of samples	Applicable UL/ANSI Types	For method refer to
2-Point Thermal Aging Dielectric Strength	100 x 100 (4 x 4)	1.6 (0.062)	200	GPO-2, GPO-3	8.11, UL 746B
2-Point Thermal Aging Dielectric Strength	100 x 100 (4 x 4)	0.8 (0.031)	200	GPO-2, GPO-3	8.11, UL 746B

NOTES –

1 The above samples are to be in the machine (grain) direction.

2 The samples are to be prepared declad by completely etching a metal clad sheet, where applicable.

3 Vertical or Horizontal flammability testing shall be performed in accordance with Table 8.2.

4 IR testing shall be performed on unclad and declad samples, where applicable. If a separate adhesive is used to apply metal cladding to the laminate, the additional Performance Profile Indexing tests in 19.11 shall be performed.

5 See Section 10 for the Ultrathin Laminate and Prepreg Test program, and the test program for laminate thicknesses below 0.8 mm nominal thickness.

8.2 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 7.2 and the relative thermal index shown in Table 7.3 for that UL/ANSI material.

8.2A A UL/ANSI material requiring a separate adhesive to bond the metal cladding shall comply with the additional Performance Profile Indexing tests shown in Adhesives for Bonding Conductors, 19.11.

8.2B An industrial laminate not intended to be a UL/ANSI type and/or having unacceptable fundamental variations in the IR spectra as indicated in 8.6 shall be evaluated per the Full Test Program, Section 9.

8.3 The criteria in 8.4 – 8.11 is to be applied when comparing industrial laminates with UL/ANSI material types.

8.4 The UL/ANSI laminate shall have a flammability classification in each thickness as indicated in Table 8.2.

Table 8.2
Abbreviated Industrial Laminate Program Requirements

UL/ANSI Grade	Acceptable values					
	Minimum flexural strength MPa (psi)		Ash content range (% by weight)		UL 94 Flammability Class	
	Thickness		Thickness		Thickness	
	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)
X	151.7 (22,000)	172.4 (25,000)	–	–	HB	HB

Table 8.2 Continued on Next Page

Table 8.2 Continued

UL/ANSI Grade	Acceptable values					
	Minimum flexural strength MPa (psi)		Ash content range (% by weight)		UL 94 Flammability Class	
	Thickness		Thickness		Thickness	
	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)
XP	82.7 (12,000)	89.6 (13,000)	–	–	HB	HB
XPC	–	68.9 (10,000)	–	–	HB	HB
XX	103.4 (15,000)	103.4 (15,000)	–	–	HB	HB
XXP	96.5 (14,000)	96.5 (14,000)	–	–	HB	HB
XXX	93.1 (13,500)	93.1 (13,500)	–	–	HB	HB
XXXP, XXXPC	82.7 (12,000)	82.7 (12,000)	–	–	HB	HB
C	117.2 (17,000)	117.2 (17,000)	–	–	HB	HB
CE, L	113.8 (16,500)	113.8 (16,500)	–	–	HB	HB
LE	110.3 (16,000)	110.3 (16,000)	–	–	HB	HB
G-3	124.1 (18,000)	137.9 (20,000)	57.7 – 67.2	57.7 – 67.2	HB	HB
G-5	379.1 (55,000)	344.7 (50,000)	55.0 – 63.3	55.0 – 63.3	V-0	V-0
G-7	68.9 (10,000)	137.9 (20,000)	85.3 – 91.6	85.3 – 91.6	V-0	V-0
G-9	–	413.7 (60,000)	55.0 – 63.3	55.0 – 63.3	V-0	V-0
G-10	413.7 (60,000)	413.7 (60,000)	55.0 – 67.7	55.0 – 67.7	HB	HB
G-11	413.7 (60,000)	413.7 (60,000)	60.5 – 70.0	60.5 – 70.0	HB	HB
FR-1	–	68.9 (10,000)	–	–	V-0 or V-1	V-0 or V-1
FR-2	82.7 (12,000)	82.7 (12,000)	–	–	V-0 or V-1	V-0 or V-1
FR-3	137.9	137.9	–	–	V-0 or V-1	V-0 or V-1

Table 8.2 Continued on Next Page

Table 8.2 Continued

UL/ANSI Grade	Acceptable values					
	Minimum flexural strength MPa (psi)		Ash content range (% by weight)		UL 94 Flammability Class	
	Thickness		Thickness		Thickness	
	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)	0.8 mm (0.031 inch)	1.6 mm (0.062 inch)
	(20,000)	(20,000)				
FR-4.0	413.7 (60,000)	413.7 (60,000)	55.0 – 78.0	55.0 – 78.0	V-0	V-0
FR-5	413.7 (60,000)	413.7 (60,000)	60.5 – 70.0	60.5 – 70.0	V-0 or V-1	V-0 or V-1
CEM-1	344.7 (50,000)	241.3 (35,000)	32.6 – 39.8	16.4 – 23.3	V-0	V-0
CEM-3.0	344.7 (50,000)	275.6 (40,000)	42.7 – 68.3	29.7 – 44.9	V-0	V-0
GPO-2	–	124.1 (18,000)	44.6 – 60.2	44.6 – 60.2	HB	V-0
GPO-3	–	124.1 (18,000)	47.8 – 57.2	47.8 – 57.2	HB	V-0
GPY	448.2 (65,500)	368.9 (53,500)	58.5 – 71.5	58.5 – 71.5	HB, V-0, or V-1	HB, V-0, or V-1

8.5 When the UL 94 flammability classification (see 8.4) is greater or less than that of the UL/ANSI reference type (see Table 8.2), the material shall be subjected to full indexing and two point thermal aging as described in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B. See Table 9.1 for the test samples required. The laminate shall not be designated as a UL/ANSI type material.

8.6 A qualitative infrared spectrum shall be obtained and shall indicate the same composition as recorded in the spectrum of the reference UL/ANSI type. Typical infrared (IR) reference spectra are shown in Figure A1.1 – Figure A1.31, for each UL/ANSI type. The IR spectrum obtained from the industrial laminate shall not indicate significant differences in comparison to the UL/ANSI reference spectra.

8.7 A material with non-compliant IR spectra fundamental variations qualifies for additional testing including full performance profile indexing and two or four point thermal aging as described in the Full Test Program, Section 9. When the laminate constituents, including resin and reinforcement material, and 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.

8.8 A Thermogravimetric Analysis (TGA) scan shall be conducted for characterization of the material.

8.9 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 8.2.

Exception: When ash content is not as shown in Table 8.2 but flammability, infrared analysis, and flexural strength are acceptable, full indexing and two point thermal aging shall be conducted as described in the

Full Test Program, Section 9. 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.

8.10 A flexural strength test shall be conducted and shall not be less than the minimum values indicated in Table 8.2.

Exception: When flexural strength is not as shown in Table 8.2 but flammability, infrared analysis, and ash content are acceptable, full indexing and a two point thermal aging shall be conducted as described in the Full Test Program, Section 9. 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.

8.11 A thermal aging program for UL/ANSI Type GPO-2 and GPO-3 industrial laminates shall be conducted and:

a) An electrical relative thermal index of 105°C shall be assigned without conducting a thermal aging program.

b) An electrical Relative Thermal Index higher than 105°C – maximum of 130°C for Type GPO-2 and maximum of 120°C for Type GPO-3 – 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 thermal aging program on 0.63 (0.025 inch) thick samples. See 9.4.

9 Full Test Program

9.1 The full test program consists of determining all of the performance characteristics of the laminate material shown in Table 7.2 in conjunction with a 2 or 4 point thermal aging program. The 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 8.2 or the UL/ANSI reference spectra. Typical infrared (IR) reference spectra of each UL/ANSI type are shown in Figure A1.1 – Figure A1.31. 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 10.

9.2 The required profile of performance tests are shown in Table 9.1, together with the samples required for the test. Samples shall be cut in the specified dimensions in the machine (grain) direction, unless otherwise specified. The samples shall be prepared from declad material by completely etching a metal clad sheet, where applicable.

9.3 Flexural strength test shall be conducted on five samples. Samples with a 1.6 mm nominal thickness, the support span shall be 25 mm (1 inch) and the rate of crosshead motion shall be 0.8 mm/min (0.03 in/min). Samples with a 0.8 mm nominal thickness, the support span shall be 16 mm (0.63 inch) and the rate of crosshead motion shall be 0.5 mm/min (0.02 in/min).

9.4 Thermal aging tests for a 2-point thermal aging program are to be conducted at elevated temperatures and times similar to that shown in Table 9.2. The dielectric strength property shall be used as the test characteristic for material UL/ANSI Types G-7, GPO-2, and GPO-3. The flexural strength property shall be used as the tested characteristic for all UL/ANSI Types. 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 Type) shall be provided for comparison purposes of the 2-point thermal aging program. If a control material of the same generic UL/ANSI Type is not available, 4-point thermal aging is required.

9.5 A comparison of the 2-point thermal aging results of the candidate and control material shall be conducted. 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 in 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.

9.6 If the evaluation of thermal aging test data for the material requires assignment of a lower temperature than those values shown in Table 7.3 for the UL/ANSI type, the material shall not be assigned a UL/ANSI type designation.

9.7 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 shall be comprised of dielectric strength (where not used as a Primary Property) and flammability. The material shall not be assigned a UL/ANSI Type designation.

9.8 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 9.7.

Exception: If the comparison of the material to a generic Polytetrafluoroethylene (PTFE) resin as determined by the PTFE Abbreviated Test Program, Table 9.3, and IR analysis compares favorably, then the thermal aging program may be waived and an electrical and mechanical relative thermal index of 130°C can 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. If an electrical and mechanical relative thermal index higher than 130°C is required, then a 4-point thermal aging program shall be performed as described in 9.8. In addition, the appropriate performance profile indexing tests as described in Table 9.1 shall be performed at the minimum and maximum laminate thickness.

9.9 An industrial laminate having an established electrical thermal index and acceptable performance profile characteristics as described in Table 9.4 meets the Direct Support Requirements (DSR) and may provide direct support of current carrying parts at 120V rms or less and 15A or less.

Table 9.1
Rigid Industrial Laminate Full Test Program and Sample Requirements

Property	Sample dimensions, length by width mm (inch)	Nominal thickness, mm (inch)	Minimum number of samples	Applicable materials	For method refer to
Short Term Performance Profile Test					
Infrared Analysis (IR)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	All	7.6, UL 746A

Table 9.1 Continued on Next Page

Table 9.1 Continued

Property	Sample dimensions, length by width mm (inch)	Nominal thickness, mm (inch)	Minimum number of samples	Applicable materials	For method refer to
	125 x 13 (5 x 0.5)	Minimum thickness	5	All	7.6, UL 746A
Thermogravimetric Analysis (TGA)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	All	7.7, UL 746A
	125 x 13 (5 x 0.5)	Minimum thickness	5	All	7.7, UL 746A
Differential Scanning Calorimetry (DSC)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	Thermoplastic Materials	UL 746A
	125 x 13 (5 x 0.5)	Minimum thickness	5	Thermoplastic Materials	UL 746A
Flexural Strength	100 x 25 (4 x 1)	1.6 (0.062)	5	All	8.10, 9.3, UL 746A
	100 x 25 (4 x 1)	0.8 (0.031)	5	All	8.10, 9.3, UL 746A
Ash Content	125 x 13 (5 x 0.5)	1.6 (0.062)	10	All (if applicable)	8.9, UL 746A
	125 x 13 (5 x 0.5)	0.8 (0.031)	10	All (if applicable)	8.9, UL 746A
Flammability Vertical	125 x 13 (5 x 0.5)	1.6 (0.062)	20	All	8.4, UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	20	All	8.4, UL 94
Flammability Horizontal	125 x 13 (5 x 0.5)	1.6 (0.062)	6	All	8.4, UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	6	All	8.4, UL 94
High Current Arc Ignition (HAI)	125 x 13 (5 x 0.5)	1.6 (0.062)	10	All	UL 746A
	125 x 13 (5 x 0.5)	0.8 (0.031)	10	All	UL 746A
Hot Wire Ignition (HWI)	125 x 13 (5 x 0.5)	1.6 (0.062)	10	All	UL 746A
	125 x 13 (5 x 0.5)	0.8 (0.031)	10	All	UL 746A
Dielectric Strength	100 x 100 (4 x 4)	1.6 (0.062)	10	All	UL 746A
Arc Resistance (ASTM D 495)	100 x 100 (4 x 4)	1.6 (0.062)	5	All	UL 746A

Table 9.1 Continued on Next Page

Table 9.1 Continued

Property	Sample dimensions, length by width mm (inch)	Nominal thickness, mm (inch)	Minimum number of samples	Applicable materials	For method refer to
Comparative Tracking Index (CTI)	100 x 100 (4 x 4)	2.5 (0.10)	10	All	UL 746A
Volume Resistivity	100 x 100 (4 x 4)	1.6 (0.062)	10	All	UL 746A
Moisture Absorption and Immersion	76 x 25 (3 x 1)	1.6 (0.062)	5	All	UL 746A
Heat Deflection	125 x 13 (5 x 0.5)	3.2 (0.125)	5	Thermoplastic Materials	UL 746A
Long Term Thermal Aging Test					
4-Point Thermal Aging Flexural Strength	100 x 25 (4 x 1)	1.6 (0.062)	400	All	UL 746B
2-Point Thermal Aging Flexural Strength	100 x 25 (4 x 1)	0.8 (0.031)	200	All	UL 746B
4-Point Thermal Aging Dielectric Strength	100 x 100 (4 x 4)	1.6 (0.062)	400	All	UL 746B
2-Point Thermal Aging Dielectric Strength	100 x 100 (4 x 4)	0.8 (0.031)	200	All	UL 746B
Secondary Flame	125 x 13 (5 x 0.5)	0.8 (0.031)	60	All	UL 746B

NOTES –

1 The above samples are to be in the machine (grain) direction.

2 The samples are to be prepared declad by completely etching a metal clad sheet, where applicable.

3 Vertical or Horizontal flammability testing shall be performed in accordance with the requested rating.

4 IR testing shall be performed on unclad and declad samples, where applicable. If a separate adhesive is used to apply metal cladding to the laminate, the additional performance profile indexing tests shown in 19.11 shall be performed.

5 IR, TGA, DSC, Flexural Strength, Ash Content, and Flammability are not required if previously determined under the Abbreviated Test Program described in Section 8.

6 Dry Dielectric Strength thermal aging testing is required. In addition, Wet Dielectric Strength thermal aging testing is required if humidity conditioning after aging will result in more severe physical and thermal damage to the material (hygroscopic material). Hygroscopic materials shall be cooled in a desiccator to prevent moisture absorption.

7 The 4-point thermal aging thickness for Dielectric Strength may be reduced if the thicker thickness exhibits flashover and does not breakdown through the sample.

8 Secondary flammability testing at 0.8 mm (0.031 inch) may be waived if performed on thinner build-up thicknesses in accordance with Section 10, Table 10.4.

9 See Section 10 for the Ultrathin Laminate and Prepreg Test program, and the test program for laminate thicknesses below 0.8 mm nominal thickness.

10 If CTI test samples are submitted at a thickness less than 2.5 mm (0.10 inch), the required number of samples varies depending on the thickness of the laminate. The number of samples shall be increased in order to provide 10 samples built up to the required 2.5 mm (0.10 inch) testing thickness.

11 Flexural Strength or Tensile Strength testing shall be performed in accordance with the material performance. If during the Flexural Strength test, the sample does not break within the 5 percent strain limit as defined in the Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM D 790, then Tensile Strength shall be evaluated using type I samples in accordance with the Standard Test Method for Tensile Properties of Plastics, ASTM D 638.

Table 9.2
Examples of Two-Point Thermal Aging Programs

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-4.0, FR-4.1, 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-3.0	180	660	800	1100	1320
	170	1260	1680	2100	2520
CEM-3.1	180	660	800	1100	1320
	170	1260	1680	2100	2520
GPO-2	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

Table 9.3
Polytetrafluoroethylene (PTFE) Abbreviated Unaged Property Test Program and Sample Requirements for Generic 130°C Electrical and Mechanical RTI

Property	Sample dimensions length by width mm (inch)	Nominal thickness mm (inch)	Minimum number of samples	Applicable material	For method refer to
Infrared Analysis Comparison (IR)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	PTFE	7.6, UL 746A
	125 x 13 (5 x 0.5)	Minimum thickness	5	PTFE	7.6, UL 746A
Thermogravimetric Analysis (TGA)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	PTFE	7.7, UL 746A
	125 x 13 (5 x 0.5)	Minimum thickness	5	PTFE	7.7, UL 746A
Differential Scanning Calorimetry (DSC)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	PTFE	UL 746A
	125 x 13 (5 x 0.5)	Minimum thickness	5	PTFE	UL 746A
Flammability Vertical	125 x 13 (5 x 0.5)	1.6 (0.062)	20	PTFE	8.4, UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	20	PTFE	8.4, UL 94
Ash Content	125 x 13 (5 x 0.5)	1.6 (0.062)	10	PTFE	8.9, UL 746A
	125 x 13 (5 x 0.5)	0.8 (0.031)	10	PTFE	8.9, UL 746A
Flexural Strength	100 x 25 (4 x 1)	1.6 (0.062)	5	PTFE	8.10, 9.3, UL 746A
	100 x 25 (4 x 1)	0.8 (0.031)	5	PTFE	8.10, 9.3, UL 746A
Tensile Strength	ASTM D 638 Type I	1.6 (0.062)	10	PTFE	UL 746A, ASTM D 638
	ASTM D 638 Type I	0.8 (0.031)	10	PTFE	UL 746A, ASTM D 638

NOTES –

1 The above samples are to be in the machine (grain) direction. The samples are to be prepared declad by completely etching a metal clad sheet, where applicable.

2 If Direct Support is necessary, the appropriate Performance Profile Index tests shall also be performed in accordance with Table 9.1 and Table 9.4.

3 The full test program shall be performed for Electrical and Mechanical RTI's higher than 130°C.

4 See Section 10 for the Ultrathin Laminate and Prepreg Test program.

5 Flexural Strength or Tensile Strength testing shall be performed in accordance with the material performance. If during the Flexural Strength test, the sample does not break within the 5 percent strain limit as defined in the Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM D 790, then Tensile Strength shall be evaluated using type I samples in accordance with the Standard Test Method for Tensile Properties of Plastics, ASTM D 638.

Table 9.4
Direct Support Requirements (DSR) of PWB Materials

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 (HAI)	Max PLC	3	Actual[a]	
Hot wire ignition (HWI)	Max PLC	4	Actual[a]	
Volume resistivity – dry	Min ohm-cm x 10^6	50	1.6[e]	(0.062)
Volume resistivity – wet	Min ohm-cm x 10^6	10	1.6[e]	(0.062)
Dielectric strength – dry	Min k Volts per mm	6.89	1.6[e]	(0.062)
Dielectric strength – wet	Min k Volts per mm	6.89	1.6[e]	(0.062)
Comparative tracking index (CTI)	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.

[e] Test sample representative of all thicknesses.

[f] VTM-0, VTM-1, VTM-2 ratings apply only to etched films.

10 Ultrathin Laminate and Prepreg Test Program

10.1 General

10.1.1 A summary of the test program for ultrathin industrial laminates is provided in Table 10.1.

Table 10.1
UL Testing and Evaluation Program for Ultrathin Industrial Laminates

Type of laminate	Laminate or build-up thickness, mm (in)	Sheet thickness is per Table 10.2	Testing	Reference
UL/ANSI[a]	0.8 (0.031) or greater	Yes	None	10.2.2.1
		No	Aging	10.2.2.2
	0.38 – 0.8 (0.015 – 0.031)	Yes	Indexing	10.2.3.1
		No	Aging and indexing	10.2.3.5
	Less than 0.38 (0.015)	Yes	Mechanical aging only and indexing	10.2.4
		No	Aging and indexing	10.2.4
Non-ANSI[b]	Less than 0.8 (0.031)	No	Aging and indexing	10.3
UL/ANSI[a] or non-ANSI[b]	Same or greater	No[c]	Aging	10.1.7

NOTE – The above test programs assume the material is previously investigated per the Abbreviated Test program in Section 8 or the Full Test program in Section 9.

[a] Candidate material infrared (IR) reference scan compares to a UL/ANSI reference scan.

[b] Candidate material infrared (IR) reference scan does not compare to a UL/ANSI reference scan.

[c] The laminate or prepreg individual sheet thickness is to be reduced for an established build-up thickness.

10.1.2 Ultrathin laminates and prepregs shall be of the same type and resin system that was previously investigated under the industrial laminate test program described in Section 8 and/or Section 9.

10.1.3 Ultrathin laminates and prepregs using a resin system not previously investigated shall be tested under a full rigid industrial laminate program including performance profile indexing, 4-point thermal aging as described in 9.1, and the ultrathin laminate and prepreg test program as described in 10.2, if the material is a UL/ANSI type, and 10.3, if the material is a non-UL/ANSI type.

Exception: If the ultrathin laminate and prepreg maximum build-up thickness is less than 1.6 mm, then the laminate shall be tested under a full rigid industrial laminate program including performance profile indexing and thermal aging at the maximum and minimum build-up thicknesses. Samples in intermediate thicknesses shall be provided and shall be tested if the results obtained on the maximum and minimum build-up thickness indicate inconsistent test results. The material shall not be assigned a UL/ANSI type designation.

10.1.4 The ultrathin material thermal aging and performance profile index test program, samples, test method, data analysis, and evaluation shall be as described in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B and the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A.

10.1.4A The ultrathin material minimum sheet thickness shall be subject to identification by infrared analysis and thermogravimetric analysis in accordance with 7.6 and 7.7. For prepreg material, a cured sample shall be provided.

10.1.5 Thermal aging samples and performance profile indexing samples shall be constructed in the minimum laminate thickness, and in the minimum build-up thicknesses using at least one minimum individual laminate and prepreg sheet thickness.

10.1.6 The established laminate minimum thickness and/or the minimum build-up thickness for ultrathin laminate and prepreg materials may be reduced by performing 2 point thermal aging. Testing shall be as described in Table 10.3 for performance profile properties, and Table 10.4 for thermal aging properties. The primary electrical property shall be dielectric strength. The primary mechanical property shall be Flexural Strength for build-up thicknesses 0.63 mm or above, and Tensile Strength for build-up thicknesses below 0.63 mm. The Secondary Property shall be flammability.

Exception: If reducing the minimum laminate thickness and/or the minimum build-up thickness, for the flammability Secondary Property, testing of the minimum laminate thickness is representative of the minimum build-up thickness at the same or thicker thicknesses.

10.1.7 The established minimum individual sheet thickness for ultrathin laminate and/or prepreg materials may be reduced by performing 2 point thermal aging, if the established build-up thickness remains the same. Testing shall be as described in Table 10.4 and the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B. The Primary Property shall be mechanical strength and shall be investigated at the established minimum build-up thickness. Flexural Strength shall be performed for build-up thicknesses 0.63 mm or above, and Tensile Strength shall be performed for build-up thicknesses below 0.63 mm. The Secondary Property shall be flammability. Performance profile testing is not required.

10.2 UL/ANSI ultrathin laminates and prepreg

10.2.1 General

10.2.1.1 Thickness and generic Relative Thermal Indices are shown in Table 10.2. All UL/ANSI type materials must comply with the minimum electrical and mechanical RTI's listed in Table 10.2 and may not exceed the electrical and mechanical RTI's listed in Table 7.3.

Table 10.2
Ultrathin Laminates and Prepreg Generic Relative Thermal Index

UL/ANSI type	Individual sheets and build-up nominal thickness[a]		Individual sheets and build-up relative thermal index	
	mm	(Mils)	Electrical (°C)	Mechanical (°C)
G-10	0.05 – 0.16	(2 – 6)	110	a
G-10	0.17 – 0.37	(7 – 14)	120	a
G-10	0.38 – 0.62	(15 – 24)	130	130
FR-4.0	0.05 – 0.09	(2 – 3)	90	90
FR-4.0	0.10 – 0.37	(4 – 14)	120	a
FR-4.0	0.38 – 0.62	(15 – 24)	130	130
FR-4.1	0.05 – 0.09	(2 – 3)	90	90
FR-4.1	0.10 – 0.37	(4 – 14)	120	a
FR-4.1	0.38 – 0.62	(15 – 24)	130	130
FR-5	0.38 – 0.62	(15 – 24)	140	140
FR-15.0	0.05 – 0.09	(2 – 3)	90	90
FR-15.0	0.10 – 0.37	(4 – 14)	120	120
FR-15.0	0.38 – 0.62	(15 – 24)	130	130
FR-15.1	0.05 – 0.09	(2 – 3)	90	90
FR-15.1	0.10 – 0.37	(4 – 14)	120	120
FR-15.1	0.38 – 0.62	(15 – 24)	130	130
GPY	0.05 – 0.37	(2 – 14)	140	a
GPY	0.38 – 0.62	(15 – 24)	140	160
CEM-3.0	0.10 – 0.47	(4 – 18)	120	a
CEM-3.0	0.48 – 0.62	(19 – 24)	130	130
CEM-3.1	0.10 – 0.47	(4 – 18)	120	a
CEM-3.1	0.48 – 0.62	(19 – 24)	130	130

NOTE – Relative thermal index investigated in accordance with 10.2.1.2, 10.2.4, and Table 10.4.

[a]The mechanical rating shall be that of the final buildup thickness.

10.2.1.2 When a higher electrical Relative Thermal Index than shown in Table 10.2 is desired for the material, the measurement of electrical characteristics (dielectric strength) shall also be required as a Primary Property. The electrical and mechanical Primary Properties shall be performed with the same 2-point thermal aging, using samples as described in 10.2.2.4. Sample requirements are shown in Table 10.4. The electrical Relative Thermal Index to be assigned is determined as described in 9.5.

10.2.1.3 The performance profile indexing tests shown in Table 10.3 shall be performed using declad samples built up to the same minimum evaluation thickness used for the 2-point thermal aging. The samples shall be built up using the minimum individual sheet thickness for which evaluation is desired.

Exception: The performance profile index tests shown in Table 10.3 do not need to be repeated to reduce the individual sheet thickness if the minimum build-up thickness is not reduced.

Table 10.3
Ultrathin Industrial Laminate and Prepreg Indexing Tests and Sample Requirements

Property	Sample dimensions length by width mm (inch)	Nominal thickness mm (inch)	Minimum number of samples	Applicable materials	For method refer to
Mechanical property					
Tensile strength (Bias cut for reinforced materials or Transverse cut for unreinforced materials, see Figure 7.1)	250 x 25 (10 x 1)	0.38 (0.015)	10	All	UL 746A and ASTM D 882 (Method A)
	250 x 25 (10 x 1)	Minimum	10	All	UL 746A and ASTM D 882 (Method A)
Tensile strength (Machine cut, see Figure 7.1)	250 x 25 (10 x 1)	0.38 (0.015)	10	All	UL 746A and ASTM D 882 (Method A)
	250 x 25 (10 x 1)	Minimum	10	All	UL 746A and ASTM D 882(Method A)
Electrical property					
High current arc ignition (HAI)	125 x 13 (5 x 0.5)	0.38 (0.015)	10	All	UL 746A
	125 x 13 (5 x 0.5)	Minimum	10	All	UL 746A
Hot wire ignition (HWI)	125 x 13 (5 x 0.5)	0.38 (0.015)	5	All	UL 746A
	125 x 13 (5 x 0.5)	Minimum	5	All	UL 746A
Flammability property					
Flammability vertical	125 x 13 (5 x 0.5)	0.38 (0.015)	20	All	8.4, UL 94
	125 x 13 (5 x 0.5)	Minimum	20	All	8.4, UL 94
Flammability horizontal	125 x 13 (5 x 0.5)	0.38 (0.015)	6	All	8.4, UL 94
	125 x 13 (5 x 0.5)	Minimum	6	All	8.4, UL 94
Identification Tests					
Infrared Analysis (IR)	125 x 13 (5 x 0.5)	Minimum sheet thickness	5	All	7.6, UL 746A
Thermogravimetric Analysis (TGA)	125 x 13 (5 x 0.5)	Minimum sheet thickness	5	All	7.7, UL 746A

NOTES –

1 The samples shall be prepared declad by completely etching a metal clad sheet, where applicable.

2 All samples are to be built up to 0.38 mm (0.015 in) thickness and the minimum thickness to be evaluated using the minimum laminate and prepreg sheet thickness shown in Table 10.2.

Table 10.3 Continued on Next Page

Table 10.3 Continued

Property	Sample dimensions length by width mm (inch)	Nominal thickness mm (inch)	Minimum number of samples	Applicable materials	For method refer to
3 Vertical or horizontal flammability testing shall be performed based on the requested flammability rating or the reference UL/ANSI material in accordance with Table 8.2.					
4 ASTM D 882 is the Standard Test Methods for Tensile Properties of Thin Plastic Sheeting.					

10.2.2 UL/ANSI Ultrathin materials built up to 0.8 mm or greater

10.2.2.1 For ultrathin materials, built up to a thickness of 0.8 mm (0.031 inch) or greater using the laminate and prepreg sheet thicknesses referenced in Table 10.2, no testing shall be required, provided they contain the same material constituents as the previously evaluated FR-4.0, FR-4.1, G-10, GPY, CEM-3, or FR-5 laminate in accordance with the abbreviated test program, Section 8. The material shall be assigned the Relative Thermal Index shown in Table 10.2 for the corresponding laminate or prepreg sheet thickness.

10.2.2.2 For ultrathin materials, built up to a thickness of 0.8 mm (0.031 inch) or greater using laminate and prepreg sheet thicknesses less than those referenced in Table 10.2, testing shall be required as described in 10.2.2.3 – 10.2.2.6.

10.2.2.3 Two-point aging is required. The Primary Property shall be mechanical strength. The mechanical strength property to be investigated shall be flexural strength.

10.2.2.4 Candidate samples shall be the minimum build-up thickness using the minimum individual sheet thicknesses for which evaluation is desired.

10.2.2.5 Control samples shall be 0.8 mm (0.031 inch), built-up from the thickness of individual sheets as limited by Table 10.2.

10.2.2.6 Thermal aging is to be conducted at 170°C and 180°C for FR-4.0, FR-4.1, G-10, and CEM-3 material, 210°C and 225°C for GPY material, and 200°C and 210°C for FR-5 material.

10.2.3 UL/ANSI Ultrathin materials built up to 0.38 – 0.8 mm

10.2.3.1 For ultrathin materials built up to a thickness of 0.38 – 0.8 mm (0.015 – 0.031 inch) using laminate and prepreg sheet thicknesses referenced in Table 10.2, testing shall be required as described in 10.2.3.2 – 10.2.3.4.

10.2.3.2 Performance profile indexing is required. Testing shall be as described in Table 10.3.

10.2.3.3 Samples shall be the minimum build-up desired using the minimum individual sheet thickness desired.

10.2.3.4 At the conclusion of the performance indexing tests, the material shall be assigned the Relative Thermal Index shown in Table 10.2 for the build-up thickness of the corresponding laminate sheet thicknesses.

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

10.2.3.5 For ultrathin materials built up to a thickness of 0.38 – 0.8 mm (0.015 – 0.031 inch) using laminate and prepreg sheet thicknesses less than those referenced in Table 10.2, testing shall be required as described in 10.2.3.6 – 10.2.3.9.

10.2.3.6 Two-point aging and performance profile indexing is required. Testing shall be as described in Table 10.3 and Table 10.4. The Primary Property shall be mechanical strength. The mechanical strength property to be investigated shall be tensile strength.

Table 10.4
Ultrathin Industrial Laminate and Prepreg Thermal Aging Sample Requirements

Property	Sample dimensions length by width mm (inch)	Nominal thickness mm (inch)	Minimum number of samples	Applicable materials	For method refer to
Mechanical property					
4-Point thermal aging tensile strength (Bias cut only, see Figure 7.1)	250 x 25 (10 x 1)	0.38 (0.015)	400	All	UL 746B and ASTM D 882 (Method A)
2-Point thermal aging tensile strength (Bias cut only, see Figure 7.1)	250 x 25 (10 x 1)	Minimum	200	All	UL 746B and ASTM D 882 (Method A)
Electrical property					
4-Point thermal aging dielectric strength	100 x 100 (4 x 4)	0.38 (0.015)	400	All	UL 746B
2-Point thermal aging dielectric strength	100 x 100 (4 x 4) (4 x 4)	Minimum	200	All	UL 746B
Flammability property					
Secondary property flammability	125 x 13 (5 x 0.5) (5 x 0.5)	Minimum	60	All	UL 746B

NOTES –

1 If the material is a UL/ANSI Type designation, 2-Point thermal aging is only required to reduce the built up thickness below 0.38 mm (0.015 inch). See Section 10.2.4.

2 If a 4-Point Dielectric Strength thermal aging program has been conducted at 1.6 mm (0.062 inch) and/or 0.8 mm (0.031 inch), a 2-Point Dielectric Strength thermal aging program shall be conducted at 0.38 mm (0.015 inch) and below.

3 Dry Dielectric Strength thermal aging testing is required. In addition, Wet Dielectric Strength thermal aging testing is required if humidity conditioning after aging will result in more severe physical and thermal damage to the material (hygroscopic material). Hygroscopic materials shall be cooled in a desiccator to prevent moisture absorption.

4 The samples shall be prepared declad by completely etching a metal clad sheet, where applicable.

5 The Control samples are to be built up to 0.38 mm (0.015 in) thickness using the minimum laminate and prepreg thickness shown in Table 10.2, and the Candidate samples are to be built up to the minimum thickness to be evaluated using the minimum laminate and prepreg sheet thickness requested.
Exception: The control sample build-up thickness may be less than 0.38 mm if the thinner thickness was previously evaluated with a long term thermal aging program to establish the relative thermal index.

6 ASTM D 882 is the Standard Test Methods for Tensile Properties of Thin Plastic Sheeting.

10.2.3.7 Candidate samples shall be the minimum build-up thickness using the minimum individual sheet thicknesses for which evaluation is desired.

10.2.3.8 Control samples shall be 0.38 mm (0.015 inch) thick, built-up from the thickness of individual sheets as limited by Table 10.2.

10.2.3.9 Thermal aging is to be conducted at 170°C and 180°C for FR-4.0, FR-4.1, G-10, and CEM-3 material, 210°C and 225°C for GPY material, and 200°C and 210°C for FR-5 material.

10.2.4 UL/ANSI Ultrathin materials built up to less than 0.38 mm

10.2.4.1 For ultrathin materials built up to a thickness less than 0.38 mm (0.015 inch), testing shall be required as described in – .

10.2.4.2 Two-point thermal aging and performance profile indexing is required. Testing shall be as described in Table 10.3 and Table 10.4. The Primary Property shall be mechanical strength. The mechanical strength property to be investigated shall be tensile strength. The Secondary Property shall be flammability.

Exception: HB-rated materials do not require Secondary Property flammability testing.

10.2.4.3 Samples shall be constructed in the minimum build-up using minimum individual laminate and prepreg sheet thicknesses.

10.2.4.4 Control samples shall be 0.38 mm (0.015 inch) using the laminate and prepreg thicknesses referenced in Table 10.2.

Exception: The control sample build-up thickness may be less than 0.38 mm if the thinner thickness was previously evaluated with a long term thermal aging program to establish the relative thermal index.

10.2.4.5 The thermal aging shall be conducted at 170°C and 180°C for FR-4.0, FR-4.1, G-10, and CEM-3 material, 210°C and 225°C for GPY material, and 200°C and 210°C for FR-5 material as described in Table 10.4.

10.3 Non-UL/ANSI ultrathin laminate and prepreg test program

10.3.1 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 to determine the electrical and mechanical Relative Thermal Index and performance profile indexing tests are required. The material shall be assigned the appropriate electrical and mechanical Relative Thermal Index determined in the thermal aging program, and shall not be assigned a UL/ANSI Type designation.

10.3.2 The Primary Properties for the 4-point thermal aging program shall be electrical (dielectric strength) and mechanical (flexural and/or tensile strength). The Secondary Property shall be flammability.

Exception: If a 4-point dielectric strength thermal aging program has been conducted on the subject material, in accordance with Section 9, a 2-point thermal aging program can be conducted at the thinner thickness.

10.3.3 The thermal aging samples, as indicated in Table 10.4 shall be constructed in the minimum laminate thickness, and in the maximum and minimum build-up thicknesses using the minimum individual laminate and prepreg sheet thickness. Samples in intermediate thicknesses shall be provided and shall be tested if the results obtained on the maximum and minimum build-up thickness indicate inconsistent test results.

10.3.4 The performance profile indexing samples, as indicated in Table 9.1 and Table 10.3, shall be constructed in the minimum laminate thickness, and in the maximum and minimum build-up thicknesses using the minimum individual laminate and prepreg sheet thickness. Samples in intermediate thicknesses shall be provided and shall be tested if the results obtained on the maximum and minimum build-up thickness indicate inconsistent test results.

Exception: The performance profile index tests shown in Table 10.3 shall not be repeated to reduce the individual sheet thickness if the minimum build-up thickness is not reduced.

10.4 Intermixing of materials that are not generically identical

10.4.1 For intermixing dielectric materials which are not generically identical, testing shall be required.

10.4.2 The combination of generically dissimilar dielectric materials shall be subjected to Section 19.9, Dissimilar Dielectric Materials Thermal Cycling Test, and Section 19.10, Flammability Test. Each individual material, in the combination of dissimilar materials, shall have been previously evaluated for performance profile indexing values and Relative Thermal Indices (RTI's) specified in this Standard.

10.4.3 The combination of generically dissimilar dielectric materials, that complies with the requirements for the Dissimilar Dielectric Materials Thermal Cycling Test and with the requirements for the Flammability Classification Test, shall be assigned a rating that does not exceed the mechanical Relative Thermal Index (RTI) of the lowest rated material. The minimum build-up thickness of the combination of the materials shall then be assigned the mechanical and electrical RTI's of the lowest rated material at this minimum build-up thickness.

10.4.4 The performance profile indexing values of the combination of generically dissimilar dielectric materials shall be assigned based on the values of the lowest rated material within the combination.

11 Non-reinforced Dielectric Materials and Other Materials Requiring Mechanical Support

11.1 General

11.1.1 The test program outlines the testing of non-reinforced 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.

11.1.2 High Density Interconnect (HDI) materials and/or Multilayer Build-Up Materials (BUM) can include very thin non-reinforced dielectric materials used to support conductor materials, intended for the production of microvias using sequential build up and related multilayer interconnect technologies.

11.1.3 Non-reinforced dielectric materials shall include, but are not limited to, very thin thickness insulating materials supporting conductor materials requiring mechanical strength from a separate core material. Materials such as resin-coated copper foil (RCF), multilayer build-up materials (BUM), 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.

11.1.4 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.

11.1.5 The dielectric and core material constructions are evaluated as Non-ANSI type materials.

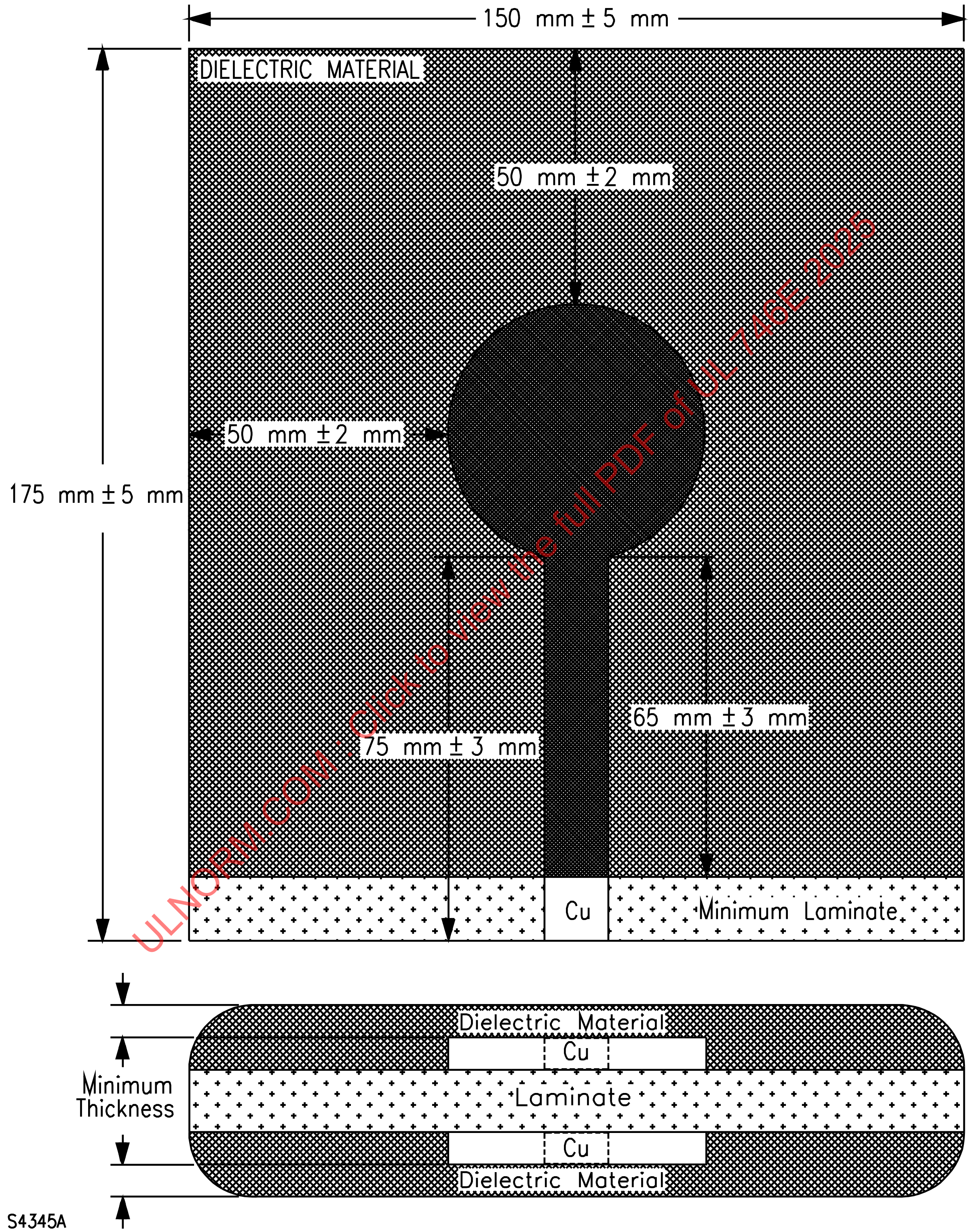
11.1.6 The dielectric material is to be applied to the core material by the curing and production processes used to fabricate the dielectric and core material multilayer construction.

11.2 Thermal aging

11.2.1 Thermal aging samples are to be constructed as described in either Figure 11.1, Figure 11.2, Figure 11.3, or Figure 11.4 incorporating traces insulated by a dielectric material. The dielectric material shall be tested on a core material suitable for the thermal aging conditioning.

Figure 11.1

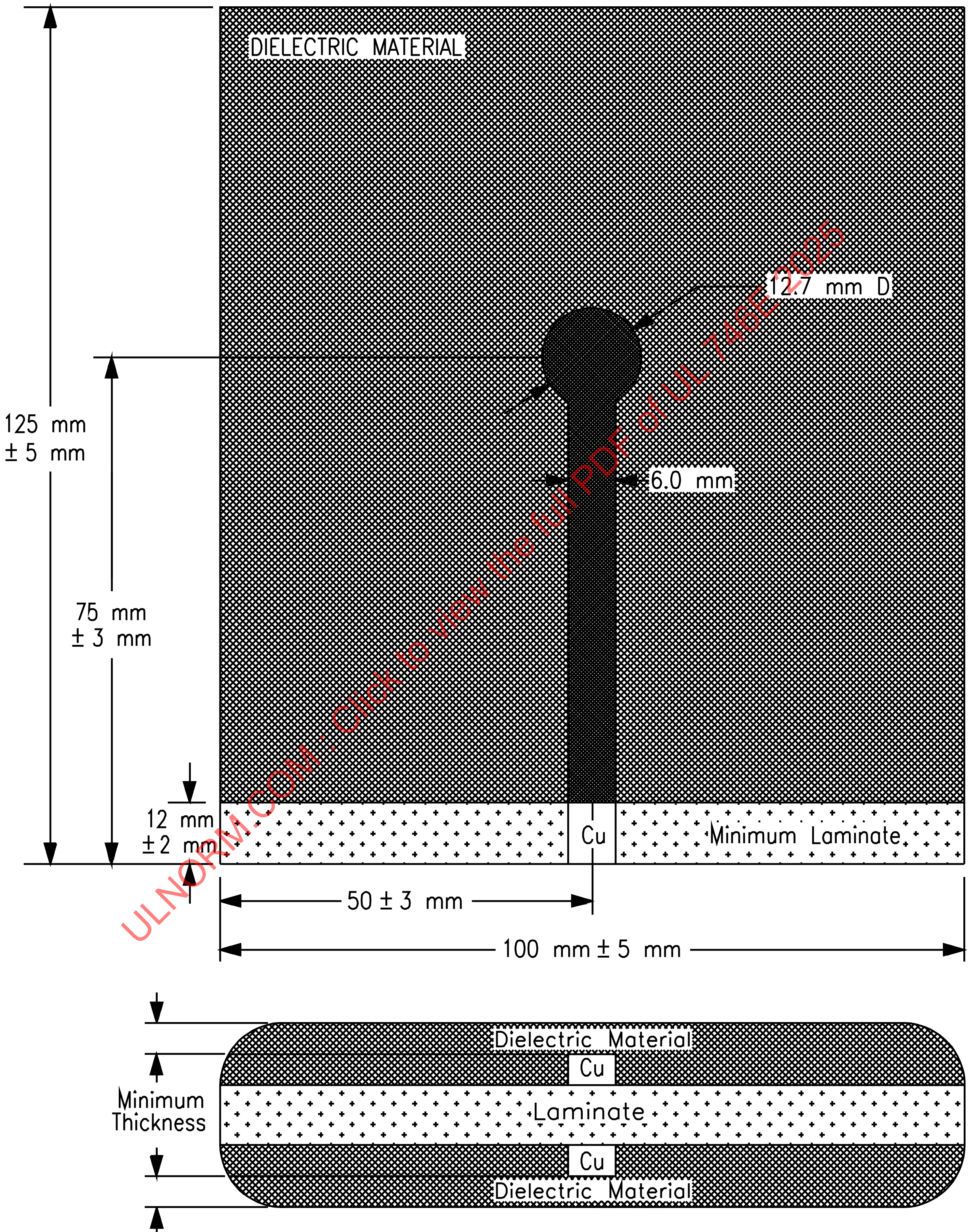
Key Hole Dielectric Aging Sample



Note: All dimensions are minimum.

