

UL 746E

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

Underwriters Laboratories Inc. (UL)
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Northbrook, IL 60062-2096

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

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

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

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

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

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

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Page	Date
1-32H	November 28, 2001
33-38	June 30, 2000
39	February 7, 2001
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UL 746E

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

First Edition – November, 1985
Second Edition – February, 1994

Third Edition

June 30, 2000

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.

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ANNEX A

TGA Conformance Criteria

FOREWORD

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

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

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

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

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

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

INTRODUCTION

1 Scope

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

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

1.3 *Deleted November 28, 2001*

2 Glossary

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

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

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

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

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

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

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

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

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

2.10 UNCLAD – A laminate material without foil.

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

3 Units of Measurement

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

3A Test Measurement Accuracy

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

3A.1 added November 28, 2001

4 Supplementary Test Procedures

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

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

4.1 revised November 28, 2001

INDUSTRIAL LAMINATES

5 General

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

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

5.2 revised November 28, 2001

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

5.3 revised February 7, 2001

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

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

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

Added 5.6 effective February 7, 2004

Table 5.1
Rigid industrial laminate profiles of performance

Table 5.1 revised November 28, 2001

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

Table 5.1 Continued on Next Page

Table 5.1 Continued

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

Table 5.1 Continued on Next Page

Table 5.1 Continued

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

NOTES

1 For dielectric strength and volume resistivity the double values are:
Dry/Wet = (40 hours/23°C/50% R.H.)/(96 hours/35°C/90% R.H.)

2 HAI— high-current arc ignition

3 HWI — hot wire ignition

4 HVTR — high-voltage tracking rate

5 HVAR— high-voltage arc resistance

6 Flam class — flammability classification

7 Die str — dielectric strength

8 CTI — comparative tracking index (All samples for the CTI are to be 3.2 mm or 0.125 inch thick.)

9 Flex str — flexural strength

10 Vol resis — volume resistivity

11 Water ab — water absorption

12 The exponent "a" in the "Vol resis" column corresponds to the pairs of numbers shown in the column. The first number in the pair corresponds to a wet condition, whereas the second number corresponds to a dry condition.

Table 5.2
Rigid industrial laminate and relative thermal index

Table 5.2 revised November 28, 2001

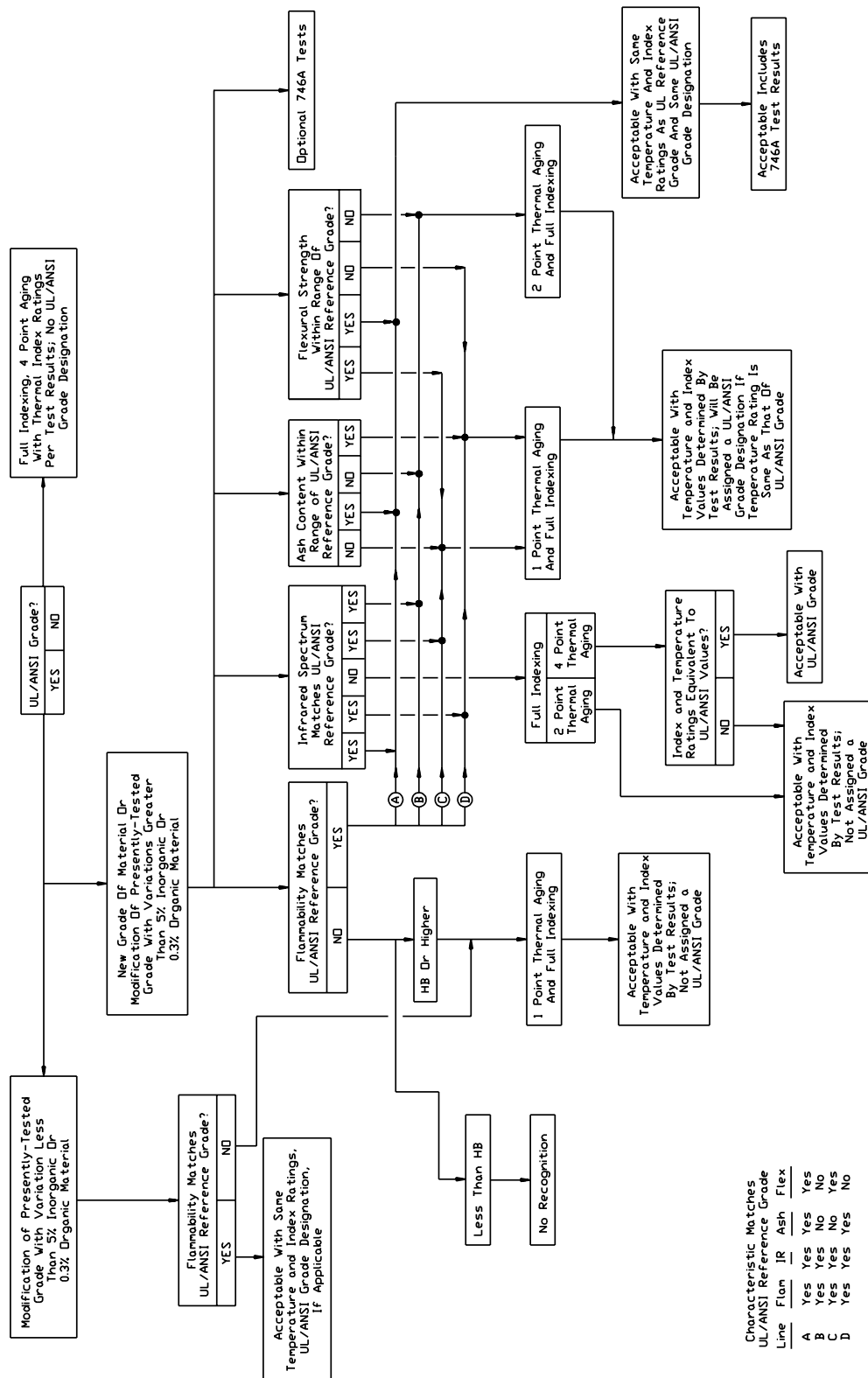
UL/ANSI Type	Minimum thickness		Temperature index	
	mm	(inch)	Electrical	Mechanical
X	0.71	(0.028)	130	130
XP	0.71	(0.028)	130	130
XPC	0.71	(0.028)	130	130
XX	0.71	(0.028)	130	130
	1.45	(0.057)	140	140
XXP	0.71	(0.028)	130	130
	1.45	(0.057)	140	140
XXX	0.71	(0.028)	130	130
	1.45	(0.057)	140	140
XXXP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

^a A temperature index of 130°C may be assigned on successful completion of a one point thermal aging test.
^b A temperature index of 120°C may be assigned on successful completion of a one point aging program.
^c For 0.63 mm (0.025 inch) thick material, a 2 point aging program is required before a temperature rating is assigned.

