

UL 746E

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

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

Fourth Edition, Dated April 17, 2006

Revisions: This Standard contains revisions through and including May 15, 2007.

SUMMARY OF TOPICS:

These revisions to Standard UL 746E are being issued to incorporate the following new and revised requirements:

- 1. Addition of the term "Base Material Thickness" to the Glossary;***
- 2. Clarification of Requirements in Tables 9.1, 10.4, 11.1, and 20.2 for Conditions Under Which the Wet and Dry Dielectric Strength Tests are Conducted; and***
- 3. Revision of Paragraph 17.1.1.1 and Addition of Paragraph 17.1.1.2 for Requirements for Metal Clad Laminates.***

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

The new and revised requirements are substantially in accordance with UL's Proposal(s) on this subject dated September 8, 2006, December 15, 2006, and March 16, 2007.

As indicated on the title page (page 1), this UL Standard for Safety is an American National Standard. Attention is directed to the note on the title page of this Standard outlining the procedures to be followed to retain the approved text of this ANSI/UL Standard.

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UL 746E

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

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This ANSI/UL Standard for Safety, which consists of the Fourth Edition with revisions through May 15, 2007, is under continuous maintenance, whereby each revision is ANSI approved upon publication.

An effective date included as a note immediately following certain requirements is one established by Underwriters Laboratories Inc.

Revisions of this Standard will be made by issuing revised or additional pages bearing their date of issue. A UL Standard is current only if it incorporates the most recently adopted revisions, all of which are itemized on the transmittal notice that accompanies the latest set of revised requirements. Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at <http://csds.ul.com>.

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INTRODUCTION

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.

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.

2.2 revised February 21, 2007

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

2.2.1 added February 21, 2007

2.3 AS RECEIVED – Specimens or samples in an unconditioned state, prior to being subject to conditioning, or without a history of conditioning.

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

2.3.1 added February 21, 2007

2.3.2 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.

2.3.2 added May 15, 2007

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

2.5 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.

2.5.1 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).

2.5.1 added February 21, 2007

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

2.5.2 added February 21, 2007

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

2.5.3 added February 21, 2007

2.5.4 CLAD MATERIAL – See Metal Clad Base Material.

2.5.4 added February 21, 2007

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

2.5.5 added February 21, 2007

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

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

2.6.1 added February 21, 2007

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

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

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

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

2.11 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.

2.11 revised February 21, 2007

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

2.13 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.

2.14 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.

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

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

2.16.1 CONDUCTOR WEIGHT – See Conductor Thickness.

2.16.1 added February 21, 2007

2.17 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.

2.17 revised February 21, 2007

2.18 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.

2.18 revised February 21, 2007

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

2.18.1 added February 21, 2007

2.19 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.

2.20 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.

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

2.20.1 added February 21, 2007

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

2.20.2 added February 21, 2007

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

2.20.3 added February 21, 2007

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

2.21.1 DESSICATOR – A sealable vessel containing anhydrous calcium chloride, or other drying agent, maintained at a relative humidity not exceeding 20 percent at $23 \pm 2^\circ\text{C}$.

2.21.1 added February 21, 2007

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

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

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

2.23.1 added February 21, 2007

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

2.23.2 added February 21, 2007

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

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

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

2.25.1 added February 21, 2007

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

2.26.1 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.

2.26.1 added February 21, 2007

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

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

2.28.1 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.

2.28.1 added February 21, 2007

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

2.28.2 added February 21, 2007

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

2.29.1 INDUSTRIAL LAMINATE – See Base Material.

2.29.1 added February 21, 2007

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

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

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

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

2.33.1 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

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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.

2.33.1 added February 21, 2007

2.34 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.

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

2.34.1 added February 21, 2007

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

2.35 revised February 21, 2007

2.35.1 METAL CLAD LAMINATE – See Metal Clad Base Laminate.

2.35.1 added February 21, 2007

2.35.2 METAL CORE LAMINATE – See Metal Base Laminate.

2.35.2 added February 21, 2007

2.35.3 METAL WEIGHT – See Conductor Weight.

2.35.3 added February 21, 2007

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

2.35.4 added February 21, 2007

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

2.35.5 added February 21, 2007

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

2.35.6 added February 21, 2007

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

2.37 PERMANENT COATING – See Permanent Materials.

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

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

2.40 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).

2.41 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.

2.41.1 PRINTED WIRING BOARD – See Printed (Circuit) Board.

2.41.1 added February 21, 2007

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

2.41.2 added February 21, 2007

2.42 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.

2.42 revised February 21, 2007

2.43 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.

2.44 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.

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

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

2.45.1 added February 21, 2007

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

2.45.2 added February 21, 2007

2.46 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).

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

2.48 SOLDER MASK – See Solder Resist.

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

2.49.1 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.

2.49.1 added February 21, 2007

2.50 SUBSTRATE – See Core Material.

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

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

2.53 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.

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

2.54 revised February 21, 2007

2.55 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.

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

2.57 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.

2.58 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.

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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 Unless otherwise specified in the individual test method, the standard atmospheric conditions surrounding the sample prior to and during the test shall be between 15°C and 35°C (59°F and 95°F) and 45 to 75 percent relative humidity (ISO 291).

4.2 revised February 21, 2007

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.