Figure 11.2

Keyhole Dielectric Aging Sample – Small Key Hole Version



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Note: All dimensions without tolerances are minimum.

Figure 11.3

Alternate Dielectric Aging Sample

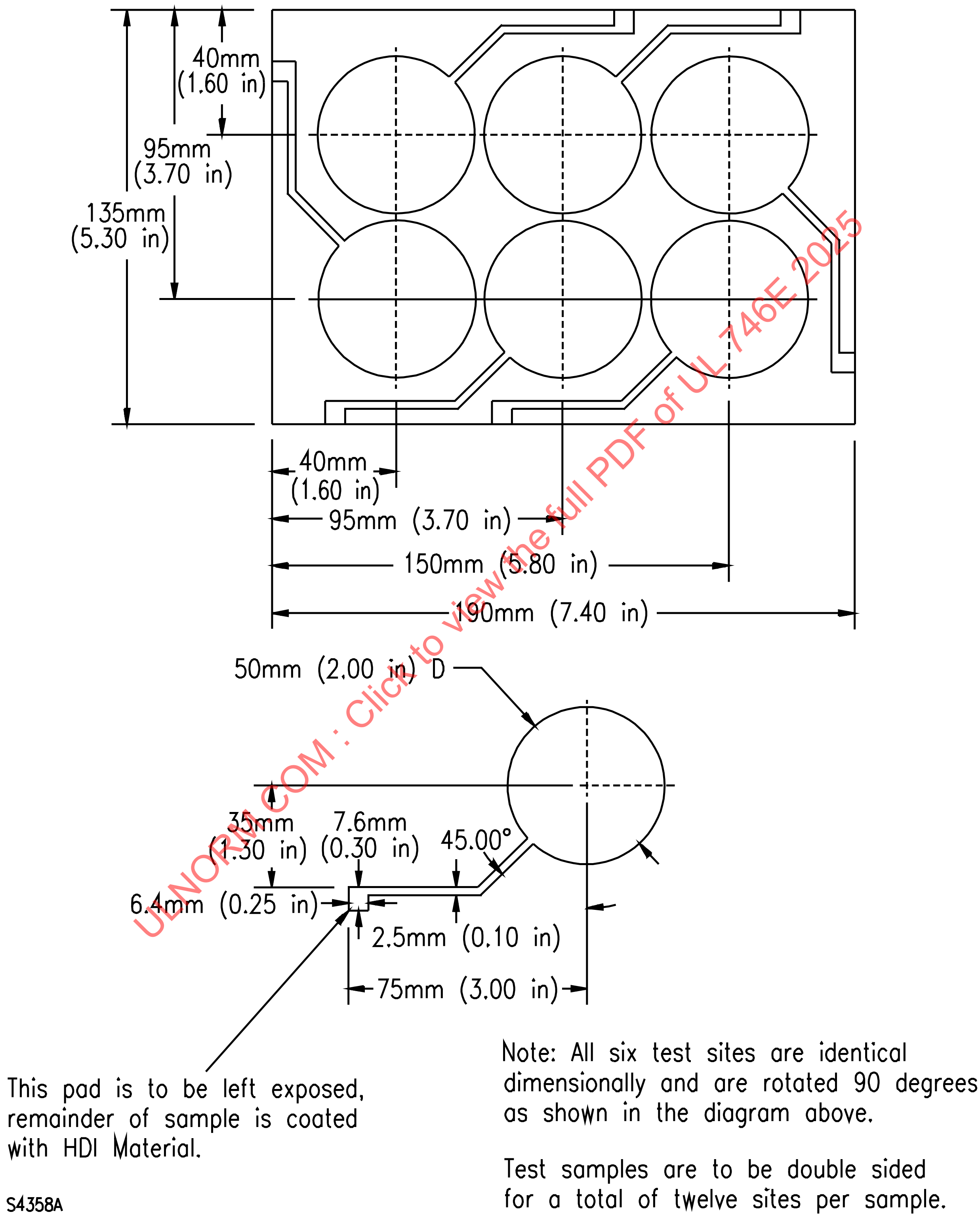
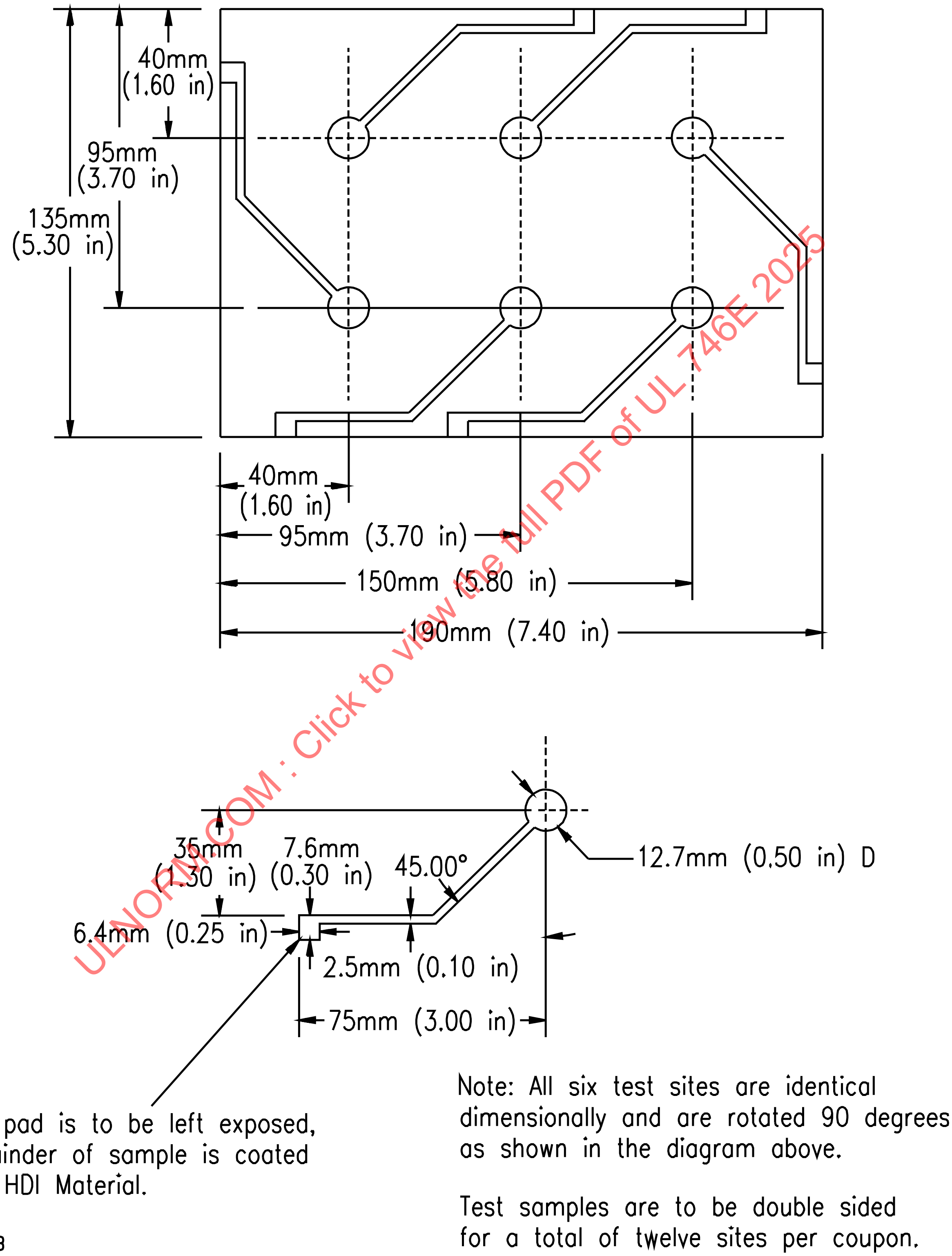


Figure 11.4

Alternate Dielectric Aging Sample – Small Pad Version



11.2.2 The thermal aging samples shown in Figure 11.1, Figure 11.2, Figure 11.3, and Figure 11.4 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 material and etched in the key hole pattern shown in Figure 11.1 or Figure 11.2. 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.

11.2.3 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.

11.2.4 The electrical relative thermal index shall be determined for the minimum core material thickness and minimum dielectric material thickness by conducting a four-point thermal aging in accordance with , the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B. The core and dielectric material shall not show evidence of wrinkling, cracking, blistering, or delamination when subjected to the thermal aging described above. The samples are to be evaluated in accordance with the criteria outlined in fixed temperature aging method or fixed time aging method in UL 746B. Dielectric strength shall be the Primary Property tested in the thermal 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.

11.2.5 Secondary Property flame samples are to be constructed as per Table 11.3, sample A and B for the flammability test and evaluated only after the Primary Property has reached end of life in the aging program; in the fixed temperature aging program at one of the four oven aging temperatures or in the fixed time aging method at one of the four fixed time periods.

11.2.6 The rate of rise for the dielectric strength test shall be maintained at a constant rate throughout the thermal aging program and shall give an average time to breakdown of between 10 and 20 seconds in accordance with ASTM D149, Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies. The rate of rise may be determined by dividing the average "as received" dielectric strength value by 20 seconds.

11.2.7 If using the key hole pattern dielectric strength aging sample, a 6 mm (0.25 inch) diameter electrode per ASTM D149, is to be used. If using the crossover pattern dielectric strength aging sample, only Test Points (TP) 1 – 6 as shown in Table 11.2 shall be tested unless warping occurs. If the sample experiences warping, Test Points (TP) 7 – 12 shall also be tested. The sides will be determined as indicated in Figure 11.5.

Figure 11.5

Side Determination

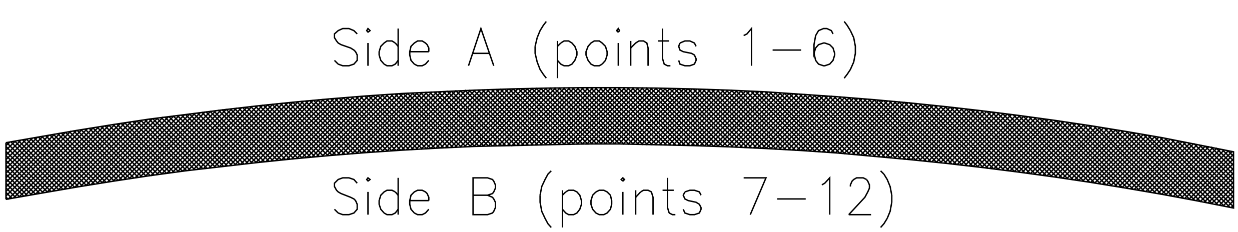


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Table 11.1
Non-Reinforced Dielectric Material Long Term Thermal Aging Test Program and Sample Requirements

Property	Sample dimensions length by width, mm (inch)	Core material thickness, mm (inch)	Dielectric (HDI) thickness, mm (inch)	Minimum number of samples	Applicable materials	For test method refer to:
4-point thermal aging dielectric strength	See alternate test patterns in Figure 11.1, Figure 11.2, Figure 11.3, or Figure 11.4	Minimum	Minimum	400	All	UL 746B
Secondary flammability	125 x 13 (5 x 0.5)	Minimum	Minimum	60	All	UL 746B
	125 x 13 (5 x 0.5)	Minimum	Maximum	60	All	UL 746B

NOTES –

1 Dielectric Strength thermal aging samples shall be constructed double-sided using one of the following alternate test patterns: Figure 11.1, Figure 11.2, Figure 11.3, or Figure 11.4.

2 Dielectric Strength thermal aging samples shall contain the minimum copper weight.

3 Dry Dielectric Strength thermal aging testing is required. In addition, Wet Dielectric Strength thermal aging testing is required if humidity conditioning after aging will result in more severe physical and thermal damage to the material (hygroscopic material). Hygroscopic materials shall be cooled in a desiccator to prevent moisture absorption.

4 Mechanical Strength samples are not required. The mechanical Relative Thermal Index of the dielectric and core material combination is based on the mechanical Relative Thermal Index of the core material.

5 Flammability samples shall be declad by completely etching the copper off all layers.

Table 11.2
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

Table 11.2 Continued on Next Page

Table 11.2 Continued

	Test points	From	To
NOTE – 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 seconds per ASTM D 149. The rate of rise may be determined by dividing the average "as received" dielectric strength value by 20 seconds. *Exception: If the non-reinforced dielectric material has been previously evaluated per UL 746E with a recognized electrical RTI, generically similar non-reinforced dielectric 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.*			

11.3 Performance profile indexing

11.3.1 Samples constructed as described in Figure 11.6 are to be subjected to the test outlined in Table 11.3 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 11.3
Performance profile indexing test samples

Test	Sample size (mm)	Number of samples	Sample code
Volume Resistivity	113 by 100	10	F
CTI	100 by 100	10	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	5	E
Sample Codes 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 coated on both surfaces of a minimum thickness core material. All copper shall be completely etched off all layers. 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. C) plaques – 100 mm (4 inch) square Samples shall be provided with the maximum resin thickness or twice the minimum resin thickness applied 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. Copper shall not be provided on external resin surfaces. D) plaques – 100 mm (4 inch) square Samples shall be provided with minimum resin thickness applied 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 form 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. Exception: The key hole conductor pattern shown in Figure 11.1 or Figure 11.2 may be used between the resin layer at the core material instead of a solid copper plane. E) Approximately 60 g (2 oz) of the dielectric material in any shape. Samples shall be provided of fully cured dielectric material. F) plaques – 113 mm by 100 mm Samples shall be provided with the maximum resin thickness or 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. Copper shall not be provided on external resin surfaces. The sample shall be constructed to allow for an electrical connection to the internal copper. Example connections include plated through holes, resin etched or removed from an area measuring at least 13 mm x 13 mm, etc. See Figure 11.7 for an example of sample construction.			

Figure 11.6

Indexing samples

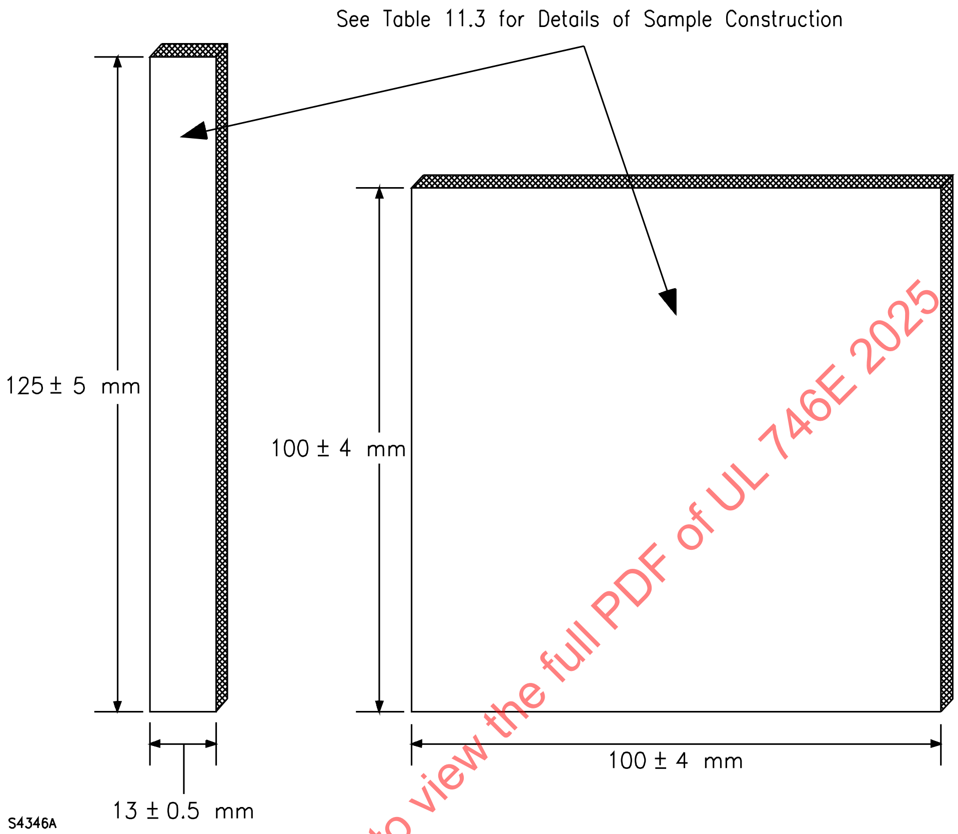
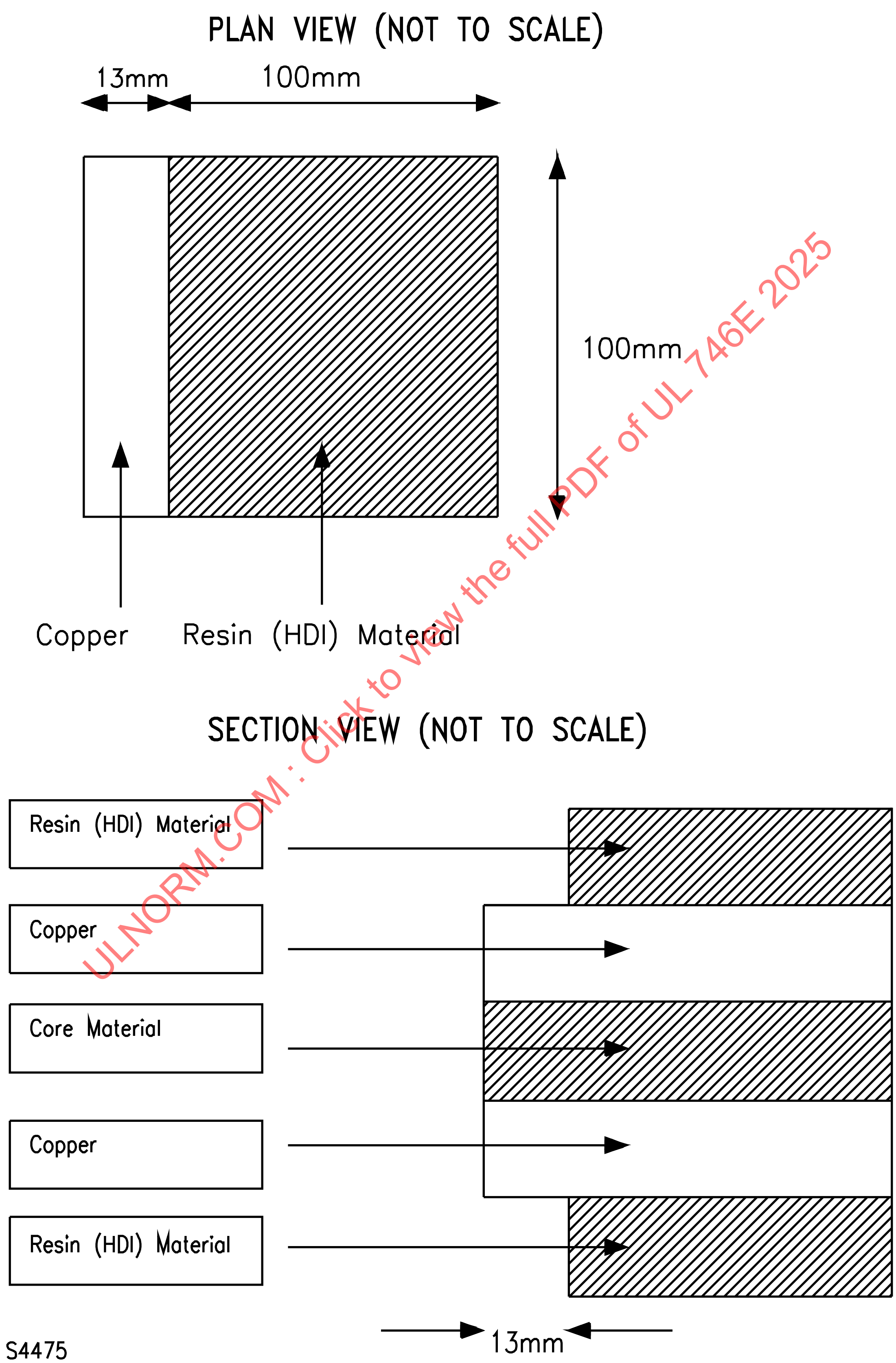


Figure 11.7

Volume and surface resistivity sample



11.4 Metal clad test program

11.4.1 General

11.4.1.1 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.

11.4.1.2 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.

11.4.1.3 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.

11.4.2 Vertical flammability evaluation

11.4.2.1 Twenty samples each constructed in accordance with Figure 11.8 (a) – (d) are to be subjected to the Flammability evaluation as described in 19.10.

Note: The example in Figure 11.8 would represent the Flammability Test Samples required for an application using minimum and maximum dielectric material thicknesses of 0.05 mm (2 mils) and 0.08 mm (3 mils) respectively and minimum and maximum number of dielectric material layers of 1 and 3 respectively.

Figure 11.8

Flammability Sample Constructions Example

minimum layer thickness and **minimum** number of layers
0.05mm (2 mil)
minimum core
0.05mm (2 mil)

a

maximum layer thickness and **minimum** number of layers
0.08mm (3 mil)
minimum core
0.08mm (3 mil)

b

maximum layer thickness and **maximum** number of layers
0.08mm (3 mil)
0.08mm (3 mil)
0.08mm (3 mil)
minimum core
0.08mm (3 mil)
0.08mm (3 mil)
0.08mm (3 mil)

c

minimum layer thickness and **maximum** number of layers
0.05mm (2 mil)
0.05mm (2 mil)
0.05mm (2 mil)
minimum core
0.05mm (2 mil)
0.05mm (2 mil)
0.05mm (2 mil)

d

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Notes:

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

11.4.3 Bond strength evaluation

11.4.3.1 Nine samples containing foil-type or clad conductors are to be constructed as described in Figure 19.1 and Figure 11.9.

a) Six of the nine samples are to be 10 day and/or 56 day conditioned and subjected to Bond Strength evaluation as described in 19.7. Compliance criteria is described in 19.7.1B.

b) Three of the nine samples are to be thermal cycling conditioned as specified in 11.4.3.3 and subjected to the bond strength evaluation as described in 19.7. Compliance criteria is described in 19.7.1B.1(c), 0.350 N/mm (2 lbf/inch) for each individual conductor trace.

11.4.3.2 *Deleted*

Figure 11.9

Bond Strength Construction Example

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 11.9 constructions A and B shall be constructed with the Maximum number of layers on each side.

11.4.3.3 Thermal cycling

a) Thermal stress at the manufacturer's specified maximum temperature and time;

b) Thermal conditioning for three cycles of the following using the scheduling described in Table 11.2:

1) 48 hours at 10°C (18°F) above the maximum operating temperature specified by the manufacturer;

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

3) 8 hours at 0°C (32°F); and

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

11.5 Test programs for revising dielectric material parameters

11.5.1 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 11.2 and 11.3 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 11.2, and

b) Thickness Dependent Indexing – HAI, HWI and Flame.

11.5.2 The dielectric material minimum thickness may be reduced by performing the following test program. The samples shall be constructed as described in 11.2 and 11.3 using the dielectric material requested minimum thickness and the thinnest core thickness:

a) 2-point thermal aging using dielectric strength as the primary property, flammability as a secondary property, and the original construction as the control in accordance with 11.2, and

b) Thickness Dependent Indexing – HAI, HWI and Flame.

11.5.3 The dielectric material maximum thickness may be increased by performing the following test program. The samples shall be constructed as described in 11.2 and 11.3 using the dielectric material requested maximum thickness:

a) Aging Flammability as a Secondary Property, and

b) Thickness Dependent Indexing – HAI, HWI and Flame.

11.5.4 The relative thermal index and performance profile indexing 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 11.3 and 19.9 using the combination of the dielectric materials:

a) Dissimilar Dielectric Materials Thermal Cycling Test in 19.9, and

b) HAI, HWI, CTI, Dielectric Strength, and flammability.

11.5.5 A range of colors can be established for dielectric material by performing the following test program. The samples shall be constructed as described in 11.3 using samples representing the range of colors:

a) Perform IR and TGA on the natural color, each additional color tested for flammability in accordance with b) and the color pigment requirements described in UL 94 and

b) Flammability tests on representative colors described in the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.

11.5.6 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 11.2 and 11.3 using samples representing the High Tg and Low Tg:

a) If the IR and TGA of each dielectric material compare favorably, 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 11.2. The performance profile indexing tests in 11.3 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.

11.5.7 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) Flammability tests on the minimum and maximum component thicknesses.

11.5.8 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.

11.5.9 Modifications to the chemical composition of the established dielectric material require testing as follows:

a) IR, TGA, Flame, and Indexing tests per 11.3

b) Determine 4-point or 2-point thermal aging test program per UL 746B, Table 19.1.

11.5.10 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 11.3 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 11.2, or

2) If the IR scans do not compare between each form, perform 4-point thermal aging on each per 11.2.

11.5.11 An alternate core material (different generic material) can be established for the dielectric material by performing the following test program. The samples shall be constructed as described in 11.2, 11.3 and 19.9.

a) Performance profile indexing on the dielectric and alternate core material combination in accordance with 11.3.

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 11.2, or

c) If the assigned RTI of the dielectric and alternate core material combination will not increase, then perform the Dissimilar Dielectric Materials Thermal Cycling Test in accordance with 19.9.

12 Metal-Based Laminates

12.1 General

12.1.1 The requirements in this Section outline the testing of metal-based laminates for use in fabricating printed wiring boards. This test program consists of three parts:

a) Performance profile characteristics, 12.2, covers the investigation of the performance profile characteristics.

b) Thermal aging, 12.3, covers the investigation of the relative thermal indices (RTIs) of the dielectric/bonding material.

c) Metal clad metal base laminates, 12.4, covers the investigation of the conductor material bonded to the dielectric material.

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

12.1.3 Dielectric/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.

12.1.4 If the dielectric/bonding material is to be built-up on the metal base (SS) or the metal core (DS), then the maximum build up thickness shall be investigated in accordance with the Ultrathin Laminate and Prepreg Test Program, Section 10. The primary mechanical property for the thermal aging program shall be Bond Strength and Delamination in accordance with 12.3.1. The maximum build up thickness shall be tested for performance profile tests (HAI, HWI, CTI, DS, VR) as described in Table 12.1. Testing of 1.6 mm dielectric build up thickness is representative of thicker samples.

Exception: Non-reinforced dielectric/bonding material does not require layered build-up samples to be tested for long term thermal aging. Testing is required for performance testing in the maximum build-up thickness.

12.2 Performance profile characteristics

12.2.1 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 12.1 for sample requirements.

Table 12.1
Metal Base Laminate Sample Requirements for Performance Characteristics

Property	For method refer to	Minimum number of samples	Sample size length by width		Base metal thickness	Dielectric material thickness[a]
			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	10	125 by 13	(5 by 0.5)	minimum	minimum
High current arc ignition (HAI)	UL 746A	10	125 by 13	(5 by 0.5)	minimum	maximum
Hot wire ignition (HWI)	UL 746A	10	125 by 13[b]	(5 by 0.5)	minimum	minimum
Hot wire ignition (HWI)	UL 746A	10	125 by 13[b]	(5 by 0.5)	minimum	maximum
Infrared analysis (IR)	UL 746A	5	125 by 13	(5 by 0.5)	–	maximum
Infrared analysis (IR)	UL 746A	5	125 by 13	(5 by 0.5)	–	minimum
Infrared analysis (IR)	UL 746A	5	125 by 13	(5 by 0.5)	minimum	maximum
Infrared analysis (IR)	UL 746A	5	125 by 13	(5 by 0.5)	minimum	minimum
Thermogravimetric analysis (TGA)[c]	UL 746A	5	125 by 13	(5 by 0.5)	–	maximum
Thermogravimetric analysis (TGA)[c]	UL 746A	5	125 by 13	(5 by 0.5)	–	minimum
Thermogravimetric analysis (TGA)	UL 746A	5	125 by 13	(5 by 0.5)	minimum	maximum
Thermogravimetric analysis (TGA)	UL 746A	5	125 by 13	(5 by 0.5)	minimum	minimum
Volume resistivity	UL 746A	10	100 by 100[d]	(4 by 4)	minimum	maximum
Dielectric strength	UL 746A	10	100 by 100[d]	(4 by 4)	minimum	maximum
Comparative tracking index (CTI)	UL 746A	10	100 by 100[d]	(4 by 4)	minimum	maximum
Moisture absorption[e]	UL 746A	5	76 by 25	(3 by 1)	minimum	maximum
Moisture absorption[e]	UL 746A	5	76 by 25	(3 by 1)	–	maximum

[a] Testing of 1.6 mm samples is representative of thicker samples.

[b] All side-edges of the sample are to be completely coated with the indicated thickness of dielectric material/bonding material for the purposes of conducting the Hot Wire Ignition Test.

Table 12.1 Continued on Next Page

Table 12.1 Continued

Property	For method refer to	Minimum number of samples	Sample size length by width		Base metal thickness	Dielectric material thickness[s]
			mm	(inch)		
[c] IR and TGA samples shall be submitted in two sets, one set with the base metal and one set without the base metal, if the dielectric material is shipped separate from the base metal.						
[d] Where suitable, 150 by 150 mm (6 by 6 inch) square (or 150 mm round) samples may be used.						
[e] Moisture absorption samples shall be provided without base metal if possible.						

12.2.2 Indexing samples are to be provided in accordance with Table 12.1 and are to be constructed as shown in Figure 12.1 by incorporating a metal base with dielectric material on one or both sides of the sample.

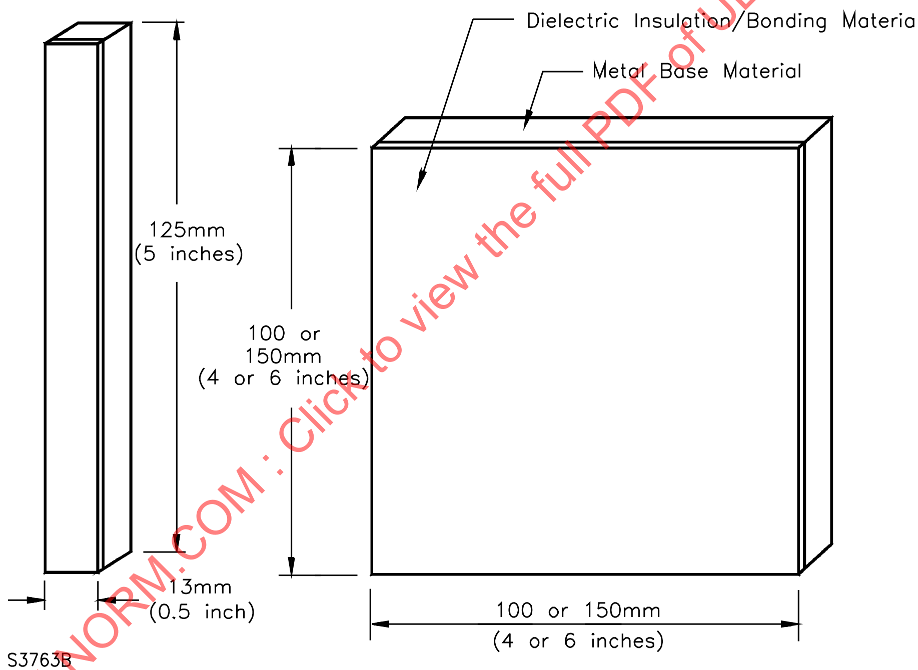
Exception No. 1: If the dielectric material without metal has established performance profile parameters at the requested thickness range, the performance profile investigation shall be flammability testing with the minimum and maximum dielectric insulation thickness and the minimum metal base thickness.

Exception No. 2: If the dielectric material has been previously evaluated at the requested thickness range and up to 1.6 mm, flammability testing with the maximum dielectric insulation thickness is not required.

12.2.3 An adhesive used to bond the dielectric material to the metal base shall be evaluated in the minimum and maximum thickness.

Figure 12.1

Indexing Sample



Sample build-up thickness is to include the base metal and dielectric material/bonding material thicknesses indicated in Table 12.1.

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

12.2.5 If the dielectric material has established performance profile parameters as a stand alone material at the requested thickness range, the performance profile investigation of the metal base laminate shall include flammability testing only with the minimum and maximum dielectric material thickness and the minimum metal base thickness.

Exception: If the dielectric material is a UL/ANSI type material or a Non-ANSI type material previously evaluated at the requested thickness range and up to 1.6 mm, the dielectric material maximum thickness flammability investigation of the metal base laminate is not required.

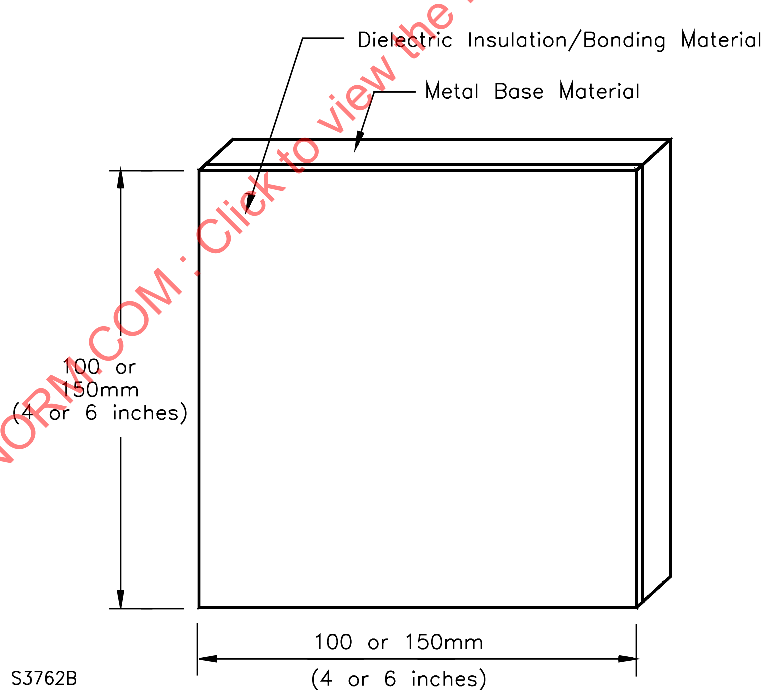
12.3 Thermal aging

12.3.1 The relative thermal indices shall be determined for the minimum base metal thickness and minimum dielectric material/bonding material thickness by conducting a four point thermal aging of the primary properties. Thermal aging shall be conducted on the metal-based laminate samples (see Figure 12.2 – Figure 12.4) in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B. The electrical primary property to be tested shall be dielectric strength in accordance with ASTM D 149, Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies. The mechanical primary property to be tested shall be bond strength between the conductor and the dielectric material/bonding material as described in 12.3.6, unless data indicates it is a secondary property. Flammability shall be tested as a secondary property.

Exception: If the dielectric material has an established electrical and mechanical relative thermal index at the requested thickness range, the thermal aging investigation is not required. The Dissimilar Materials Thermal-Cycling test shall be performed to determine the adhesion/bond strength between the minimum thickness dielectric material and the minimum thickness metal base in accordance with 19.9, the Dissimilar Dielectric Materials Thermal-Cycling test. The thermal cycling oven conditioning shall be performed at 10°C above the rated RTI of the dielectric material instead of the maximum operating temperature.

Figure 12.2

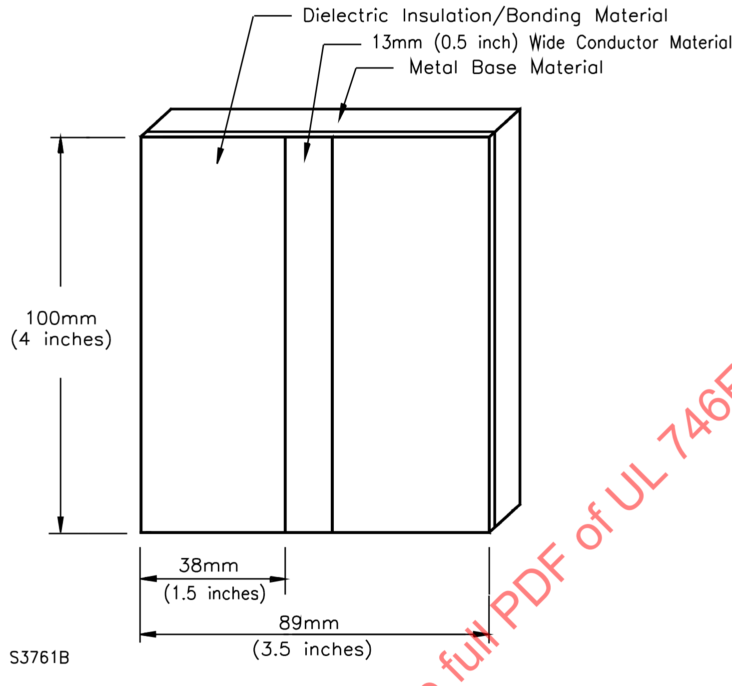
Dielectric Strength Sample



Sample build-up thickness is to include the base metal and dielectric material/bonding material thicknesses indicated in Table 12.2.

Figure 12.3

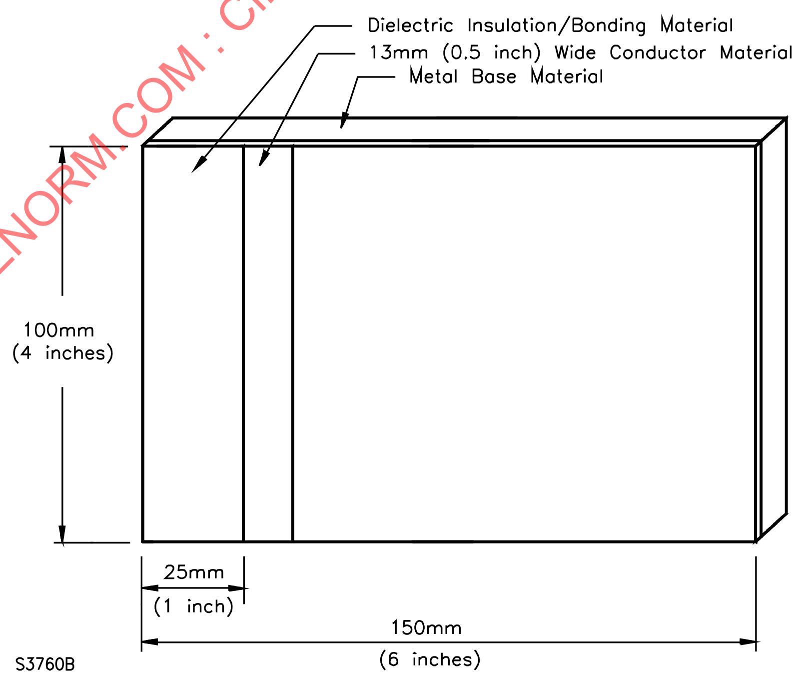
Bond Strength Sample



Sample build-up thickness is to include the base metal and dielectric material/bonding material thicknesses indicated in Table 12.2.

Figure 12.4

Combination Sample – Dielectric Strength and Bond Strength Sample



Sample build-up thickness is to include the base metal and dielectric material/bonding material thicknesses indicated in Table 12.2.

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

a) As shown in Figure 12.2, dielectric strength sample, and Figure 12.3, bond strength sample; or

b) As shown in Figure 12.4 for a combination dielectric strength and bond strength sample.

12.3.3 The samples shown in Figure 12.1 and Figure 12.2 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 12.3 or Figure 12.4.

12.3.4 Clad samples are to be prepared with at least 33 µ (1 oz/ft^2) of conductor material to permit bond strength testing to be performed.

12.3.5 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.

Table 12.2
Metal Base Laminate Sample for Thermal Aging

Property	Long term thermal aging program	Metal base thickness	Dielectric material/bonding material thickness	Sample	Minimum number of samples	For method refer to
Dielectric strength[a]	four point	Minimum	Minimum	Figure 12.2	400	746B
Bond strength	four point	Minimum	Minimum	Figure 12.3	400	746B
Flammability	Secondary Property	Minimum	Maximum	125 by 13 mm (5 by 0.5 inches)	100	746B
Dissimilar thermal-cycling	–	Minimum	Minimum	Figure 19.1	3	Exception to 12.3.1, 12.3.10

[a] Dry Dielectric Strength thermal aging testing is required. In addition, Wet Dielectric Strength thermal aging testing is required if humidity conditioning after aging will result in more severe physical and thermal damage to the material (hygroscopic material).

12.3.6 Bond strength is to be evaluated by peeling a uniform 13 mm (0.5 inch) width of conductor material from the minimum thickness dielectric material/bonding material with the minimum thickness metal base 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 material/bonding material is to be maintained at not less than 85 degrees. The force required to separate the conductor material from the dielectric material/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. The minimum bond strength after thermal aging shall retain at least 50 percent of the initial property value.

12.3.7 For a reduction in dielectric material thickness, a 2-point thermal aging program, secondary flammability testing and all performance index tests shall be conducted.

12.3.8 For an increase in dielectric material thickness, secondary flammability testing and all maximum thickness performance index tests shall be conducted.

12.3.9 For a reduction in base metal thickness, a 2-point thermal aging program, secondary flammability testing and all performance index tests shall be conducted.

12.3.10 For a change in base metal composition or base metal surface treatment, a Dissimilar Dielectric Materials Thermal-Cycling test, in accordance with 19.9, shall be conducted on samples with minimum metal base thickness and minimum dielectric material thickness.

12.3.11 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 material/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 material/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 Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

12.4 Metal clad metal base laminates

12.4.1 The requirements for metal clad metal base laminates are described in Metal Clad Laminates, Section 19. See Table 12.3 for metal clad metal base laminate sample requirements.

Table 12.3
Metal Base Laminate Sample Requirements for Metal Clad Constructions

Property	For method refer to:	Minimum number of samples	Sample size length by width mm (inch)	Base metal thickness	Dielectric thickness	Conductor thickness
Metal clad tests						
Bond strength/ delamination	19.7	10	Figure 19.1	Minimum	Minimum	Minimum plated up to 34 microns
Bond strength/ delamination	19.7	10	Figure 19.1	Minimum	Minimum	Maximum above 102 mic (3 oz)
Flammability vertical with thermal stress	19.10 and UL 94	20	125 x 13 (5 x 0.5)	Minimum	Minimum	–

NOTES –

1. All the samples shall be double sided unless single sided material is intended for production.

2. For multilayer sample construction, see 19.3.2 and 19.3.3.

3. All flammability samples shall be prepared declad by completely etching a metal clad sheet.

13 Metal Clad Flexible Film

13.1 The requirements for metal clad flexible films are in the Standard for Polymeric Materials – Flexible Dielectric Film Materials for Use In Printed Wiring Boards and Flexible Materials Interconnect Constructions, UL 746F.

VULCANIZED FIBRE

14 General

14.1 Profiles of performance and relative thermal indices for vulcanized fibre are given in Table 14.1 and Table 14.2. 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 Table 14.1 and Table 14.2.

Table 14.1
Vulcanized Fibre Generic Temperature Index

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 14.2
Summary of Performance Indexing Data on Vulcanized Fibre

Thickness		Hot wire ignition (PLC)	High voltage arc resistance (ASTM D495) (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

15 Vulcanized Fibre Test Program

15.1 Vulcanized fibre is to be evaluated on the basis of unaged property tests. See Table 15.1 for the required tests and samples.