Table 5.3
Industrial laminate constituents

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

Figure 5.1
UL testing and evaluation program for rigid industrial laminates



SB2974B

6 Abbreviated Test Program

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

6.1 revised November 28, 2001

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

Table 6.1 revised November 28, 2001

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

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

6.2 revised November 28, 2001

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

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

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

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

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

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

Revised 6.6 effective February 7, 2004

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

Added 6.6.1 effective February 7, 2004

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

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

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

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

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

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

a) The electrical temperature index values shall compare favorably with the values shown in Table 5.2.

b) An electrical temperature index of 105°C (221°F) shall be assigned without conducting a thermal aging program.

c) An electrical temperature index higher than 105°C (221°F) may be assigned as the result of a one point thermal aging program on 1.40 mm (0.055 inch) thick samples, or a two point aging program on 0.71 mm (0.028 inch) thick samples. See 7.3.

6.9 revised November 28, 2001

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

Table 6.2
Industrial laminates abbreviated program

Table 6.2 revised November 28, 2001

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

Table 6.2 Continued on Next Page

Table 6.2 Continued

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

^a Approximately 0.8 mm (0.031 inch) thickness.

^b Approximately 1.6 mm (0.062 inch) thickness.

^c 1.6 mm (0.062 inch) thickness only.

^d If not specified otherwise, both the 0.8 mm (0.031 inch) and 1.6 mm (0.062) thicknesses shall be tested.

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

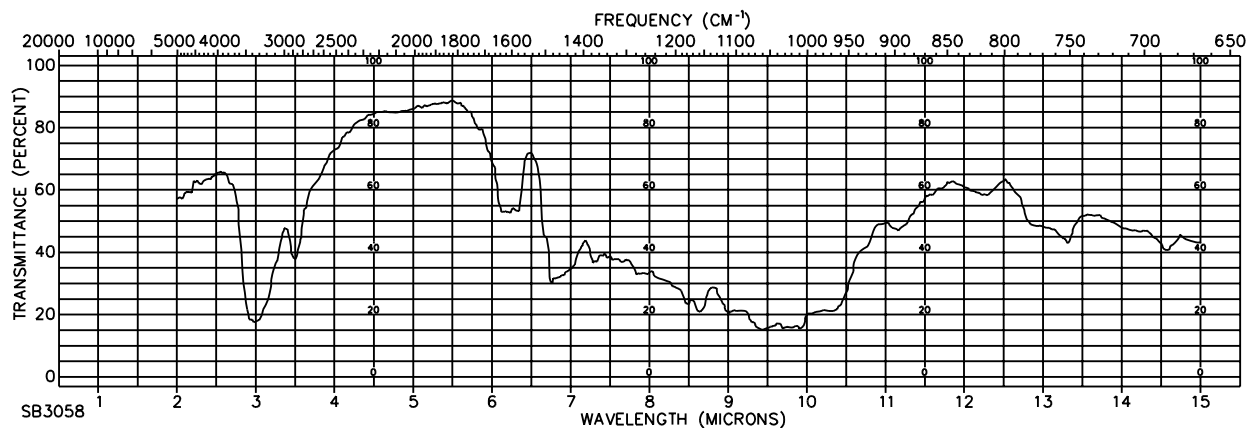


Figure 6.2
Typical IR spectrum for industrial laminates UL/ANSI Types XX, XXP, XXX

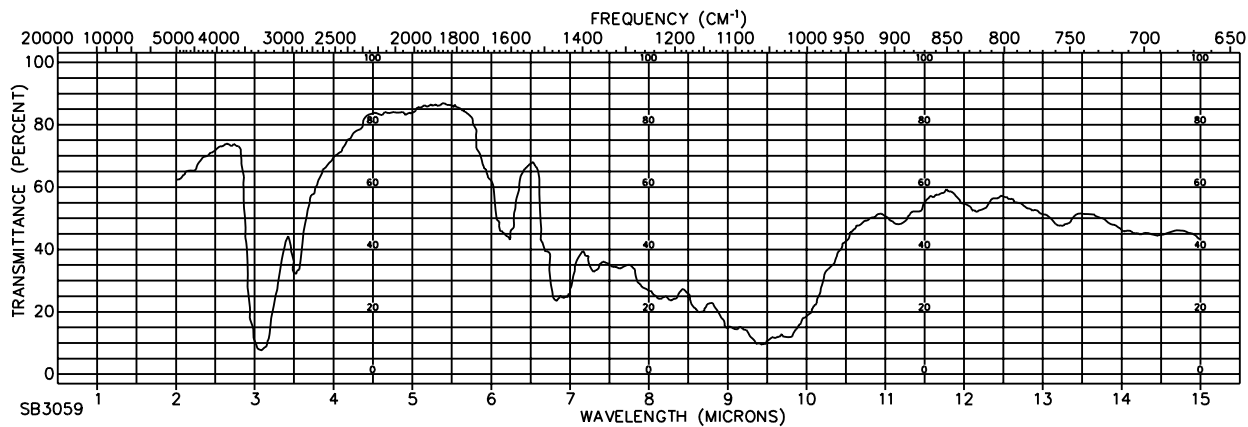


Figure 6.3
Typical IR spectrum for industrial laminates UL/ANSI Types XXXP and XXXPC