5.1 revised February 21, 2007

5.2 Flammability samples shall be preconditioned as described in Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, or industrial laminate and solder resist materials shall be preconditioned using the alternate conditions of 125 ±2°C for 24 hours, unless otherwise specified.

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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 is a list of test procedures referenced in this standard.

- a) ASTM D 149 – Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies.
- b) ASTM D 257 – Standard Methods of Test for DC Resistance or Conductance of Insulating Materials.
- c) ASTM D 348 – Standard Test Methods for Rigid Tubes Used for Electrical Insulation.
- d) ASTM D 495 – Standard Test Method for High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation.
- e) ASTM D 570 – Standard Test Method of Test for Water Absorption of Plastics.
- f) ASTM D 619 – Standard Test Methods for Vulcanized Fibre Used for Electrical Insulation.
- g) ASTM D 882 – Standard Test Methods for Tensile Properties of Thin Plastic Sheeting.
- h) ASTM D 1000 – Standard Test Method for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications.
- i) ASTM D 1224 – Standard Test Methods for Zinc and Cadmium in Paper.
- j) ASTM D 3850 – Standard Test Method for Rapid Thermal Degradation of Solid Electrical Insulating Materials by Thermogravimetric Method (TGA).
- k) ASTM D 5423 – Standard Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation.
- l) ASTM E 3 – Standard Guide for Preparation of Metallographic Specimens.
- m) IPC TM-650 2.1.1 – Microsectioning Manual Method.
- n) ISO 291 – Plastics – Standard Atmospheres for Conditioning and Testing.

6.2 revised February 21, 2007

INDUSTRIAL LAMINATES

7 General

7.1 Profiles of minimum performance, relative thermal indices, and major constituents of industrial laminates are given in Tables 7.1 – 7.3. These profiles are minimum characteristics required for an industrial laminate to be assigned a UL/ANSI type designation.

Table 7.1
Rigid industrial laminate profiles of performance

Table 7.1 revised February 21, 2007

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc) PLC		Min HWI (Sec) PLC	Max HVAR (Sec) PLC	Max HVTR (in/mm) PLC	D 495 PLC	Min dielectric strength KV/mm	Min flexural strength psi	CTI (V) PLC	Vol resis ohm-cm x10 ^a	Water ab %Chg
	mm	inch		OS	AS									
X	0.71	0.028	HB	(24) 3	(200) 0	(6) 5	(300) 0	(11.7) 4	–	–	22,000	–	–	–
	1.45	0.057	HB	(24) 3	(200) 0	(8) 4	(300) 0	(9.6) 4	(5) 3	9.6/–	25,000	–	–	–
XP	0.71	0.028	–	(10) 4	(200) 0	(7) 4	(300) 0	(8.4) 4	–	26.9/–	12,000	–	–	–
	1.45	0.57	HB	(19) 3	(145) 0	(7) 4	(300) 0	(8.0) 4	–	19.4/–	13,000	–	–	–
XPC	0.71	0.028	HB	(10) 4	(200) 0	(7) 4	(15) 3	(10.0) 4	–	–	–	–	–	–
	1.45	0.057	HB	(16) 3	(200) 0	(8) 4	(300) 0	(10.8) 4	(6) 3	21.8/–	10,000	–	–	–
XX	0.71	0.028	HB	(8) 4	(200) 0	(6) 5	(300) 0	(11.0) 4	–	29.9/–	15,000	–	–	–
	1.45	0.057	HB	(12) 4	(200) 0	(7) 4	(300) 0	(15.4) 4	–	19.5/–	15,000	–	–	–
XXP	0.71	0.028	HB	(11) 4	(200) 0	(5) 5	(300) 0	(12.1) 4	–	–	14,000	–	–	–
	1.45	0.057	HB	(15) 3	(200) 0	(7) 4	(300) 0	(22.0) 4	(5) 3	15.7/–	14,000	–	–	–
XXX	0.71	0.028	–	(10) 4	(200) 0	(8) 4	(300) 0	(13.3) 4	–	–	13,500	–	–	–
	1.45	0.057	HB	(11) 4	(200) 0	(10) 4	(300) 0	(12.1) 4	(4) 3	–	13,500	–	–	–
XXXXP	0.71	0.028	HB	(18) 3	(200) 0	(6) 5	(300) 0	(7.5) 4	–	38.4/ 18.6	12,000	–	–	–
	1.45	0.057	HB	(17) 3	(200) 0	(8) 4	(300) 0	(11.3) 4	(6) 3	–	12,000	(100) 4	–	–