Table 15.1
Vulcanized Fibre Abbreviated Test Program and Sample Requirements

Property	Sample dimensions length by width mm (inch)	Nominal thickness mm (inch)	Minimum number of samples	For method refer to
Infrared Analysis Comparison (IR)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	UL 746A
	125 x 13 (5 x 0.5)	Minimum thickness	5	UL 746A
Thermogravimetric Analysis (TGA)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	UL 746A
	125 x 13 (5 x 0.5)	Minimum thickness	5	UL 746A
Zinc Chloride Analysis	125 x 13 (5 x 0.5)	1.6 (0.062)	5	ASTM D619 See Note
Flexural Strength	100 x 25 (4 x 1)	1.6 (0.062)	5	UL 746A
Dielectric Strength	100 x 100 (4 x 4)	1.6 (0.062)	10	UL 746A

Table 15.1 Continued on Next Page

Table 15.1 Continued

Property	Sample dimensions length by width mm (inch)	Nominal thickness mm (inch)	Minimum number of samples	For method refer to
Flammability	125 x 13 (5 x 0.5)	1.6 (0.062)	20	UL 94
	125 x 13 (5 x 0.5)	Minimum thickness	20	UL 94
NOTE – Zinc Chloride Analysis: The amount of zinc chloride is back-calculated by the total amount of zinc measured in the ASTM D619 extract by atomic absorption (AA) spectroscopy, atomic emission spectroscopy (AES) or inductively coupled plasma spectrometry (ICP) for measurement.				

15.2 Vulcanized fibre test data which compares favorably with the requirements of 15.3 shall be considered acceptable, and be assigned the same relative thermal index and profiles of performance values shown in Table 14.1 and Table 14.2.

15.3 The following criteria shall be used in determining if the material compares favorably with this data.

a) The infrared (IR) spectrum obtained shall indicate the same composition as recorded in the IR spectrum of the Vulcanized Fibre. A typical IR reference spectrum is shown in Figure A1.32. The IR spectrum obtained from the vulcanized fibre shall not indicate significant differences in comparison to the reference spectra.

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 6.89 KV/mm (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. The amount of zinc chloride confirms the efficiency of the leaching process used to produce vulcanized fibre.

15.4 When the material does not compare favorably with the criteria in 15.3, a full set of unaged property tests and a four temperature thermal aging shall be required.

15.5 When unaged property criteria other than those found in Table 14.2, or a temperature index higher than shown in Table 14.1 is desired, applicable indexing tests in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A or aging tests in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, shall be performed to determine those properties.

FILAMENT WOUND TUBING

16 General

16.1 Profiles of performance and relative thermal indices for filament wound tubing are given in Table 16.1 and Table 16.2. These are the minimum characteristics needed for a material to be assigned a UL/ANSI type designation.

16.2 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 16.1
Generic Temperature Index for Filament Wound Tubing

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 16.2
Summary of Performance Profile Indexing Data on Filament Wound Tubing

UL/ANSI designation	Nominal 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 perpendicu lar 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

17 Filament Wound Tubing Test Program

17.1 Filament wound tubing is to be evaluated on the basis of unaged property tests. See Table 17.1 for the required tests and samples.

Table 17.1
Filament Wound Tubing Abbreviated Test Program and Sample Requirements

Property	Sample dimensions length by outer diameter by inner diameter mm (inch)	Nominal wall thickness mm (inch)	Minimum number of samples	For method refer to
Infrared Analysis Comparison (IR)	25 x 16 x 13 (1 x 0.625 x 0.5)	1.6 (0.062)	5	UL 746A
Thermogravimetric Analysis (TGA)	25 x 16 x 13 (1 x 0.625 x 0.5)	1.6 (0.062)	5	UL 746A
Axial Compressive Strength	25 x 16 x 13 (1 x 0.625 x 0.5)	1.6 (0.062)	10	ASTM D348
Ash Content	25 x 16 x 13 (1 x 0.625 x 0.5)	1.6 (0.062)	10	UL 746A
Horizontal Flammability	125 x 16 x 13 (5 x 0.625 x 0.5)	1.6 (0.062)	6	UL 94

17.2 A material which compares favorably with the UL/ANSI values given in Filament Wound Tubing, Section 16 for the properties tested in Table 17.1 may be assigned the same file of performance values shown in Table 16.1 and Table 16.2.

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

a) The infrared (IR) spectrum obtained shall indicate the same composition as recorded in the IR spectrum of the Filament Wound Tubing. A typical IR reference spectrum is shown in Figure A1.33 or Figure A1.34. The IR spectrum obtained from the filament wound tubing shall not indicate significant differences in comparison to the reference spectra.

b) The minimum axial compression strength values shall not be less than 89.6 MPa (13,000 psi) for 1.6 mm (0.062 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.

17.4 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 17.2.

17.5 When unaged property criteria other than those given in Table 16.2, or a relative thermal index higher than shown in Table 16.1 is desired, a four point thermal aging test as described in the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, or performance profile indexing as described in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, shall be performed to determine those properties.

Table 17.2
Filament Wound Tubing Full Test Program and Sample Requirements

Samples:	
1.6 mm (0.062 inch) thick wall:	
35 Samples –	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 Samples –	25 mm (1 inch) long and 13 mm (0.5 inch) I.D., 16 mm (0.625 inch) O.D.
0.8 mm (0.031) thick wall:	
35 Samples –	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 Samples –	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 (ASTM D348)	
2. Dielectric strength	
3. Arc resistance (ASTM D495)	
4. Horizontal flammability	
5. High current arc ignition (HAI)	
6. Hot wire ignition (HWI)	
7. Infrared analysis (IR)	
8. Ash content	
Two point thermal aging test (Per UL 746B):	
Axial compressive strength	

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

18 General

18.1 Any additional processing of industrial laminates performed by the manufacturer shall be tested according to Sections 13 – 19.

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

19 Metal Clad Laminates

19.1 General

19.1.1 The metal clad laminate test program in 19.2 – 19.11 shall be performed in addition to the programs of investigation for industrial laminates (see Sections 7 – 10) to determine if a new surface treatment or conductor material on the laminate will provide the same results as given previously on the unclad laminate without the new surface.

19.1.2 The base material in the minimum thickness to be used in the specific application shall have previously been investigated for mechanical strength, moisture absorption, combustibility, resistance to ignition from electrical sources, dielectric strength, insulation resistance, resistance to arc-tracking, and resistance to creeping and distortion at the temperatures to which the material is subjected in the end product. The base material shall not display a loss of these properties beyond the minimum required level as a result of aging, and a Relative Thermal Index shall be assigned to the base material.

19.1.3 When a base material is intended for use in printed wiring boards in low-energy circuits, in which the risk of electric shock or injury to persons is not involved, compliance of the base material shall, as a minimum, be determined by flammability testing.

19.1.4 The metal clad test program and sample requirements are shown in Table 19.1.

Table 19.1
Metal Clad Test Program and Sample Requirements

Property	Sample dimensions length by width, mm (inch)	Laminate or build-up thickness, mm (inch)	Copper thickness	Minimum number of samples	For method refer to:
Metal clad tests					
Bond strength/delamination	Figure 19.1	Minimum	Minimum	10	Section 19.7
Bond strength/delamination	Figure 19.1	Minimum	Maximum above 102 mic (3 oz)	10	Section 19.7
Flammability vertical with thermal stress	125 x 13 (5 x 0.5)	Minimum	–	20	Section 19.10 and UL 94

NOTES:

1. All the samples shall be double sided unless single sided material is intended for production.

2. For multilayer sample construction, see 19.3.2 and 19.3.3 and Figure 19.5, Figure 19.8, and Figure 19.9.

3. All the flammability samples shall be prepared declad by completely etching a metal clad sheet.

19.1.5 The metal clad samples shall be subjected to Thermal stress, 19.6, to determine the material assembly soldering process parameters.

19.1.6 Assembly soldering process (solder limits) is described in 10.13 of the Standard for Printed Wiring Boards, UL 796. The acceptability of the assembly soldering process is determined by investigation of the metal clad material physical properties following the thermal stress test. The assembly soldering process is not prescriptive and does not represent the exact assembly soldering process.

19.1.7 The board maximum surface temperature during the assembly soldering process determines the thermal stress test peak temperature.

19.1.8 Materials for use with reflow assembly processes shall be thermally stressed using the default 260°C profile with thermal stress conditions of 260°C peak temperature and six (6) cycles, unless specified otherwise. If a low temperature profile is being used in assembly, the manufacturer can specify the 245°C or 230°C profile for testing. If a lower number of cycles are being used in assembly, the manufacturer can specify three (3) cycles instead of six (6) cycles.

19.1.9 If special/unique thermal stress reflow conditions are defined by the manufacturer or OEM/ODM purchase order, the following parameters are needed: ramp rate (R1), cooling rate (C1), peak temperature (T2), dwell time (t2), and the number of cycles (X).

19.1.10 Materials for use with wave soldering and/or selective soldering assembly processes shall be thermally stressed using conditions specified by the manufacturer: the maximum temperature, maximum time, and maximum cycles. Unless specified otherwise, the default standardized conditions described in 19.1.8 for reflow assembly shall represent wave soldering and/or selective soldering processes.

19.1.11 *Deleted*

19.1.12 Following the thermal stress test, the flammability for the metal clad industrial laminate shall meet the end use product application flammability rating requirements in accordance with 19.10.

19.1.13 If the metal cladding is bonded by means of a separate adhesive to the laminate, additional testing is required per 19.11.

19.1.14 The metal clad parameter variation test program is shown in Table 19.2.

Table 19.2
Variation in Metal Clad Parameters

Variation	Testing			For method refer to:
	Bond strength	Delamination and blistering	Flammability	
Metal clad parameter variations				
Reduce minimum build-up thickness	X	X	X	Sections 19.7 and 19.10
Reduce laminate or prepreg individual sheet thickness with same build-up	–	X	–	Sections 19.3, 19.7, and 19.10
Single sided to double sided	X	X	X	Sections 19.7 and 19.10
Increase assembly reflow process	X	X	X	Sections 19.7 and 19.10
Decrease minimum external copper thickness	X	X	–	Section 19.7
Increase maximum external copper thickness above 102 mic (3 oz)	X	X	–	Section 19.7
Increase maximum internal copper thickness	–	X	–	Section 19.7
Increase maximum diameter	–	X	–	Section 19.7
Increase maximum operating temperature (Not to exceed the lowest of the electrical or mechanical RTI of the material)	X	X	–	Section 19.7

NOTES:

1. Adhesive for metal cladding requires additional testing in accordance with Additional tests, Section 19.11.

2. Dissimilar materials require additional testing in accordance with Dissimilar Dielectric Materials Thermal Cycling Test, Section 19.9.

19.2 Single layer sample construction

19.2.1 Four samples are to be prepared from the minimum thickness metal-clad laminate. The metal foil shall consist of the lightest and heaviest weights to be investigated. The metal foil contained on the samples shall measure ±10 percent of the desired weight. If the desired metal foil weight is up to and including 102 μ (3 oz/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 102 μ (3 oz/ft^2) maximum. [Minimum metal weight of less than 33 μ (1 oz/ft^2) will require samples to be plated up to the equivalent of 33 μ (1 oz/ft^2) to permit bond strength testing to be performed.] For metal foil weights heavier than 102 μ (3 oz/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 samples are to be labeled to indicate the initial minimum metal weight used in their production.

19.2.2 Samples 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 19.1.

19.2.3 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.

19.2.4 The construction of singlelayer flammability samples shall be as follows:

a) The minimum thickness laminate shall be investigated.

b) All metal shall be etched completely from the external surfaces.

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

19.3 Multi-layer sample construction

19.3.1 Four samples are to be prepared as described in 19.3.2 and 19.3.3.

19.3.2 A representative multilayer laminate construction shall include but not be limited to the thinnest individual dielectric material sheets and bonding sheets, the minimum external conductor weight, the maximum internal conductor weight, two or the minimum number of internal conductor layers, whichever is greater, the minimum total build up construction, and shall not exceed the minimum production thickness plus the thickness of two or the minimum number of internal conductor layers, whichever is greater. A representative multilayer laminate construction shall include at least one internal conductor layer of the maximum metal weight. Each combination of materials or construction shall be provided for investigation. See 19.3.3 and Figure 19.2.

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

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

a) The thinnest individual sheets of laminate and prepreg shall be included. The minimum bonding layer thickness shall be included in contact with any internal conductor layer 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 19.1 shall be included in the internal patterned conductor layers, and on both the external patterned conductor layers of the sample with good registration. The internal patterns shall mirror the external conductor pattern. If additional internal patterned layers are included beyond the required two internal conductor layers, the additional layers can mirror the external pattern or can be determined by the manufacturer.

c) 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. 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 19.3, a second 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 19.3. The second set of Bond Strength and Delamination test samples shall contain the minimum multilayer build up construction that can 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. The external metal foil shall consist of the lightest and heaviest weights to be investigated. If the desired metal foil weight is up to and including 102 μ (3 oz/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 102 μ (3 oz/ft^2) maximum. [Minimum external metal weight of less than 33 μ (1 oz/ft^2) will require samples to be plated up to the equivalent of 33 μ (1 oz/ft^2) to permit bond strength testing to be performed.] For external metal foil weights heavier than 102 μ (3 oz/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 samples are to be labeled to indicate the initial minimum metal weight used in their production.

f) Each generic dielectric 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 the thickness of two or the minimum number of internal patterned conductor layers, whichever is greater. If the multilayer is constructed per Figure 19.2, example (c), each generic bonding layer shall be subjected to Bond Strength testing per 19.7.

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.

19.3.4 The construction of multilayer flammability samples as shown in Figure 19.4 "b" or Figure 19.5 "c" shall be as follows:

a) The buildup shall include the thinnest individual laminate and prepreg/bonding sheets. The build-up thickness shall be the minimum total thickness that would result from two 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 dielectric material layer.

c) All metal shall be etched from internal and external surfaces.

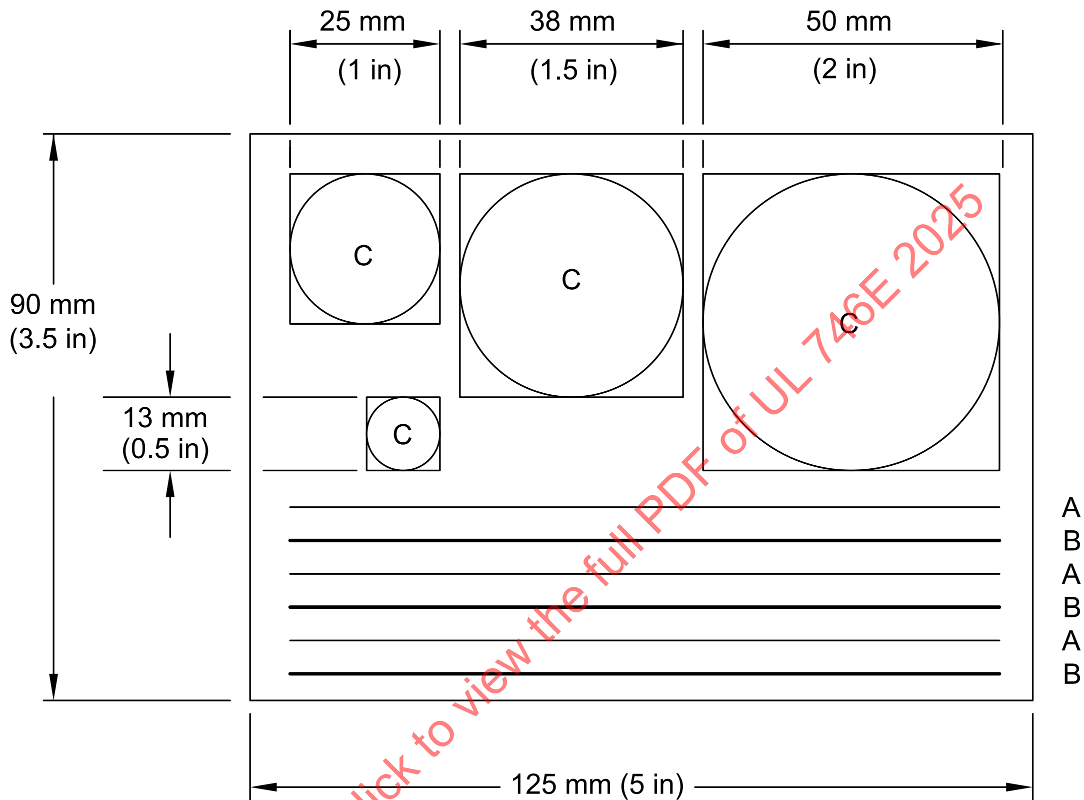
(Note: The flammability samples shall be the same construction as the Bond Strength and Delamination samples minus the copper).

19.3.5 Testing of a pure package multilayer construction will represent mass laminate and single layer constructions of the same minimum build up thickness and copper weights parameters. Single layer does not represent multilayer.

19.3.6 Testing of a metal clad multilayer dissimilar dielectric material construction shall be subjected to 19.9, Dissimilar Dielectric Materials Thermal Cycling Test, and 19.10, Flammability Test. Each individual material, in the combination of dissimilar materials, shall have been previously evaluated for performance profile indexing values and Relative Thermal Indices (RTIs) specified in this Standard.

Figure 19.1

Metal Clad Industrial Laminate Bond Strength and Delamination Test Pattern Coupon



s2970c

NOTES:

Figure 19.1 notes for bond strength and delamination test pattern coupon.

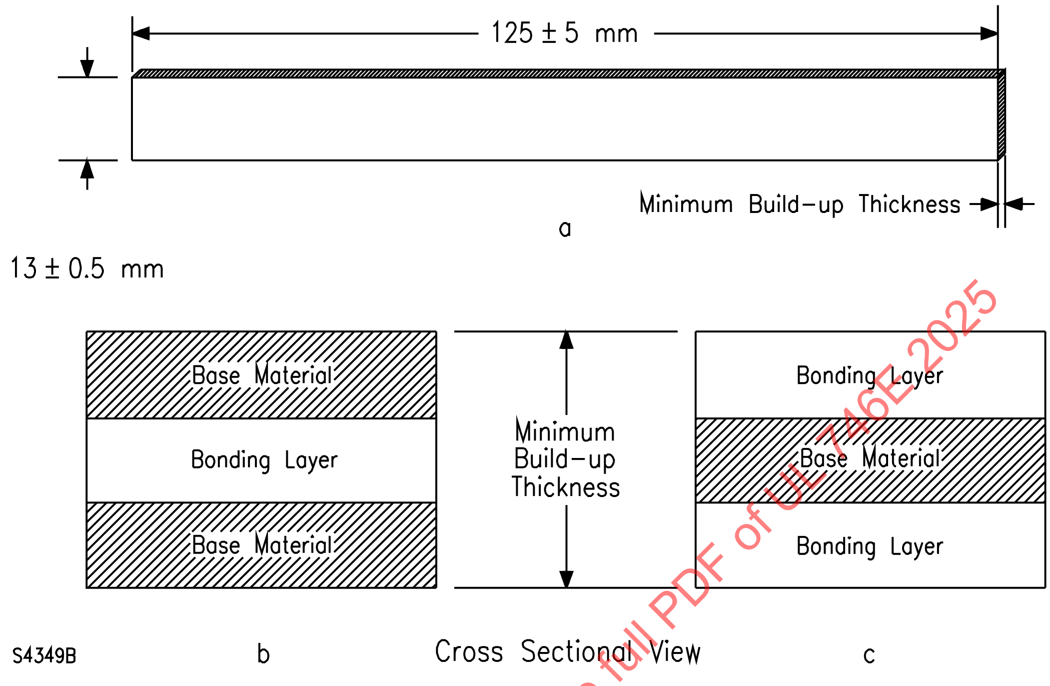
A – Conductor trace 0.8 ±0.13 mm (0.031 inch) wide.

B – Conductor trace 1.6 ±0.13 mm (0.062 inch) conductor with an absolute minimum width not less than 1.47 mm wide.

C – Large conductor areas – Shall be 13 mm (0.5 inch), 25 mm (1.0 inch), 38 mm (1.5 inch) and 50 mm (2.0 inch) diameters, square or circular shape.

Figure 19.2

Typical Multilayer Flame Sample



Above Figure 19.2 (b) and Figure 19.2 (c) are used for construction identification in the following Figure 19.3 – Figure 19.9.

Figure 19.3

Cross Section of Uncoated Flammability Coupons

Single or double sided laminates

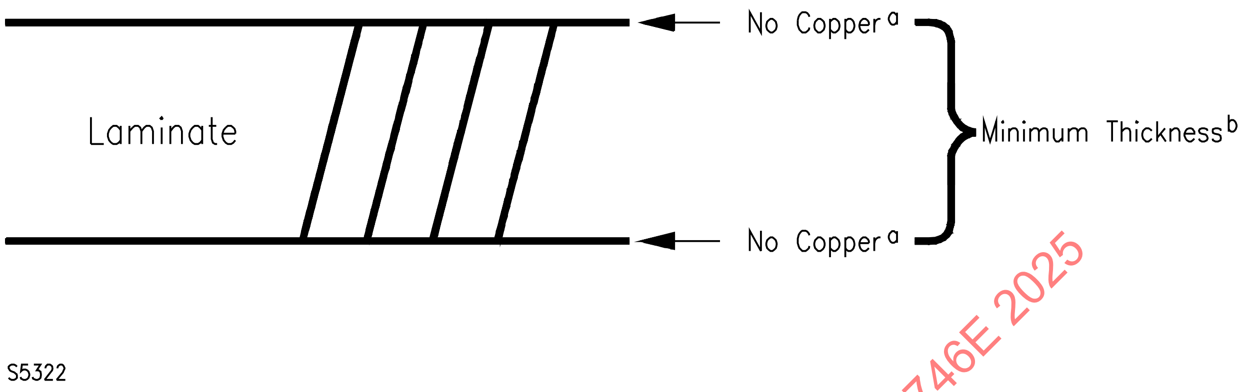


Figure 19.3 notes for single or double-sided laminates flammability coupon

[a] No Copper – Copper must be completely etched off.

[b] Minimum Thickness –

1. The laminate shall be the same thickness and constructed with the same buildup as the laminate used for the Bond/Peel Strength and Delamination samples.

2. The nominal minimum thickness (See Table 7.5) of the flame samples will be the minimum build up thickness listed in the material manufacturer's UL file for the corresponding achieved flammability rating.

3. When only a "Flammability Only" rating is being evaluated, the construction of the samples shall represent actual production material when metal cladding is present.

Figure 19.4

Cross Section of Uncoated Flammability Coupons

Multilayer "b" laminates

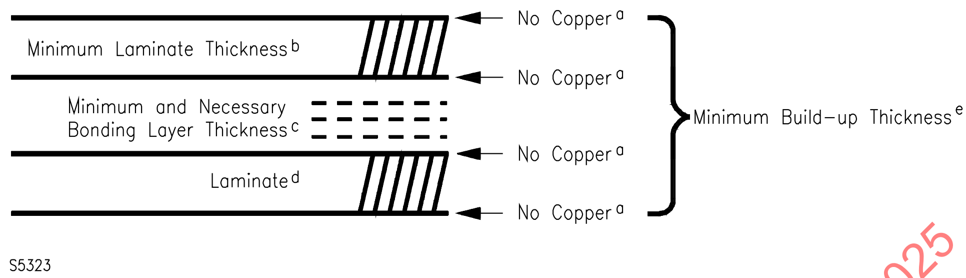


Figure 19.4 notes for multilayer “b” laminate flammability coupon

[a] No Copper – Copper must be completely etched off.

[b] Minimum Laminate Thickness – The minimum laminate thickness required in production shall be included in the minimum buildup thickness.

[c] Minimum and Necessary Bonding Thickness

1. The minimum bonding layer used in production shall be built-up using one or any number of any thickness of bonding sheets/prepreg plies. At least one bonding sheet/prepreg ply shall be the minimum individual sheet thickness used in production. The total thickness between the laminates shall be the minimum bonding layer. Example: 2 sheets of 2 mil thick bonding sheets/prepreg plies shall equal a 4 mil minimum bonding layer.

2. The bonding layer for the minimum build up thickness used in production, shall be built-up using one or any number of any thickness of bonding sheets/prepreg plies necessary to have good layer registration without inside delamination or air entrapment.

Note: The minimum bonding layer thickness for Multilayer “b” construction may be considerably thicker than the minimum bonding layer thickness for Multilayer “c” construction because a thicker bonding layer may be necessary to also have good registration without inside delamination or air entrapment against the maximum thickness internal conductor.

[d] Laminate Thickness – The laminate thickness required in production to support the maximum internal conductor thickness that can be accommodated in the minimum buildup thickness shall be included.

[e] Minimum Build-up Thickness

1. The multilayer construction shall be the same build up thickness as the Bond/Peel Strength and Delamination samples – the same individual sheet thickness, quantity and position in the buildup of the laminate and bonding sheets/prepreg piles – minus the copper.

2. The nominal minimum thickness (See Table 7.5) of the flame samples will be the minimum build up thickness listed in the material manufacturer's UL file for the corresponding achieved flammability rating.

3. When a “Flammability Only” rating is being evaluated, the construction of the samples shall represent actual production material when metal cladding is present.

Figure 19.5

Cross Section of Uncoated Flammability Coupons

Multilayer "c" laminates

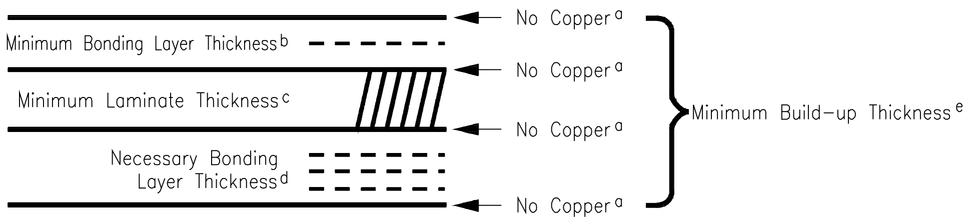


Figure 19.5 notes for multilayer "c" laminate flammability coupon

[a] No Copper – Copper must be completely etched off.

[b] Minimum Bonding Layer Thickness

1. The minimum bonding layer used in production shall be built-up using one or any number of any thickness of bonding sheets/prepreg plies. At least one bonding sheet/prepreg ply shall be the minimum individual sheet thickness used in production. The total thickness between the minimum surface foil and the minimum laminate shall be the minimum bonding layer. Example: 2 sheets of 2 mil thick bonding sheets/prepreg plies shall equal a 4 mil minimum bonding layer.

2. When required in production this spacing may be built-up using a laminate layer supporting the minimum surface foil plus one or any number of any thickness of bonding sheets/prepreg plies.

[c] Minimum Laminate Thickness – The minimum laminate thickness required in production shall be included in the minimum buildup thickness.

[d] Necessary Bonding Layer Thickness – The bonding layer for the minimum build up thickness used in production, shall be built-up using one or any number of any thickness of bonding sheets/prepreg plies necessary to have good layer registration without inside delamination or air entrapment.

[e] Minimum Build-up Thickness

1. The multilayer construction shall be the same build up thickness as the Bond/Peel Strength and Delamination samples – the same individual sheet thickness, quantity and position in the buildup of the laminate and bonding sheets/prepreg plies – minus the copper.

2 The nominal minimum thickness (See Table 7.4) of the flame samples will be the minimum build up thickness listed in the material manufacturer's UL file for the corresponding achieved flammability rating.

3. When a "Flammability Only" rating is being evaluated, the construction of the samples shall represent actual production material when metal cladding is present.

Figure 19.6

Cross Section of Bond/Peel Strength and Delamination Coupons

Single sided laminates

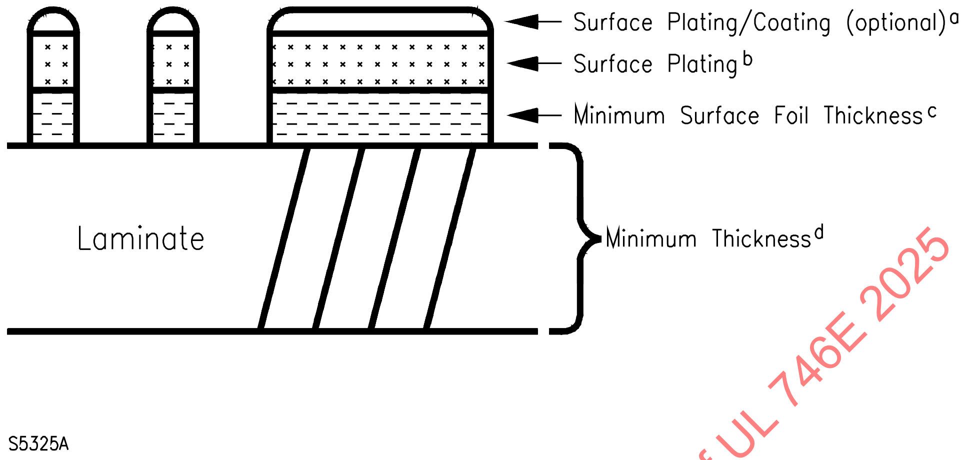


Figure 19.6 notes for single sided bond/peel strength and delamination coupon

[a] Surface Plating/Coating – Samples shall be prepared with a surface treatment/coating such as oxide to prevent adhesion of solder during the thermal stress conditioning.

[b] Surface Plating – Surface plating plus surface foil thickness shall total 34 µ (1 oz cu/sq ft) to enable Bond/Peel Strength testing.

[c] Minimum Surface Foil Thickness

1. When prefabricated copper foil is used, the minimum foil thickness not exceeding 102µ (3 oz cu/sq ft) used in production shall be employed on the samples. If the maximum surface foil thickness required in production is greater than 102µ (3 oz cu/sq ft), the maximum surface foil thickness may be used on an additional set of samples fabricated with the maximum surface foil thickness.

2. When an adhesive is incorporated between the surface foil and the laminate surface, a separate set of Bond/Peel and Delamination samples shall be required. See 19.11, Additional tests.

3. When this surface foil is any material except copper foil, a separate set of Bond/Peel and Delamination samples shall be required.

4. When this surface foil is fabricated directly on the laminate surface via an additive process, a separate set of Bond/Peel and Delamination samples shall be required.

[d] Minimum Laminate Thickness – The laminate shall be constructed with the same buildup as the laminate used in production.

Figure 19.7

Cross Section of Bond/Peel Strength and Delamination Coupons

Double sided laminate

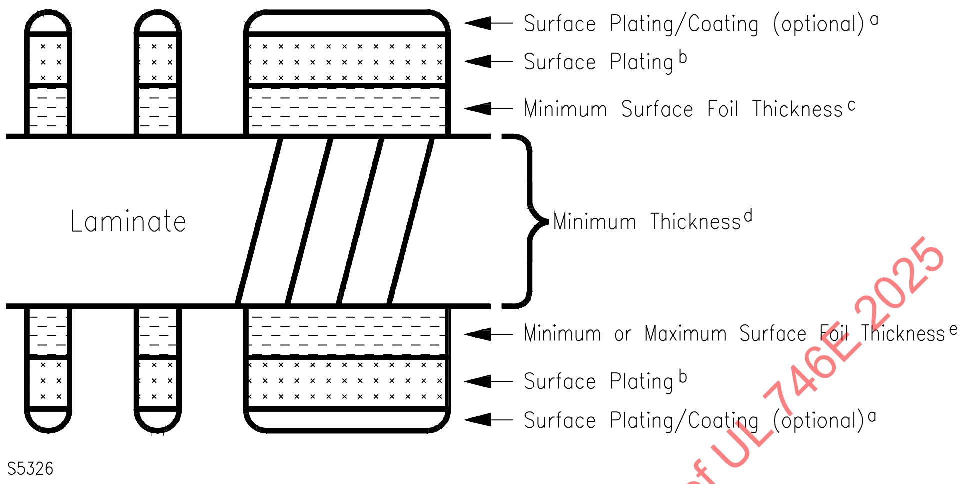


Figure 19.7 notes for double sided bond/peel strength and delamination coupon

[a] Surface Plating/Coating – Samples shall be prepared with a surface treatment/coating such as oxide to prevent adhesion of solder during the thermal stress conditioning.

[b] Surface Plating – Surface plating plus surface foil thickness shall total 34 µ (1 oz cu/sq ft).to enable Bond/Peel Strength testing.

[c] Minimum Surface Foil Thickness

1. When prefabricated copper foil is used, the minimum foil thickness not exceeding 102 µ (3 oz cu/sq ft) used in production shall be employed on the samples.

2. When an adhesive is incorporated between the surface foil and the laminate surface, a separate set of Bond/Peel and Delamination samples shall be required. See 19.11, Additional tests.

3. When this surface foil is any material except copper foil, a separate set of Bond/Peel and Delamination samples shall be required.

4. When this surface foil is fabricated directly on the laminate surface via an additive process, a separate set of Bond/Peel and Delamination samples shall be required.

[d] Minimum Laminate Thickness – The laminate shall be constructed with the same buildup as the laminate used in production.

[e] Minimum or Maximum Surface Foil Thickness

1. If the maximum surface foil thickness required in production is not greater then 102 µ (3 oz cu/sq ft), the minimum surface foil thickness shall be used on this side also.

2. If the maximum surface foil thickness required in production is greater than 102 µ (3 oz cu/sq ft) the maximum surface foil thickness may be used on this side, **or** an additional set of samples fabricated with the maximum surface foil thickness to be used in production shall be provided.

Figure 19.8

Cross Section of Bond/Peel Strength and Delamination Multilayer Laminate "b" Coupons

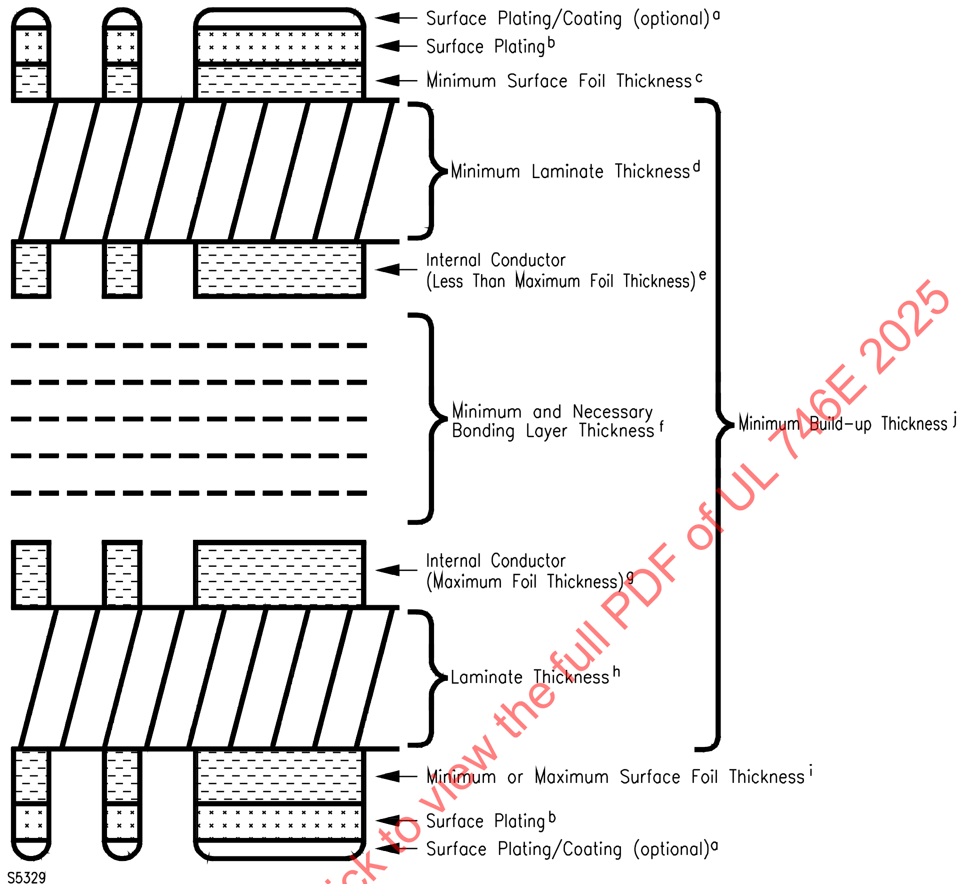


Figure 19.8 notes for multilayer "b" laminate bond/peel strength and delamination coupon

[a] Surface Plating/Coating – Samples shall be prepared with a surface treatment/coating such as oxide to prevent adhesion of solder during the thermal stress conditioning.

[b] Surface Plating – Surface plating plus surface foil thickness shall total 34µ (1 oz cu/sq ft) to enable Bond/Peel Strength testing.

[c] Minimum Surface Foil Thickness

1. When prefabricated copper foil is used, the minimum foil thickness not exceeding 102µ (3 oz cu/sq ft) used in production shall be employed on the samples.

2. When an adhesive is incorporated between the surface foil and the laminate surface, a separate set of Bond/Peel and Delamination samples shall be required. See 19.11, Additional tests. When an adhesive is incorporated between the surface foil and the laminate surface, a separate set of Bond/Peel and Delamination samples shall be required. See 19.11, Additional tests.

3. When this surface foil is any material except copper foil, a separate set of Bond/Peel and Delamination samples shall be required.

4. When this surface foil is fabricated directly on the laminate surface via an additive process, a separate set of Bond/Peel and Delamination samples shall be required.

[d] Minimum Laminate Thickness – The minimum laminate thickness required in production shall be included in the minimum buildup thickness.

[e] Internal Conductor of Less Than Maximum Thickness – The thinner than maximum foil thickness is incorporated to allow for the inclusion of the minimum bonding layer thickness.

[f]Minimum and Necessary Bonding Thickness

1. The minimum bonding layer used in production shall be built-up using one or any number of any thickness of bonding sheets/prepreg plies. At least one bonding sheet/prepreg ply shall be the minimum individual sheet thickness used in

production. The total thickness between the laminates shall be the minimum bonding layer. Example: 2 sheets of 2 mil thick bonding sheets/prepreg plies shall equal a 4 mil minimum bonding layer.

2. The bonding layer for the minimum build up thickness used in production, shall be built-up using one or any number of any thickness of bonding sheets/prepreg plies necessary to have good layer registration without inside delamination or air entrapment.

3. When a second set of Bond/Peel Strength and Delamination samples are required to accommodate the internal conductor of maximum thickness, additional bonding sheets/prepreg plies may be necessary to have good layer registration without inside delamination or air entrapment.

Note: The minimum bonding layer thickness for Multilayer "b" construction may be considerably thicker than the minimum bonding layer thickness for Multilayer "c" construction because a thicker bonding layer may be necessary to also have good registration without inside delamination or air entrapment against the maximum thickness internal conductor.

[g] Internal Conductor Maximum Foil Thickness – 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 Multi-layer sample construction, Section 19.3, a second 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 Multi-layer sample construction, Section 19.3. The second set of Bond Strength and Delamination test samples shall contain the minimum multilayer construction build up that can accommodate the maximum internal metal weight to be used in production. [See 19.3.3(d)].

[h] Laminate Thickness

1. The laminate thickness required in production to support the maximum internal conductor thickness that can be accommodated in the minimum buildup thickness shall be included.

2. The second set of Bond/Peel and Delamination samples (when required) shall contain the minimum laminate thickness necessary to support the maximum internal conductor thickness required in production. These coupons may be thicker than those of the minimum build up thickness.

[i] Minimum or Maximum Surface Foil Thickness

1. If the maximum surface foil thickness required in production is not greater then 102μ (3 oz cu/sq ft), the minimum surface foil thickness shall be used on this side also.

2. If the maximum surface foil thickness required in production is greater than 102μ (3 oz cu/sq ft) the maximum surface foil thickness may be used on this side, **or** an additional set of samples fabricated with the maximum surface foil thickness to be used in production shall be provided.

[j] Minimum Build-up Thickness – The minimum build up thickness of the multilayer Bond/Peel Strength and Delamination samples shall not exceed the minimum production thickness plus the thickness of the internal conductors.

1. The thickness of the Bond/Peel Strength samples may be thicker than the Flammability samples of the same construction due to the thickness and percent of the internal conductor metal retained in the Bond/Peel Strength samples.

2. The thickness of the Delamination samples may be thicker than the Bond/Peel samples due to the percent of the internal conductor metal retained in the Delamination samples.

Figure 19.9

Cross section of bond/peel strength and delamination multilayer laminate "c" coupons

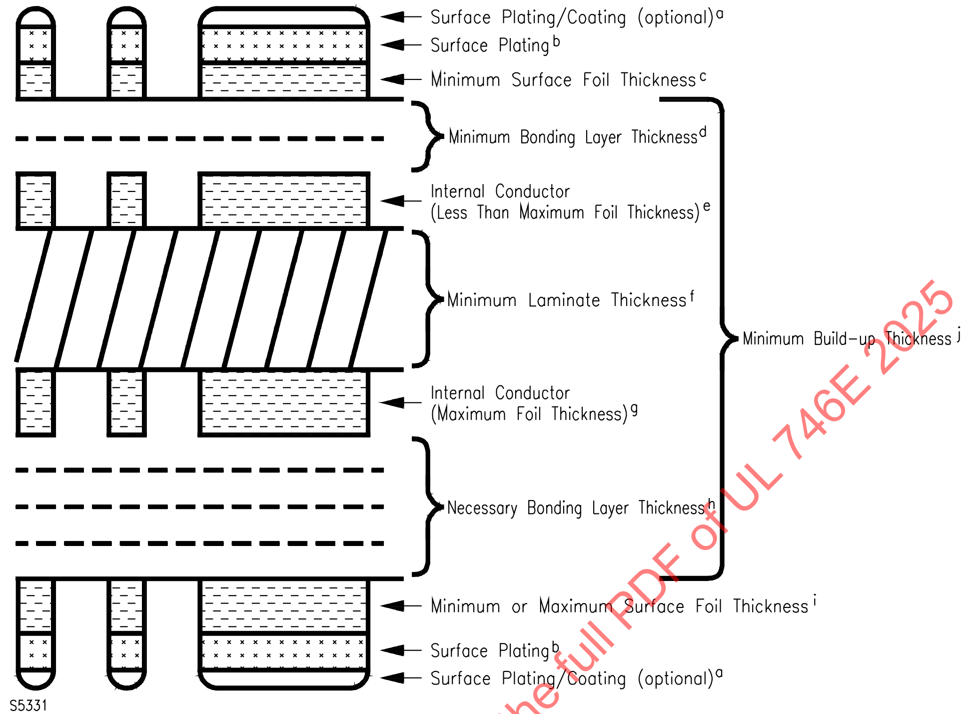


Figure 19.9 notes for multilayer “c” laminate bond/peel strength and delamination coupon

[a] Surface Plating/Coating – Samples shall be prepared with a surface treatment/coating such as oxide to prevent adhesion of solder during the thermal stress conditioning.

[b] Surface Plating – Surface plating plus surface foil thickness shall total 34 μ (1 oz cu/sq ft) to enable Bond/Peel Strength testing.

[c] Minimum Surface Foil Thickness

1. When prefabricated copper foil is used, the minimum thickness not exceeding 102 μ (3 oz cu/sq ft) used in production shall be employed on the samples.

2. When an adhesive is incorporated between the surface foil and the bonding layer surface, a separate set of Bond/Peel and Delamination samples shall be required. See 19.11, Additional tests.

3. When this surface foil is any material except copper foil, a separate set of Bond/Peel and Delamination samples shall be required.

4. When this surface foil is fabricated directly on the bonding layer surface via an additive process, a separate set of Bond/Peel and Delamination samples shall be required.

5. When this surface foil is on one side of a laminate layer (cap layer), a separate set of Bond/Peel and Delamination samples shall be required.

[d] Minimum Bonding Layer Thickness

1. The minimum bonding layer used in production shall be built-up using one or any number of any thickness of bonding sheets/prepreg plies. At least one bonding sheet/prepreg ply shall be the minimum individual sheet thickness used in production. The total thickness between the minimum surface foil and the minimum laminate shall be the minimum bonding layer. Example: 2 sheets of 2 mil thick bonding sheets/prepreg plies shall equal a 4 mil minimum bonding layer.

2. When required in production this spacing may be built-up using a laminate layer (cap layer) supporting the minimum surface foil plus one or any number of any thickness of bonding sheets/prepreg plies.

[e] Internal Conductor of Less Than Maximum Thickness – The thinner than maximum foil thickness is incorporated to allow for the inclusion of the minimum bonding layer thickness.

[f] Minimum Laminate Thickness

1. The minimum laminate thickness required in production shall be included in the minimum build up thickness.

2. When required for thicker conductors, the minimum laminate thickness required in production necessary to support the maximum internal conductor thickness required in production shall be used in the build up of a second set of Bond/Peel Strength and Delamination samples.