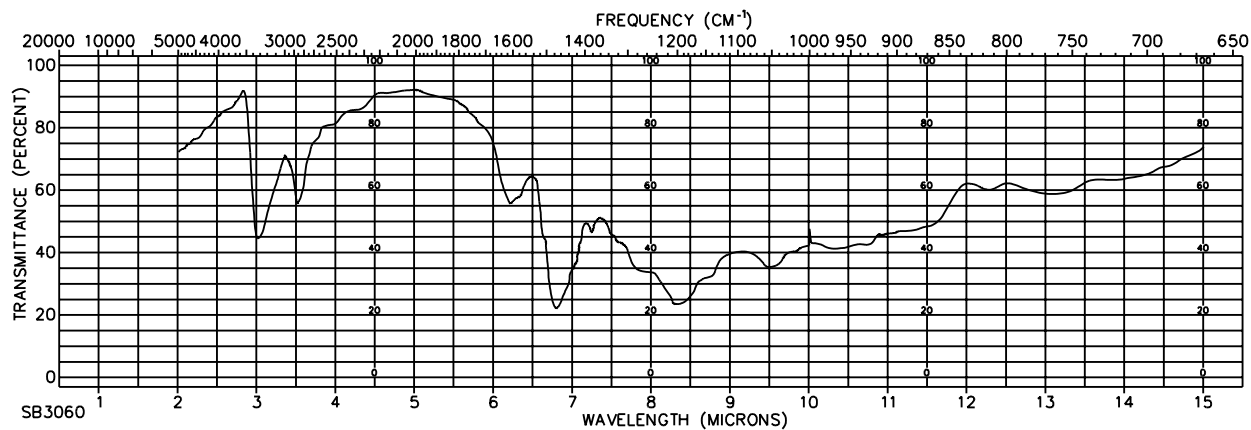


Figure 6.4
Typical IR spectrum for industrial laminates UL/ANSI Types C, CE, L, and LE

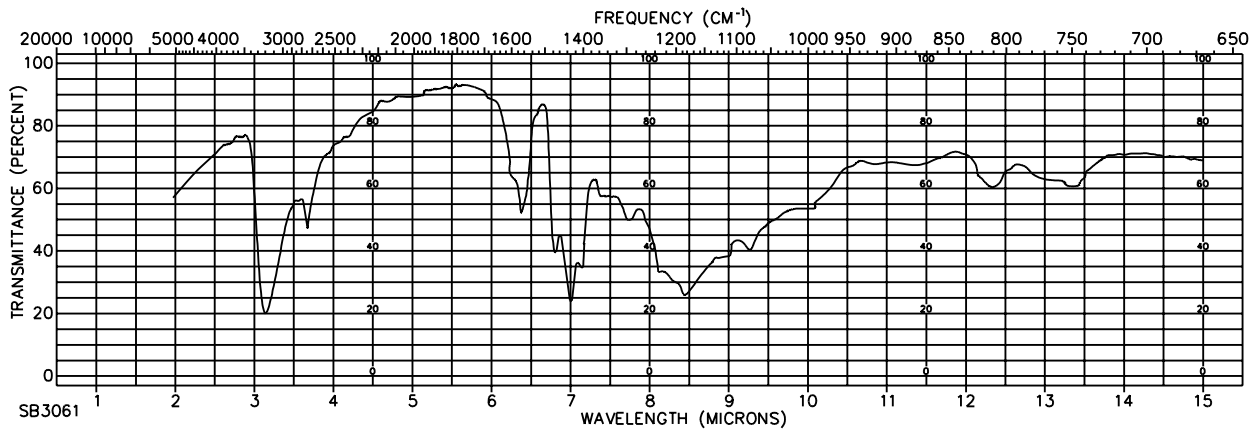


Figure 6.5
Typical IR spectrum for industrial laminates UL/ANSI Types G-5 and G-9