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Table 7.1 Continued

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc) PLC		Min HWI (Sec) PLC	Max HVAR (Sec) PLC	Max HVTR (in/mm) PLC	D 495 PLC	Min dielectric strength KV/mm	Min flexural strength psi	CTI (V) PLC	Vol resis ohm-cm x10 ^a	Water ab %Chg
	mm	inch		OS	AS									
XXXPC	0.71	0.028	HB	(11) 4	(128) 0	(5) 5	(300) 0	(13.0) 4	—	—	12,000	—	—	—
	1.45	0.057	HB	(19) 3	(200) 0	(6) 5	(300) 0	(11.6) 4	—	—	12,000	(100) 4	7,5	—
C	0.63	0.025	—	(7) 4	(200) 0	(8) 4	(300) 0	(11.7) 4	—	—	17,000	—	—	—
	1.40	0.055	HB	(7) 4	(200) 0	(9) 4	(300) 0	(10.6) 4	(4) 3	8.9/—	17,000	—	—	—
CE	0.63	0.025	—	(7) 4	(200) 0	(9) 4	(300) 0	(15.0) 4	—	18.3/—	16,500	—	—	—
	1.40	0.055	HB	(6) 4	(200) 0	(9) 4	(300) 0	(14.3) 4	(6) 3	15.9/—	16,500	—	—	—
L	0.63	0.025	—	(10) 4	(200) 0	(5) 5	(300) 0	(14.0) 4	—	—	16,500	—	—	—
	1.45	0.057	HB	(11) 4	(200) 0	(6) 5	(300) 0	(15.0) 4	(4) 3	7.3/—	16,500	—	—	—
LE	0.63	0.025	—	(10) 4	(200) 0	(7) 4	(300) 0	(15.7) 4	—	—	16,000	—	—	—
	1.45	0.057	HB	(6) 4	(200) 0	(9) 4	(300) 0	(17.2) 4	(4) 3	11.0/—	16,000	—	—	—
G-3	0.63	0.025	HB	(6) 4	(200) 0	(9) 4	(300) 0	(12.0) 4	—	30.6/—	18,000	—	—	—
	1.40	0.055	HB	(6) 4	(200) 0	(17) 3	(300) 0	(24.0) 4	—	16.3/—	20,000	—	—	—
G-5	0.63	0.025	V-0	(24) 3	(200) 0	(11) 4	(300) 0	(0.2) 0	—	—	55,000	—	—	—
	1.40	0.055	V-0	(57) 2	(200) 0	(18) 3	(300) 0	(0.2) 0	(62) 2	28.0/—	50,000	—	—	—
G-7	0.63	0.025	V-0	(6) 4	(200) 0	(15) 3	(300) 0	(0.1) 0	—	14.8/—	10,000	—	—	—
	1.40	0.055	V-0	(6) 4	(200) 0	(11) 4	(300) 0	(0.1) 0	—	7.7/—	20,000	—	—	—
G-9	0.63	0.025	V-0	(53) 2	(200) 0	(6) 5	(300) 0	(11.7) 4	—	23.2/—	—	—	—	—
	1.40	0.055	V-0	(83) 1	(200) 0	(20) 3	(300) 0	(0.2) 0	—	25.2/—	60,000	—	—	—

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UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc) PLC		Min HWI (Sec) PLC	Max HVAR (Sec) PLC	Max HVTR (in/mm) PLC	D 495 PLC	Min dielectric strength KV/mm	Min flexural strength psi	CTI (V) PLC	Vol resis ohm-cm x10 ^a	Water ab %Chg
	mm	inch		OS	AS									
G-10	0.63	0.025	HB	(39) 2	(200) 0	(9) 4	(300) 0	(0.8) 0	—	32.0/ 29.8	60,000	—	—	—
	1.40	0.055	HB	(42) 2	(200) 0	(12) 4	(300) 0	(0.8) 0	(32) 2	—	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/—	60,000	—	—	—
	1.40	0.055	HB	(7) 4	(200) 0	(17) 3	(300) 0	(12.0) 4	—	34.1/—	60,000	—	—	—
FR-1	0.71	0.028	V-1, V-0	(17) 3	(200) 0	(120) 3	(300) 0	(0.0) 4	(126) 2	—	—	—	—	—
	1.45	0.057	V-0	(18) 3	(200) 0	(120) 3	(300) 0	(0.0) 4	(126) 2	19.7/ 15.7	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	12,000	—	—	—
	1.45	0.057	V-1, V-0	(18) 3	(200) 0	(9) 4	(300) 0	(10.5) 4	(93) 2	—	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	20,000	—	—	—
	1.45	0.057	V-1, V-0	(200) 0	(200) 0	(133) 0	(300) 0	(35.0) 4	—	—	20,000	(100) 4	8,8	—
FR-4	0.63	0.025	V-0	(16) 3	(200) 0	(300) 0	(300) 0	(10.4) 4	—	31.8/ 30.7	60,000	—	—	—
	1.40	0.055	V-0	(48) 2	(200) 0	(300) 0	(300) 0	(13.7) 4	(14) 3	—	60,000	(100) 4	9,9	0.20
FR-5	0.63	0.025	V-1, V-0	(16) 3	(200) 0	(18) 3	(300) 0	(16.6) 4	—	31.2/ 29.6	60,000	—	—	—
	1.40	0.055	V-1, V-0	(48) 2	(200) 0	(44) 2	(300) 0	(16.5) 4	(4) 3	—	60,000	(100) 4	9,9	0.20
CEM-1	0.63	0.025	V-0	(33) 2	(200) 0	(25) 3	(120) 1	(24.0) 4	—	38.6/ 35.9	50,000	—	—	—
	1.57	0.062	V-0	(42) 2	(200) 0	(79) 1	(120) 1	(14.7) 4	(109) 2	30.3/ 28.1	35,000	(200) 3	8,8	0.14
CEM-3	0.63	0.025	V-0	(44) 2	(200) 0	(120) 0	(120) 1	(11.4) 4	—	29.5/—	50,000	—	—	—
	1.40	0.055	V-0	(47) 2	(200) 0	(120) 0	(120) 1	(11.3) 4	—	35.4/ 35.4	40,000	(225) 3	8,21	0.21