[g] Internal Conductor Maximum Foil Thickness – 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 Multi layer sample construction, Section 19.3, a second 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 Section 19.3. The second set of Bond Strength and Delamination test samples shall contain the minimum multilayer construction build up that can accommodate the maximum internal metal weight to be used in production. [See 19.3.3(d)].

[h] Necessary Bonding Layer Thickness.

1. The bonding layer for the minimum build up thickness used in production, shall be built-up using one or any number of any thickness of bonding sheets/prepreg plies necessary to have good layer registration without inside delamination or air entrapment.

2. When a second set of Bond/Peel Strength and Delamination samples are required to accommodate the internal conductor of maximum thickness, additional bonding sheets/prepreg plies may be necessary to have good layer registration without inside delamination or air entrapment.

[i] Minimum or Maximum Surface Foil Thickness

1. If the maximum surface foil thickness required in production is not greater then 102 μ (3 oz cu/sq ft), the minimum surface foil thickness shall be used on this side also.

2. If the maximum surface foil thickness required in production is greater than 102 μ (3 oz cu/sq ft) the maximum surface foil thickness may be used on this side **or** an additional set of samples fabricated with the maximum surface foil thickness to be used in production shall be provided.

[j] Minimum Build-up Thickness – The minimum build up thickness of the multilayer Bond/Peel Strength and Delamination samples shall not exceed the minimum production thickness plus the thickness of the internal conductors.

1. The thickness of the Bond/Peel Strength samples may be thicker than the Flammability samples of the same construction due to the thickness and percent of the internal conductor metal retained in the Bond/Peel Strength samples.

2. The thickness of the Delamination samples may be thicker than the Bond/Peel samples due to the percent of the internal conductor metal retained in the Delamination samples.

19.4 Data collection

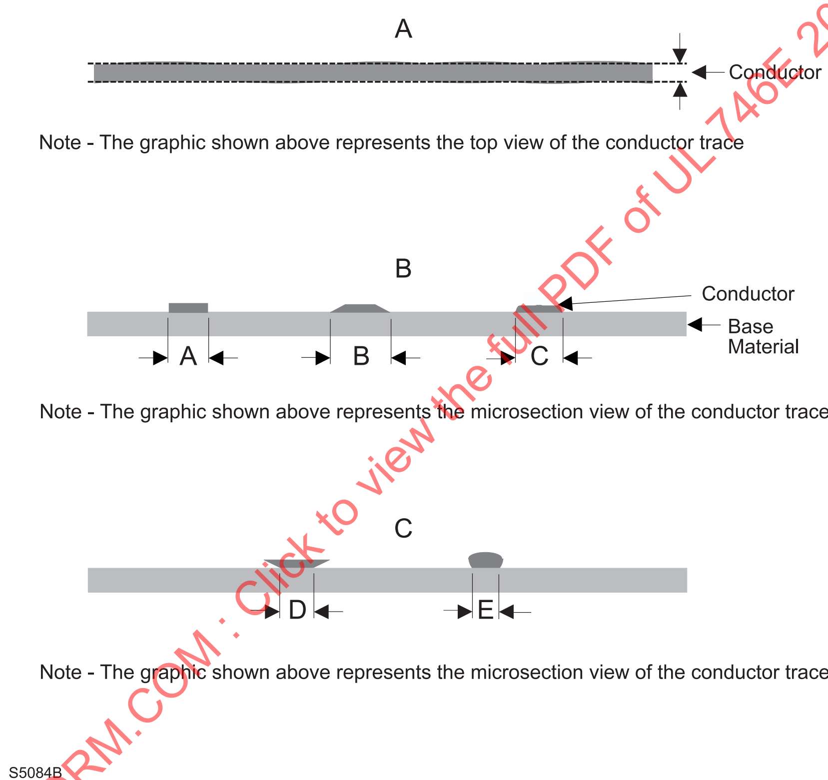
19.4.1 The conductor trace average width shall be determined by measuring the average contact or interface area of the conductor material to base material. See Figure 19.10. Each of the following conductor widths shall be determined:

a) A 0.8 mm (0.031 inch) wide conductor and

b) A 1.6 mm (0.062 inch) wide conductor.

Figure 19.10

Measuring conductor average width



19.4.2 In cases where the contact or interface area of the materials cannot be viewed from above due to the conductor dimensions, (see Figure 19.10 C), the average contact or interface area of the separated materials shall be used to measure the conductor average width.

19.4.3 The maximum area conductor diameter shall be determined on the sample test pattern. Alternate conductor area diameters shall also be determined if necessary for the test method.

19.4.4 The external conductor thickness (weight) including foil thickness and plating shall be determined on the sample test pattern. In addition, the external conductor foil and conductor surface plating thickness shall be determined on the sample test pattern to verify the total conductor thickness is appropriate for the bond strength pull.

19.4.5 For samples with internal conductor test patterns, the internal conductor thickness (weight) shall be determined for each internal conductor layer.

19.4.6 The average build up thickness of the sample shall be determined where no conductor material resides on the internal or external surfaces of the printed wiring board construction.

19.4.7 The measuring device used to measure the build up thickness and test pattern parameters shall have an accuracy of 10 percent of the measured parameter. Microsection analysis shall be used to determine the external and internal conductor thicknesses.

19.5 Microsection analysis

19.5.1 General

19.5.1.1 The purpose of the microsection examination is to evaluate and determine compliance of the materials, construction, and test pattern of the metal clad laminate, film and prefabricated multilayer laminate with the applicable standard and test method sample coupon construction requirements. The same basic procedures may be used to evaluate other areas of the sample construction.

19.5.1.2 Guidelines for preparing microsection samples are described in the Standard Practice for Preparation of Metallographic Specimens, ASTM E 3, and Microsectioning, Manual and Semi or Automatic Method, IPC TM-650 2.1.1.

19.5.2 Test samples

19.5.2.1 The microsection samples shall be cut from the test coupon to include representative areas of the parameters to be measured. This may require multiple microsections. All samples must maintain required traceability. Three common types of cutting tools are diamond saws, routers, and punching dies. Samples shall be cut perpendicular to the evaluation surface with enough clearance to prevent damage to the examination area. The recommended minimum clearance is 2.5 mm (0.1 inch). Depending on the test coupon design, care shall be exercised in choosing a microsection location such that a complete examination can be made.

19.5.2.2 Samples sizes are generally not more than 12 to 25 mm (0.5 to 1.0 in.) square. The sample height shall be determined for convenience in handling during polishing.

19.5.2.3 Samples shall be cleaned thoroughly with isopropyl or ethyl alcohol to remove all greases, oils, and residue from the cutting tools. Dry the sample thoroughly. Cleanliness during sample preparation is important for good adhesion of the mounting resin. Poor adhesion of the mounting resin can cause gaps between the sample and the mounting material which make proper examination difficult.

19.5.2.4 Samples shall be mounted prior to grinding and polishing in a castable resin/potting material. A release agent shall be applied to the plate and mount mold. The sample shall stand in the mount perpendicular to the base with the surface to be evaluated facing the mounting surface. Clips or tape may be used to support the sample until the potting material is cured.

19.5.2.5 The mount mold shall be filled with potting material carefully to reduce bubbles in the potting material. Allow samples to cure and remove mount mold.

19.5.2.6 A description of the basic grinding and polishing steps is outlined in 19.5.2.7 – 19.5.2.9.

19.5.2.7 The samples shall be rough planar ground using an abrasive medium. ANSI 180 – 240 grit abrasive paper (or equivalent) may be used as a starting grit size using metallographic equipment to remove the sectioning/cutting damage. The sample shall be held firmly in contact with the rotating wheel in a circular path against the rotation of the wheel. Rinse the sample with running water and dry. Wheel speeds of 200 to 300 rpm are generally used during grinding. Rotate the sample 90 degrees planar between successive grit size and grind to remove the scratches from the previous step. The successive grinding time may be three times longer than the previous step. Scratches are grooves in the surface of the sample produced by the abrasive particles in the grinding paper. The surface of the sample shall be flat with one set of unidirectional grinding scratches. Water flow must be maintained for removal of grinding debris and to prevent overheating and damage to the sample.

19.5.2.8 Continue grinding the samples with fine grit size. ANSI 400 – 1200 grit (or equivalent) may be used in successive order to remove the rough and finer grinding damage/scratches. Less time shall be spent on the larger grit and more time on the smaller grit for better sample quality. The scratch removal can be verified by microscopic inspection between steps. Rinse and dry samples between each step to avoid contamination by grinding particles.

19.5.2.9 Polish the samples to remove the scratches from intermediate steps. Diamond polish is preferred. Smearing of the test material or potting material may occur if lubrication levels are too low or if excessive load is used during grinding. Increase or change the lubricant and reduce the applied load to reduce smearing.

19.5.3 Micro-etching the sample surface

19.5.3.1 When the required microsection quality has been achieved, the sample shall be etched to allow examination of the copper foil and plating interface.

19.5.3.2 The etching solution shall be prepared daily and is a mixture of 7 drops Ammonium Hydroxide solution and 9 drops Hydrogen Peroxide solution. The Ammonium Hydroxide solution is 1:1 ratio solution of reagent grade Ammonium Hydroxide and deionized water. The Hydrogen Peroxide solution is 1:1 ratio solution of stabilized Hydrogen Peroxide (3 percent by volume) and deionized water.

19.5.3.3 The etching solution shall be applied for 2 to 3 seconds. If necessary, repeat the application of the etchant 2 to 3 times to show the plating surface. Rinse in running tap or deionized water to remove etchant.

Note: Over etching may obscure the demarcation line between the copper foil and electroplate copper, preventing accurate evaluation. Thin copper foil and special plating processes require the etching time to be modified.

19.5.4 Material and test pattern parameter examination

19.5.4.1 The microsection sample shall be evaluated at a minimum 100X magnification with bright field illumination.

19.5.4.2 All parameters required by the standard shall be measured and observed including, but not limited to, overall construction build up thickness, laminate layer thickness, bonding layer thickness, number and thickness of reinforcement layers, conductor thickness (weight), conductor base width, etc.

19.6 Thermal stress

19.6.1 Purpose

19.6.1.1 The thermal stress test is designed to evaluate the physical fatigue of test samples exposed to the anticipated board assembly soldering process. There shall be no wrinkling, cracking, blistering, or loosening of any conductor or any delamination of the materials as a result of the thermal stress test.

19.6.2 Apparatus

19.6.2.1 Thermal stress reflow conditions shall be conducted using the following apparatus:

Reflow Oven – The reflow system shall have adequate environmental controls to maintain the tolerance range and limits in the designated reflow profiles. IR reflow requires attention to the uniformity of temperature across the sample due to the susceptibility of the materials to infrared absorption.

19.6.2.2 Thermal stress shall be conducted using one of the apparatus specified below for other soldering processes:

a) Convection Oven – Attention shall be directed to maintaining the test temperature, when introducing and removing the samples into and from the oven chamber.

b) Sand Bath – Attention shall be directed to the uniformity of temperature throughout the fluidized bed, and avoid mechanical damage imposed by an inadequately fluidized sand bath. Samples shall be prepared to prevent adhesion of sand. Samples shall not be tested for flammability if sand adheres to the sample.

c) Solder Pot – Attention shall be directed to the samples when removing them from the solder pot so the solder does not join with the conductor traces. Samples shall be prepared with a surface treatment/coating such as oxide to prevent adhesion of solder. Samples shall be prepared so as not to have solder or solder resist on the conductors during testing.

19.6.3 Procedure

19.6.3.1 All samples are to be conditioned at 121°C ±2°C (250°F ±3.6°F) for a minimum of 1.5 hours prior to being subjected to the thermal stress unless specified otherwise by the manufacturer.

19.6.3.2 Thermal stress shall be conducted within 30 minutes after removal from the 121°C oven. If not conducted within 30 minutes, the samples shall be stored in a desiccator to prevent moisture absorption.

19.6.3.3 All samples shall be subjected to reflow soldering conditions or equivalent process specified by the manufacturer. The standardized thermal stress conditions described in Table 19.3 shall be used for this investigation.

Table 19.3
Sample Thermal Stress Standardized Conditions

Assembly Process	Maximum Peak Temp	Dwell Time	Cycles
Reflow 260°C, 245°C or 230°C	T1 (default 260°C)	IPC TM-650 2.6.27	X (default 6)
Reflow Special	T2	t2 plus profile conditions	X
Wave / Selective soldering	T3	t3	X

Notes:

1 – Default reflow conditions are 260°C peak temperature and six cycles. Manufacturer shall specify alternate conditions if necessary for the thermal stress test.

2 – Reflow – The peak temperature (T1) and number of cycles (X) shall be specified.

3 – Reflow Special – Unique conditions defined by the manufacturer for ramp rate (R1), cooling rate (C1), peak temperature (T2), dwell time (t2) and cycles (X).

4 – Wave / Selective – The peak temperature (T3) and dwell time (t3) shall be specified.

5 – The peak temperature shall be measured on the material surface.

6 – See reflow profile figures in IPC TM-650 2.6.27

19.6.3.4 Materials for use with reflow assembly processes shall be thermally stressed using one of the standardized profile conditions: Reflow 260°C, Reflow 245°C, Reflow 230°C, or Special Reflow in accordance with IPC-TM-650 2.6.27. The Reflow 260°C profile using six (6) cycles shall be the default thermal stress conditions, unless specified otherwise.

19.6.3.5 Materials for use with wave solder and/or selective soldering assembly processes shall be thermally stressed using the maximum temperature, maximum time, and maximum cycles specified by the manufacturer. One (1) cycle shall be the default unless specified otherwise.

19.6.4 Retest

19.6.4.1 A retest is to be performed when a change in thermal stress is desired to increase the temperature, dwell time, and/or number of cycles.

19.7 Bond strength delamination and blistering test

19.7.1 As received

19.7.1.1 *Deleted*

19.7.1A Purpose

19.7.1A.1 The purpose of this test method is to provide a consistent procedure for assessing the physical endurance and bond strength of metallic conductors on materials, following exposure to assembly solder process and thermal conditioning based on the maximum operating temperature. The test is designed to assess physical fatigue of test samples exposed to the anticipated printed wiring board production soldering temperatures and anticipated service temperatures, via elevated temperature conditioning.

19.7.1B Compliance criteria

19.7.1B.1 The average bond strength between the conductor and base material shall not be less than:

a) 0.525 N/mm (3 lbf/inch) for each individual conductor trace, for the as received bond strength after being subject to thermal stress; and

b) 0.525 N/mm (3 lbf/inch) for each individual conductor trace, for the 240 hours (10 day) bond strength after being subject to thermal stress and 240 hours (10 day) oven conditioning; or

c) 0.350 N/mm (2 lbf/inch) for each individual conductor trace, for the 1344 hours (56 day) bond strength after being subject to thermal stress and 1344 hours (56 day) oven conditioning.

19.7.1B.2 There shall be no presence of any wrinkling, cracking, blistering, or loosening of any conductor, or any delamination, wrinkling, cracking, blistering, or loosening of any film, adhesive, base material, bonding film, cover material, dielectric material, or other insulation material as a result of the pre-conditioning, thermal stress, oven conditioning, or cooling.

19.7.1C Test samples

19.7.1C.1 Four (4) samples shall include all material components representing a minimum build-up construction as described in 19.2 or 19.3.

19.7.1C.2 A representative conductor pattern is shown in Figure 19.1.

19.7.1C.3 Cover materials shall not be present on the external surfaces of the samples. The bond strength test shall be conducted by peeling the conductor from the base material without obstruction of cover materials.

19.7.1D Apparatus

19.7.1D.1 A pry tool, such as a knife or scalpel, capable of separating the conductor from the substrate adhesive or film material to initiate the conductor bond strength pull.

19.7.1D.2 A conditioning (convection) oven capable of maintaining the specified conditioning temperatures.

19.7.1D.3 A bond strength tester capable of providing and measuring the force required to separate the conductor material from the substrate material with an accuracy within 10 percent of the measured force value.

19.7.1E As received

19.7.1E.1 Measure and verify the sample construction parameters as described in 19.4.

19.7.1E.2 Examine the (as-received) samples using normal or corrected 20/20 vision, and record any presence of any wrinkles, cracks, blisters, or loose conductors, or any delamination, wrinkles, cracks, blisters, or loose materials.

19.7.1E.3 Subject the samples to the Thermal Stress Test, 19.6. When the samples have cooled to room temperature, the unbroken area circles and the entire sample shall be examined and there shall be no wrinkling, cracking, blistering, or loosening of any conductor or any delamination of the dielectric material and bonding sheets. A bond strength test, as described in the Standard for Printed Wiring Boards, UL 796, shall be performed on two of each of the 1.6 mm and 0.8 mm conductor widths on the four test samples. When the results do not conform with the criteria of 19.7.2, testing shall be discontinued.

19.7.2 Oven conditioning

19.7.2.1 Following the bond-strength testing, two of the four test samples are to be placed in an oven for 240 hours (10 days) at an elevated temperature based on the operating temperature rating of the material being investigated. The two remaining samples (of the four) are to be placed in a conditioning oven for 1344 hours (56 days) at an elevated temperature based on the operating temperature rating of the material being investigated. The elevated conditioning temperature is determined using the formulas in 19.7.2.2. At the conclusion of the oven conditioning, the bond-strength testing is to be repeated. The samples 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 dielectric material and bonding sheets. The alternate 1344-hour (56-day) oven conditioning temperature may be used if the laminate manufacturer anticipates that the higher test temperature and increased bond-strength test requirements of the 240-hour (10-day) oven conditioning program would be too severe for the product.

Exception: For film type materials, separate two test samples besides As-received samples are to be placed in an oven for 240 hours (10 days). Also, another separate two samples besides As-received samples are to be placed in a conditioning oven for 1344 hours (56 days). Thus, for film type materials, total 8 samples (4 for As-received, 2 for 10 days, and 2 for 56 days) are needed.

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

$t_2 = 1.076(t_1 + 288) – 273$ [for 240 hours (10 days) oven conditioning]

$t_3 = 1.02(t_1 + 288) – 273$ [for 1344 hours (56 days) oven conditioning]

in which:

t_1 is the desired or established maximum operating temperature (MOT) in °C and is not greater than the established relative thermal index (RTI);

t_2 is the oven temperature for 240 hours in °C; and

t_3 is the oven temperature for 1344 hours in °C.

See Table 19.4 for the 240 hour (10 day) and 1344 hour (56 day) oven conditioning temperatures.

19.8 Delamination and blistering

19.8.1 *Deleted*

19.8.2 Purpose

19.8.2.1 The purpose of this test method is to provide a consistent procedure for assessing the physical endurance of material, following exposure to assembly solder process and thermal conditioning based on the maximum operating temperature. The test is designed to assess physical fatigue of test samples exposed to the anticipated production soldering temperatures and anticipated service temperatures via elevated temperature conditioning.

19.8.3 Compliance criteria

19.8.3.1 There shall be no presence of any wrinkling, cracking, blistering, or loosening of any conductor, or any delamination, wrinkling, cracking, blistering, or loosening of any film, adhesive, base material, bonding film, cover material, or other insulation material as a result of the pre-conditioning, thermal stress, oven conditioning, or cooling.

19.8.4 Test samples

19.8.4.1 Four (4) samples shall include all material components representing a minimum build-up construction as described in 19.2 or 19.3.

19.8.4.2 A representative conductor pattern is shown in Figure 19.1.

19.8.4.3 Cover materials shall not be present on the external surfaces of the samples.

19.8.5 Apparatus

19.8.5.1 A conditioning (convection) oven capable of maintaining the specified conditioning temperatures.

19.8.6 Procedure

19.8.6.1 Measure and verify the sample construction parameters as described in 19.4.

19.8.6.2 Examine the (as-received) samples using normal or corrected 20/20 vision, and record any presence of any wrinkles, cracks, blisters, or loose conductors, or any delamination, wrinkles, cracks, blisters, or loose materials.

19.8.6.3 Subject the samples to the Thermal Stress Test, 19.6, and the oven conditioning in 19.7.2, there shall be no wrinkling, cracking, blistering, or loosening of any conductor or any delamination of the base material or prepreg after either the thermal stress or oven conditioning.

19.9 Dissimilar dielectric materials thermal cycling test

19.9.1 General

19.9.1.1 Three samples constructed as described in Section 19.3 and Figure 19.1, are to be conditioned as described in 19.9.2. Following the conditioning, there shall be no wrinkling, cracking, blistering, or loosening of any conductor or any delamination of the base material or prepreg.

19.9.2 Thermal cycling

19.9.2.1 Thermal conditioning for three cycles of the following using the scheduling described in Table 19.5, Thermal cycling scheduling – to be used with a manual process (see also Table 30.1, Thermal Cycling Scheduling to be Used with a Manual Process, in UL 796):

a) 48 hours at 10°C (18°F) above the maximum operating temperature (MOT) specified by the manufacturer,

Exception: if a material in the dissimilar construction does not have an MOT, alternate 48 hour conditions shall be used at 10C (18F) above the RTI of lowest rated material RTI. The material RTI shall be determined based on the dissimilar construction minimum total build up thickness as described in 19.3.

b) 64 hours at 35 ±2°C (95 ±3.6°F) at 90 ±5 percent humidity,

c) 8 hours at 0°C (32°F), and

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

Table 19.4
Oven conditioning temperatures for the desired (or established) MOT

t_1, Desired (or established) MOT (°C)	t_2, Oven temperature (°C) for 240-hour (10-day) oven conditioning	t_3, Oven temperature (°C) for 1344-hour (56-day) oven conditioning
75	118	98
80	123	103
85	129	108
90	134	113
105	150	128
120	167	144
125	172	149
130	177	154
150	199	174
155	204	179
160	210	184
170	220	195

Table 19.4 Continued on Next Page

Table 19.4 Continued

t_1, Desired (or established) MOT (°C)	t_2, Oven temperature (°C) for 240-hour (10-day) oven conditioning	t_3, Oven temperature (°C) for 1344-hour (56-day) oven conditioning
175	226	200
180	231	205

NOTE – The temperatures represented by t_2 and t_3 are calculated based on the formulas in 19.7.2.2 with the conditioning values rounded up to the next whole integer.

Table 19.5
Thermal cycling scheduling – to be used with a manual process

Day	Time (Note)	Conditioning
Day 1	3:00 PM	In oven @ TI °C (T + 10°C)
Day 2	–	(In oven)
Day 3	3:00 PM	Out of oven – into H.C. @ 90% R.H.
Day 4	–	(In H.C.)
Day 5	–	(In H.C.)
Day 6	7:00 AM	Out of H.C. – Into Freezer @ 0°C
Day 6	3:00 PM	Out of Freezer – into H.C. @ 90% R.H.
Day 7	–	(In H.C.)
Day 8	–	(In H.C.)
Day 9	7:00 AM	Out of H.C. – end of cycle

NOTES –

1. Day 1 – 9 represents one cycle.
2. All times may be adjusted in equal increments to reflect a later starting date.
3. Samples shall be stored at 23°C ±2°C (73.4 ±3.6°F) and 50% R.H. between cycles.
4. T = Maximum Operating Temperature (MOT) of Printed Wiring Board.
5. TI = Thermal Conditioning Temperature.
6. HC = Humidity Chamber.
7. A programmable conditioning chamber with the software ramp rate and cooling rate set at the chamber maximum limitation can be used as an alternate to the manual process.

19.10 Flammability test

19.10.1 Following the Thermal stress test, 19.6, the flammability test shall be performed in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.

Exception No. 1: See flammability sample alternate precondition values in 4.4.

Exception No. 2: If the declad 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.

19.10.2 The flammability sample dimensions shall be as specified in Table 19.1 in accordance with the requested flammability classification. The sample edges are to be smooth, and the radius on the corners is not to exceed 1.3 mm.

19.10.3 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.

19.11 Adhesives for bonding conductors

19.11.1 When a separate adhesive is used to bond the cladding material to the dielectric material, the following tests shall be required: Bond Strength, Delamination and Blistering, Flammability, Infrared Analysis, Comparative Tracking Index (CTI), High Current Arc Ignition (HAI), and Hot Wire Ignition (HWI). 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, Tests for Flammability of Plastic Materials for Parts and Devices in Appliances, UL 94.

Exception: Where it is determined the above test has previously been conducted on a declad sample with the minimum and maximum adhesive where the metal is removed by etching, additional testing is not required.

19.11.2 Test samples for the Bond Strength, Delamination and Blistering tests in 19.7 and 19.8 shall be constructed as indicated in Section 19.2 and/or Section 19.3 and shall include the minimum adhesive thickness that corresponds with the metal weights to be evaluated. Double sided constructions can be evaluated to represent single sided constructions.

19.11.2A Test samples for the Flammability, HAI and HWI tests shall be declad samples constructed with the minimum laminate thickness and the minimum and maximum adhesive thickness that corresponds with the metal weights to be evaluated. Where applicable, double sided and single sided constructions shall be evaluated.

Exception No. 1: If the dielectric material only has been previously evaluated for flammability in the minimum and maximum thickness and the flammability classification is V-0, flammability testing of the minimum film with the maximum adhesive shall be required for a V-0. Double sided constructions can be evaluated to represent single sided constructions.

Exception No. 2: If the dielectric material flammability classification is VTM-0, flammability testing of the minimum film with the maximum adhesive shall be required for a VTM-0. Double sided constructions can be evaluated to represent single sided constructions.

Exception No. 3: If the dielectric material flammability classification is VTM-0 and the requested flammability classification of the dielectric material and adhesive combination is V-0, the following constructions require evaluation:

a) If single sided construction only:

1) Minimum dielectric thickness and minimum adhesive thickness single sided

2) Minimum dielectric thickness and maximum adhesive thickness single sided

b) If single sided and double sided construction:

1) Minimum dielectric thickness and minimum adhesive thickness single sided

2) Minimum dielectric thickness and maximum adhesive thickness double sided

Exception No. 4: If the dielectric material flammability classification is both VTM-0 and V-0 based on the thickness range, the above testing requirements shall be followed for each different flammability classification.

Exception No. 5: For HAI and HWI testing, if the dielectric material in the minimum and maximum thickness meets Table 9.4 Direct Support values for HAI and HWI and the flammability classification is VTM-0 or V-0, then electrical ignition testing of the minimum film with the maximum adhesive thickness shall be required. Double sided constructions can be evaluated to represent single sided constructions.

Exception No. 6: If the absolute minimum dielectric material with the absolute maximum adhesive thickness is not intended for production, two sets of samples shall be subject to flammability, HAI and HWI testing (if applicable). The first set of samples shall include for each material component the absolute minimum film thickness with the corresponding maximum adhesive thickness (which may not be the absolute maximum adhesive thickness to be used in production.) The second set of samples shall include for each material component the absolute maximum adhesive thickness with the corresponding minimum film thickness (which may not be the absolute minimum film thickness to be used in production.)

19.11.2B The flammability and performance profile index values of the dielectric material only and dielectric and adhesive combination shall be limited to the lowest rated individual values.

19.11.2C The CTI test samples shall be declad samples constructed with 2.5 mm (0.10 inch) laminate thickness and the maximum adhesive thickness that corresponds with the metal weights to be evaluated.

19.11.3 Adhesive material used to bond the conductive material to the dielectric material shall be identified by the generic type of adhesive material, the manufacturer, and grade designation.

19.11.4 Each adhesive shall be subject to identification by infrared analysis.

19.11.5 Adhesive shall not be water soluble.

19.11.6 Each adhesive and dielectric material combination shall be identified using a unique grade designation. See Marking, Section 23.

20 Prefabricated Multilayered Laminates – Mass Lamination

20.1 General

20.1.1 Where the prefabricated multilayered laminate (Mass Laminate) construction was previously investigated for the industrial laminate Original Equipment Manufacturer (OEM) under the test program described in 19.3 – 19.11, no additional testing is required for the product.

20.1.2 Where the Mass Laminate is fabricated from previously investigated ultra thin laminates and prepregs by other than the OEM, the Mass Laminate shall be investigated as described in Table 20.1 in accordance with 19.3 – 19.11.

Table 20.1
Test Program for Mass Laminate Packages Fabricated by Other Than OEM

Variation	Acceptable by CCIL/MCIL	Testing		
		Bond strength	Delamination and blistering	Flame
Adding a laminate and prepreg (Not intermixing)	Yes	–	X	–
	No	X	X	X
Adding a laminate and prepreg (Intermixing each combination)	Yes	–	X	X
	No	X	X	X

20.2 Product limitations

20.2.1 A prefabricated multilayer laminate (Mass 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 stress limits that were tested.

20.3 Test samples

20.3.1 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.

20.3.2 Bond strength and flammability testing shall follow the thermal stress test per 19.1.12 – 19.10.1.

20.4 Processes

20.4.1 Each sample shall be manufactured using each step of the most severe process with regard to temperature and time duration of any given step.

20.4.2 The process of forming the conductor shall result in smooth edges without excessive undercutting and with dimensions not less than represented by the test board. Undercutting shall not be greater than the conductor thickness, per side.

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

20.4.4 Additional testing is required for any one or more of the following changes. Tests shall be conducted as indicated in Section 19, Thermal Stress, Bond Strength, Delamination and Blistering, and Flammability, unless otherwise indicated:

a) A change in any process when the temperature on the surface of the laminate exceeds 100°C (212°F) or the maximum operating temperature of the laminate construction, whichever is greater.

b) A change in etchant.

PERMANENT COATINGS

21 Permanent Coatings

21.1 General

21.1.1 The flammability rating of the combination of the permanent coating applied to a laminate material shall be determined as described in 21.2 – 21.4 after the combination has been subjected to thermal stress conditioning.

21.1.2 Variations in material composition shall be evaluated in accordance with Polymer Variations section of the Standard for Polymeric Materials – Short-Term Evaluations, UL 746A.

21.2 Test samples

21.2.1 Test samples are to be prepared:

a) Using one of each generic grade of previously investigated UL/ANSI type laminate 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 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 ±5 mm (5 inch) long by 13 mm ±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 samples per set (having the dimensions indicated above).

21.2.2 The following sets of samples are to be prepared according to 21.2.1:

a) One set of uncoated samples provided in both the 1.6 mm (0.062 inch) and the minimum thickness.

b) One set of samples is to be prepared by coating both sides of the minimum thickness material with the minimum coating thickness anticipated to be applied by the printed wiring board manufacturer.

c) One set of samples is to be prepared by coating both sides of the minimum thickness material with the maximum coating thickness anticipated to be applied by the printed wiring board manufacturer.

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.

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

21.2.4 The sample sets described in 21.2.2(b), 21.2.2(c), 21.2.2(d) and 21.2.2(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 21.2.2(b), 21.2.2(c), 21.2.2(d), and 21.2.2(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.

21.2.5 Infrared analysis testing is to be performed on each color tested for flammability in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. A cured sample is to be provided, if possible. As an alternative, a 50 g (2 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.

21.3 Thermal stress

21.3.1 All samples shall be subjected to a thermal stress, as described in Section 19.6, simulating a solder operation at a time/temperature value determined by the coating manufacturer based on the anticipated board assembly process.

21.4 Flammability test

21.4.1 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.

21.4.2 The permanent coating shall not receive a flammability classification better than the base material (uncoated samples).

22 Conformal Coatings

22.1 General

22.1.1 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.

22.1.2 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.

22.1.3 Testing is to be conducted on each type of industrial laminate material that is to be considered.

22.1.4 Flammability and infrared analysis tests are to be conducted in accordance with Section 21, the permanent coatings test program. Conformal coating flammability samples shall not be subjected to thermal stress conditioning. The conformal coating shall not receive a flammability classification better than the base material (uncoated samples).

Exception: Flammability tests are not required where the base industrial laminate material is classed HB.

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

22.1.6 Voltage transient tests shall be performed in accordance with 22.4, and dielectric voltage-withstand and breakdown voltage tests shall be performed in accordance with 22.5.

Exception No. 1: Dielectric testing of UL/ANSI FR-4.0 or FR-4.1 are representative of UL/ANSI FR-5, G-10, G-11, CEM-1, CEM-3.0, and CEM-3.1 materials.

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

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

22.1.7 If only one sample from a set of five samples does not comply with the requirements, another set of five samples is to be tested. All samples from this second set shall comply with the applicable test requirements.

22.1.8 Variations in material composition shall be evaluated in accordance with Polymer Variations, Section 8.9 of the Standard for Polymeric Materials – Short-Term Evaluations, UL 746A.

22.2 Test samples

22.2.1 Samples are to be prepared for the voltage transient test (see 22.4.1) and the dielectric voltage-withstand and breakdown-voltage test (see 22.5.1):

a) Using the single-sided test pattern shown in Figure 22.1 applied on one side of the core laminate;

b) Using a core laminate copper weight 17 mic or 33 mic for the test pattern traces to support the test voltage. Copper traces shall be smooth with all burrs and/or defects removed before applying coating.

c) Using a core laminate thickness 1.6 mm or 0.8 mm to support the test voltage;

d) Using the minimum electrical spacing between:

1) The parallel trace conductors;

2) The trace and point conductors; and

3) The point to point conductors;

e) Using the minimum conformal coating thickness;

f) Using normal production means employing any primer or cleaner recommended by the coating manufacturer where this feature is to be considered.

1) If the primer and/or cleaner is optional, test samples with and without primer/cleaner application.

2) The applied coating shall be uniform thickness.

3) The applied coating shall be smooth, homogeneous and tack-free at ambient conditions.

4) The applied coating shall be free of foreign material.

5) The applied coating shall have no bubbles, pinholes, blisters, cracking, crazing, peeling, or wrinkles.

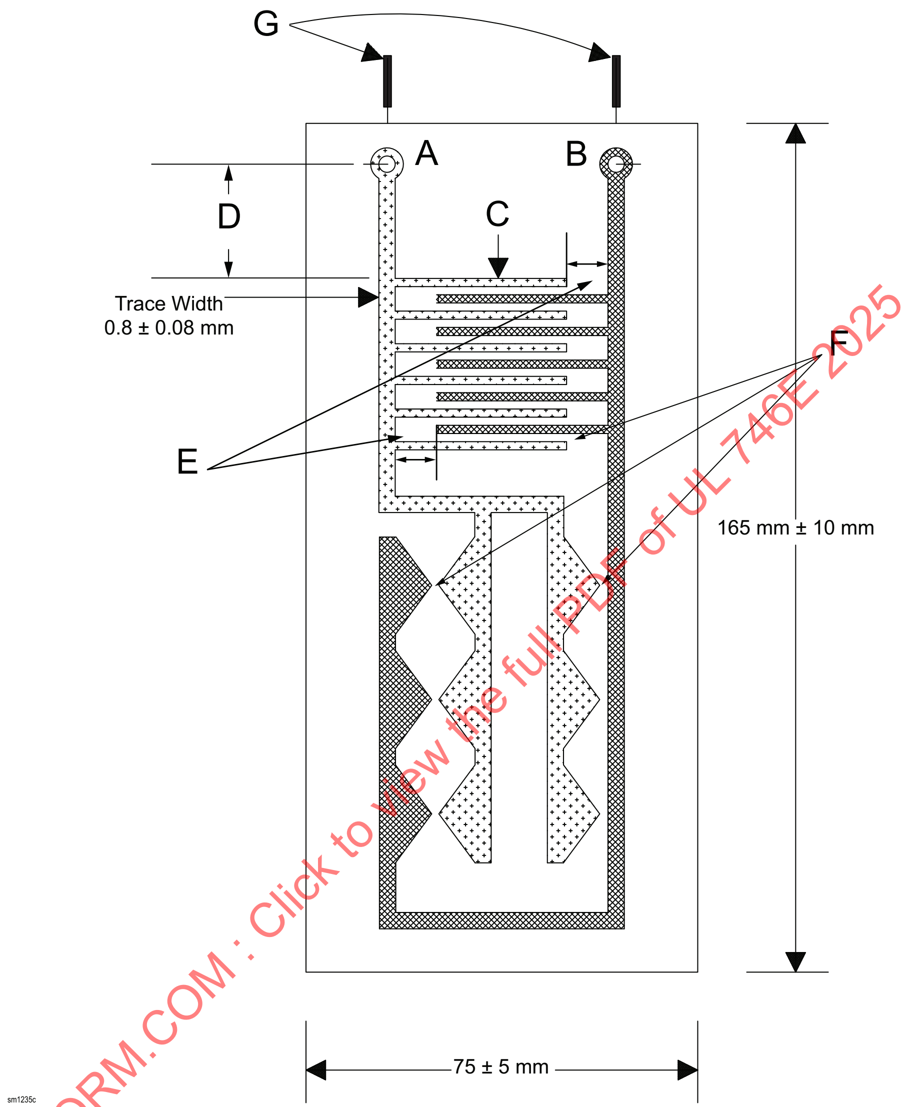
6) The curing process is to be specified by the coating manufacturer and shall be used when preparing samples.

g) Soldering high-temperature insulated lead wires to the test pattern that are appropriate size and length for the test voltage and the thermal conditioning temperature. The lead wires shall be soldered and secured in the sample through holes.

See Table 22.1 for a description of the test program and all test samples required.

Figure 22.1

Conformal coating dielectric test pattern



Notes:

A and B – Plated-through holes, or pads, for lead wire connection for testing purposes. Conductor trace width 0.8 mm ±0.08 mm

C – Comb pattern (parallel traces) conductor trace width 0.5 mm ±0.05 mm

D – Minimum distance of 30 mm to prevent flashover between lead wire connections and comb pattern

E – Distance between the comb pattern trace termination and the opposite polarity conductor shall be greater than the minimum desired spacing

F – Minimum desired spacing between trace to trace, point to point and trace to point conductor spacings

G – High temperature (i.e. PTFE, Silicone, etc.) insulated test leads soldered to the test pattern through the back of the board for testing purposes

H – Any unspecified dimension in Figure 22.1 shall be greater than the minimum conductor spacing desired and shall be sufficient to prevent flashover.

22.2.2 Conformal coating test samples shall also be prepared for flammability and identification testing as described in Section 21.2. The flammability samples shall be prepared by coating both sides of the core laminate with the conformal coating thickness as specified in Table 22.1, and with any additional inks and/or solder resists if employed.

22.2.3 The abrasion resistance test is an optional test based on the anticipated end product application requirements. The abrasion resistance test requires a minimum of five copper clad test samples as described in 22.2.1 and Figure 22.1.

Table 22.1
Conformal coating test samples

Test	Quantity of each coating thickness	Dimensions, mm (inch)	Coating thickness		
			None	Min	Max
Voltage transient, dielectric withstand voltage and breakdown voltage[a] after:					
As received (unconditioned)	10[f]	See b	–	X	–
Environmental conditioning	10[f]	See b	–	X	–
Humidity conditioning	10[f]	See b	–	X	–
Thermal conditioning	10[f]	See b	–	X	–
Abrasion resistance[c]	10[f]	See b	–	X	–
Flammability	20[d]	125 x 13 x 0.8 (5 x 0.5 x 0.031)	X	X	X
	20[d]	125 x 13 x 1.6 (5 x 0.5 x 0.062)	X	X	X
	20[d]	Optional reduced[e] thicknesses	X	X	X
Infrared Analysis	4 ounce liquid sample with MSDS or cured sample	–	–	–	–

[a] If only one sample from a set of five samples does not comply with the requirements, another set of five samples is to be tested. All samples from this second set shall comply with the appropriate requirements.

[b] Samples are to be constructed at either 1.6 mm (0.062 in) or 0.8 mm (0.031 in) in accordance with 22.2.1 and shall be provided with the minimum electrical spacings, and minimum coating thickness using the test pattern shown in Figure 22.1. The test pattern shall be single-sided and etched using copper weight between 17 mic (0.5 oz/ft^2) and 33 mic (1 oz/ft^2) sufficient to accommodate the testing voltage. The samples are to be prepared by applying the coating on the side of the sample with the test pattern by normal production means using an intended primer or cleaner. High-temperature lead wires shall be attached that are considered acceptable for the voltage stress and temperatures anticipated. The high-temperature lead wires shall be at least 200 mm long and be attached as shown in Figure 22.1.

[c] The Abrasion Resistance test is optional.

[d] Sixty flammability samples are required for each laminate thickness as follows: 20 uncoated, 20 with the minimum coating thickness, and 20 with the maximum coating thickness. The conformal coating shall be coated on both sides of the core laminate. This results in an overall total of 120 samples for a routine investigation of the required two thicknesses and 180 samples if an optional (thinner) laminate thickness is submitted.

[e] If the optional investigation of a laminate at a thickness of less than 0.8 mm (0.031 inch) is requested, an additional set of uncoated, minimum-thickness-coating, and maximum-thickness-coating flammability samples are required.

[f] An additional set of five samples may be submitted in case of retest as indicated in Note a.

22.3 Sample conditioning

22.3.1 Environmental conditioning: Samples are to be subjected to three complete cycles of indoor and/or outdoor environmental conditioning as described in Table 22.2 and then subjected to the voltage transient test and the dielectric voltage withstand and breakdown-voltage test.

Table 22.2
Indoor and outdoor cycling conditions

For indoor end-use applications	For outdoor end-use applications
24 hours at T[a]; followed immediately by a minimum 96 hours exposure at 35.0±2.0°C (95.0 ±3.6°F), 90 percent relative humidity; followed by 8 hours at 0.0 ±2.0°C (32.0 ±3.6°F).	A minimum of 24 hours immersed in 25.0 ±2.0°C (77.0 ±3.6°F) water; followed immediately by 24 hours at T[a]; followed immediately by at least 96 hours exposure at 35.0 ±2.0°C (95.0 ±3.6°F), 90 percent relative humidity; followed by 8 hours at −35 ±2.0°C (−31.0±3.6°F).
[a] T is the normal operating temperature, but not less than 60°C (140°F).	

22.3.2 Humidity conditioning: Samples are to be humidity conditioned for 168 hours at 90 – 95 percent relative humidity at 35.0 ±2.0°C (95.0 ±3.6°F). Within two minutes of removal from the test chamber or sealed transporting container, the samples are to be subjected to the voltage transient test and dielectric voltage-withstand and breakdown-voltage test described in 22.4.1 and 22.5.1.

22.3.3 Thermal conditioning: Samples 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 22.2. See Table 22.3 for common maximum operating temperatures and their corresponding oven aging temperatures. The thermal endurance profile lines for UL/ANSI grades FR-2, FR-3, FR-4.0, XXXPC, and GPO-2 industrial laminates may be representative of other laminates. The FR4 thermal endurance profile lines represent FR-4.0 and FR-4.1 laminates. After conditioning, the samples 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 22.4.1 and 22.5.1.

Exception: On the same thermal endurance profile line in Figure 22.2, 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.

Table 22.3
Oven conditioning temperatures

Conformal coating operating temperature	Thermal oven aging temperature									
	1000 Hours					300 Hours				
	FR-4.0	XXXPC	FR-3	FR-2	GPO-2	FR-4.0	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

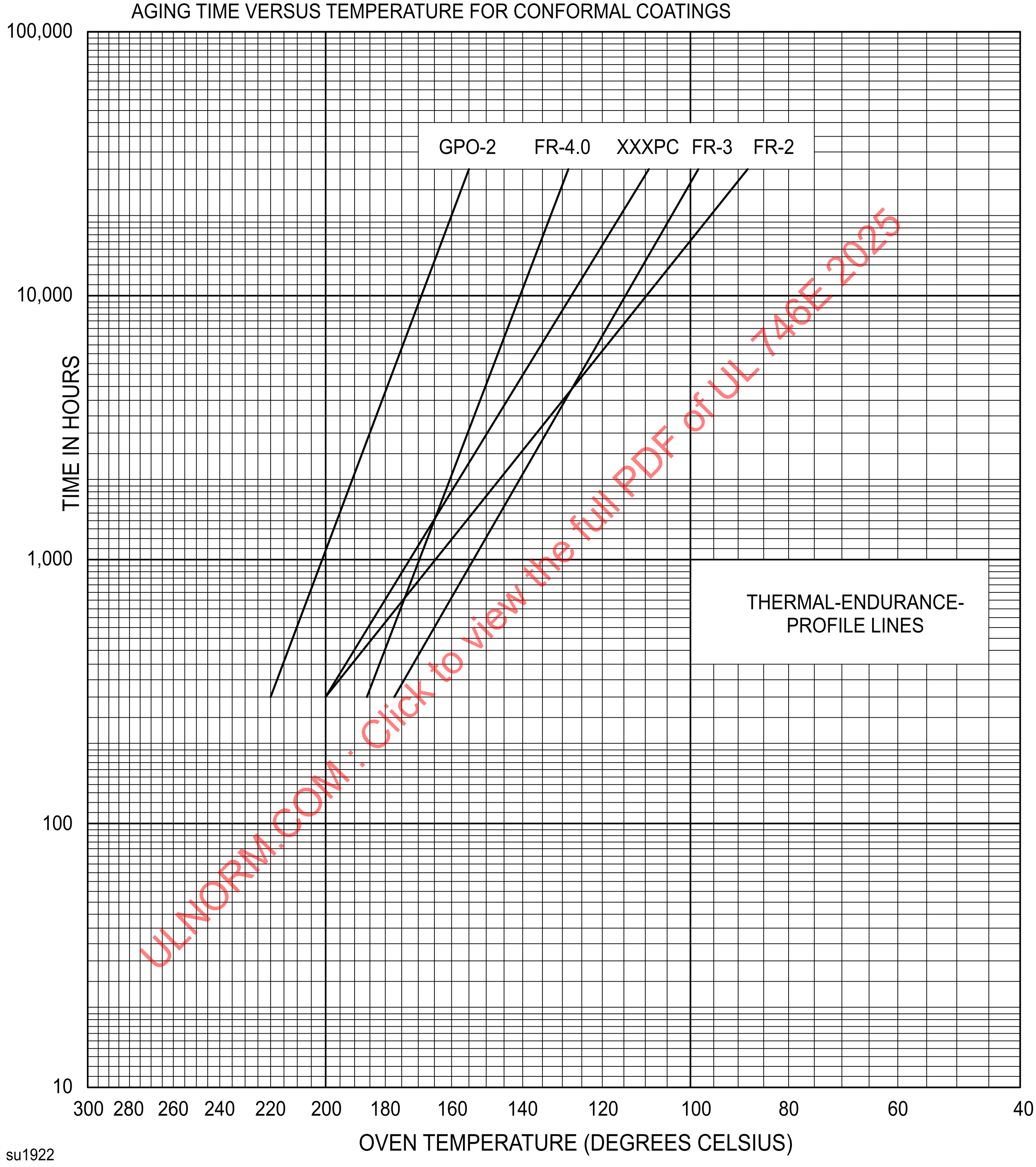
Table 22.3 Continued on Next Page

Table 22.3 Continued

Conformal coating operating temperature	Thermal oven aging temperature									
	1000 Hours					300 Hours				
	FR-4.0	XXXPC	FR-3	FR-2	GPO-2	FR-4.0	XXXPC	FR-3	FR-2	GPO-2
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	–	–	–	–

Figure 22.2

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



22.4 Voltage transient test

22.4.1 After conditioning and immediately prior to voltage transient testing, the samples 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. A 50 – 60 Hz and 120 V voltage source is to be applied on the samples between opposite legs of the test pattern, namely lead A and lead B in Figure 22.1. 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.