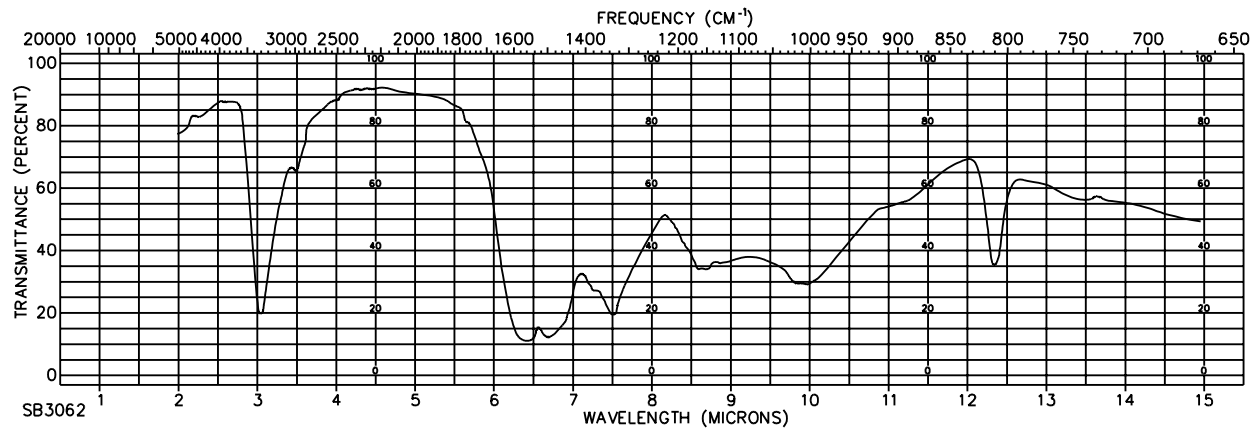


Figure 6.6
Typical IR spectrum for industrial laminates UL/ANSI Type G-7

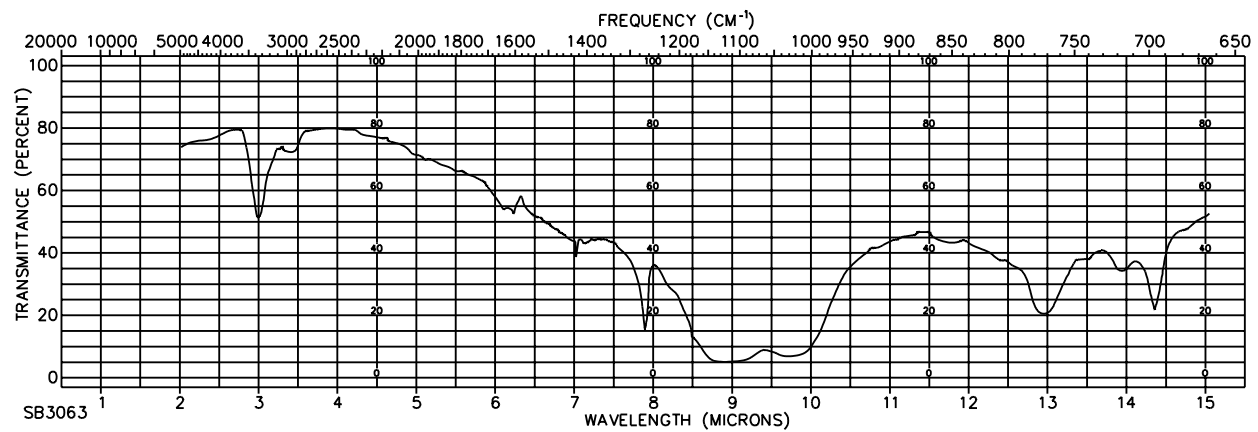


Figure 6.7
Typical IR spectrum for industrial laminates UL/ANSI Types G-10

Revised Figure 6.7 effective February 7, 2004

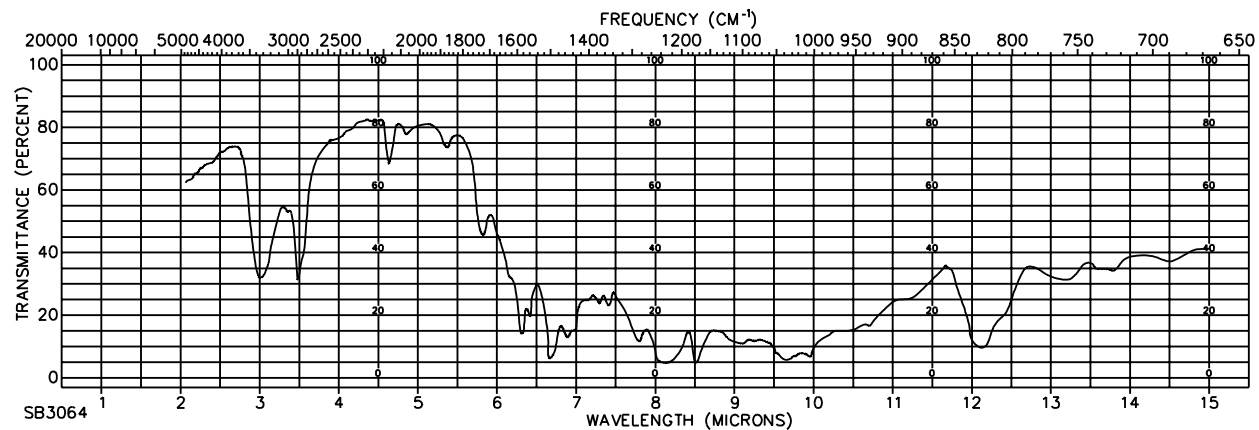
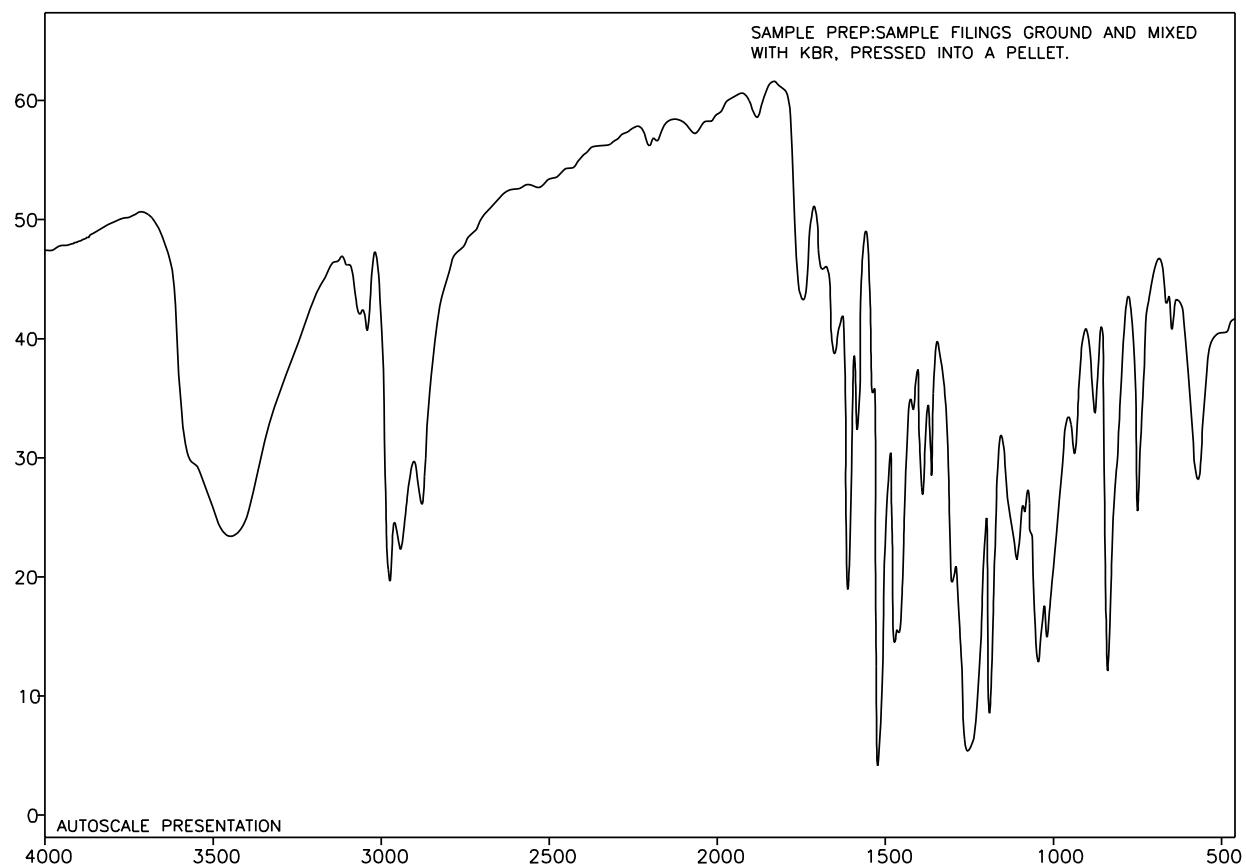