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Table 7.1 Continued

UL/ANSI Type	Min thickness		Flam class	Min HAI (Arc) PLC		Min HWI (Sec) PLC	Max HVAR (Sec) PLC	Max HVTR (in/mm) PLC	D 495 PLC	Min dielectric strength KV/mm	Min flexural strength psi	CTI (V) PLC	Vol resis ohm-cm x10 ^a	Water ab %Chg
	mm	inch		OS	AS									
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) 2	–	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) 1	–	18,000	(500) 1	–	0.28
GPY	0.63	0.025	HB, V-1, V-0	3 0	(200) 0	(300) 0	(15) 3	0	–	38.9/ 37.8	65,000	–	8,14	–
	1.40	0.055	V-1, V-0	3 0	(200) 0	(300) 0	(300) 0	0	1	–	53,500	(100) 4	–	–

NOTES

- 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.)
- HAI– high-current arc ignition
- HWI – hot wire ignition
- HVTR – high-voltage tracking rate
- HVAR– high-voltage arc resistance
- Flam class – flammability classification
- CTI – comparative tracking index (All samples for the CTI are to be 3.2 mm or 0.125 inch thick.)
- Vol resis – volume resistivity
- Water ab – water absorption
- The exponent “a” in the “Vol resis” column corresponds to the pairs of numbers shown in the column. The first number in the pair corresponds to a wet condition, whereas the second number corresponds to a dry condition.

Table 7.2
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	0.63	(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
CEM-1	0.63	(0.025)	0.8	(0.031)	130	140

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Table 7.2 Continued

UL/ANSI Type	Minimum thickness		Nominal thickness		Relative thermal index	
	mm	(inch)	mm	(inch)	Electrical	Mechanical
CEM-3	0.63	(0.025)	0.8	(0.031)	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 1-point thermal aging program.

^b A maximum relative thermal index of 120°C may be assigned on successful completion of 1-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 9.3, for additional information regarding 1- and 2-point thermal aging programs.

Table 7.3
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
FR-4	Epoxy	Continuous filament woven glass fabric
FR-5	Epoxy	Continuous filament woven glass fabric
CEM-1	Epoxy	Continuous filament woven glass fabric surfaces, cellulose paper core
CEM-3	Epoxy	Continuous filament woven glass fabric surfaces, nonwoven glass core
GPO-2	Polyester	Random laid material of glass fibers
GPO-3	Polyester	Random laid material of glass fibers

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Table 7.3 Continued on Next Page



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Table 7.3 Continued

UL/ANSI type	Resin	Reinforcement material
FR-6	Polyester	Random laid material of glass fibers
GPY	Polyimide	Continuous filament woven glass fabric

7.2 An industrial laminate shall be evaluated with samples provided in accordance with the thickness tolerances given in Table 7.4.

7.2 revised February 21, 2007

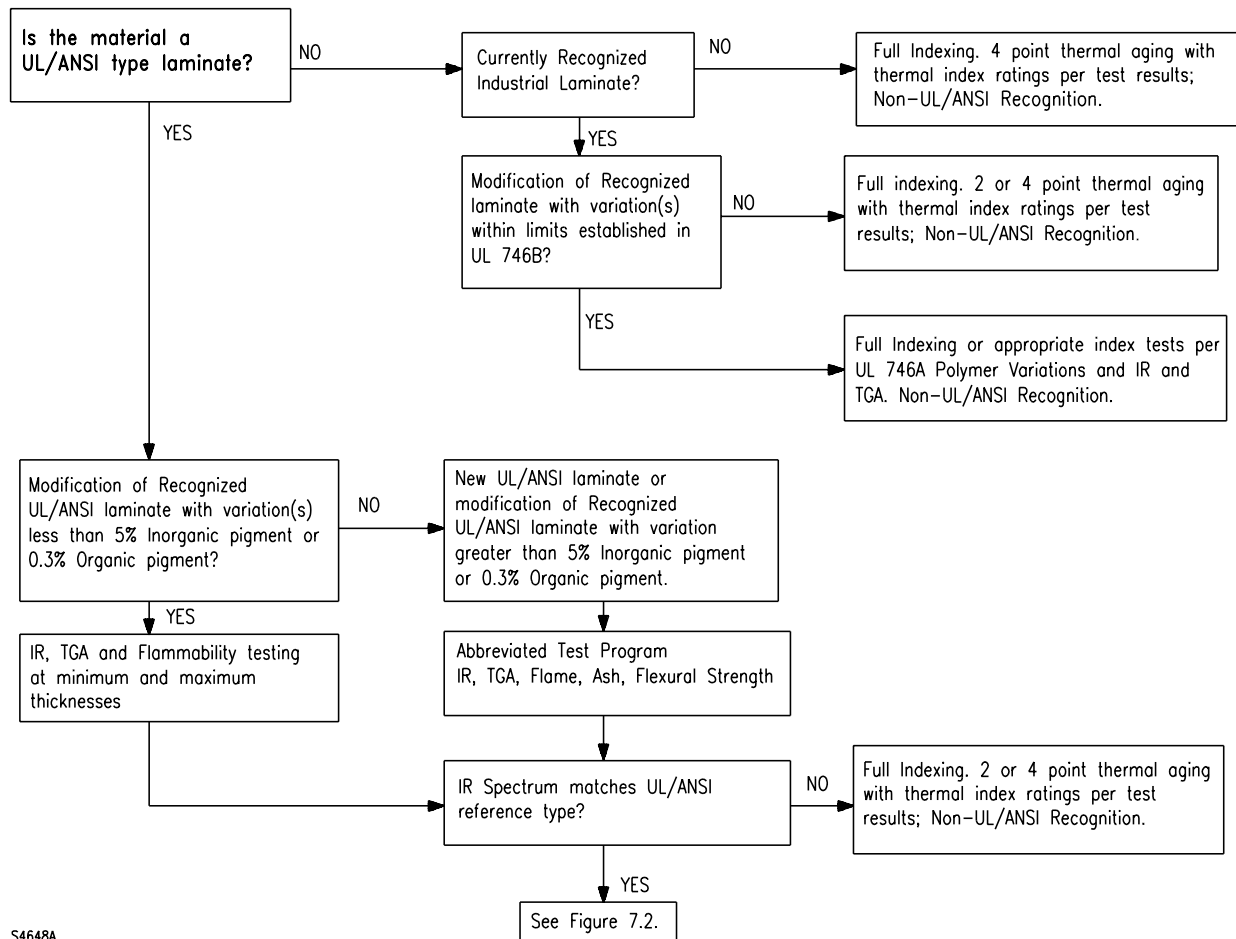
Table 7.4
Industrial laminate build-up thickness and tolerances