22.4.2 All samples, unconditioned and conditioned, are to be subjected to the voltage transient test.

22.4.3 There shall be no ignition, dielectric breakdown through the coating, or evidence of a carbon path being created on the surface of the coating material.

22.5 Dielectric withstand voltage and breakdown voltage test

22.5.1 The samples subjected to the voltage transient test described in 22.4.1 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.

22.5.2 The conditioned samples (see 22.3.1 – 22.3.3) are to withstand the dielectric stress for one minute without breakdown.

22.5.3 The conditioned samples shall have an average dielectric breakdown value at least fifty percent of the unconditioned samples average dielectric breakdown.

22.6 Abrasion resistance test

22.6.1 General

22.6.1.1 Five samples of Figure 22.1 are to be subjected to the following test. The Abrasion resistance test is optional and shall be performed based on the end product requirements.

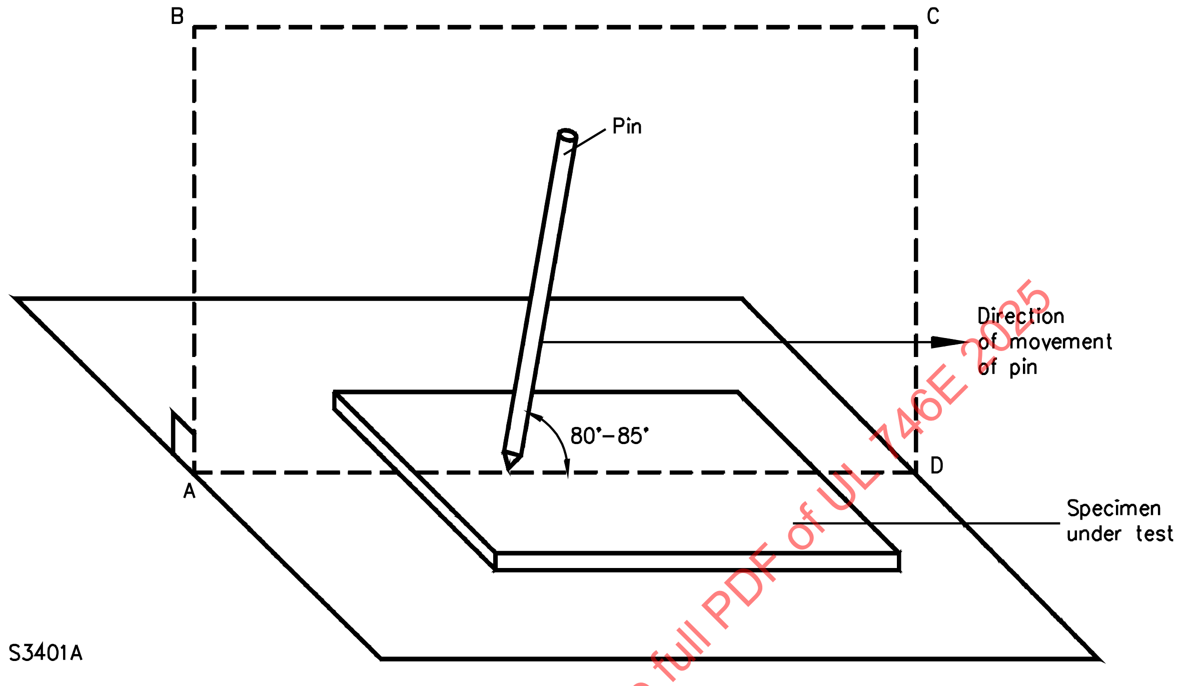
22.6.1.2 Scratches are made across five pairs of conducting parts and the intervening separations at points where the separations will be subject to the maximum potential gradient during the tests.

22.6.1.3 The scratches are made by means of a hardened steel pin, the end of which has the form of a cone having a tip angle of 40 degrees, its tip being rounded and polished, with a radius of 0.25 mm ± 0.02 mm.

22.6.1.4 Scratches are made by drawing the pin along the surface in a plane perpendicular to the conductor edges at a speed of 20 mm/s ± 5 mm/s as shown in Figure 22.3. The pin is so loaded that the force exerted along its axis is 10 N ± 0.5 N.

Figure 22.3

Abrasion resistance test for coating layers



NOTE – The pin is in the place ABCD which is perpendicular to the sample under test.

22.6.1.5 The five scratches shall be at least 5 mm apart and at least 5 mm from the edge of the sample.

22.6.1.6 After this test, the coating layer shall neither have loosened nor have been pierced and it shall withstand an electric strength test as specified in 22.6.2 between conductors.

22.6.2 Electric strength

22.6.2.1 The dielectric material is subjected to a voltage substantially sine-wave form having a frequency of 50 Hz or 60 Hz. The test voltage is based on the assumption that the working voltage across the dielectric material will be less than 184 V or less than 1.41 kV between primary and secondary (SELV – safety extra low voltage) circuitry. Working voltages above these levels shall be evaluated based on the end product performance requirements. See Table 22.4 for the test voltage.

Table 22.4
Abrasion resistance electric strength test voltage

Working voltage (peak or d.c.)	Test voltage, volts r.m.s.
Less than 184 V	2000
Less than 1.41 kV	3000

22.6.2.2 The voltage applied to the dielectric material under test is gradually raised from zero to the prescribed voltage and held at that value for 60 seconds.

22.6.2.3 There shall be no dielectric material breakdown during the test. Dielectric material breakdown is considered to have occurred when the current which flows as a result of the application of the test voltage rapidly increases in an uncontrolled manner, i.e. the dielectric material does not restrict the flow of the current. Corona discharge or a single momentary flashover is not regarded as dielectric material breakdown.

MARKING

23 Details

23.1 An industrial laminate, vulcanized fibre, filament wound tubing or other material that complies with the requirements in this Standard shall include the following markings on the smallest unit shipping containers for the material:

a) The manufacturer's name, trademark, or symbols by which the organization responsible for the product may be identified;

b) The distinctive material designation; and

c) An identification code to indicate the factory at which the material is produced, when manufactured at more than one location.

23.2 A prefabricated multilayered laminate (Mass Laminate) shall be limited to a unique grade designation for each ultrathin laminate and prepreg combination.

23.3 A metal base laminate shall be limited to a unique grade designation for each dielectric insulation material. Multiple types of metal materials may be used with one dielectric insulation material under the same grade designation.

23.4 Material formulation changes or polymer variations shall require a new unique product designation. The extent of the name change shall be obvious to the user.

Exception: In cases where testing of a polymer variation shows the same or better results, the material may retain the same designation if the compliance criteria are met as defined in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, Section 9.9, Polymer Variations.

23.5 When a separate adhesive is used to bond the cladding material to a dielectric material, each combination shall be identified using a unique grade designation.

SUPPLEMENT SA – FOLLOW-UP INSPECTION

The information contained in this supplement is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. As such, this supplement may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary to fulfill the objectives of the standard.

SA1 Scope

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

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

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

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

SA2 Glossary

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

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

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

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

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

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

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

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

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

SA3 Responsibility of the Manufacturer

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

SA3.2 The manufacturer shall confine all Recognition 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.

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 samples 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 the Standard for Polymeric Materials – Short Term Property Evaluation, UL 746A. 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 the Standard for Polymeric Materials– Short Term Property Evaluations, UL 746A. 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 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 the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. The results obtained in the Follow-Up Tests are to satisfy the requirements specified in the Procedure.

SA6.6 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.

SA6.7 ZINC CHLORIDE ANALYSIS (for Vulcanized Fibre materials only) – The zinc chloride analysis values shall be obtained in accordance with the methods described in ASTM D619 for extraction and atomic absorption (AA) spectroscopy, atomic emission spectroscopy (AES) or inductively coupled plasma spectrometry (ICP) for measurement. The results obtained in the Follow-Up Tests are to satisfy the requirements specified in the Procedure.

ANNEX A
Typical IR Spectrums

A1 General

A1.1 The graphs shown in Figure A1.1 – Figure A1.34 represent typical infrared spectrums for various types of UL/ANSI industrial laminates.

Figure A1.1

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

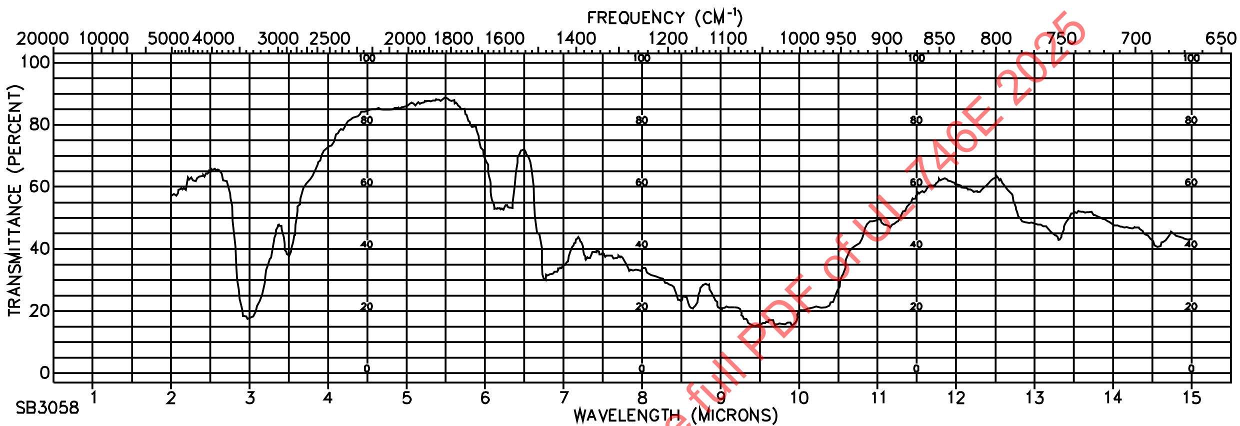


Figure A1.2

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

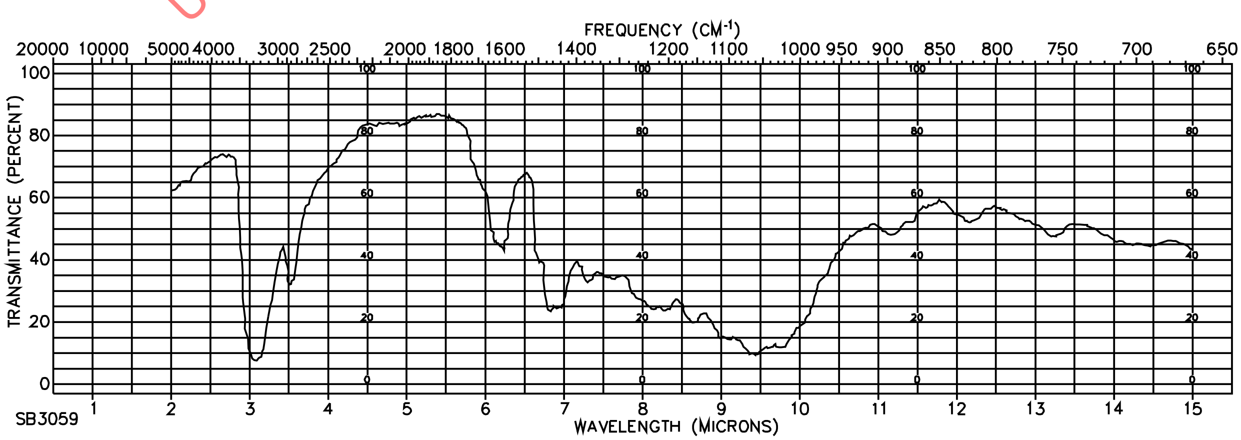


Figure A1.3

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

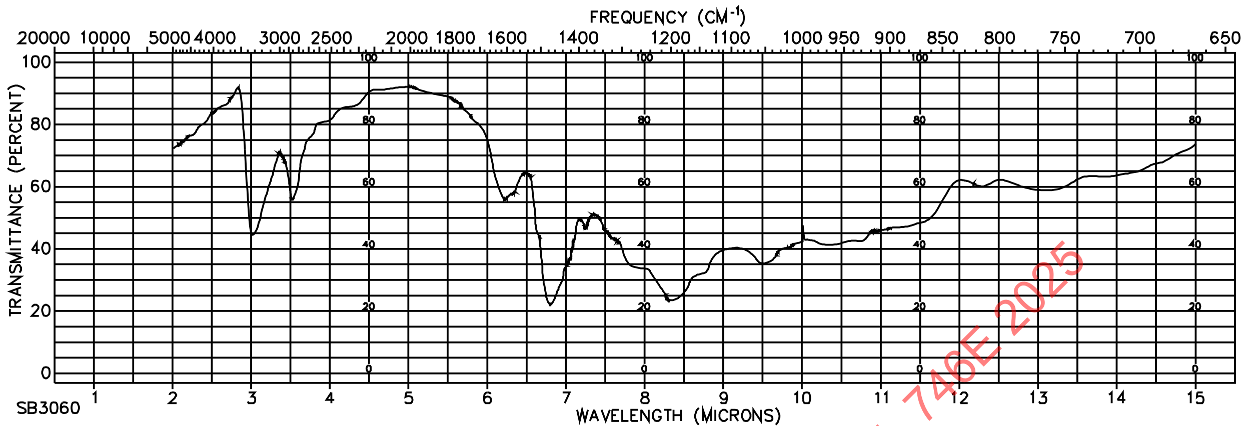


Figure A1.4

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

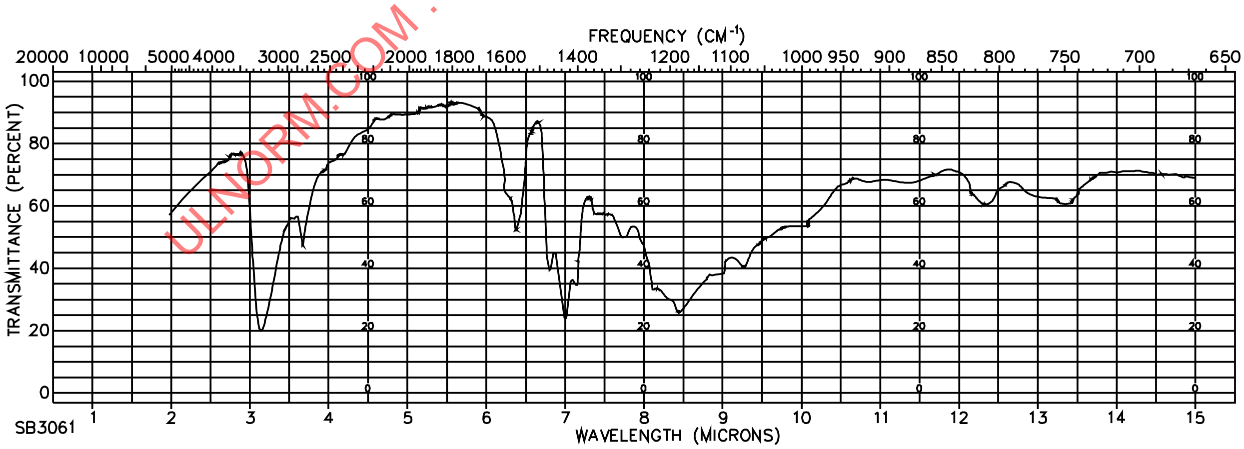


Figure A1.5

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

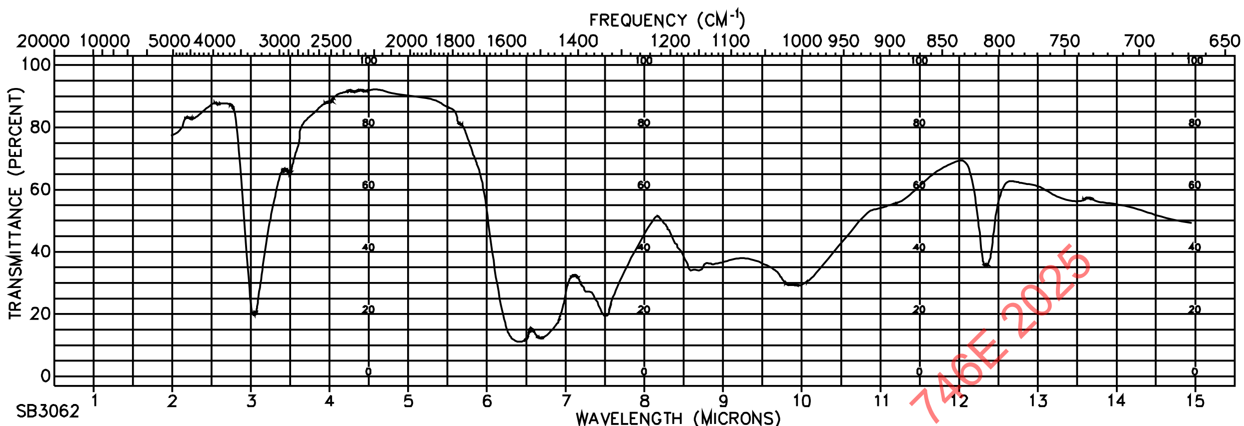


Figure A1.6

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

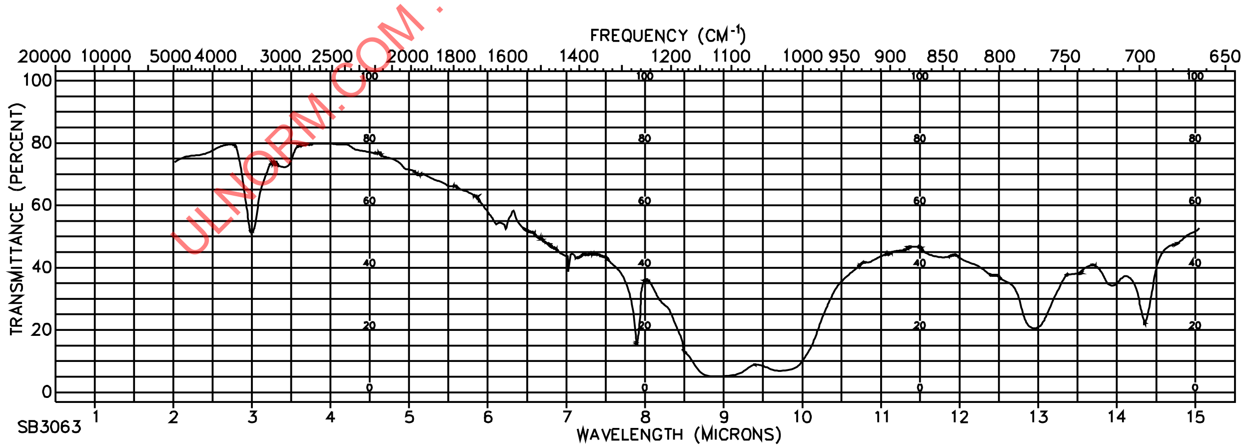


Figure A1.7

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

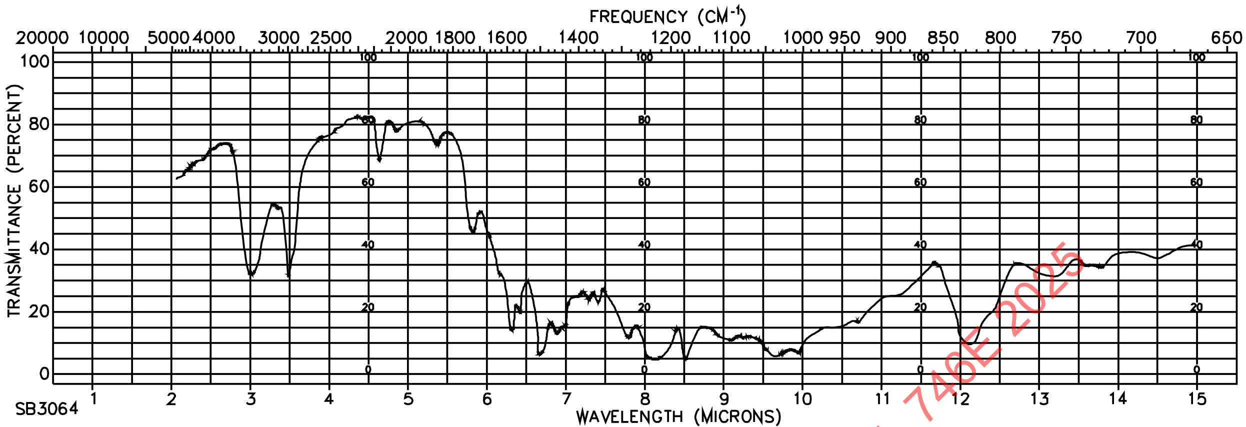


Figure A1.8

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0

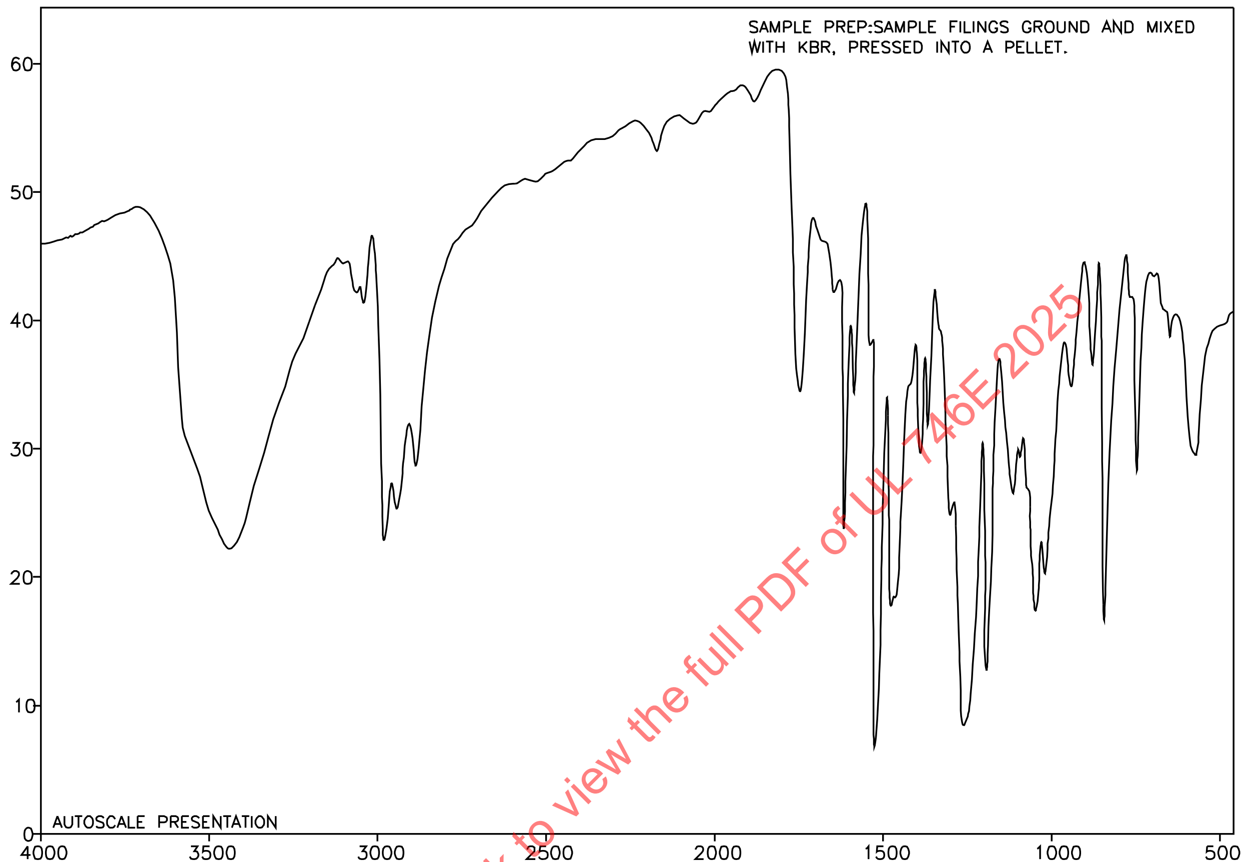
Transmittance/Wavenumber (cm−1)

File#1: NEMA0010

S5140

Figure A1.9

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



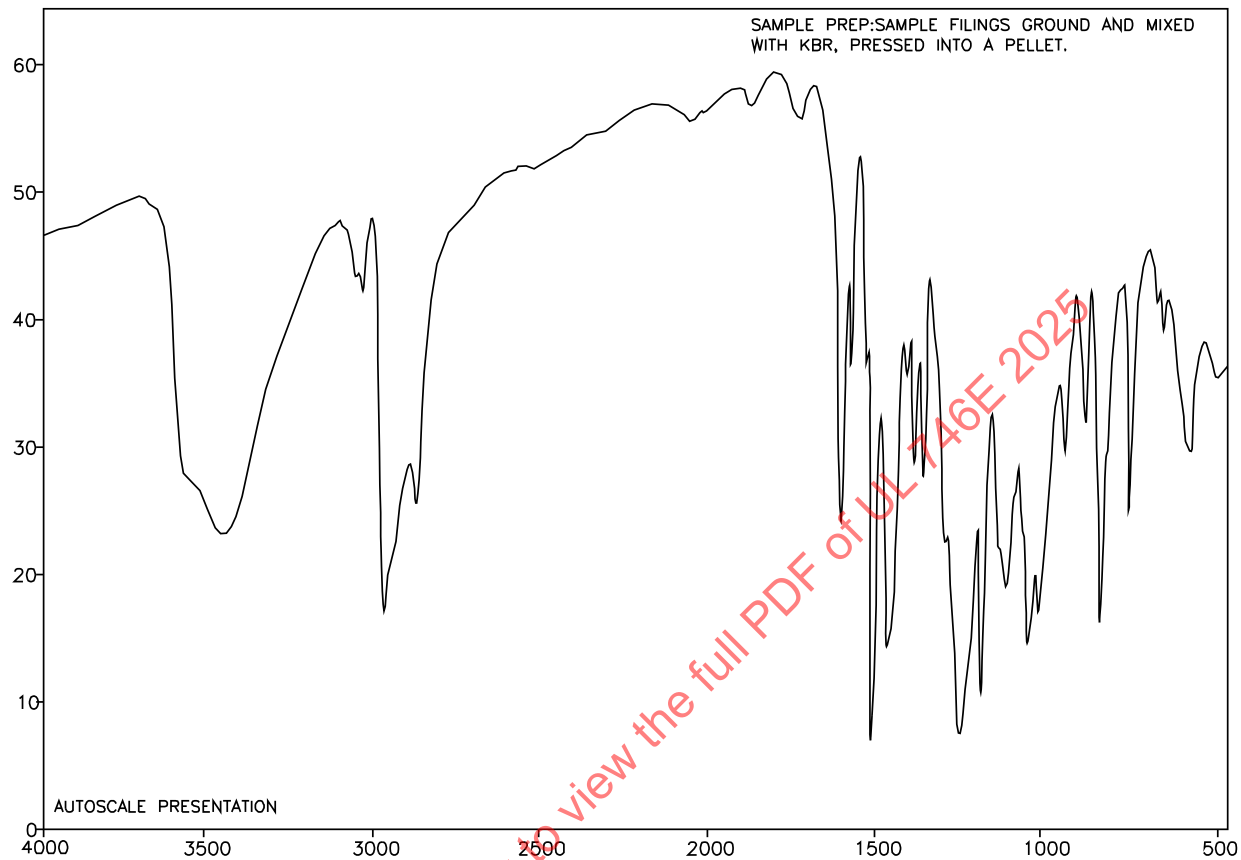
Transmittance/Wavenumber (cm−1)

File#1: NEMA0011

S5141

Figure A1.10

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



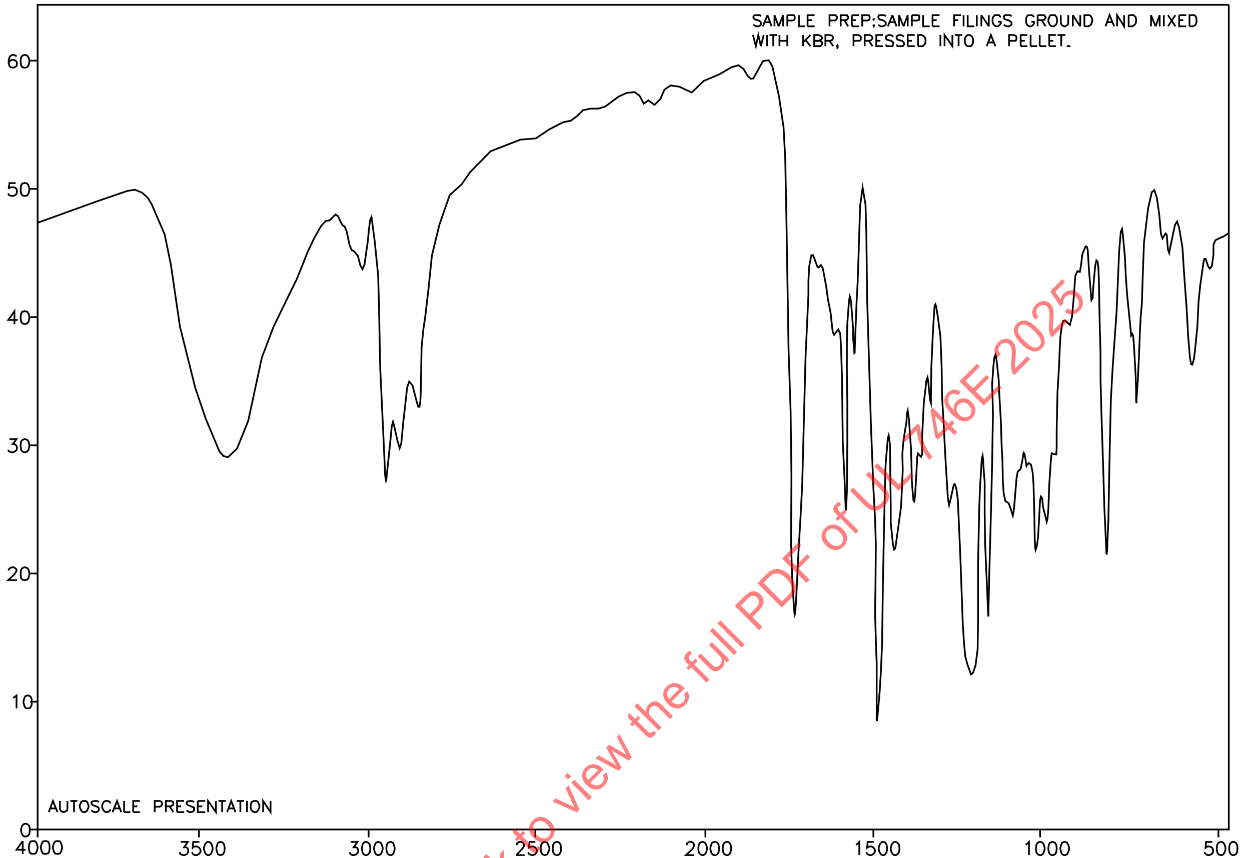
Transmittance/Wavenumber (cm−1)

File #1: NEMA0012

S5142

Figure A1.11

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



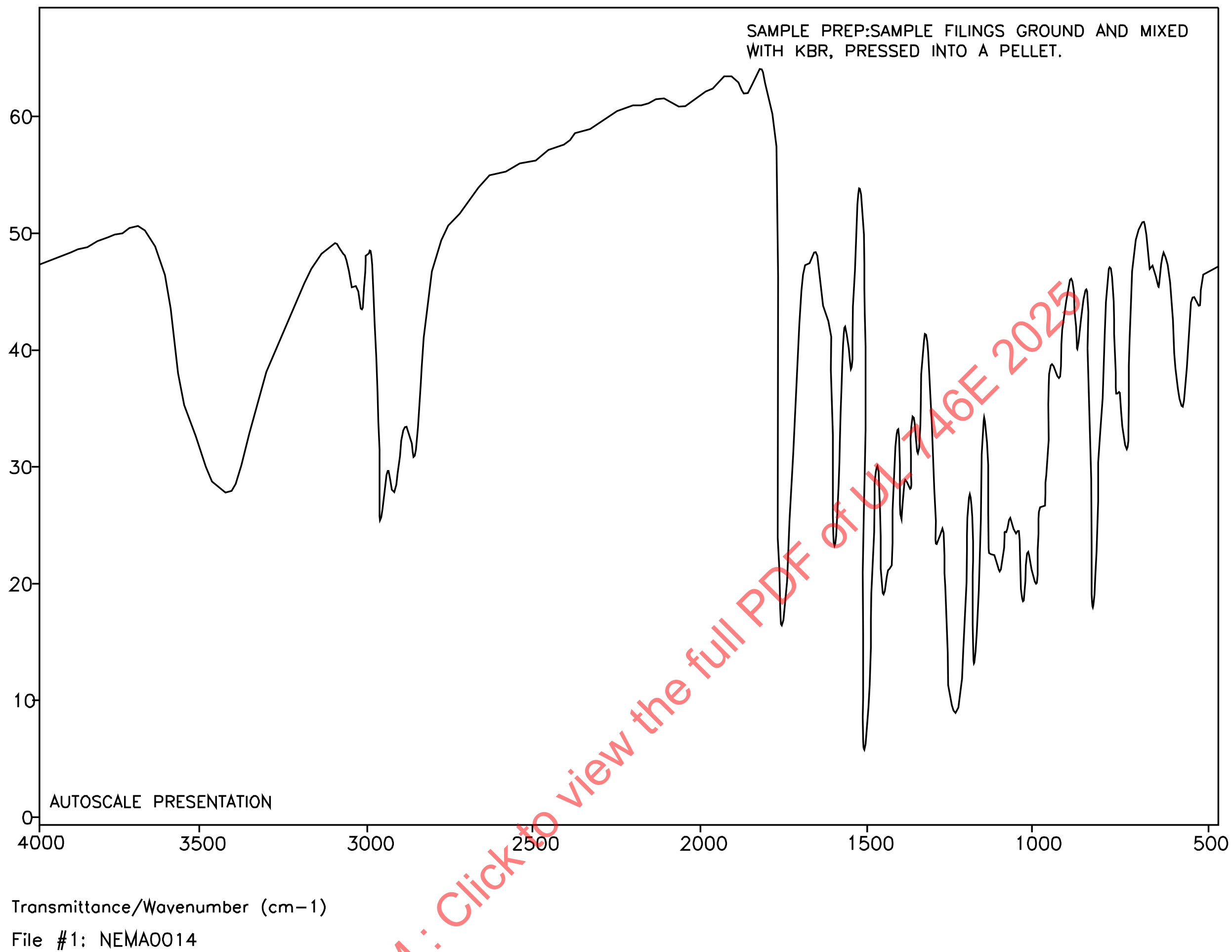
Transmittance/Wavenumber (cm−1)

File #2: NEMA0013

S5143

Figure A1.12

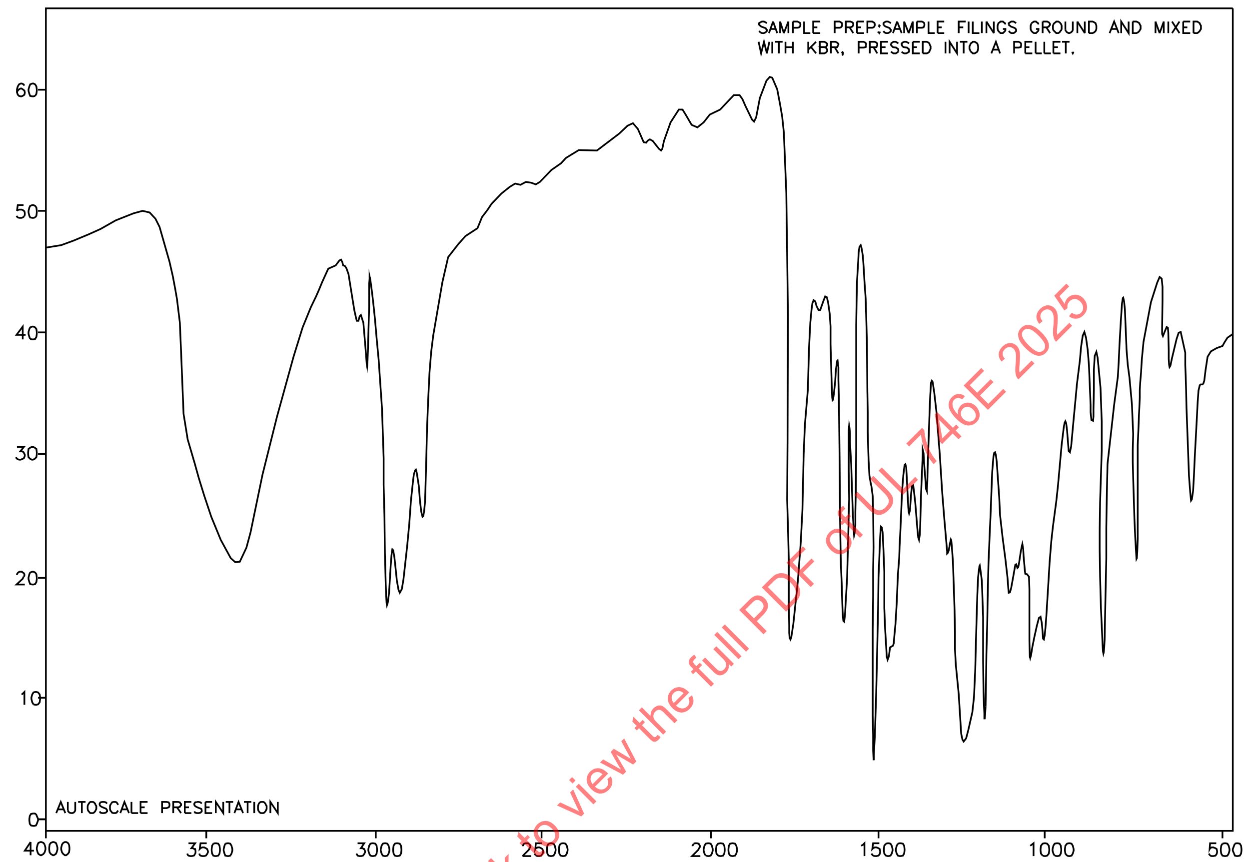
Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



S5144

Figure A1.13

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



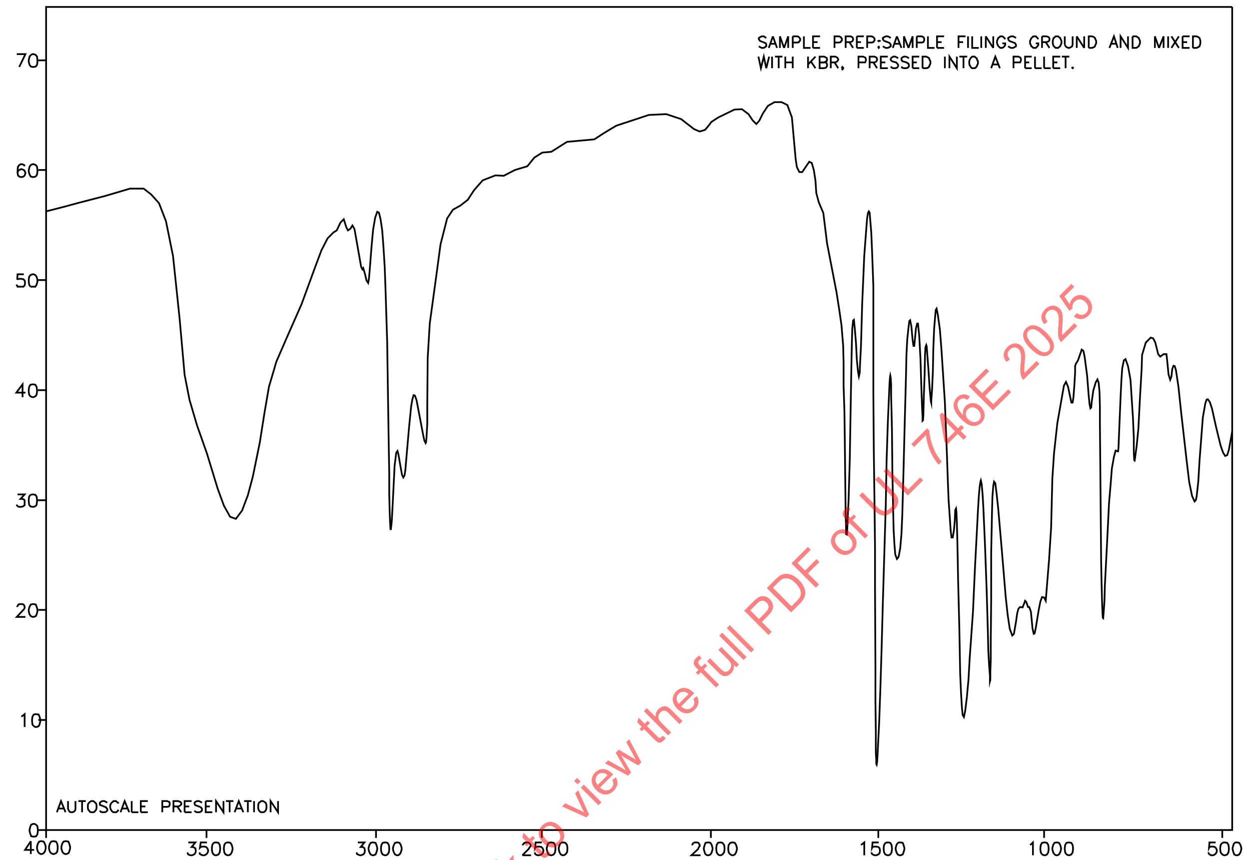
Transmittance/Wavenumber (cm−1)