Figure 6.8

Revised Figure 6.8 effective February 7, 2004

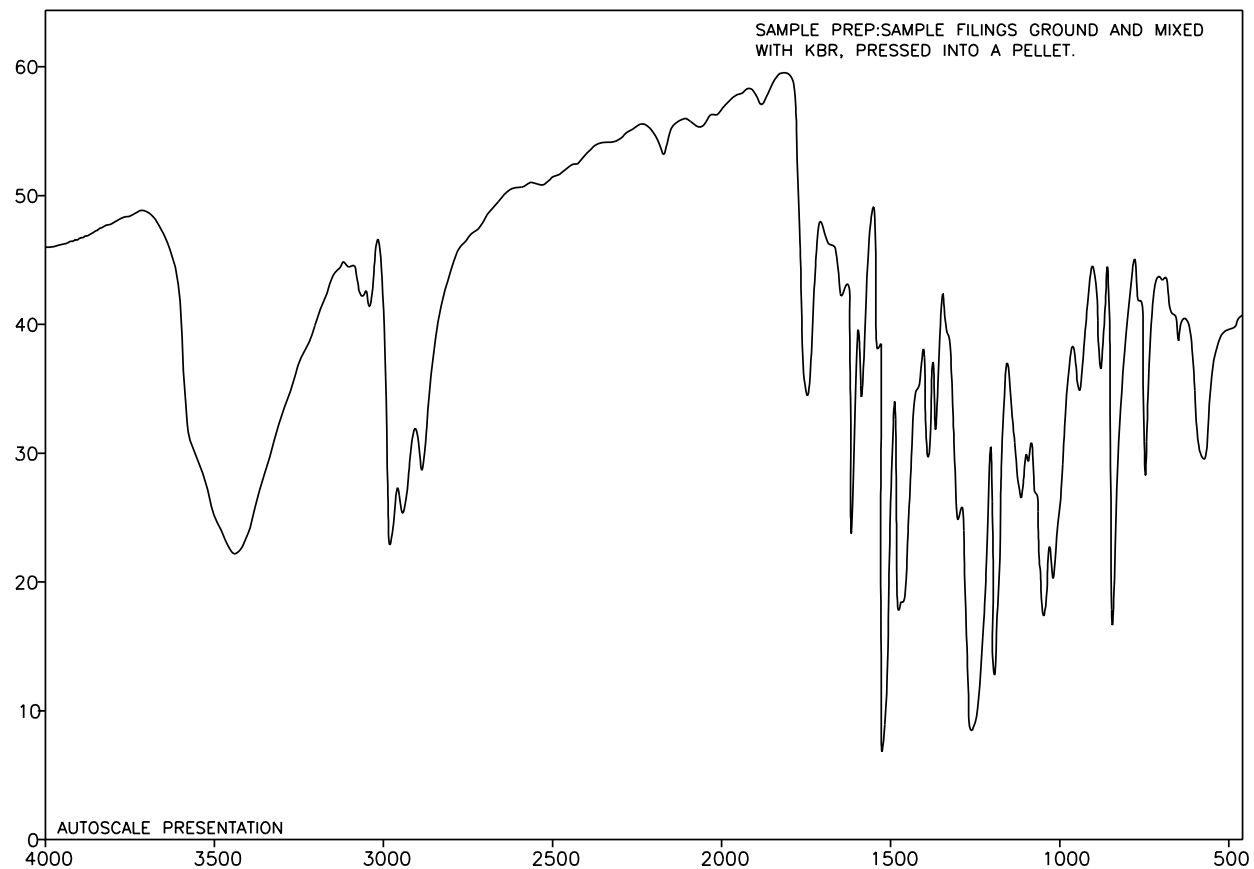
Transmittance/Wavenumber (cm⁻¹)

File#1: NEMA0010

S5140

Figure 6.9

Revised Figure 6.9 effective February 7, 2004



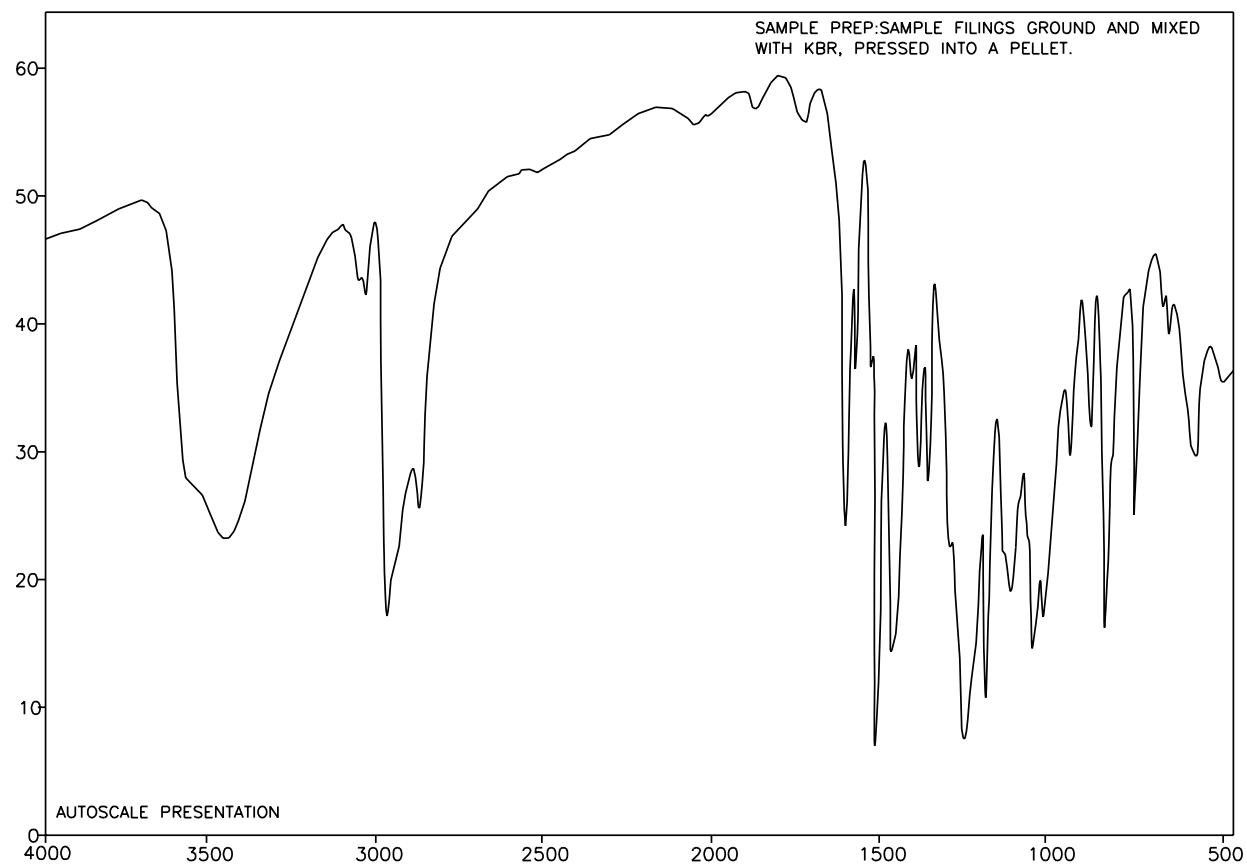
Transmittance/Wavenumber (cm-1)