Table 7.4 revised February 21, 2007

Laminate minimum thickness,		Thickness tolerance,	
mm	(in)	mm	(in)
Less than 0.020	Less than 0.0007	± 0.003	± 0.0001
0.020 – 0.074	0.0007 – 0.003	± 0.003	± 0.0001
0.075 – 0.099	0.003 – 0.004	± 0.007	± 0.0003
0.010 – 0.19	0.004 – 0.007	±0.02	±0.0008
0.20 – 0.37	0.008 – 0.014	±0.03	±0.0012
0.38 – 0.62	0.015 – 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

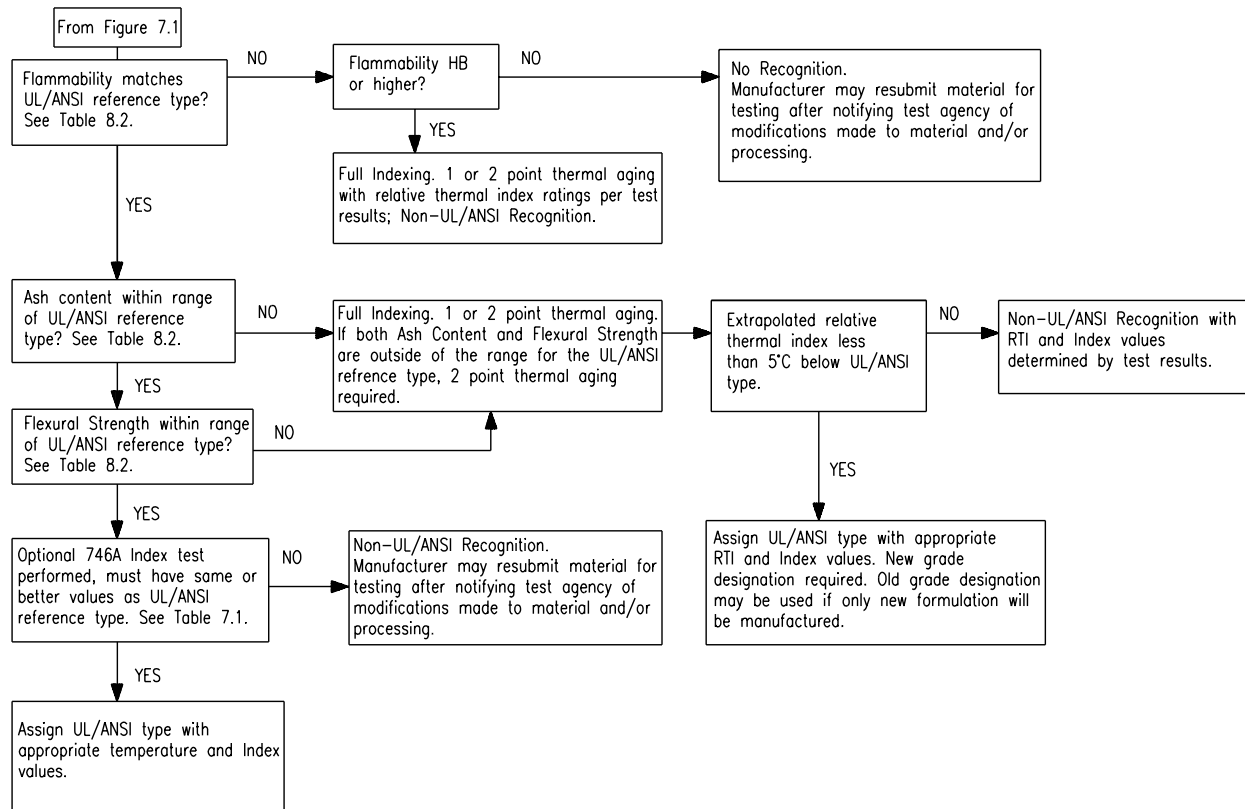
7.3 Industrial laminates are evaluated for designation as a specific UL/ANSI material type or other designation by using the procedures in this Standard to obtain a profile of performance for comparison with those of known UL/ANSI material types. Figure 7.1 shows the procedures to be followed in this evaluation.