File #1: NEMA0017

S5145

Figure A1.14

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



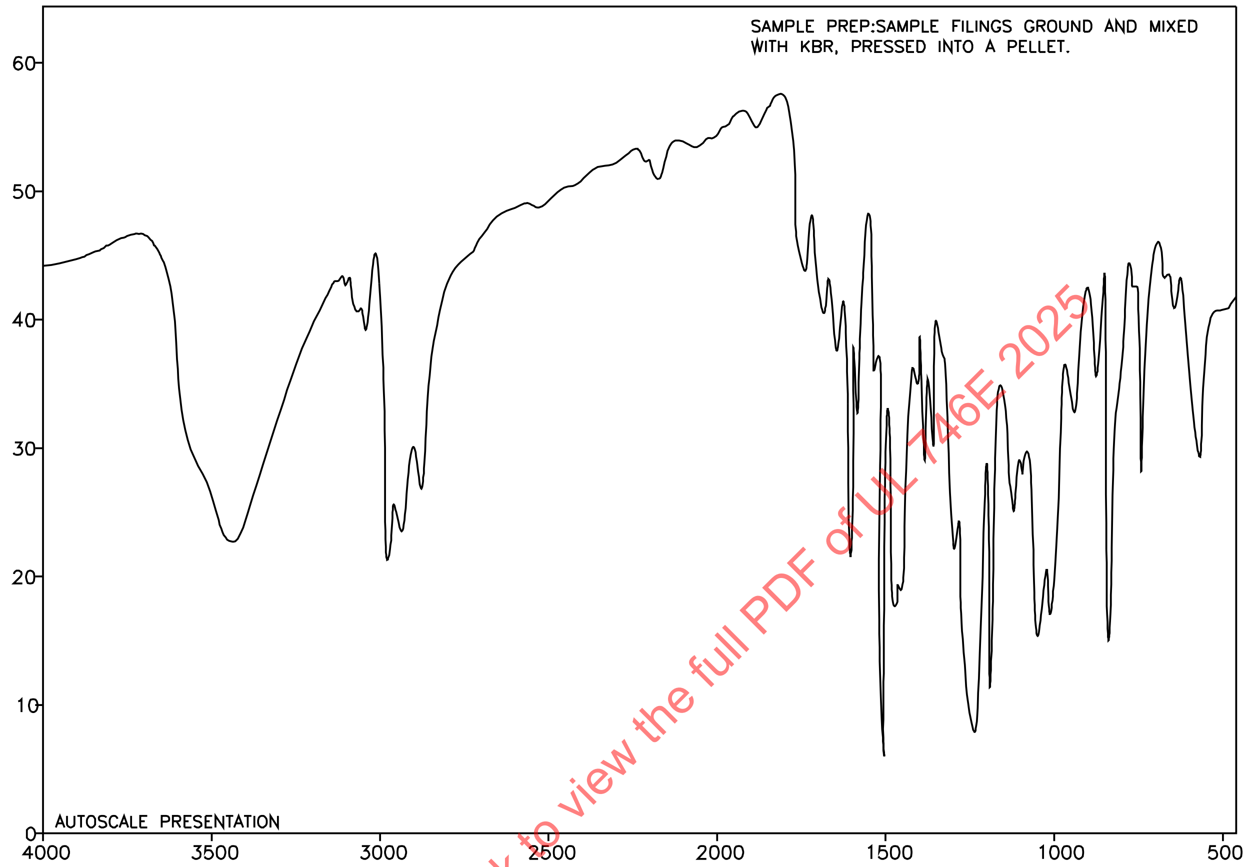
Transmittance/Wavenumber (cm−1)

File #1: NEMA0018

S5146

Figure A1.15

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



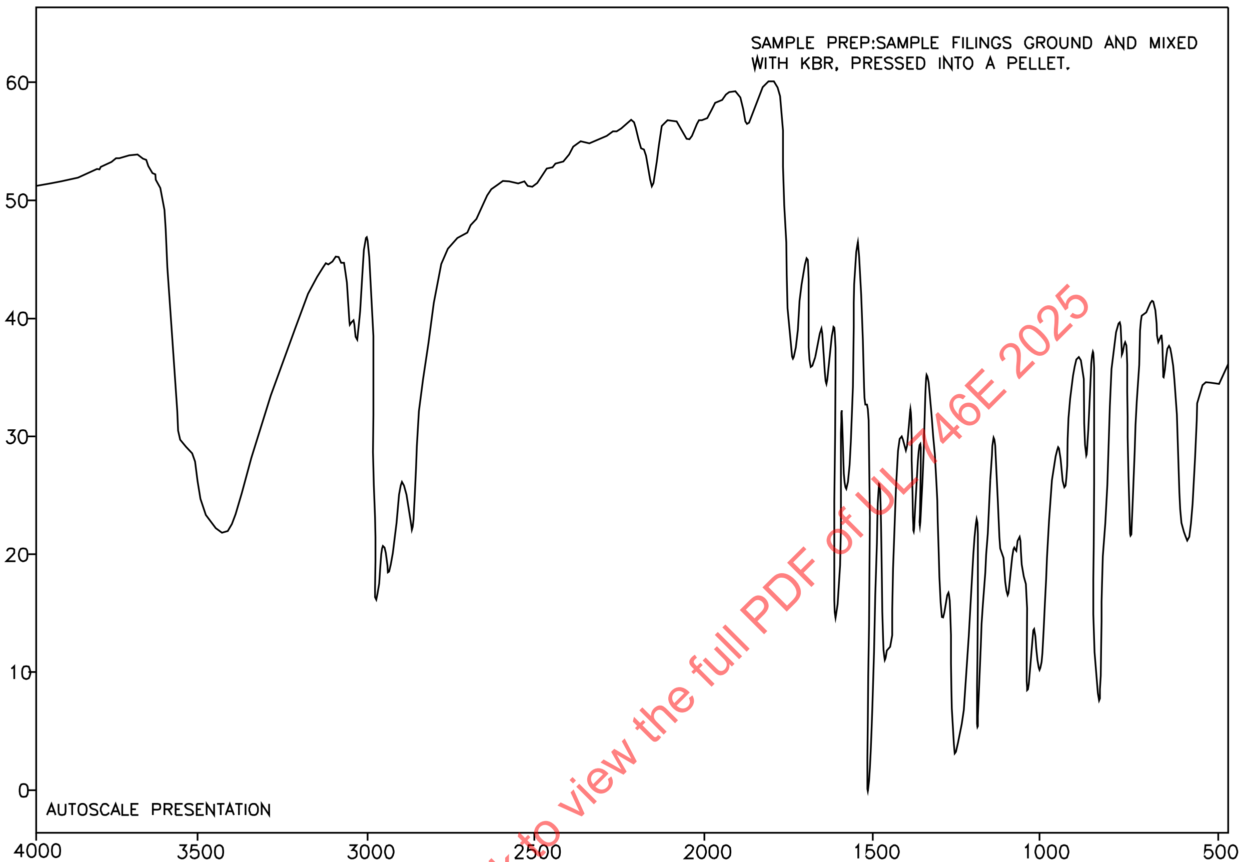
Transmittance/Wavenumber (cm−1)

File #2: NEM00021

S5147

Figure A1.16

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



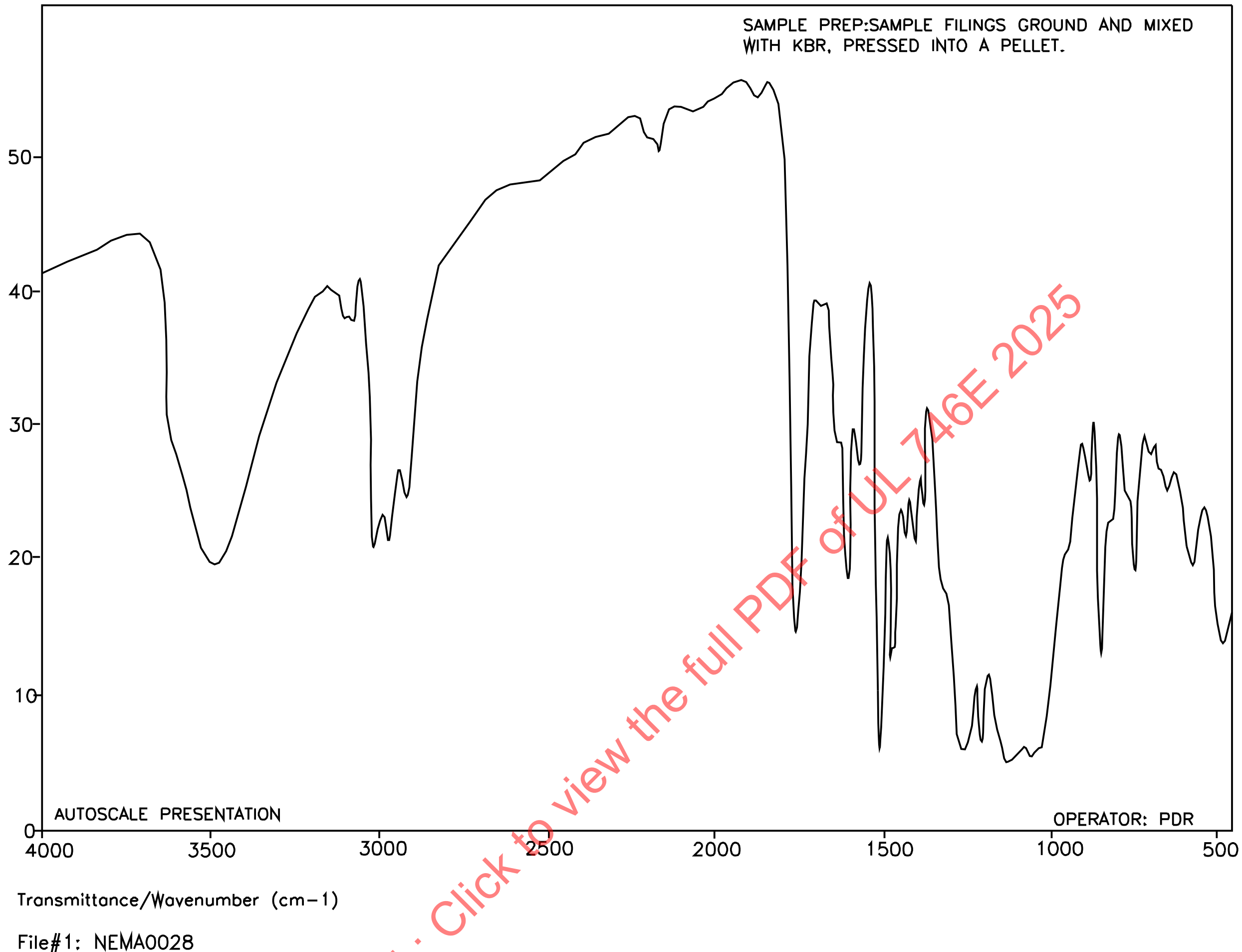
Transmittance/Wavenumber (cm−1)

File #1: NEMA0026

S5148

Figure A1.17

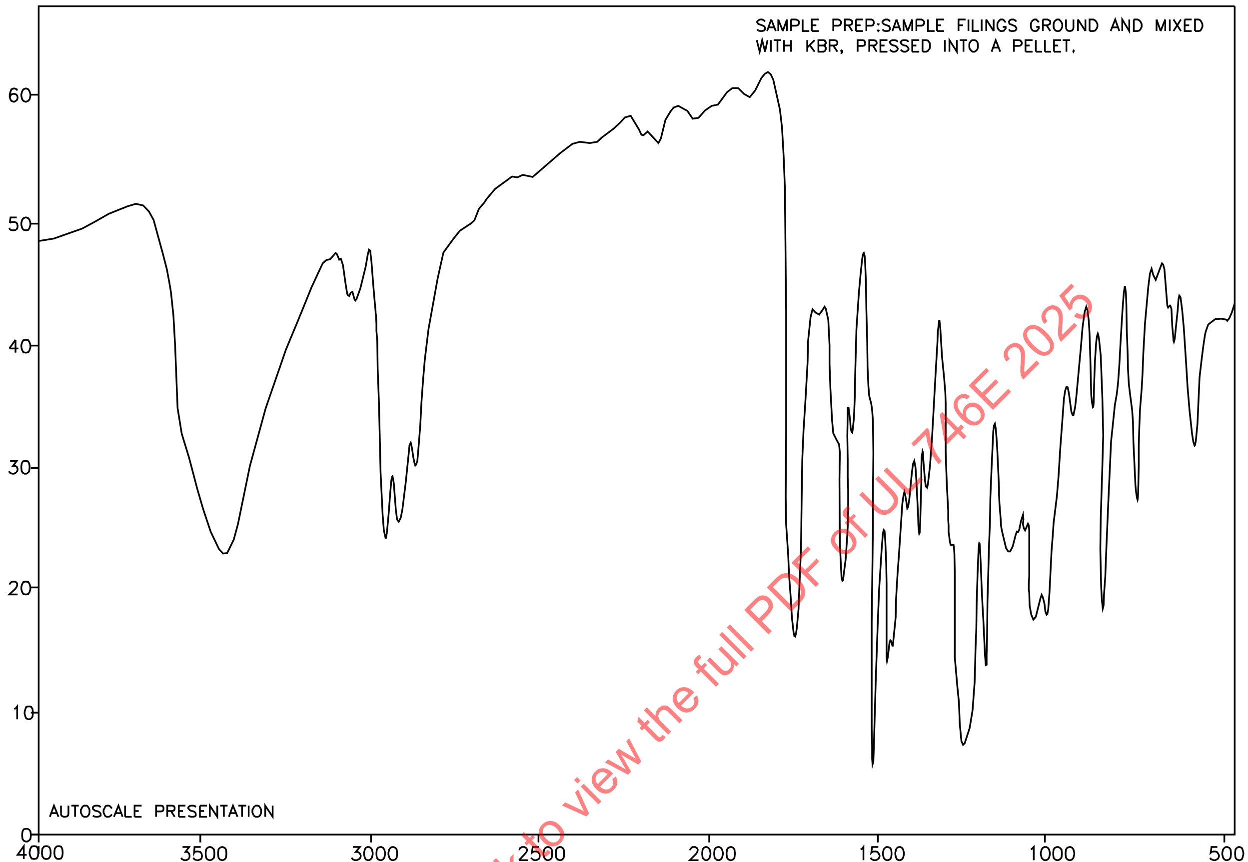
Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



S5149

Figure A1.18

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



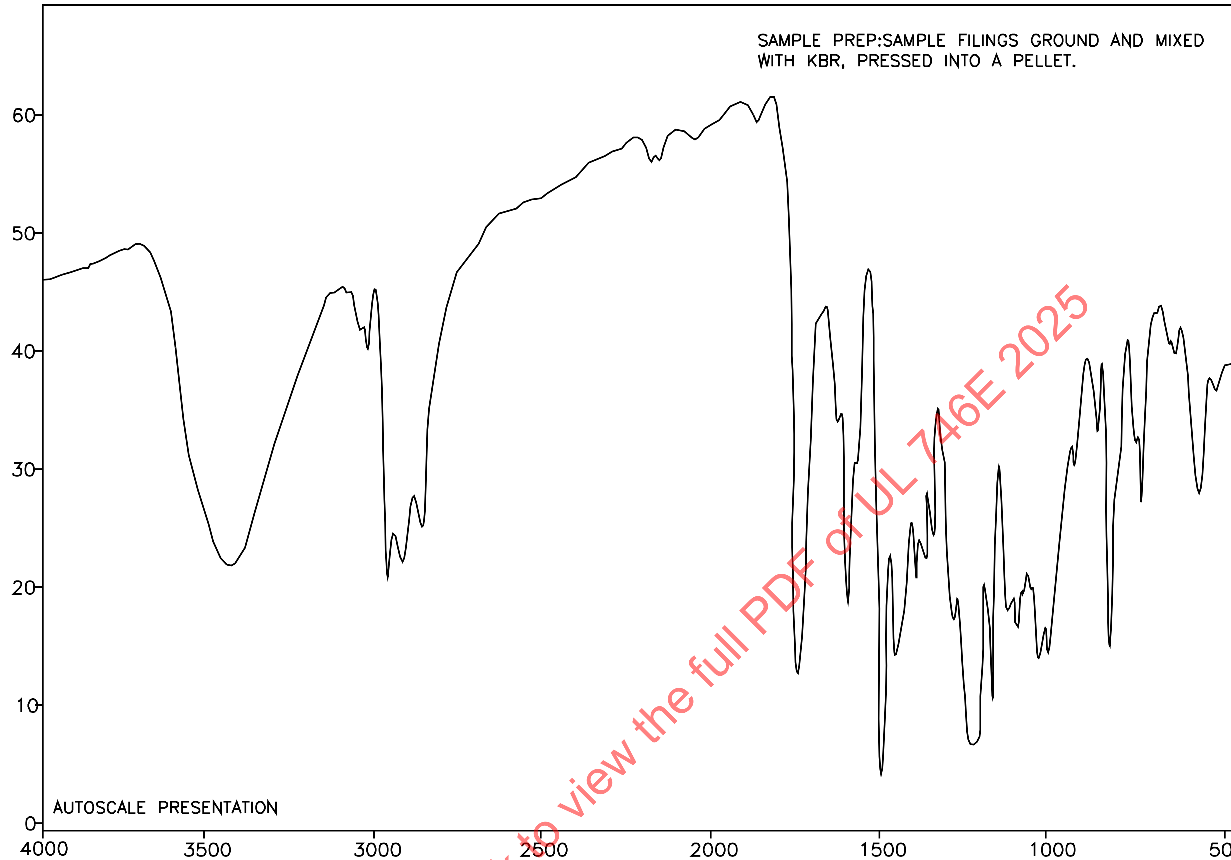
Transmittance/Wavenumber (cm−1)

File #1: NEMA0030

S5150

Figure A1.19

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



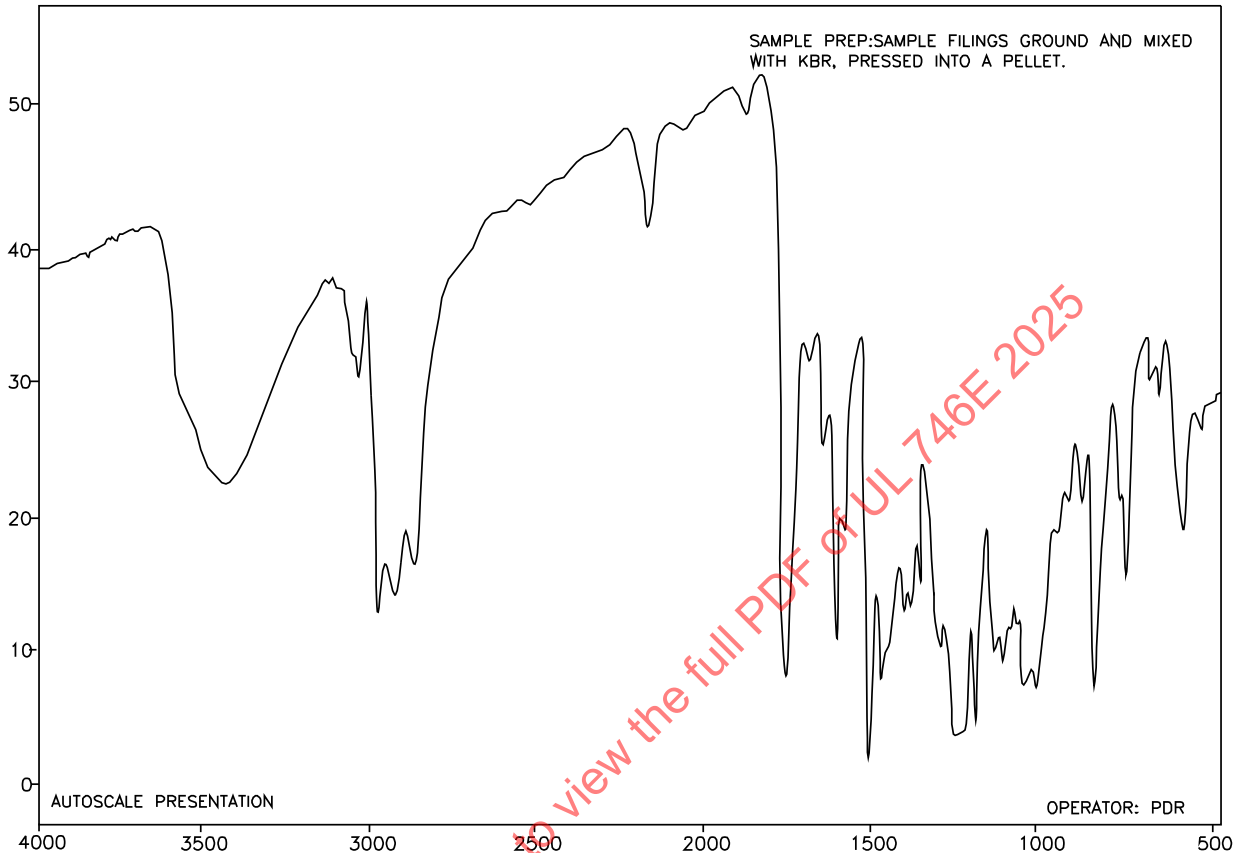
Transmittance/Wavenumber (cm−1)

File #2: NEMA0031

S5151

Figure A1.20

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



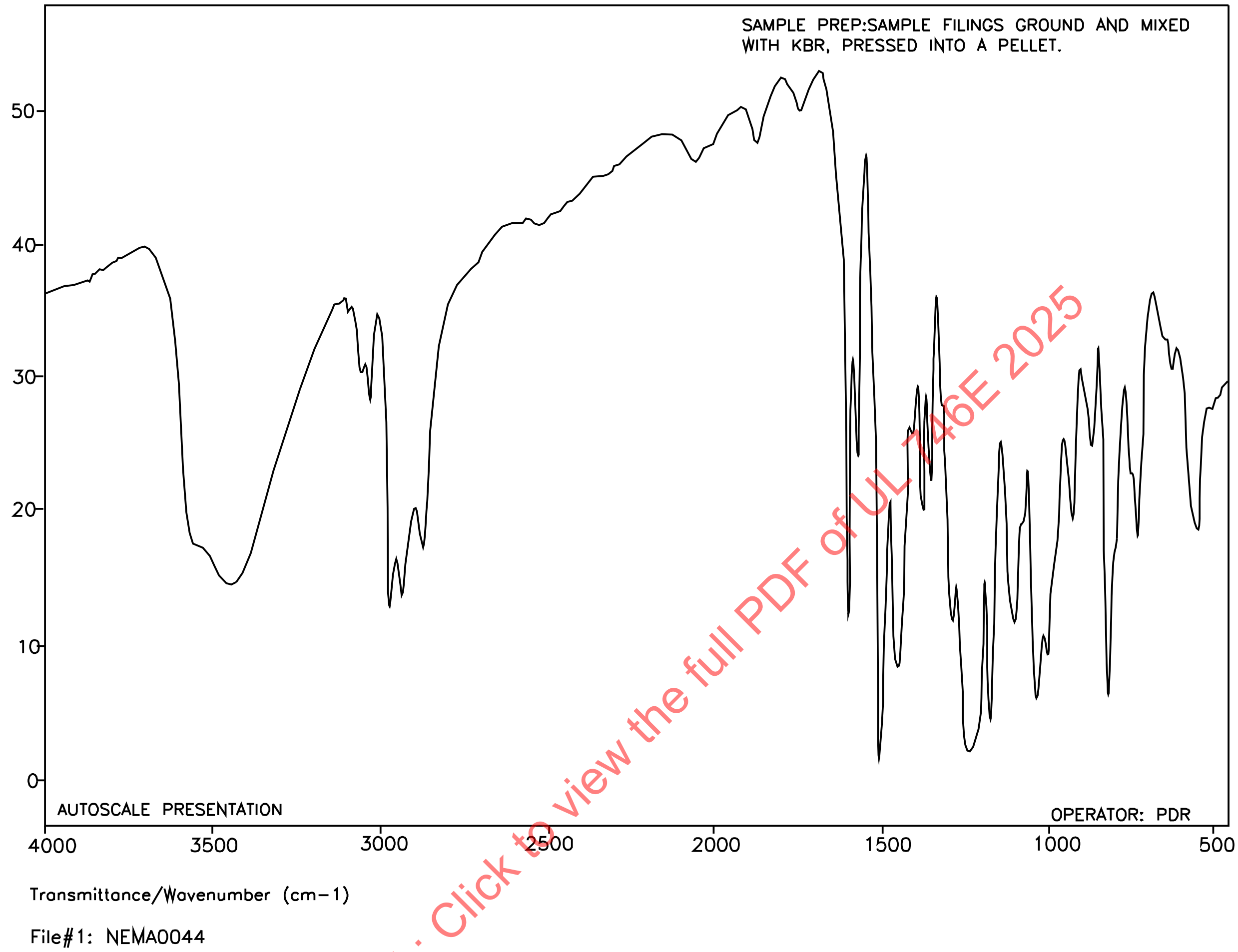
Transmittance/Wavenumber (cm−1)

File #3: NEMA0038

S5152

Figure A1.21

Typical IR Spectrum for Industrial Laminates UL/ANSI Type FR-4.0



S5153

Figure A1.22

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

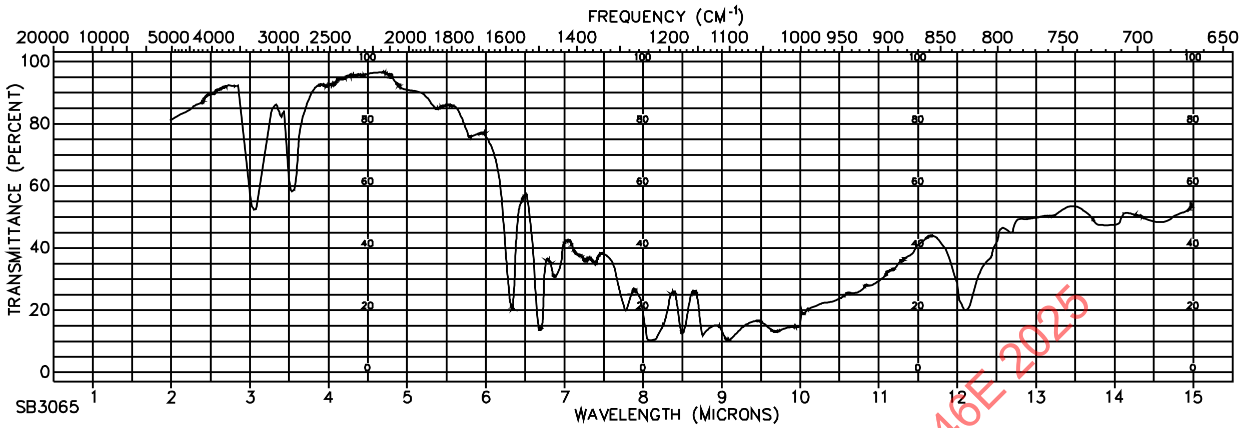


Figure A1.23

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

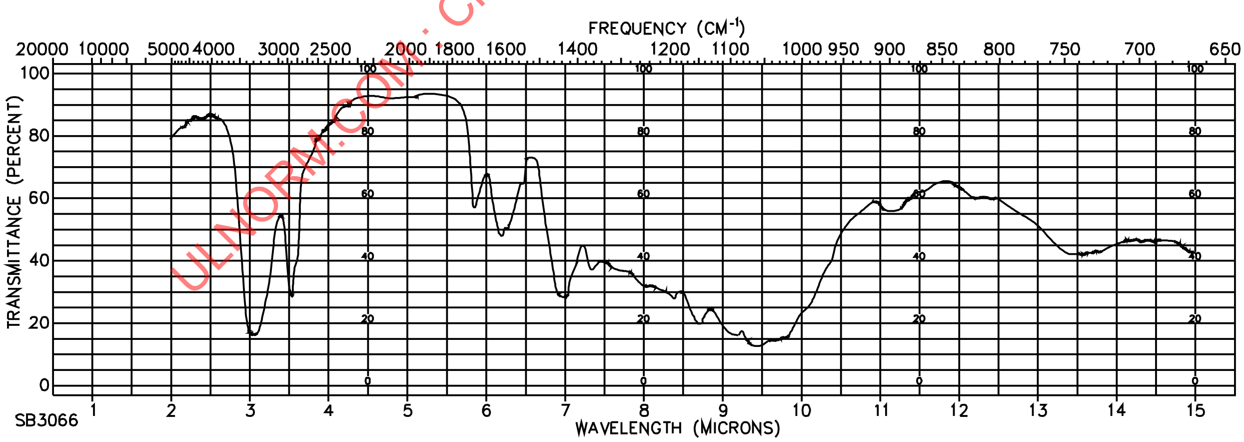


Figure A1.24

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

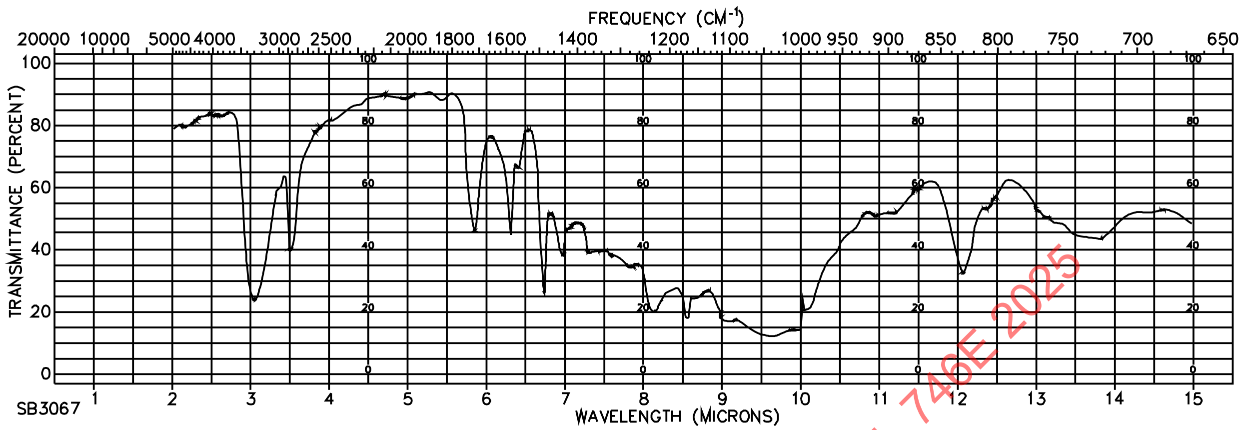


Figure A1.25

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

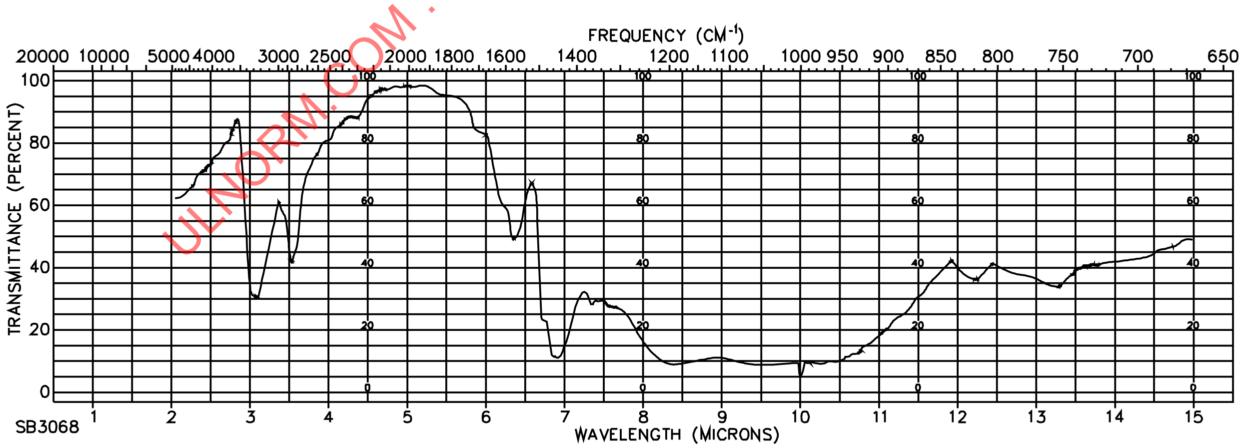


Figure A1.26

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

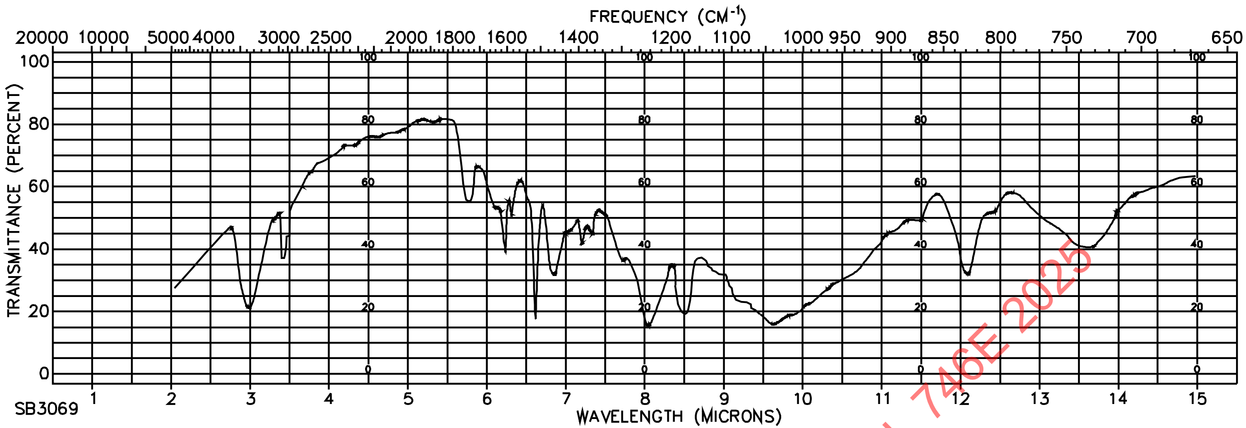


Figure A1.27

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

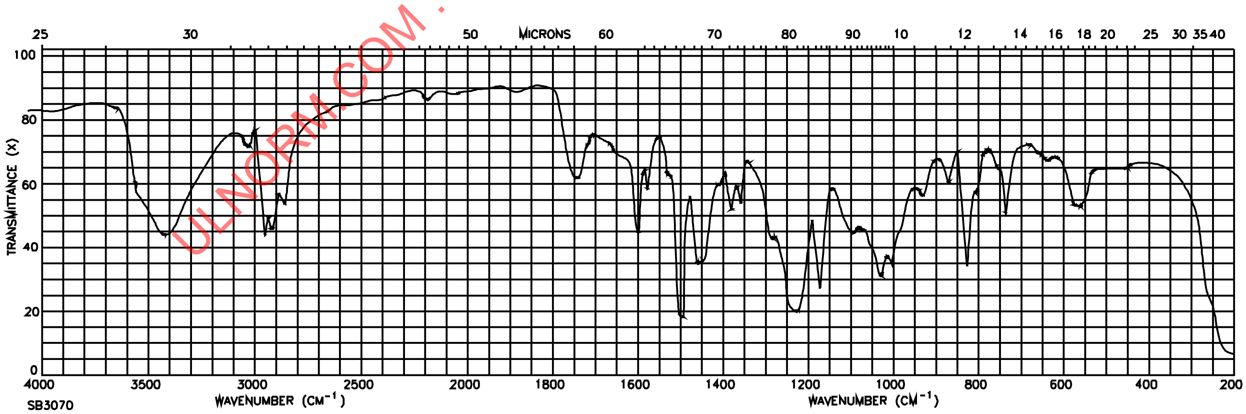


Figure A1.28

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

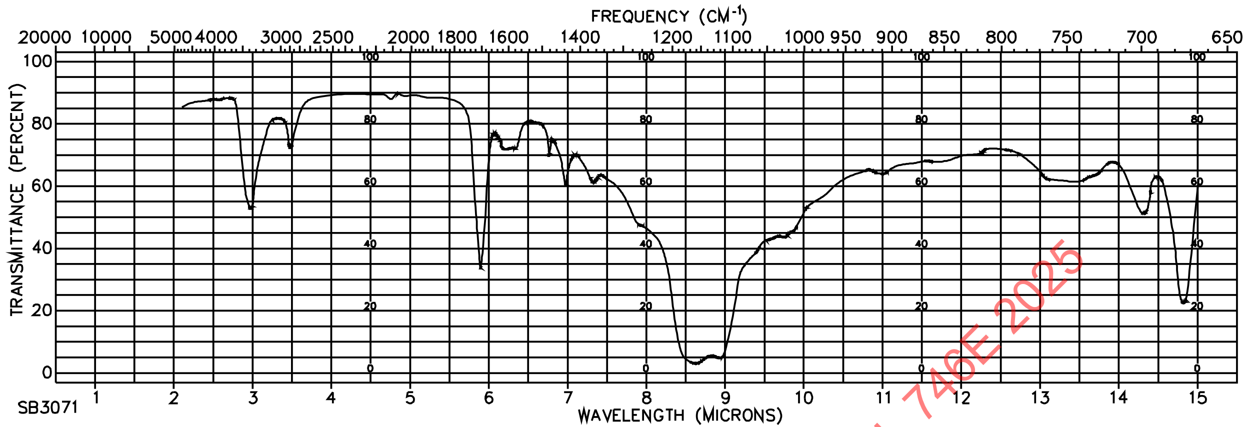


Figure A1.29

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

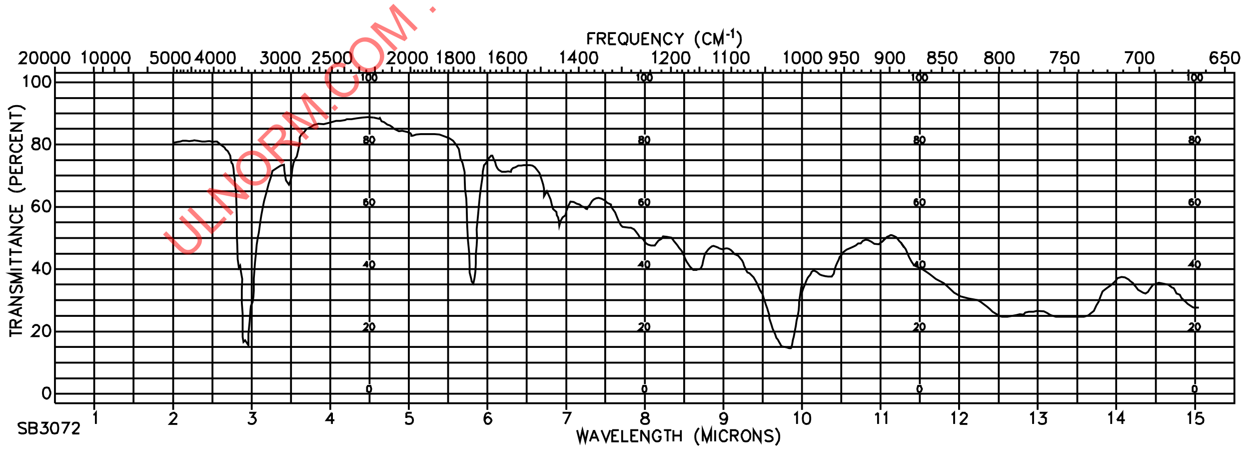


Figure A1.30

Typical IR spectrum for industrial laminates UL/ANSI Type GPY

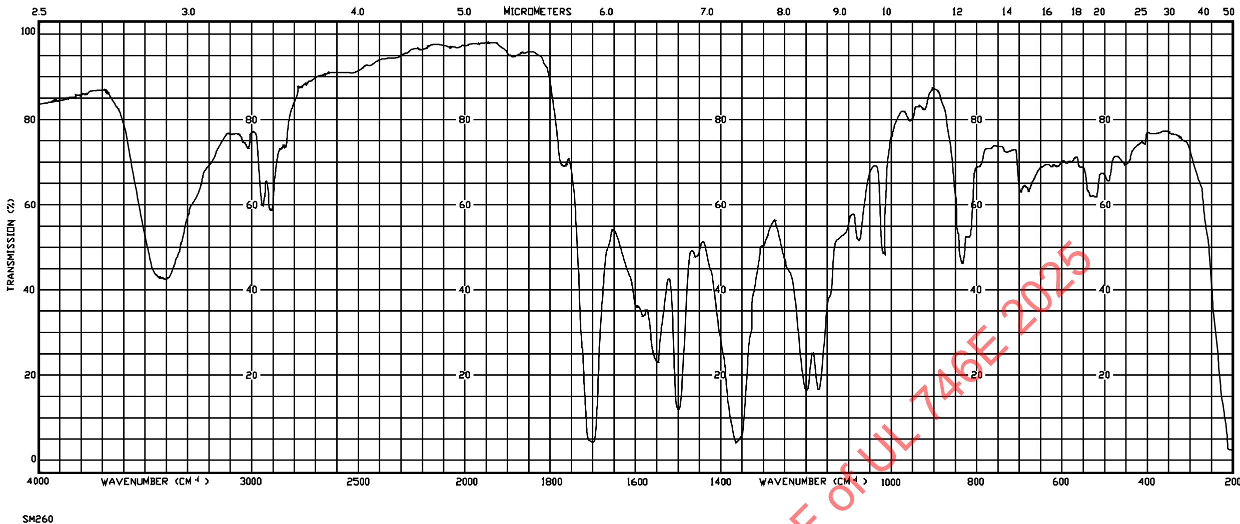


Figure A1.31

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

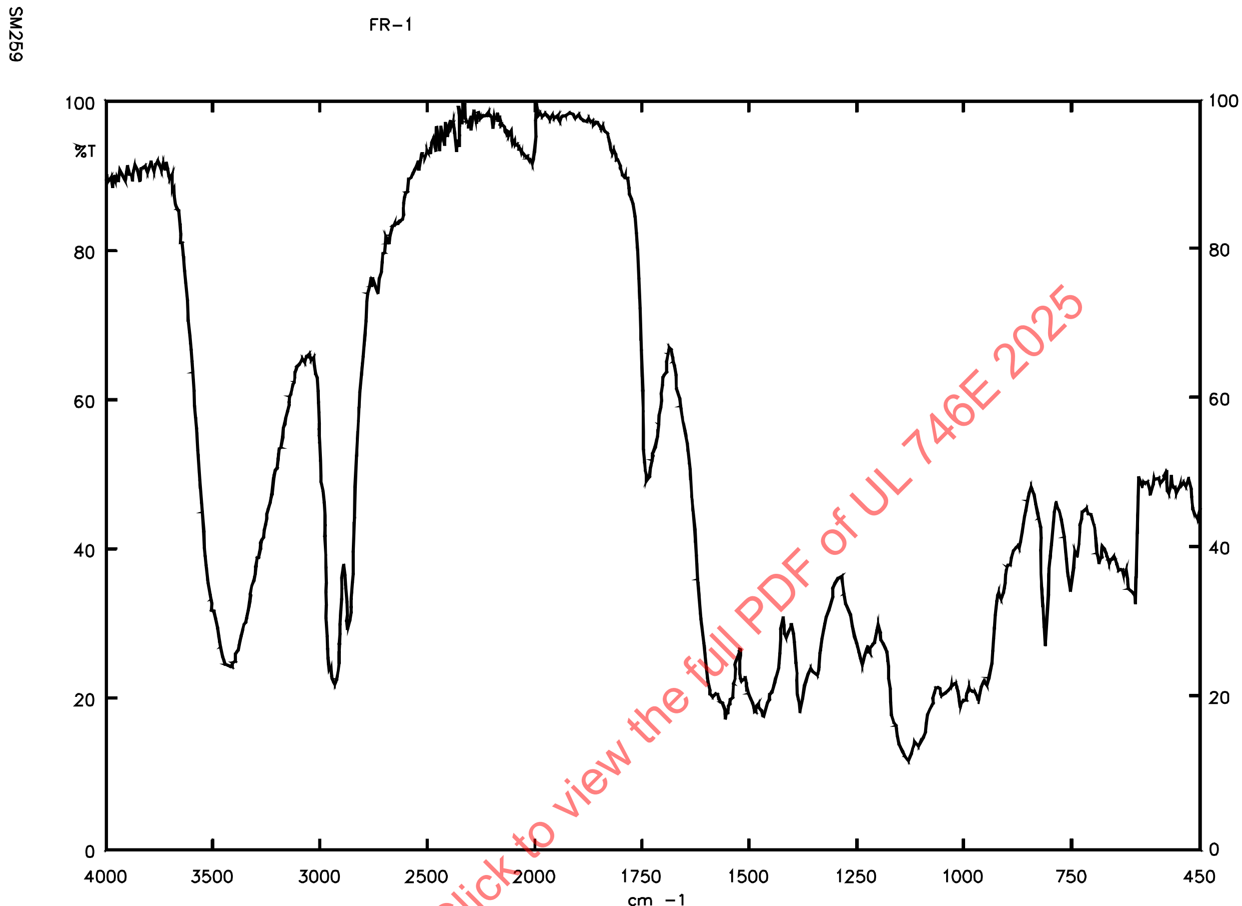


Figure A1.32

Typical infrared spectrum-vulcanized fibre

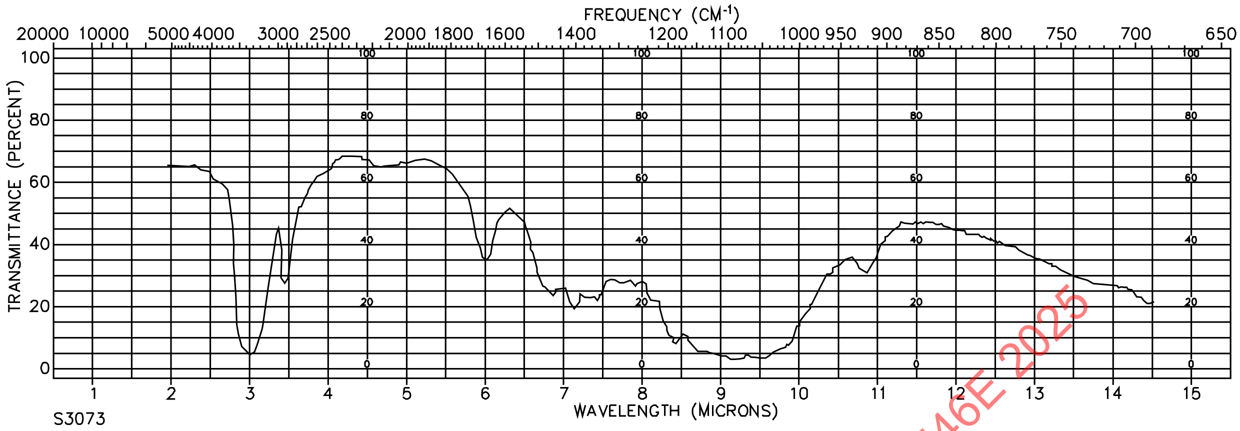


Figure A1.33

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

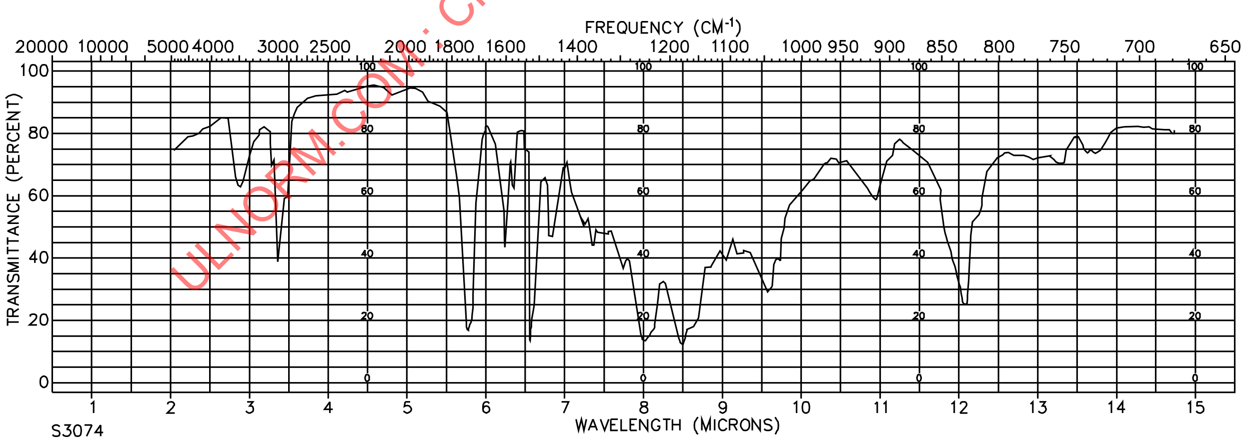
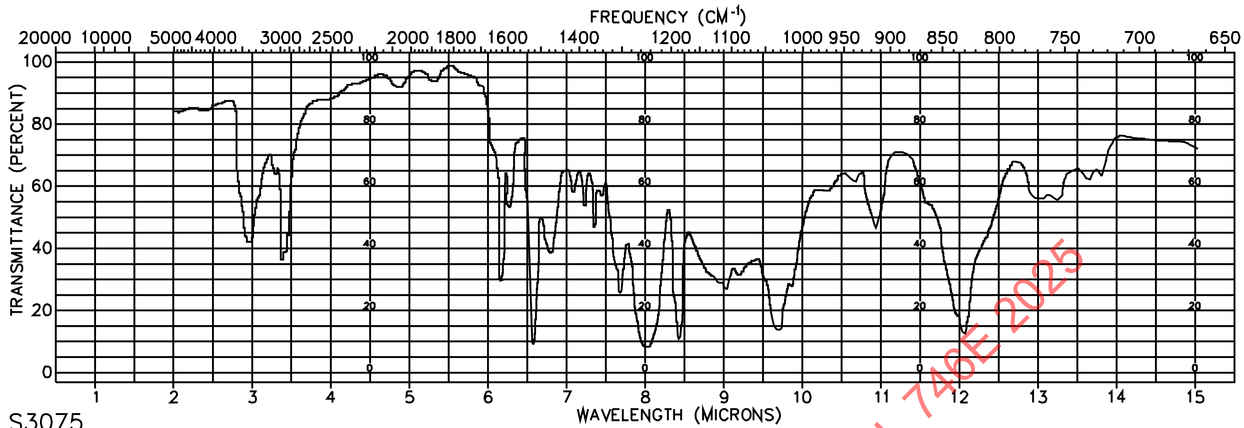


Figure A1.34

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



S3075

ANNEX B
End-of-life Conditioning of Industrial Laminates

B1 General

B1.1 The graphs shown in Figure B1.1 – Figure B1.77 represent the amount of time for various industrial laminates to achieve property end-of-life by the destructive testing method versus inverse absolute temperature.