File#1: NEMA0011

S5141

Figure 6.10

Revised Figure 6.10 effective February 7, 2004



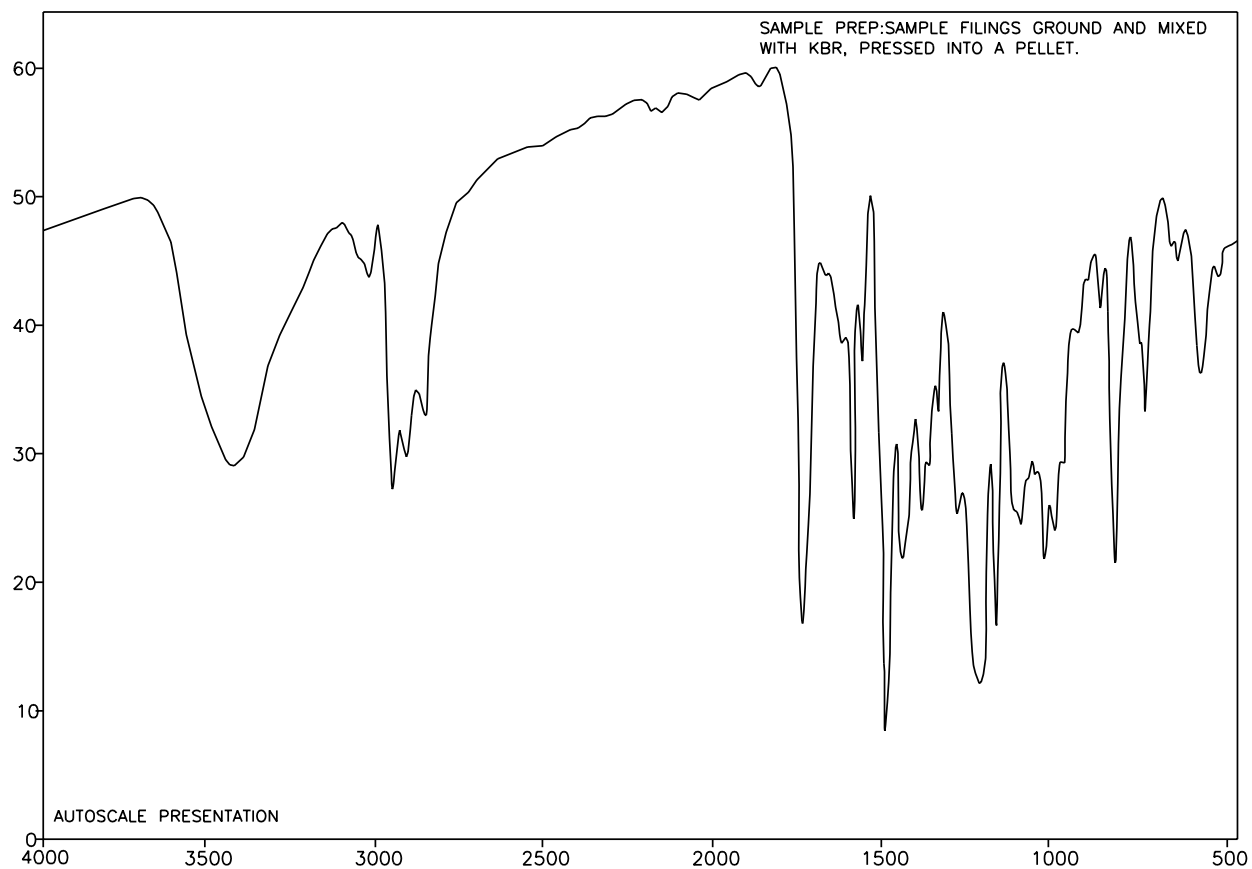
Transmittance/Wavenumber (cm-1)

File #1: NEMA0012

S5142

Figure 6.11

Revised Figure 6.11 effective February 7, 2004

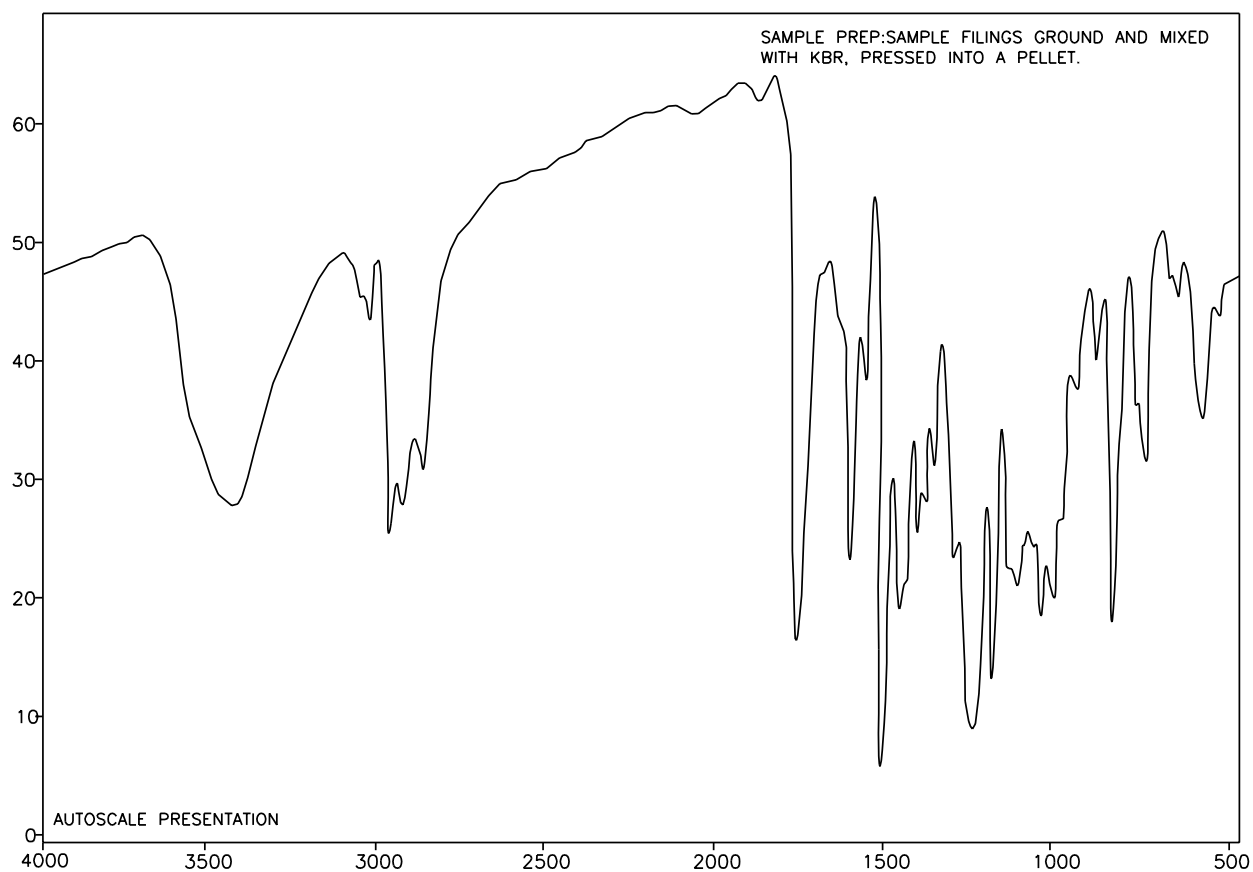
Transmittance/Wavenumber (cm⁻¹)