Figure 7.1
Testing and evaluation program for rigid industrial laminates



S4648A

Figure 7.2
Testing and evaluation program for rigid industrial laminates (continued)



S4649A

7.4 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 Tables 7.1 and 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 7.1.

7.5 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.

7.6 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 and Related Material – Coverage of Variations in Material Composition, Section 19 of the Standard for Polymeric Materials – Long Term Evaluations, UL 746B.

7.6 added April 17, 2006

7.7 Where modification of a previously tested grade consists of a variation of the original percentage of dye or pigment of not more than 5 percent inorganic or 0.3 percent organic, infrared analysis and thermogravimetric analysis in accordance with the Standard for Polymeric Materials – Short Term Property 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, is required. Higher loading requires additional long term thermal aging for flexural or dielectric strength properties and flammability in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

7.7 revised April 17, 2006

7.8 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.

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Table 8.1
Industrial laminate abbreviated unaged property test program and sample requirements

Table 8.1 revised February 21, 2007

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	UL 746A
Thermogravimetric Analysis (TGA)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	All	UL 746A
Flexural Strength	100 x 25 (4 x 1)	1.6 (0.062)	10	All	UL 746A
	100 x 25 (4 x 1)	0.8 (0.031)	10	All except XPC, G-9, FR-1, GPO-2, GPO-3	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	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	UL 746A
Flammability Vertical	125 x 13 (5 x 0.5)	1.6 (0.062)	20	All	UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	20	All	UL 94
Flammability Horizontal	125 x 13 (5 x 0.5)	1.6 (0.062)	6	All	UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	6	All	UL 94
GPO-2 or GPO-3 Thermal Aging (Optional - See 8.9)					
2-Point Thermal Aging Flexural Strength	100 x 25 (4 x 1)	0.8 (0.031)	200	GPO-2, GPO-3	UL 746B
2-Point Thermal Aging Dielectric Strength	100 x 100 (4 x 4)	1.6 (0.062)	200	GPO-2, GPO-3	UL 746B
2-Point Thermal Aging Dielectric Strength	100 x 100 (4 x 4)	0.8 (0.031)	200	GPO-2, GPO-3	UL 746B
a) The above samples are to be in the machine (grain) direction. b) The samples are to be prepared declad by completely etching a metal clad sheet, where applicable. c) Vertical or Horizontal flammability testing shall be performed in accordance with Table 8.2. d) 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 17.9 shall be performed. e) See Section 10 for the Ultrathin Laminate and Prepreg Test program.					

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 7.1 and the relative thermal index shown in Table 7.2 for that UL/ANSI material. A UL/ANSI material requiring a separate adhesive to bond the metal cladding shall comply with the additional Performance Profile Indexing tests shown in 17.9.1, 17.9.2, and 17.9.3. 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. See Section 9.

8.3 The criteria in 8.4 – 8.9 is to be applied when comparing industrial laminates with UL/ANSI material types.

8.4 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. Sample thicknesses are given in Table 8.2. A laminate shall have a flammability classification in each thickness as indicated in Table 8.2, except a laminate, subjected additionally to the testing indicated in 8.5, shall have a flammability class of HB or higher.

Table 8.2
Abbreviated industrial laminate program requirements

Table 8.2 revised February 21, 2007

UL/ANSI Grade	Acceptable values					
	Minimum flexural strength (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	22,000	25,000	–	–	HB	HB
XP	12,000	13,000	–	–	HB	HB
XPC	–	10,000	–	–	HB	HB
XX	15,000	15,000	–	–	HB	HB
XXP	14,000	14,000	–	–	HB	HB
XXX	13,500	13,500	–	–	HB	HB
XXXP, XXXPC	12,000	12,000	–	–	HB	HB
C	17,000	17,000	–	–	HB	HB
CE, L	16,500	16,500	–	–	HB	HB
LE	16,000	16,000	–	–	HB	HB
G-3	18,000	20,000	57.7 – 67.2	57.7 – 67.2	HB	HB
G-5	55,000	50,000	55.0 – 63.3	55.0 – 63.3	V-0	V-0
G-7	10,000	20,000	85.3 – 91.6	85.3 – 91.6	V-0	V-0
G-9	–	60,000	55.0 – 63.3	55.0 – 63.3	V-0	V-0
G-10	60,000	60,000	55.0 – 67.7	55.0 – 67.7	HB	HB
G-11	60,000	60,000	60.5 – 70.0	60.5 – 70.0	HB	HB
FR-1	–	10,000	–	–	V-0 or V-1	V-0 or V-1
FR-2	12,000	12,000	–	–	V-0 or V-1	V-0 or V-1
FR-3	20,000	20,000	–	–	V-0 or V-1	V-0 or V-1
FR-4	60,000	60,000	55.0 – 67.7	55.0 – 67.7	V-0	V-0
FR-5	60,000	60,000	60.5 – 70.0	60.5 – 70.0	V-0 or V-1	V-0 or V-1
CEM-1	50,000	35,000	32.6 – 39.8	16.4 – 23.3	V-0	V-0