Figure B1.1

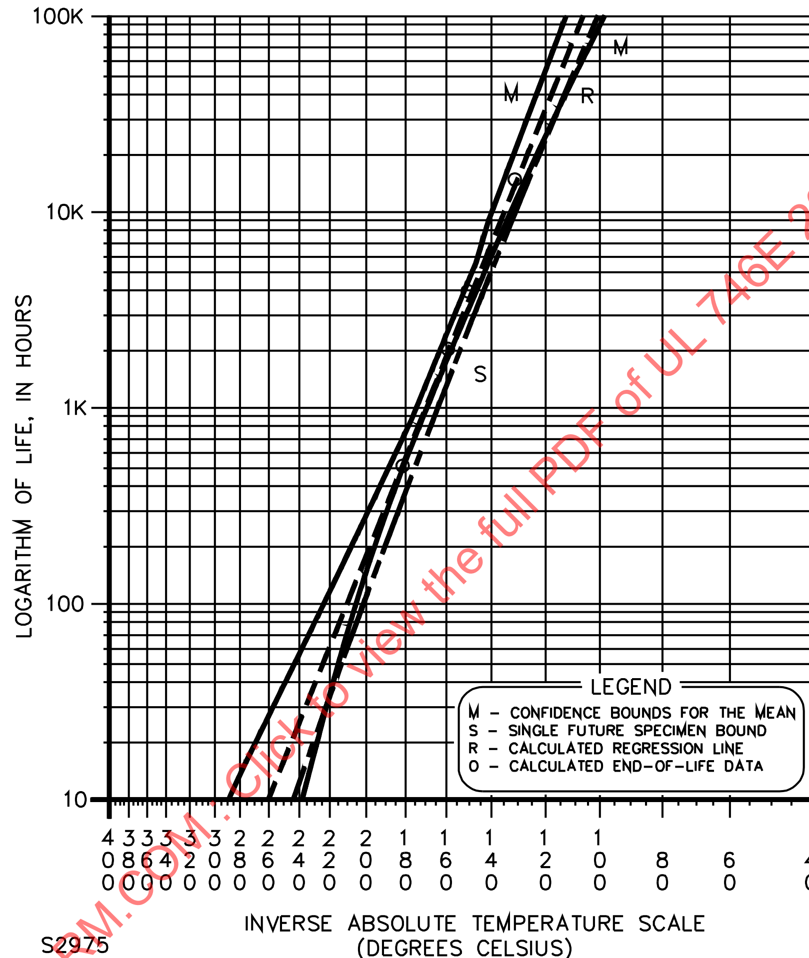
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: XP represented: X, XPC

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	14000
150	3600
160	2000
180	500

Correlation coefficient K = 0.9988

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

$A = 1/0.743299 \times 10^9$;
$B = 12101.4$

Where L is in hours and T is in degrees celsius

Figure B1.2

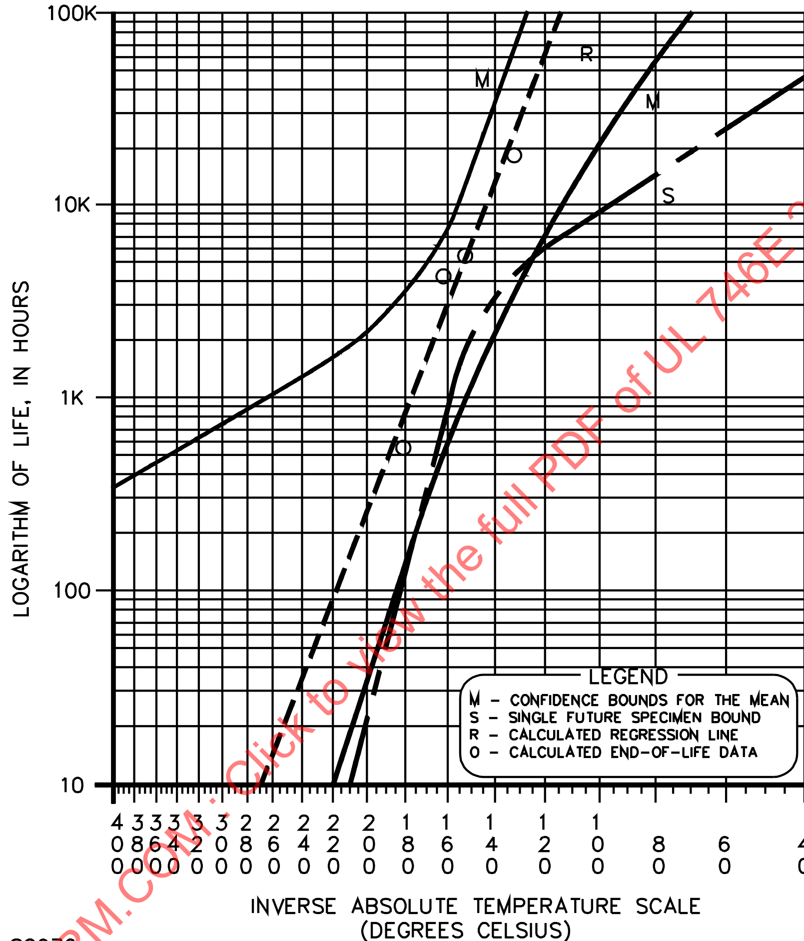
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: XP represented: X, XPC

Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength

Color:



S2976

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 arrehenius 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 B1.3

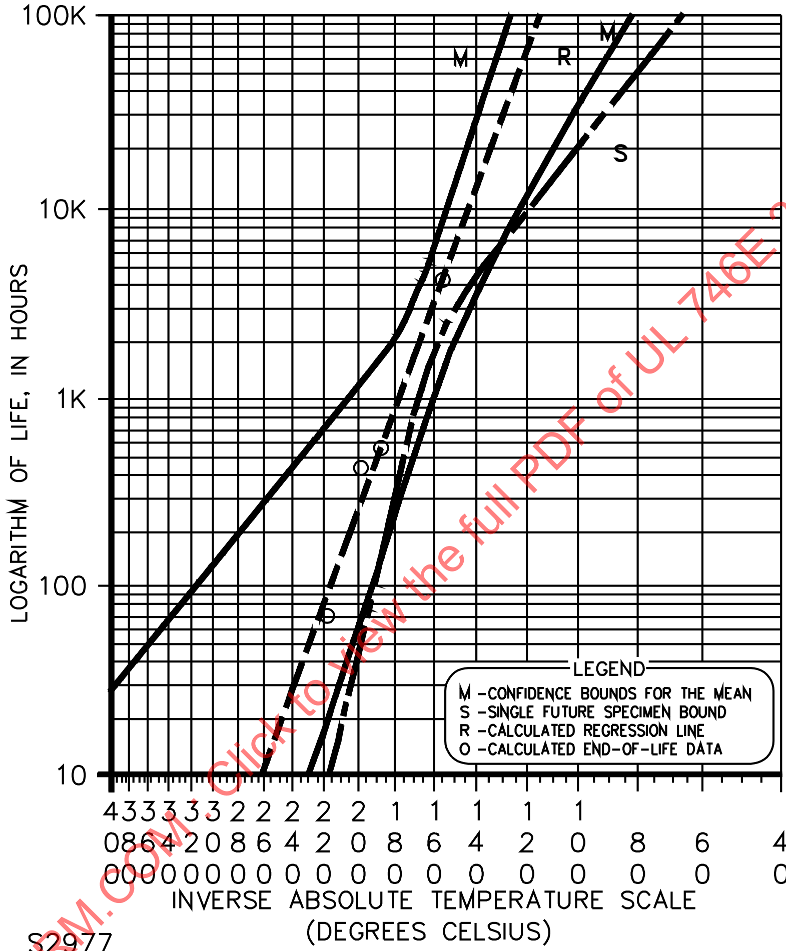
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

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 X 10^9;
B = 12108.2

Where L is in hours and T is in degrees celsius

Figure B1.4

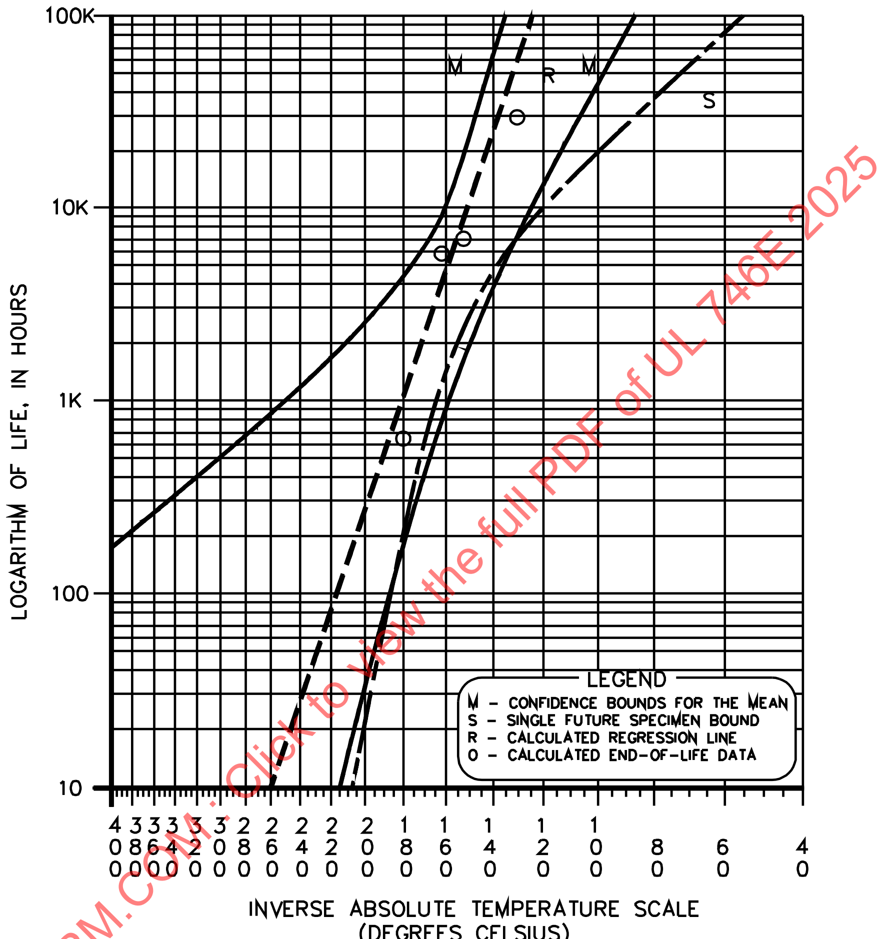
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: XX represented: XXX, XXP

Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength

Color:



S2978

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 arrehenius 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 B1.5

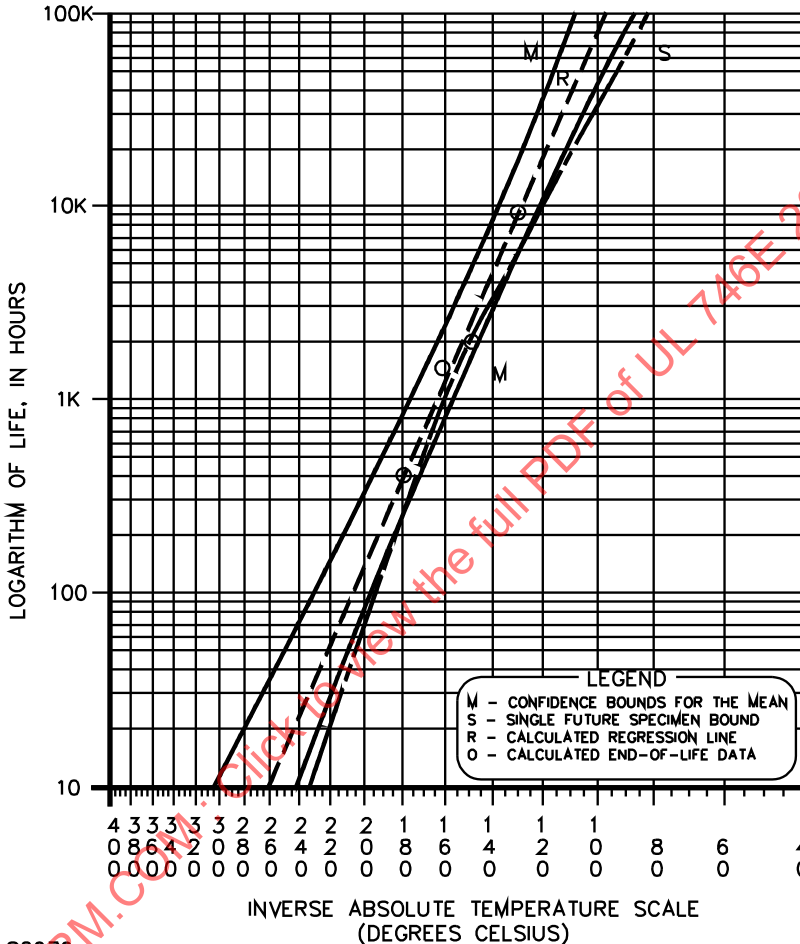
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: XXXPC represented: XXXP

Thickness: 0.79 mm (1/32 inch)

Property: Flexural strength

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 arrehenius 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 B1.6

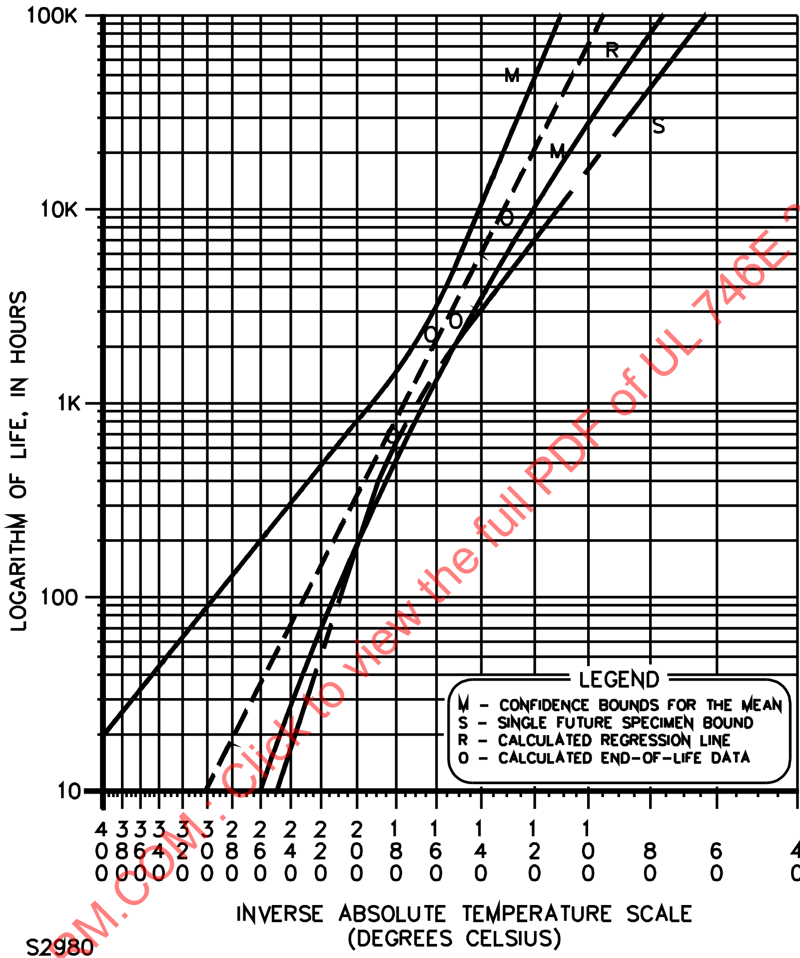
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: XXXPC represented: XXXP

Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength

Color:



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 arrehenius 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 B1.7

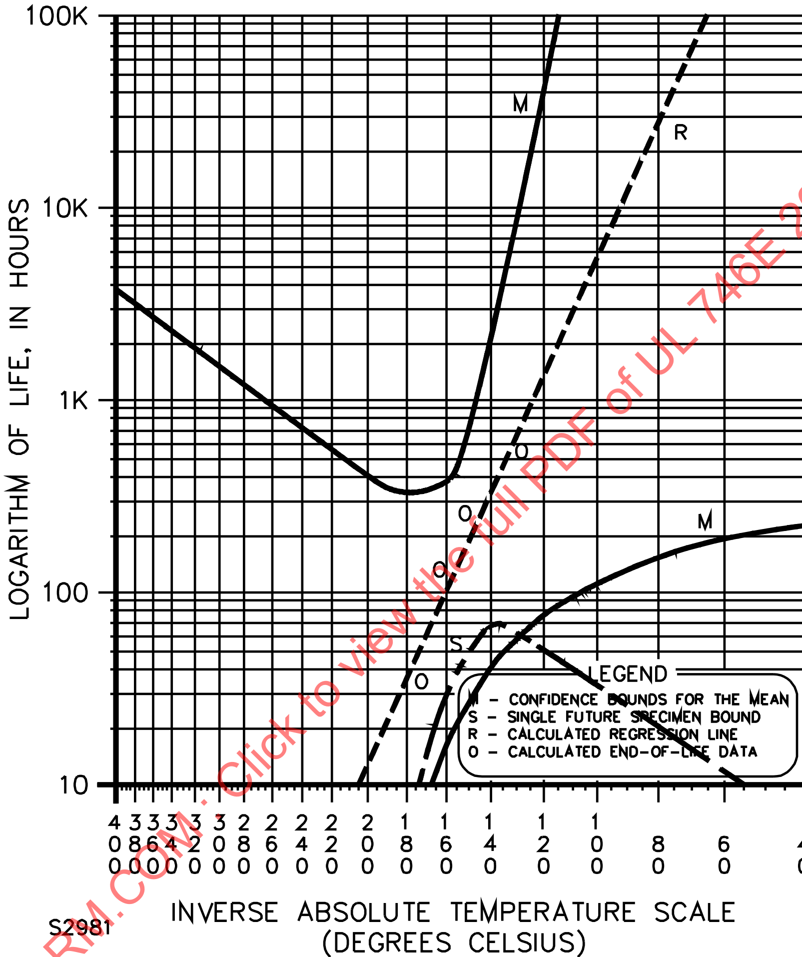
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: CE represented: C, L, LE

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	390
150	260
160	110
170	33

Correlation coefficient K = 0.9128

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

$A = 1/0.298287 \times 10^{9}$;
$B = 10392.4$

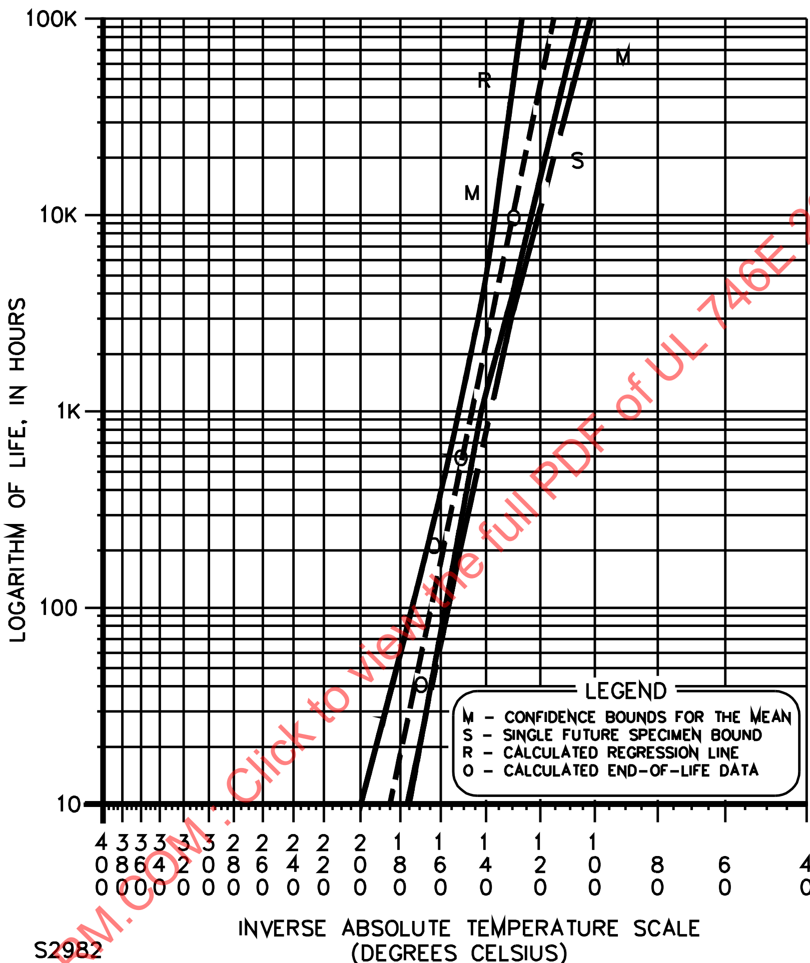
Where L is in hours and T is in degrees celsius

Figure B1.8

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: Flexural strength — Color:



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 arrehenius 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 B1.9

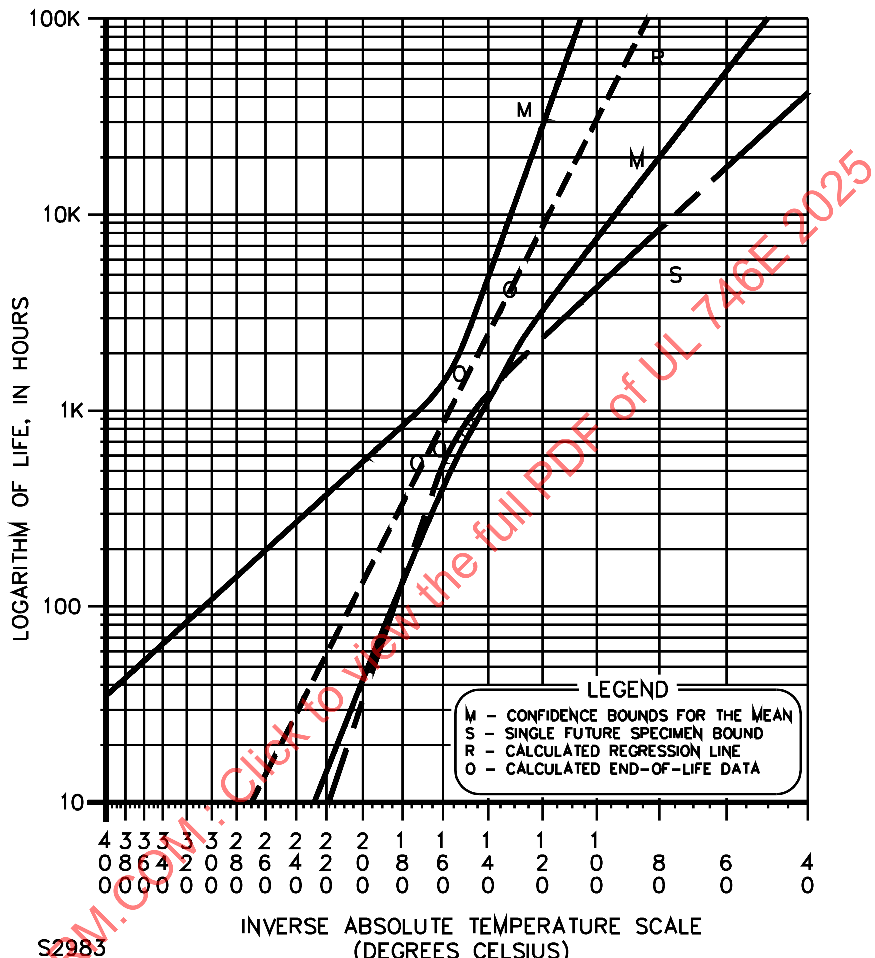
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: CE represented: C, L, LE

Thickness: 0.79 mm (1/32 inch)

Property: Dielectric strength

Color:



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 arrehenius 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 B1.10

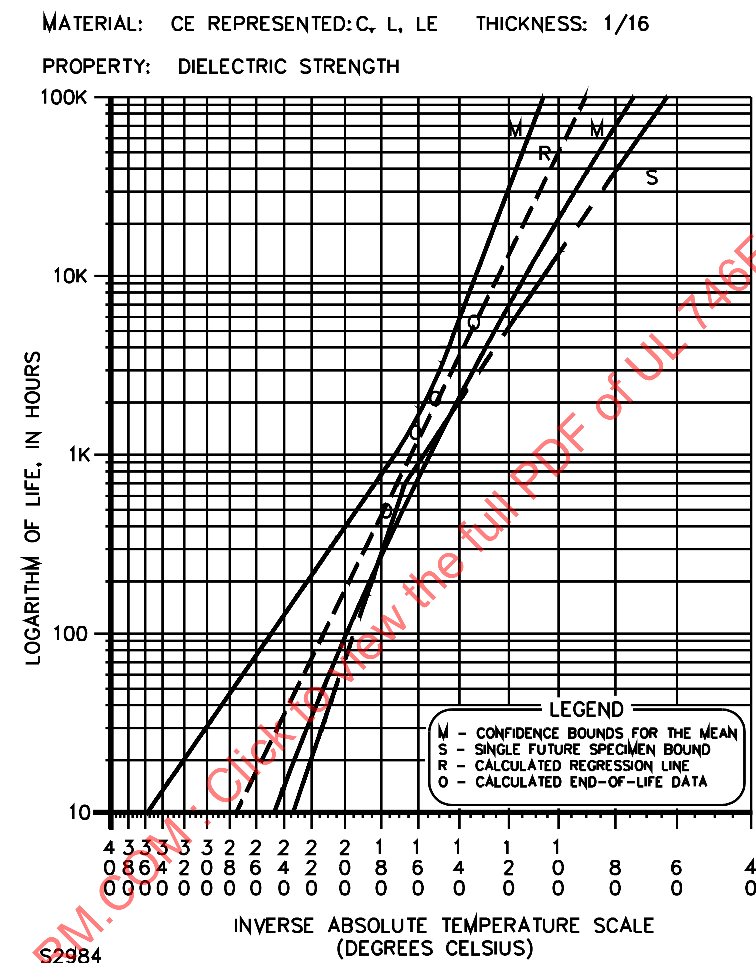
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: CE represented: C, L, LE

Thickness: 1.59 mm (1/16 inch)

Property: Dielectric strength

Color:



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 arrehenius equation: $L = A\,(2.718282)^{B/(T + 273.16)}$

$A = 1/0.677959 \times 10^{7}$;
$B = 9832.96$

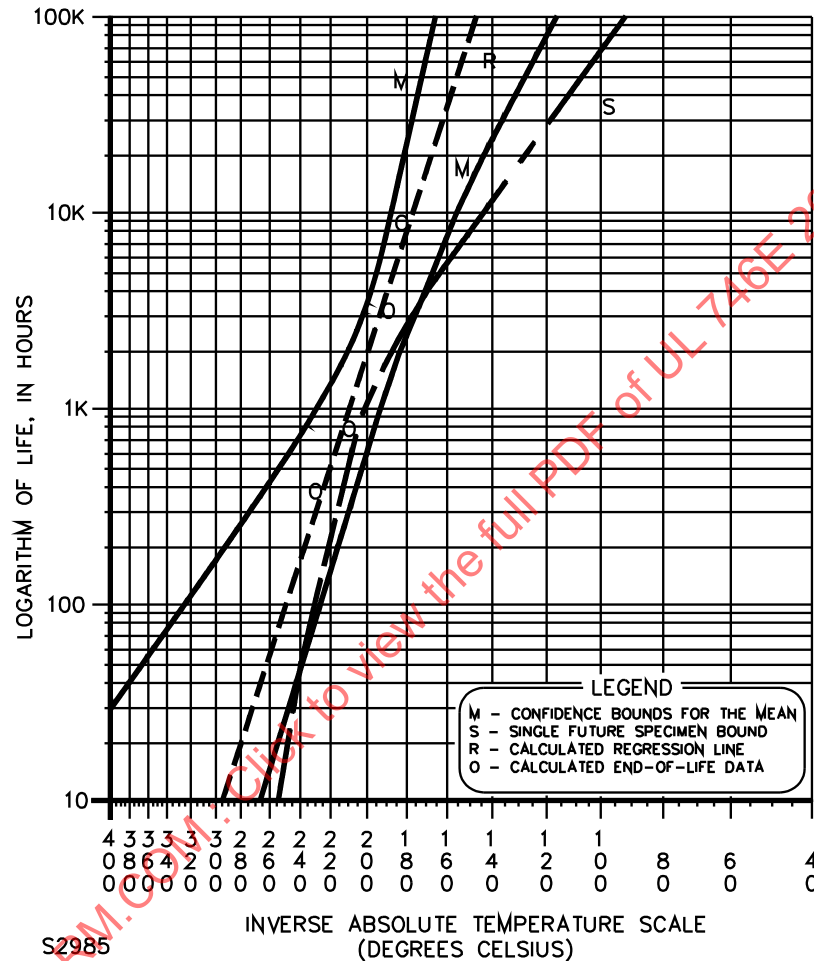
Where L is in hours and T is in degrees celsius

Figure B1.11

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

Material: G-3 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
180	9000
190	2600
210	760
230	320

Correlation coefficient K = 0.9837

The arrehenius 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 B1.12

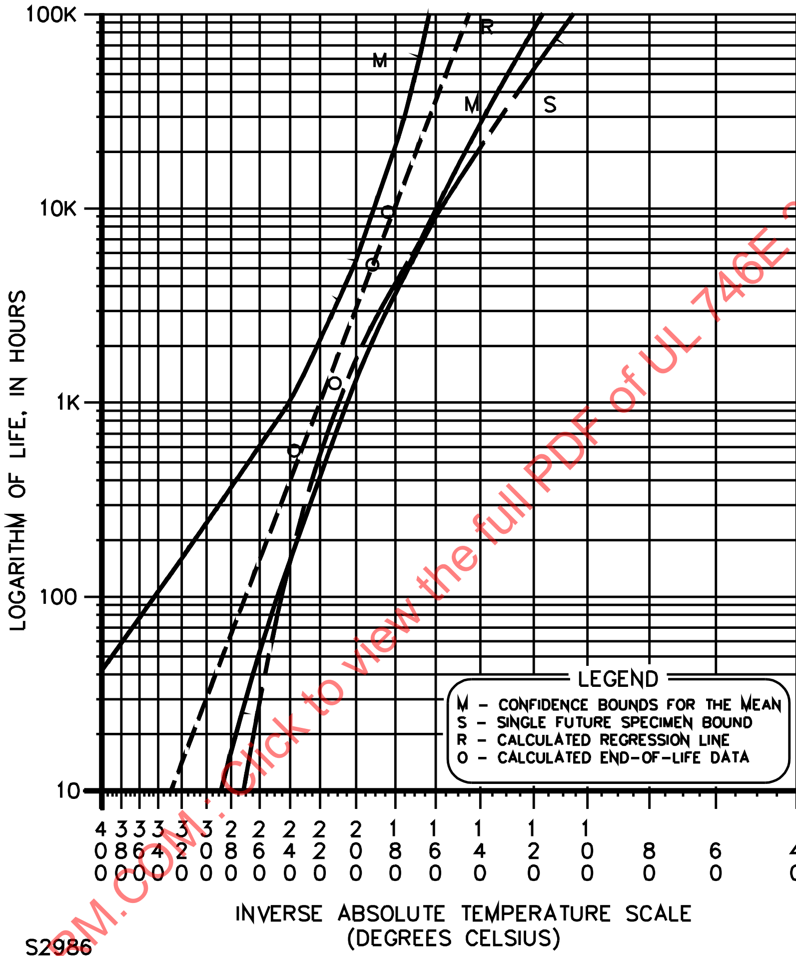
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: G-3

Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength

Color:



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 arrehenius equation: $L = A\,(2.718282)^{B/(T + 273.16)}$

$A = 1/0.144708 \times 10^9$;
$B = 12588.5$

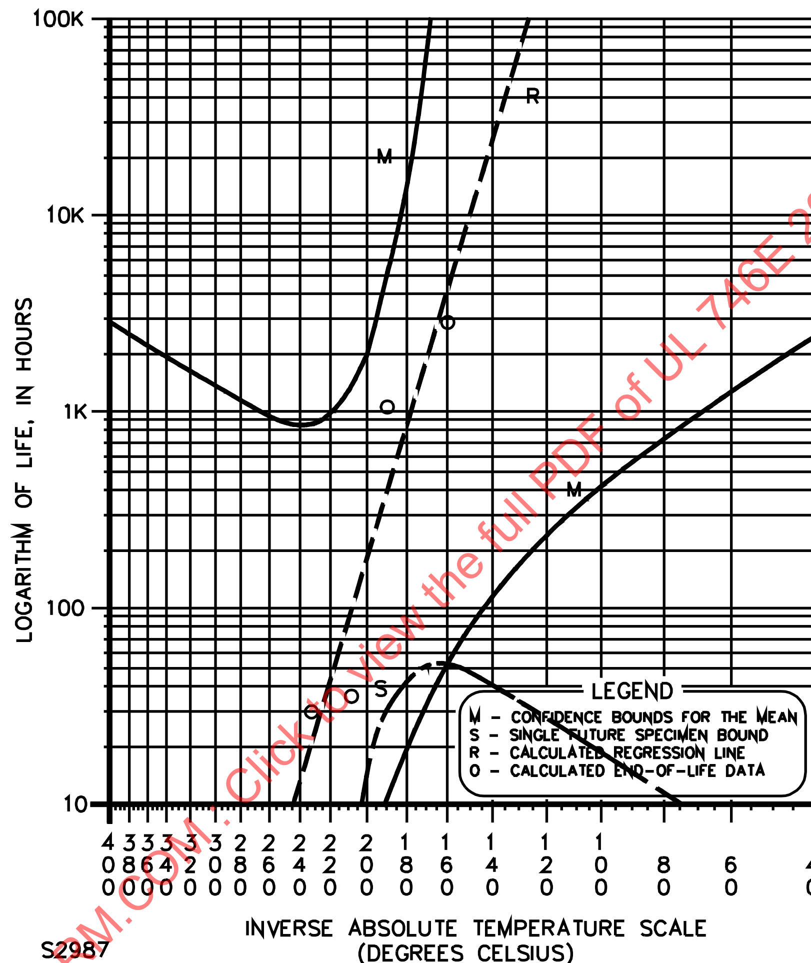
Where L is in hours and T is in degrees celsius

Figure B1.13

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

Material: G-3 Thickness: 0.79 mm (1/32 inch)

Property: Dielectric strength Color:



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 arrehenius 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 B1.14

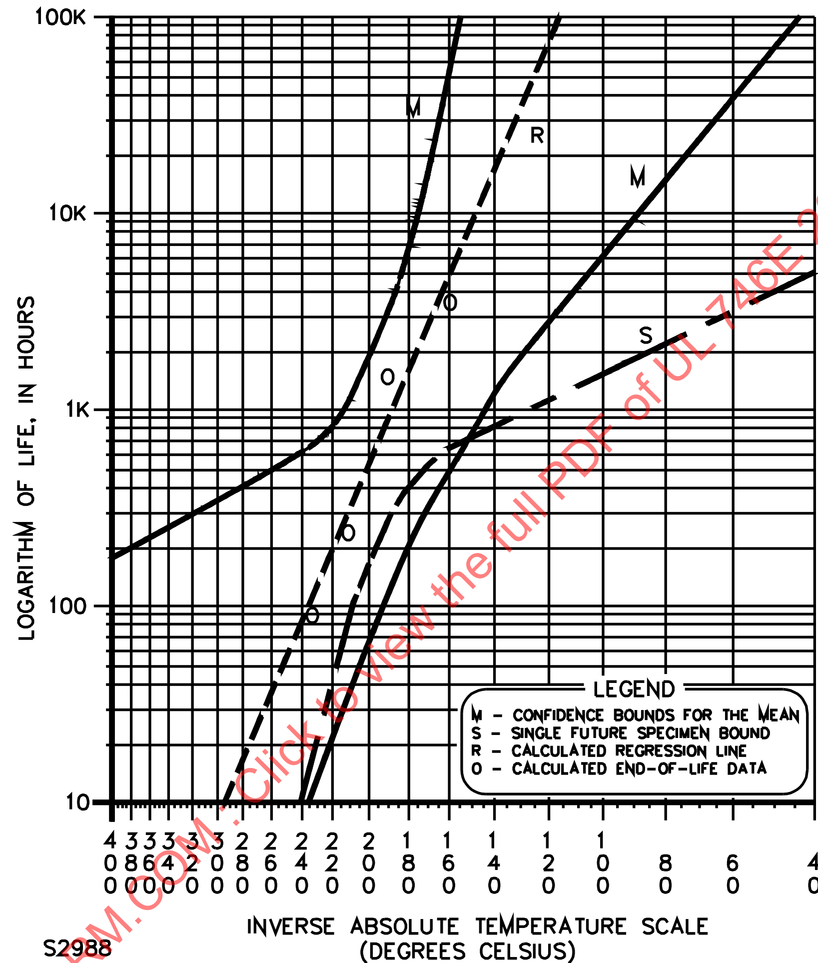
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: G-3

Thickness: 1.59 mm (1/16 inch)

Property: Dielectric strength

Color:



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 arrehenius 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 B1.15

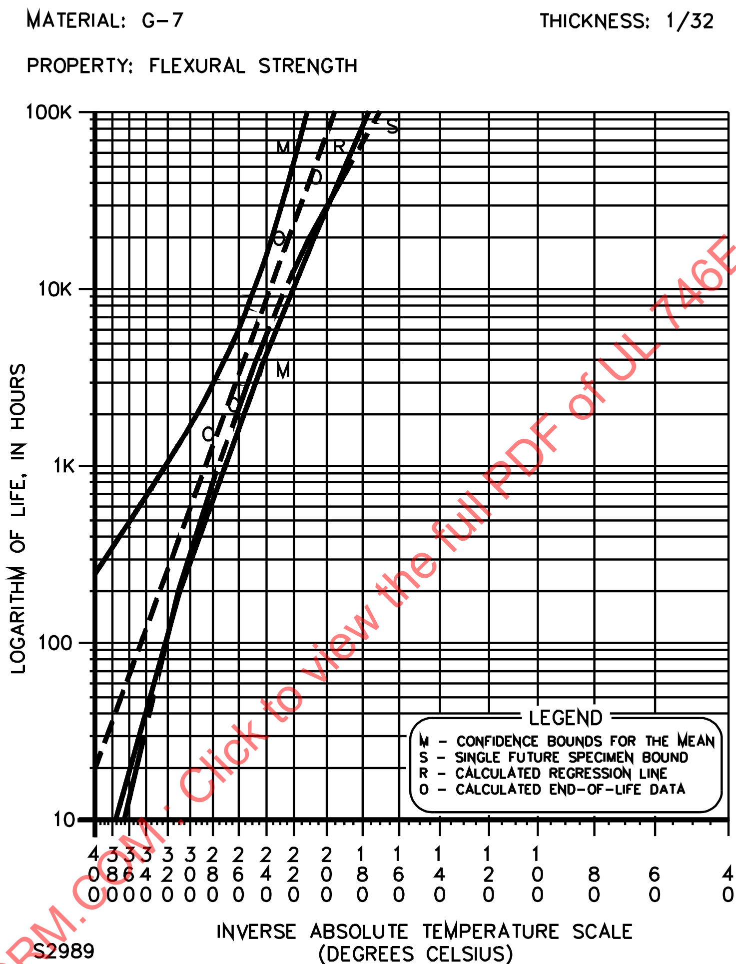
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: G-7

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
210	40000
230	17000
270	1600
280	1500