File #2: NEMA0013

S5143

Figure 6.12

Revised Figure 6.12 effective February 7, 2004

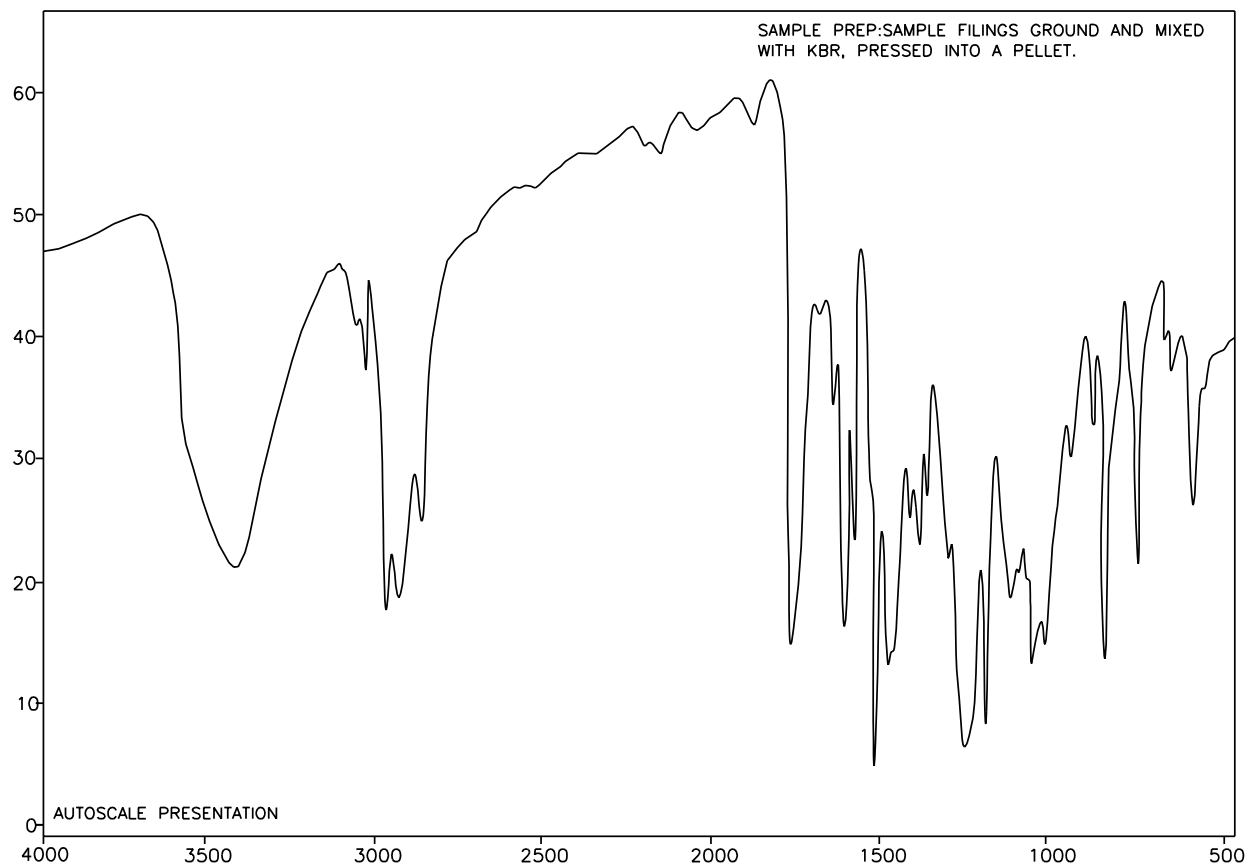


File #1: NEMA0014

S5144

Figure 6.13

Revised Figure 6.13 effective February 7, 2004



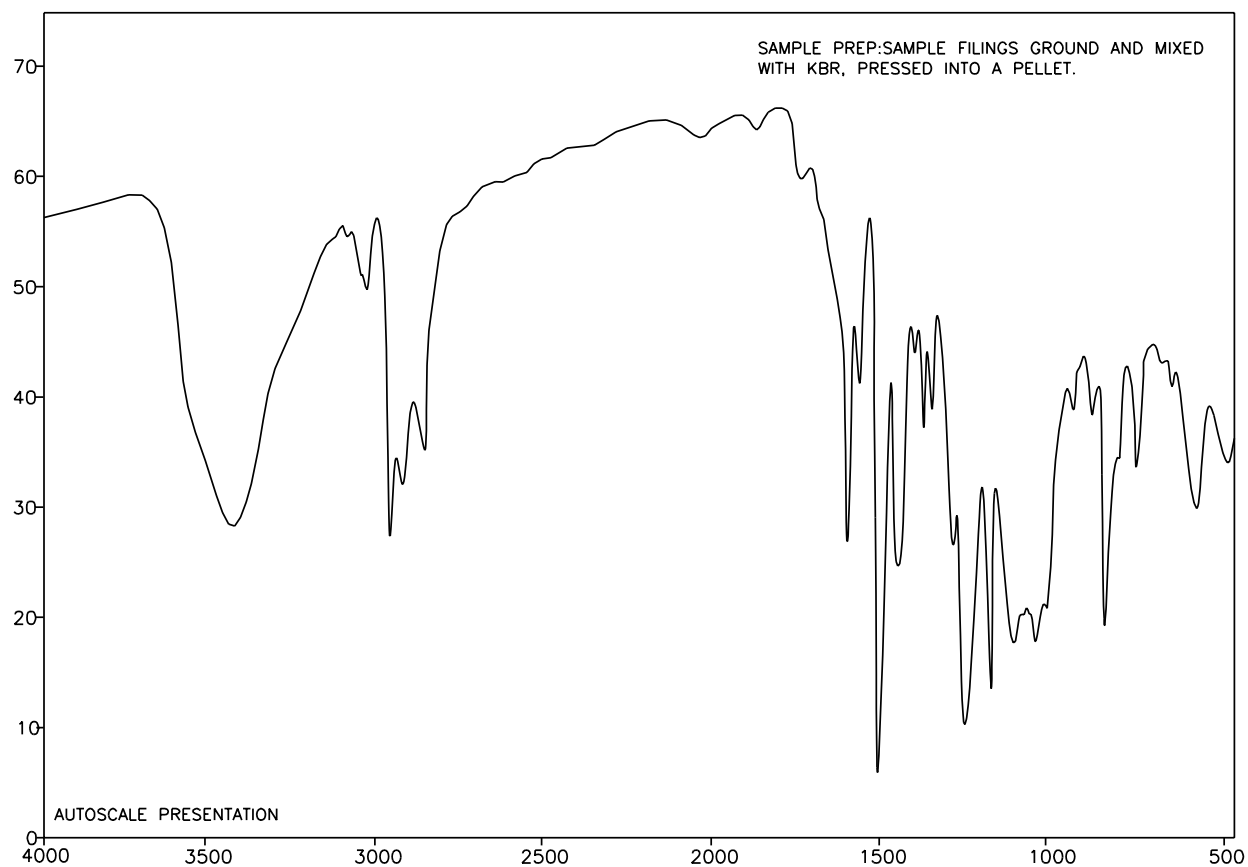