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Table 8.2 Continued on Next Page



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Table 8.2 Continued

UL/ANSI Grade	Acceptable values					
	Minimum flexural strength (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)
CEM-3	50,000	40,000	42.7 – 68.3	29.7 – 44.9	V-0	V-0
GPO-2	–	18,000	44.6 – 60.2	44.6 – 60.2	–	V-0
GPO-3	–	18,000	47.8 – 57.2	47.8 – 57.2	–	V-0
GPY	65,500	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 one 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 made from resin obtained by surface scraping of the glossy side of the industrial laminate in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. The spectrum obtained shall indicate the same composition as recorded in the spectrum of the reference UL/ANSI type. Typical infrared (IR) reference spectra are shown in Figures D1.1 – D1.31, 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. Appendix A contains the infrared analysis conformance criteria.

8.6 revised February 21, 2007

8.6.1 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. The material shall not be given a UL/ANSI type designation.

8.6.1 added February 21, 2007

8.7 An ash content analysis is to be conducted in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, on materials that contain a noncombustible reinforcement such as fiberglass. To determine compliance, the ash content shall fall within the range of values shown in Table 8.2.

Exception No. 1: When ash content is not as shown in Table 8.2 but flammability, infrared analysis, and flexural strength are acceptable, full indexing and one point thermal aging shall be conducted as described in the Full Test Program, Section 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.

Exception No. 2: When ash content and flexural strength are not as shown in Table 8.2 but flammability and infrared analysis are acceptable, full indexing and two point thermal aging shall be conducted as described in the Full Test Program, Section 9. See Table 9.1. When test results are determined to be equivalent to the UL/ANSI type, a relative thermal index and a UL/ANSI type designation shall be assigned.

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

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

- a) The electrical relative thermal index values shall compare favorably with the values shown in Table 7.2.
- b) An electrical relative thermal index of 105°C shall be assigned without conducting a thermal aging program.
- c) 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 9.3.

8.10 Thermogravimetric Analysis (TGA) shall be conducted in accordance with the Standard Test Method for Rapid Thermal Degradation of Solid Electrical Insulating Materials by the Thermogravimetric Method, ASTM D 3850, for characterization of the laminate. Appendix B contains the thermogravimetric analysis conformance criteria.

8.10 revised April 17, 2006

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 7.1 in conjunction with a 1, 2, or 4 point thermal aging program. The 1 or 2 point thermal aging program shall not result in the assignment of a UL/ANSI type designation if the infrared analysis or flammability classification of the material does not compare favorably with the UL/ANSI type data shown in Table 8.2 or the UL/ANSI reference spectra. Typical infrared (IR) reference spectra of each UL/ANSI type are shown in Figures D1.1 – D1.31. 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.

9.1 revised February 21, 2007

9.2 The required profile of performance tests are shown in Table 9.1 together with the samples required for the test. Test methods shall be in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, and the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A.

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Table 9.1
Rigid industrial laminate full test program and sample requirements

Table 9.1 revised May 15, 2007

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	UL 746A
Thermogravimetric Analysis (TGA)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	All	UL 746A
Differential Scanning Calorimetry (DSC)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	Thermoplastic Materials	UL 746A
Flexural Strength	100 x 25 (4 x 1)	1.6 (0.062)	10	All	UL 746A
	100 x 25 (4 x 1)	0.8 (0.031)	10	All	UL 746A
Ash Content	125 x 13 (5 x 0.5)	1.6 (0.062)	10	All (if applicable)	UL 746A
	125 x 13 (5 x 0.5)	0.8 (0.031)	10	All (if applicable)	UL 746A
Flammability Vertical	125 x 13 (5 x 0.5)	1.6 (0.062)	20	All	UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	20	All	UL 94
Flammability Horizontal	125 x 13 (5 x 0.5)	1.6 (0.062)	6	All	UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	6	All	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)	5	All	UL 746A
	125 x 13 (5 x 0.5)	0.8 (0.031)	5	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
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

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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
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 de-clad 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 de-clad samples, where applicable. If a separate adhesive is used to apply metal cladding to the laminate, the additional performance profile indexing tests shown in 17.9 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, 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).
- 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) See Section 10 for the Ultrathin Laminate and Prepreg Test program.
- 9) 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.

9.3 Thermal aging tests for a 1- or 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 1- or 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.

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Table 9.2
Examples of two-point thermal aging programs

Table 9.2 revised February 21, 2007

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

9.4 A comparison of the 1-point thermal aging results of the candidate and control material is to be conducted. Both the candidate material and the control material are assumed to have the same activation energy of degradation as the desired UL/ANSI type, i.e., the lifelines generated for both the candidate and control materials are assumed to have the same slope as the lifeline of the requested UL/ANSI type. If the extrapolated relative thermal index of the candidate material is more than 5°C (9°F) below the relative thermal index of the UL/ANSI type, the material shall not be assigned a relative thermal index unless aging tests are conducted at one additional temperature. See 9.5 for the 2 point thermal aging data evaluation procedure.

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 7.2 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 (see the infrared analysis conformance criteria in Appendix A), 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 105°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 105°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.