Correlation coefficient K = 0.9933

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

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

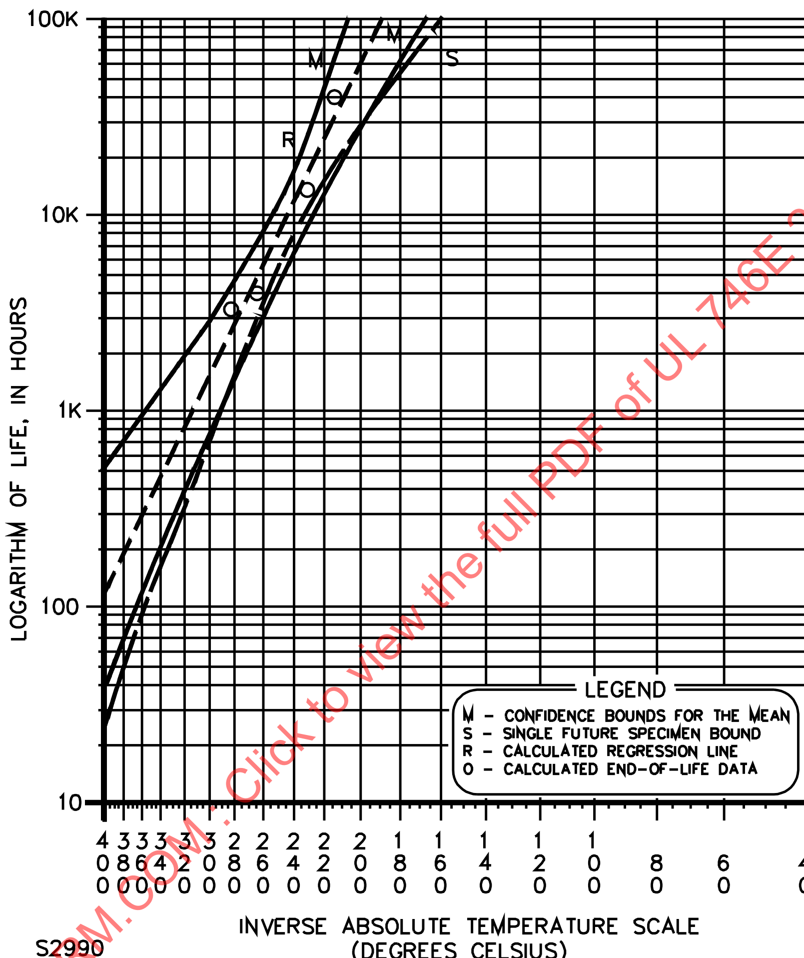
Where L is in hours and T is in degrees celsius

Figure B1.16

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

Material: G-7 | Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength | Color:



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 arrehenius equation: $L = A\,(2.718282)^{B/(T + 273.16)}$

A = 1/27611.8;
B = 10012.3

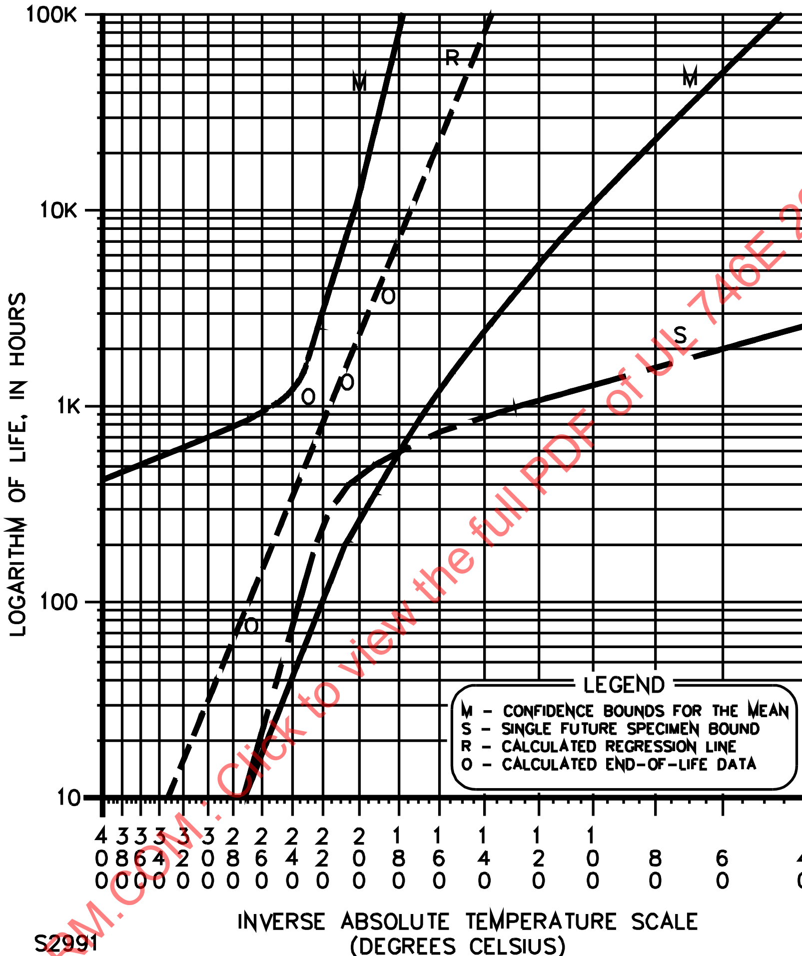
Where L is in hours and T is in degrees celsius

Figure B1.17

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

Material: G-7 Thickness: 0.79 mm (1/32) inch

Property: Dielectric strength Color:



S2991

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 arrehenius equation: $L = A\,(2.718282)^{B/(T + 273.16)}$

$A = 1/0.186425 \times 10^{8}$;
B = 11553

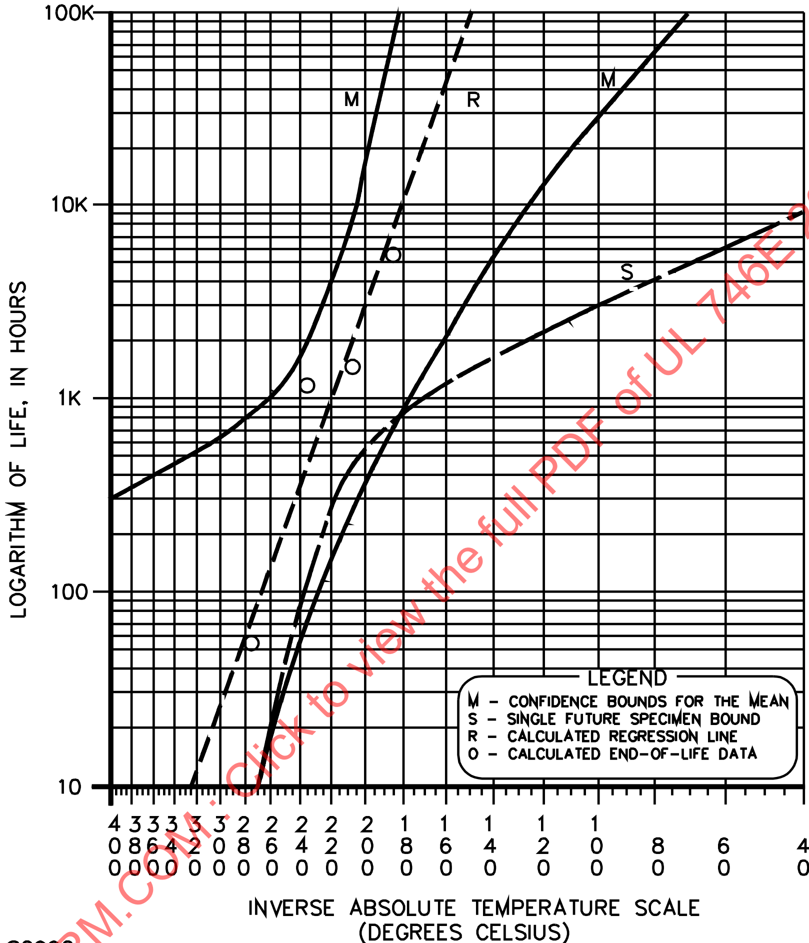
Where L is in hours and T is in degrees celsius

Figure B1.18

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

Material: G-7 Thickness: 1.59 mm (1/16 inch)

Property: Dielectric strength Color:



S2992

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 arrehenius 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 B1.19

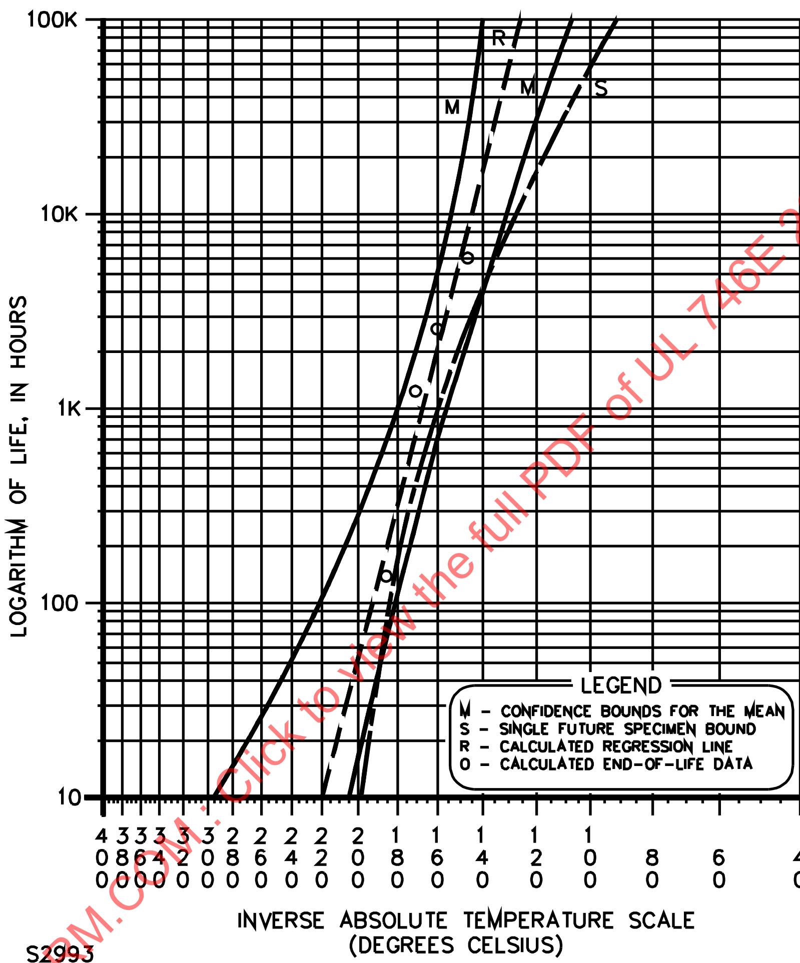
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: G-9 represented: G-5

Thickness: 0.79 (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
150	5000
160	2200
170	1200
190	120

Correlation coefficient K = 0.9882

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

$A = 1/0.82422 \times 10^{15}$;
$B = 18208.9$

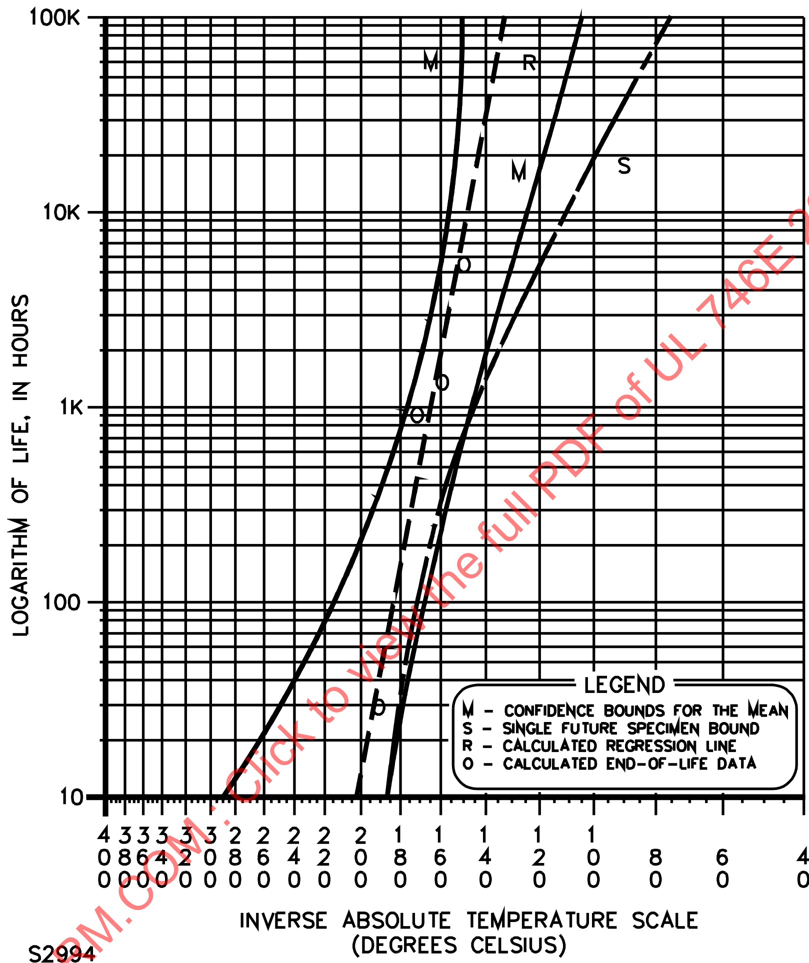
Where L is in hours and T is in degrees celsius

Figure B1.20

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

Material: G-9 Represented: G-5 — Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength — Color:



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 arrehenius equation: $L = A\,(2.718282)^{B/(T + 273.16)}$

$A = 1/0.70143 \times 10^{22}$;
$B = 25948.4$

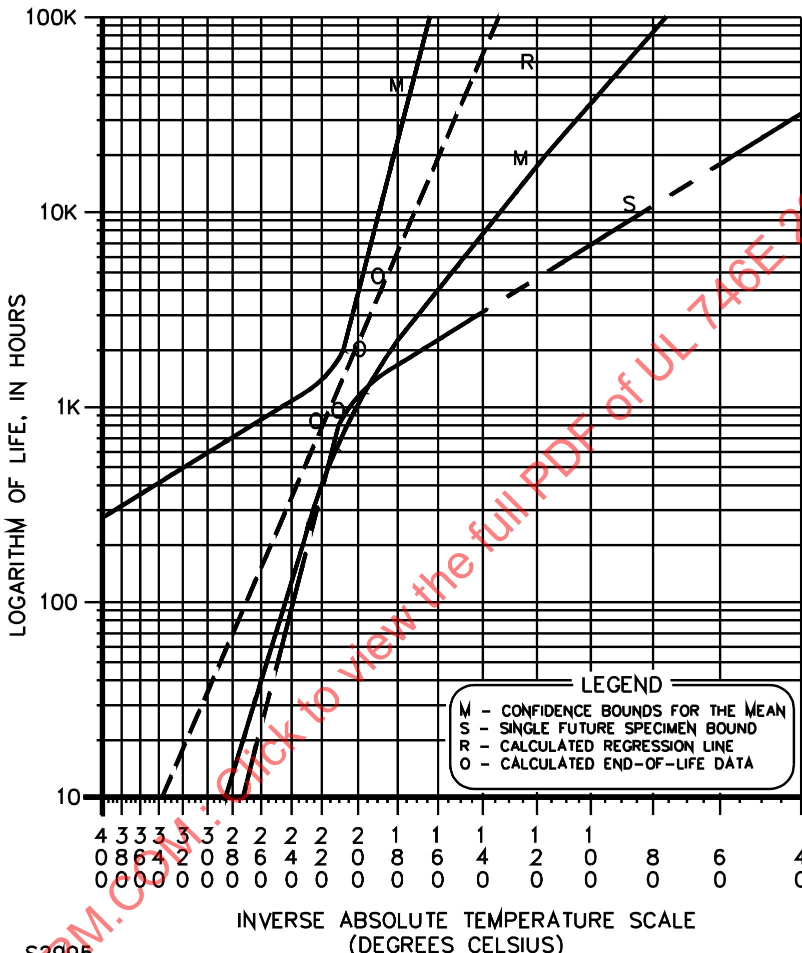
Where L is in hours and T is in degrees celsius

Figure B1.21

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

Material: G-11 represented: FR-5 Thickness: 0.79 mm (1/32 inch)

Property: Flexural strength Color:



S2995

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 arrehenius equation: $L = A\,(2.718282)^{B/(T + 273.16)}$

$A = 1/0.117396 \times 10^{8}$
$B = 11218.2$

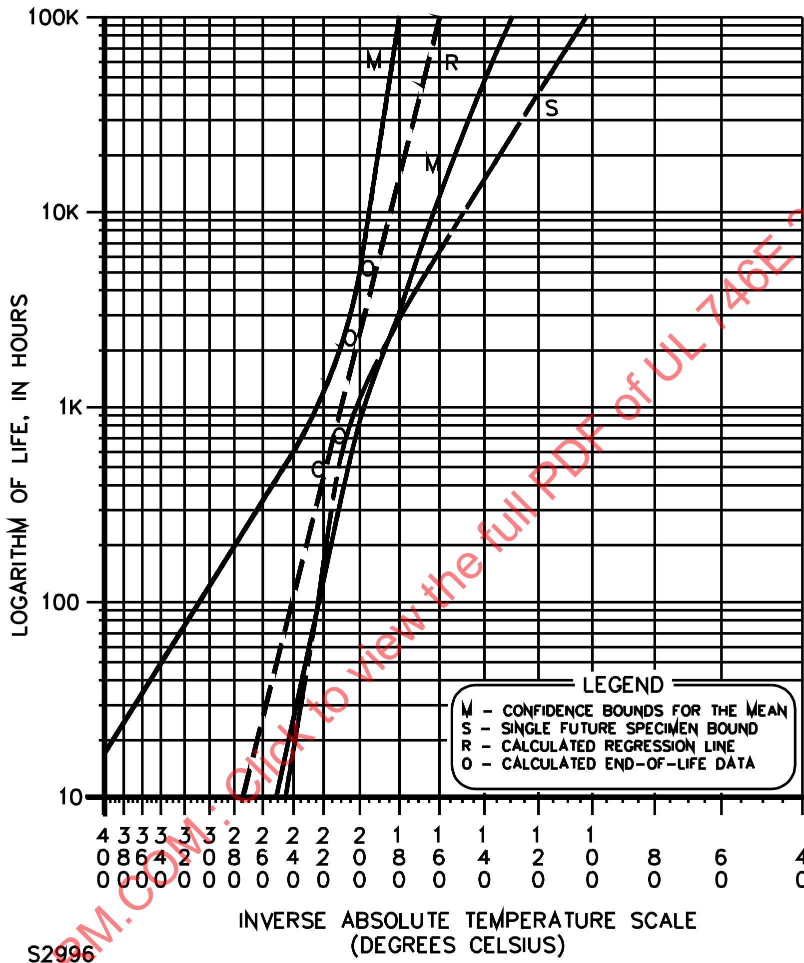
Where L is in hours and T is in degrees celsius

Figure B1.22

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

Material: G-11 represented: FR-5 Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength Color:



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 arrehenius equation: $L = A\,(2.718282)^{B/(T + 273.16)}$

$A = 1/0.155348 \times 10^{15}$;
$B = 19046.3$

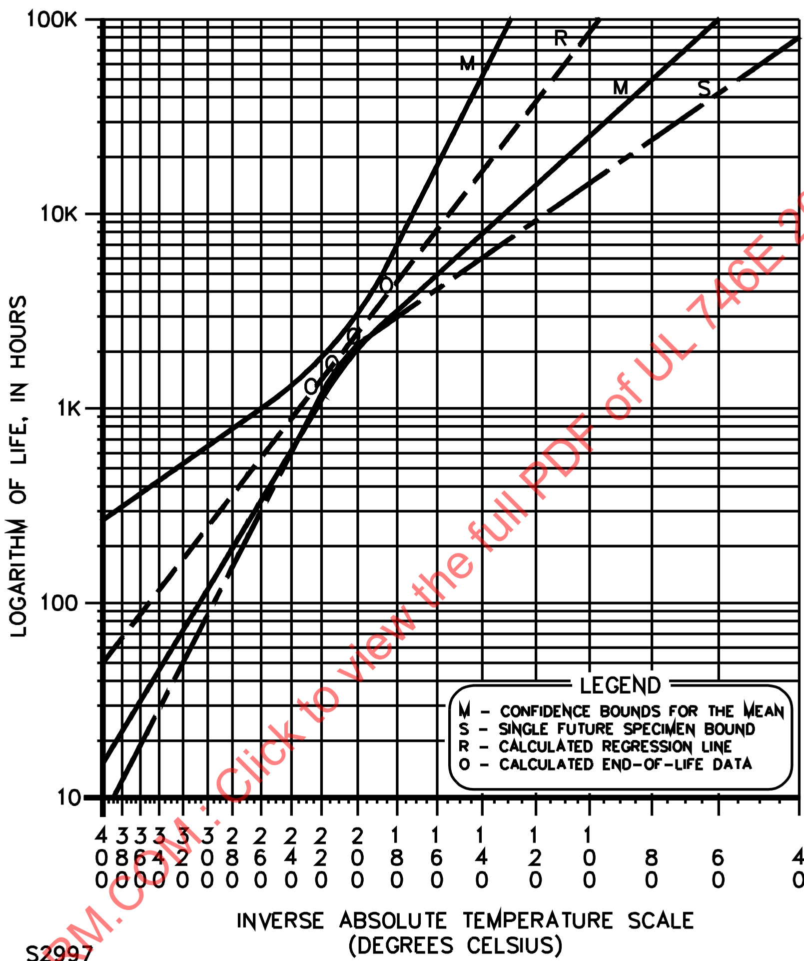
Where L is in hours and T is in degrees celsius

Figure B1.23

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

Material: G-11 Represented: FR-5 0.79 mm (1/32 inch)

Property: Dielectric strength Color:



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 arrehenius 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 B1.24

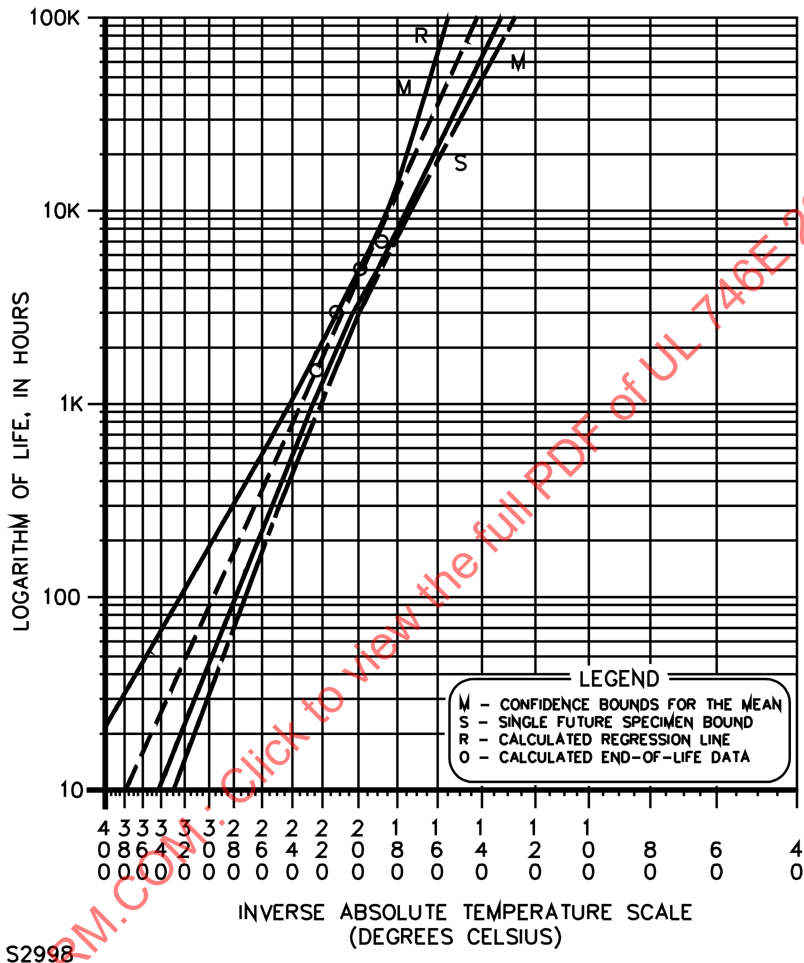
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: G-11 represented:FR-5

Thickness: 1.59 mm (1/16 inch)

Property: Dielectric strength

Color:



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 arrehenius 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 B1.25

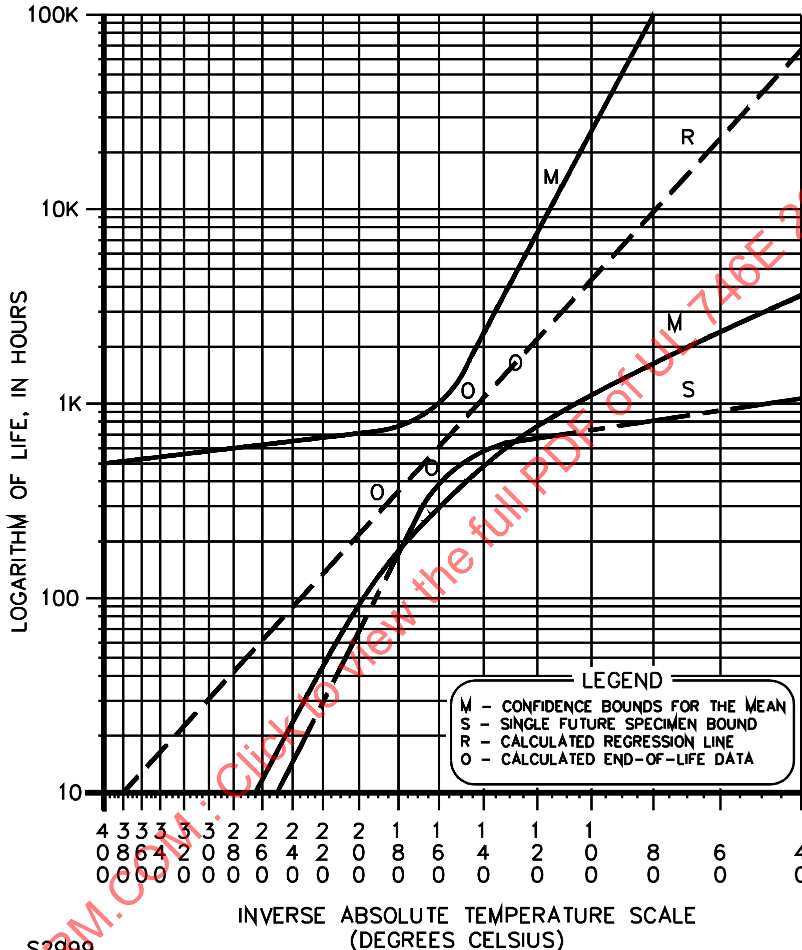
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: FR-2

Thickness: 0.79 mm (1/32 inch)

Property: Flexural strength

Color:



S2999

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 arrehenius equation: $L = A\,(2.718282)^{B/(T + 273.16)}$

A = 1/319.402;
B = 5267.49

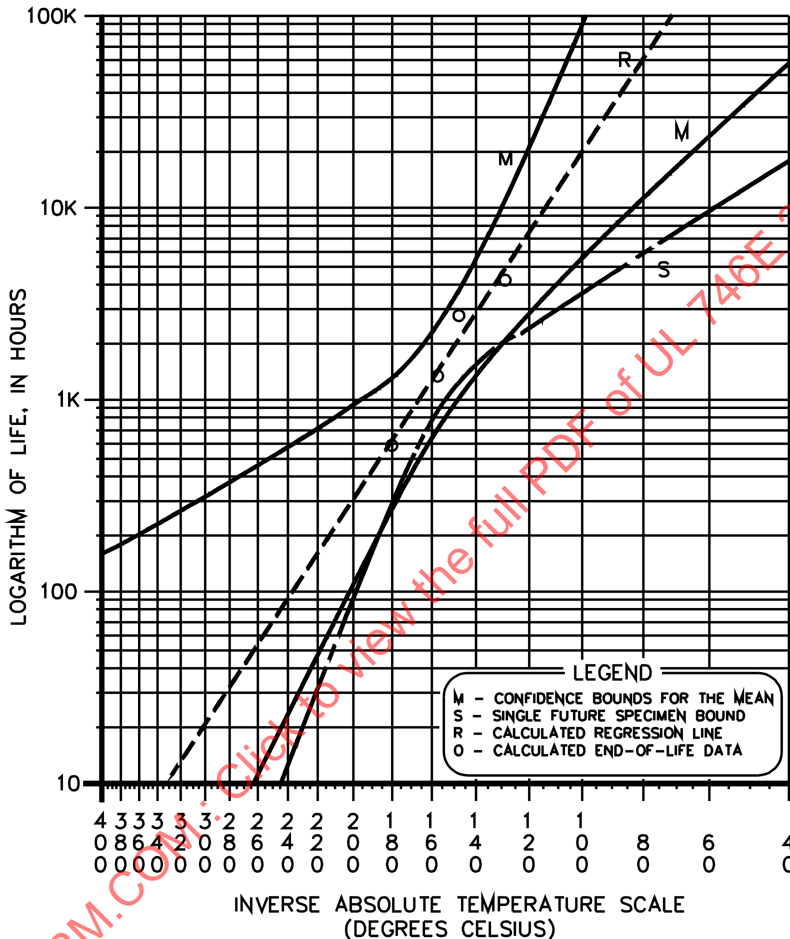
Where L is in hours and T is in degrees celsius

Figure B1.26

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

Material: FR-2 Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength Color:



S3000

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 arrehenius 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 B1.27

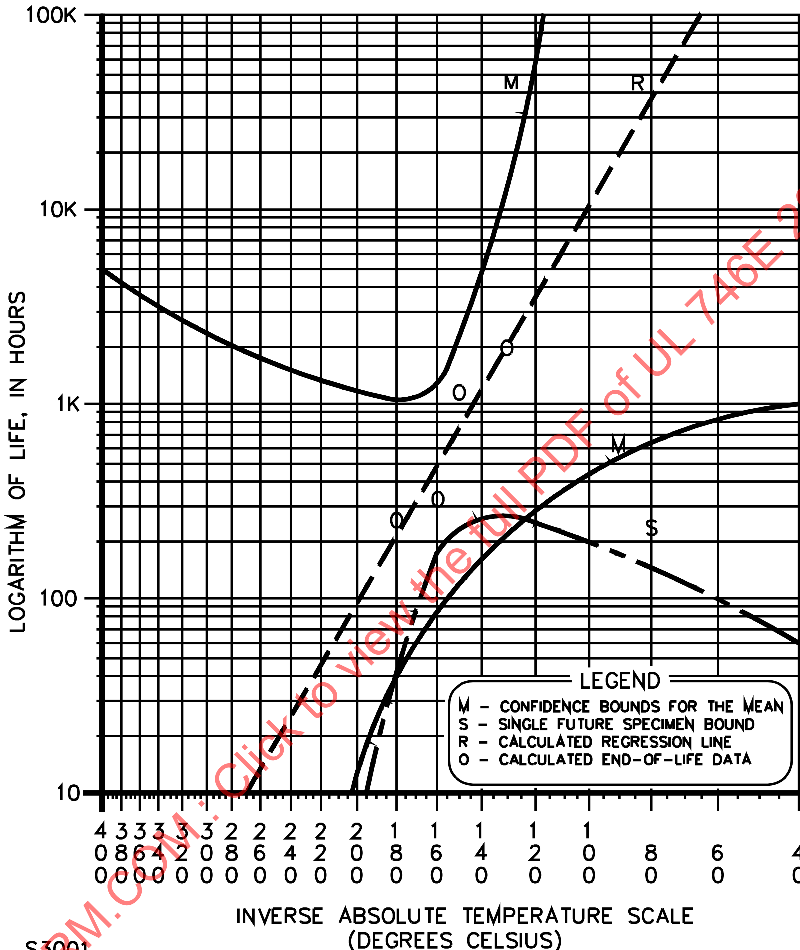
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: FR-3

Thickness: 0.79 mm (1/32 inch)

Property: Flexural strength

Color:



S3001

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 arrehenius 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 B1.28

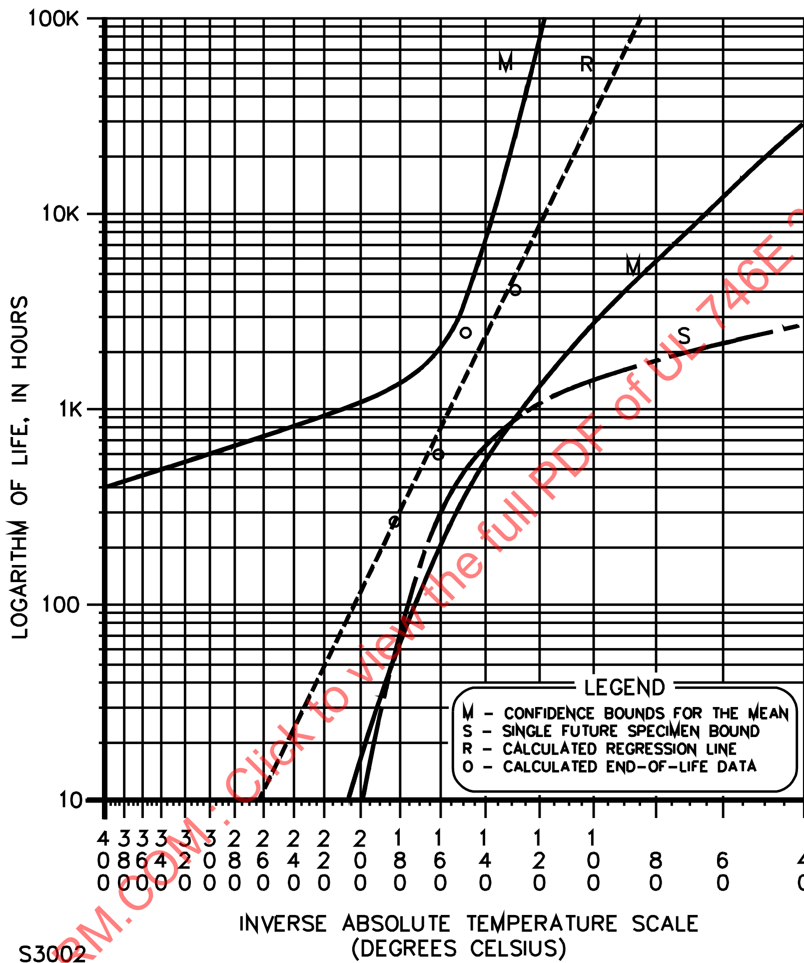
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: FR-3

Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength

Color:



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 arrehenius 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 B1.29

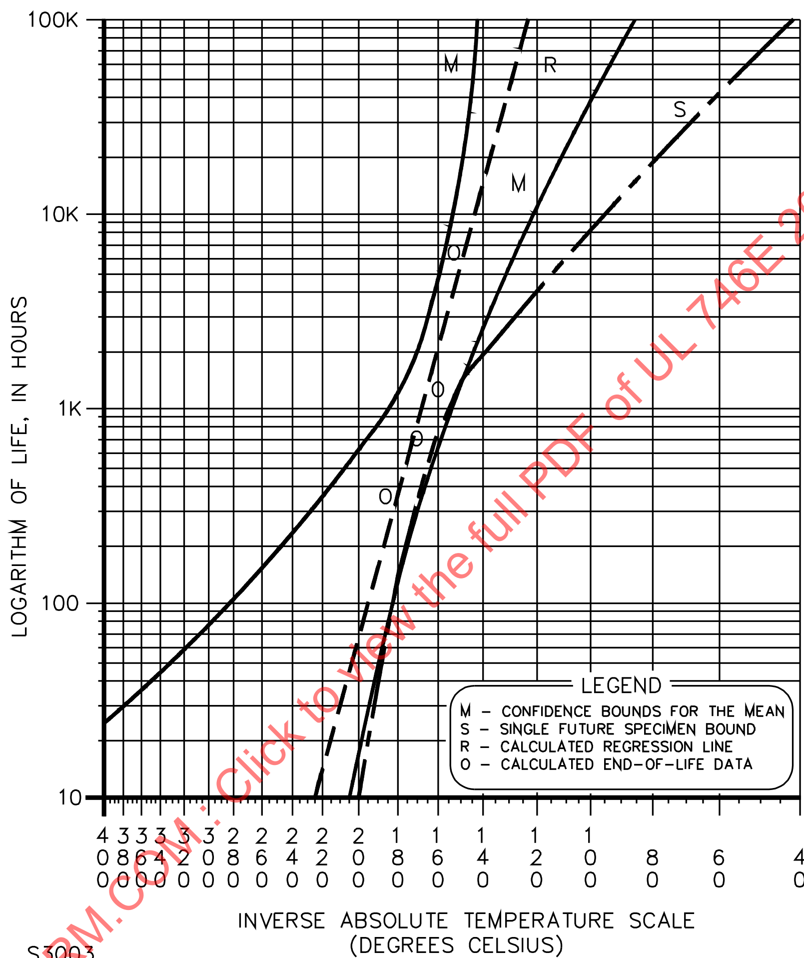
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: FR-4.0 represented: G-10

Thickness: 0.79 mm (1/32 inch)

Property: Flexural strength

Color:



S3003

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 arrehenius 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 B1.30

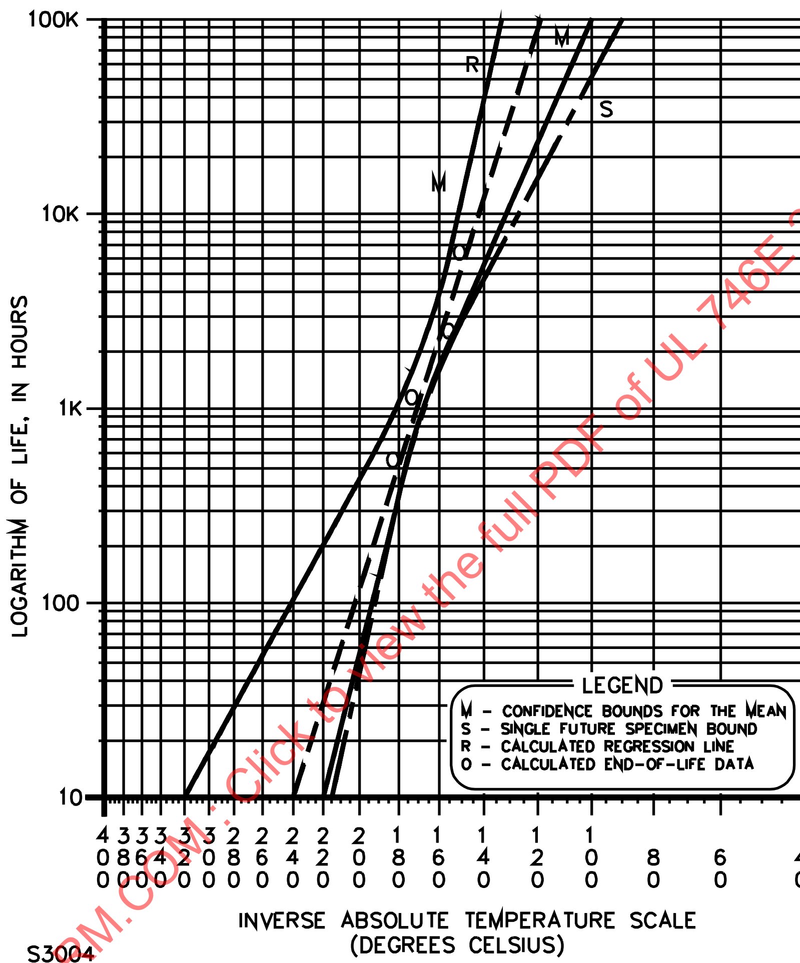
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material: FR-4.0 represented: G-10

Thickness: 1.59 mm (1/16 inch)

Property: Flexural strength

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

$A = 1/0.788381 \times 10^{12}$;
$B = 15204.9$

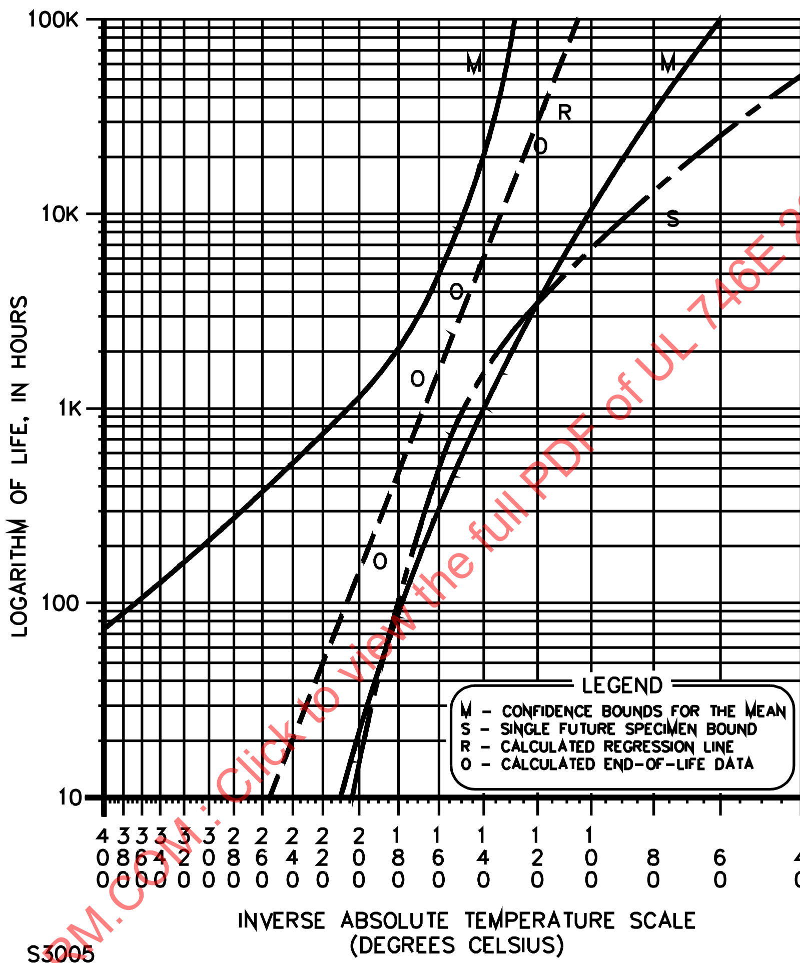
Where L is in hours and T is in degrees celsius

Figure B1.31

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

Material: FR-4.0 represented: G-10 Thickness: 0.79 mm (1/32 inch)

Property: Flexural strength Color:



S3005

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 arrehenius 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 B1.32

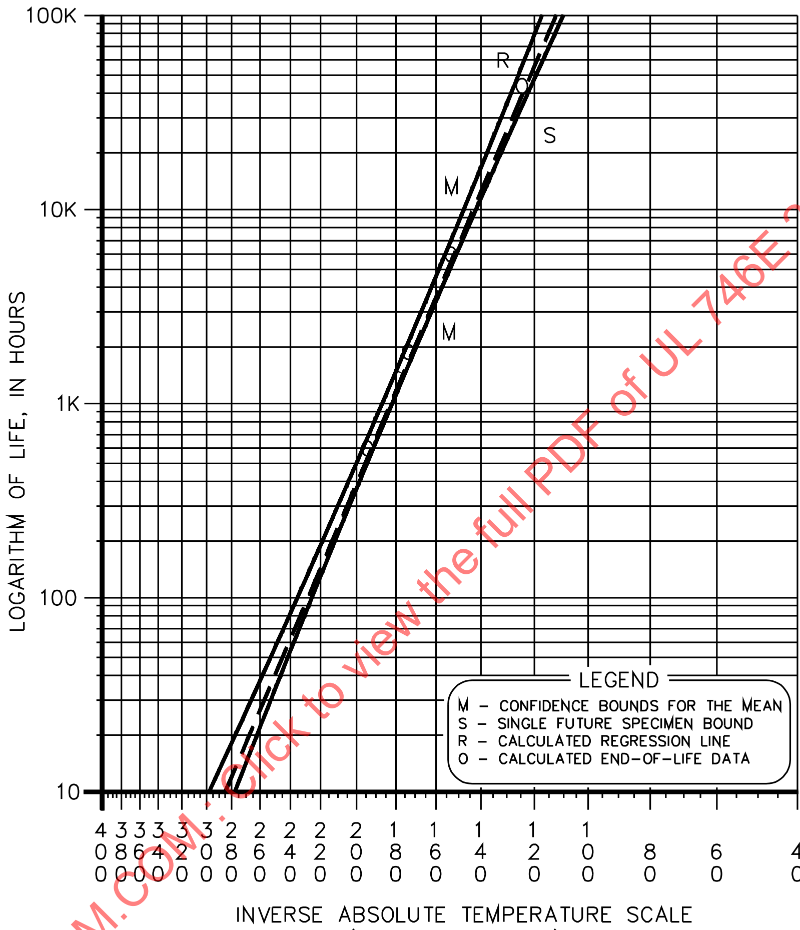
Logarithm of hours to achieve property end-of-life by the destructive testing method vs. inverse absolute temperature

Material:FR-4.0 represented: G-10

Thickness: 1.59 mm (1/16 inch)

Property: Dielectric strength

Color:



S3006

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 arrehenius 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