9.8 revised April 17, 2006

Table 9.3
Polytetrafluoroethylene (PTFE) abbreviated unaged property test program and sample requirements for generic 105°C electrical and mechanical RTI

Table 9.3 revised February 21, 2007

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	UL 746A
Thermogravimetric Analysis (TGA)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	PTFE	UL 746A
Differential Scanning Calorimetry (DSC)	125 x 13 (5 x 0.5)	1.6 (0.062)	5	PTFE	UL 746A
Flammability Vertical	125 x 13 (5 x 0.5)	1.6 (0.062)	20	PTFE	UL 94
	125 x 13 (5 x 0.5)	0.8 (0.031)	20	PTFE	UL 94
Ash Content	125 x 13 (5 x 0.5)	1.6 (0.062)	10	PTFE	UL 746A
	125 x 13 (5 x 0.5)	0.8 (0.031)	10	PTFE	UL 746A
Flexural Strength	100 x 25 (4 x 1)	1.6 (0.062)	10	PTFE	UL 746A
	100 x 25 (4 x 1)	0.8 (0.031)	10	PTFE	UL 746A
The above samples are to be in the machine (grain) direction. The samples are to be prepared by completely etching a metal clad sheet, where applicable. If Direct Support is necessary, the appropriate Performance Profile Index tests shall also be performed. The full test program shall be performed for Electrical and Mechanical RTI's higher than 105°C. See Section 10 for the Ultrathin Laminate and Prepreg Test program.					

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 and may provide direct support of current carrying parts at 120V rms or less and 15A or less.

Table 9.4
Performance level categories (PLC) of industrial laminates used as the base material of
printed-wiring boards that provide direct support of current-carrying parts

Table 9.4 revised February 21, 2007

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

Table 10.1 revised April 17, 2006

Type of laminate	Build-up thickness, mm (in)	Sheet thickness is per Table 8.2	Testing	Reference
UL/ANSI ^a	0.8 (0.031) or greater	Yes	None	10.2.2.1
UL/ANSI ^a	0.8 (0.031) or greater	No	Aging	10.2.2.2
UL/ANSI ^a	0.38 – 0.8 (0.015 – 0.031)	Yes	Indexing	10.2.3.1
UL/ANSI ^a	0.38 – 0.8 (0.015 – 0.031)	No	Aging and indexing	10.2.3.5
UL/ANSI ^a	Less than 0.38 (0.015)	c	Aging and indexing	10.2.4
Non-ANSI ^b	c	c	Aging and indexing	10.3
UL/ANSI or non-ANSI	Same or greater	No ^d	Aging	10.1.6

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

Table 10.1 Continued

Type of laminate	Build-up thickness, mm (in)	Sheet thickness is per Table 8.2	Testing	Reference
^b Candidate material infrared (IR) reference scan does not compare to a UL/ANSI reference scan. ^c Parameter does not affect the required test program. Sample build up shall include minimum individual sheet thickness. ^d The established individual sheet thickness is to be reduced for a ultrathin laminate and/or prepreg.				

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.

10.1.4 The evaluation of thermal aging data shall be conducted as described in 9.7.

10.1.5 The test program, samples, method, data analysis, and evaluation shall be as described in the Standard for Safety for Polymeric Materials – Long Term Property Evaluations, UL 746B.

10.1.6 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. The Primary Property shall be mechanical strength. 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.

10.1.6 added April 17, 2006

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 for FR-4, G-10, GPY, FR-5, and CEM-3 material. All UL/ANSI type materials must comply with the minimum electrical and mechanical RTI's listed in Table 10.2 and may not exceed the electrical and mechanical RTI's listed in Table 7.2.

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Table 10.2
Ultrathin laminates and prepreg generic relative thermal index

Table 10.2 revised February 21, 2007

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 – 0.15	(2 – 6)	110	b
G-10	0.17 – 0.35	(7 – 14)	120	b
G-10	0.38 – 0.61	(15 – 24)	130	130
FR-4	0.05 – 0.07	(2 – 3)	90	b
FR-4	0.10 – 0.35	(4 – 14)	120	b
FR-4	0.38 – 0.76	(15 – 24)	130	130
FR-5	0.38 – 0.61	(15 – 24)	140	140
GPY	0.05	(2)	140	b
GPY	0.10 – 0.35	(4 – 14)	140	b
GPY	0.38 – 0.76	(15 – 30)	140	160
CEM-3	0.10	(4)	120	b
CEM-3	0.25 – 0.40	(10 – 18)	120	b
CEM-3	0.48 – 0.62	(19 – 24)	130	130
CEM-3	0.63 – 0.96	(25 – 38)	130	140

^a The laminate or unpressed, semi-cured prepreg thickness.
^b 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 declared 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 indexing tests and sample requirements

Table 10.3 revised February 21, 2007

Property	Sample dimensions length by width mm (inch)	Minimum thickness mm (inch)	Minimum number of samples	Applicable materials	For method refer to
Mechanical property					
Tensile strength (Bias cut, see Figure 10.1)	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 10.1)	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	UL 94
	125 x 13 (5 x 0.5)	Minimum	20	All	UL 94
Flammability horizontal	125 x 13 (5 x 0.5)	0.38 (0.015)	6	All	UL 94
	125 x 13 (5 x 0.5)	Minimum	6	All	UL 94
NOTES – 1) The samples shall be prepared 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. 3) Vertical or horizontal flammability testing shall be performed based on 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.					