Transmittance/Wavenumber (cm-1)

File #1: NEMA0017

S5145

Figure 6.14

Revised Figure 6.14 effective February 7, 2004



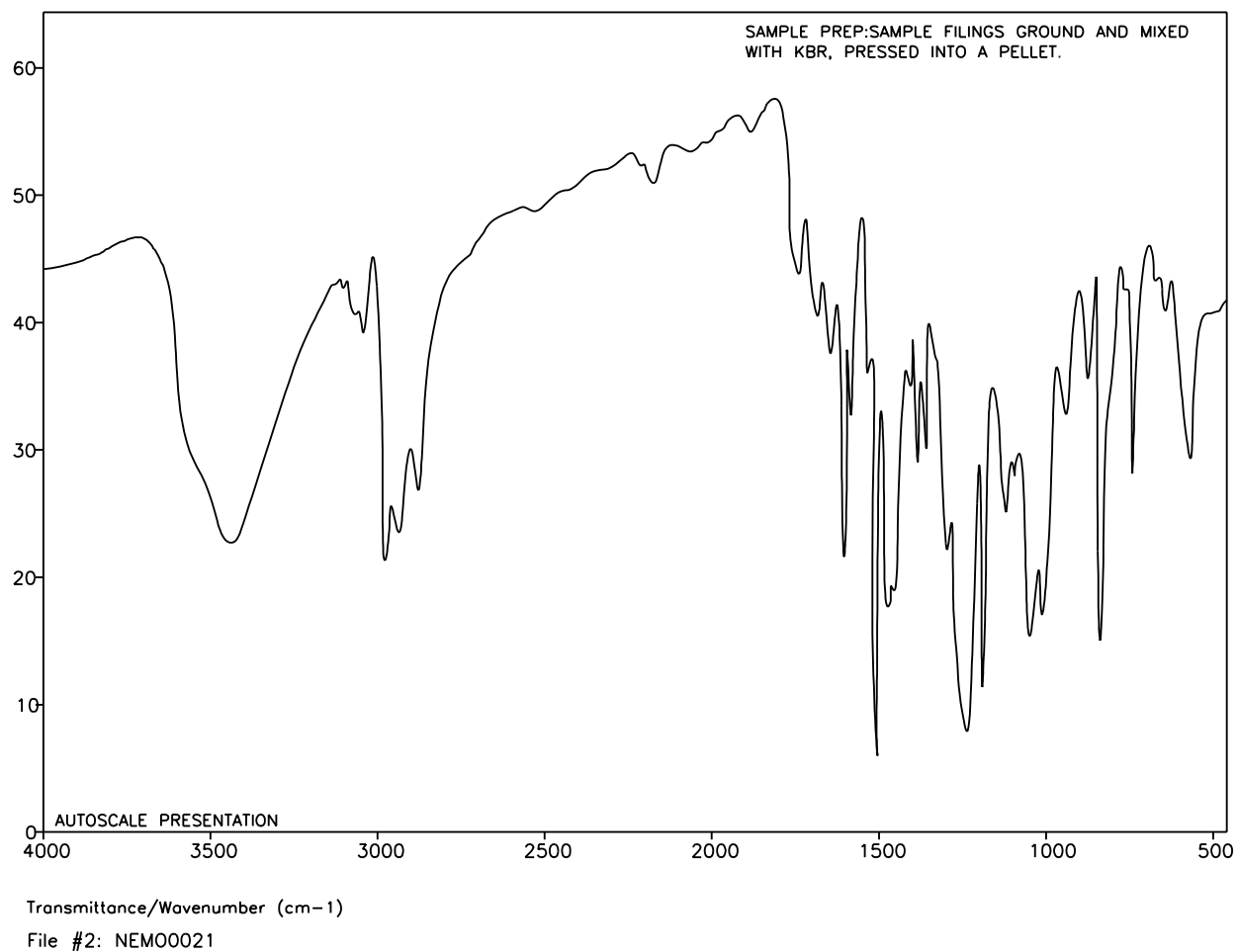
Transmittance/Wavenumber (cm-1)

File #1: NEMA0018

S5146

Figure 6.15

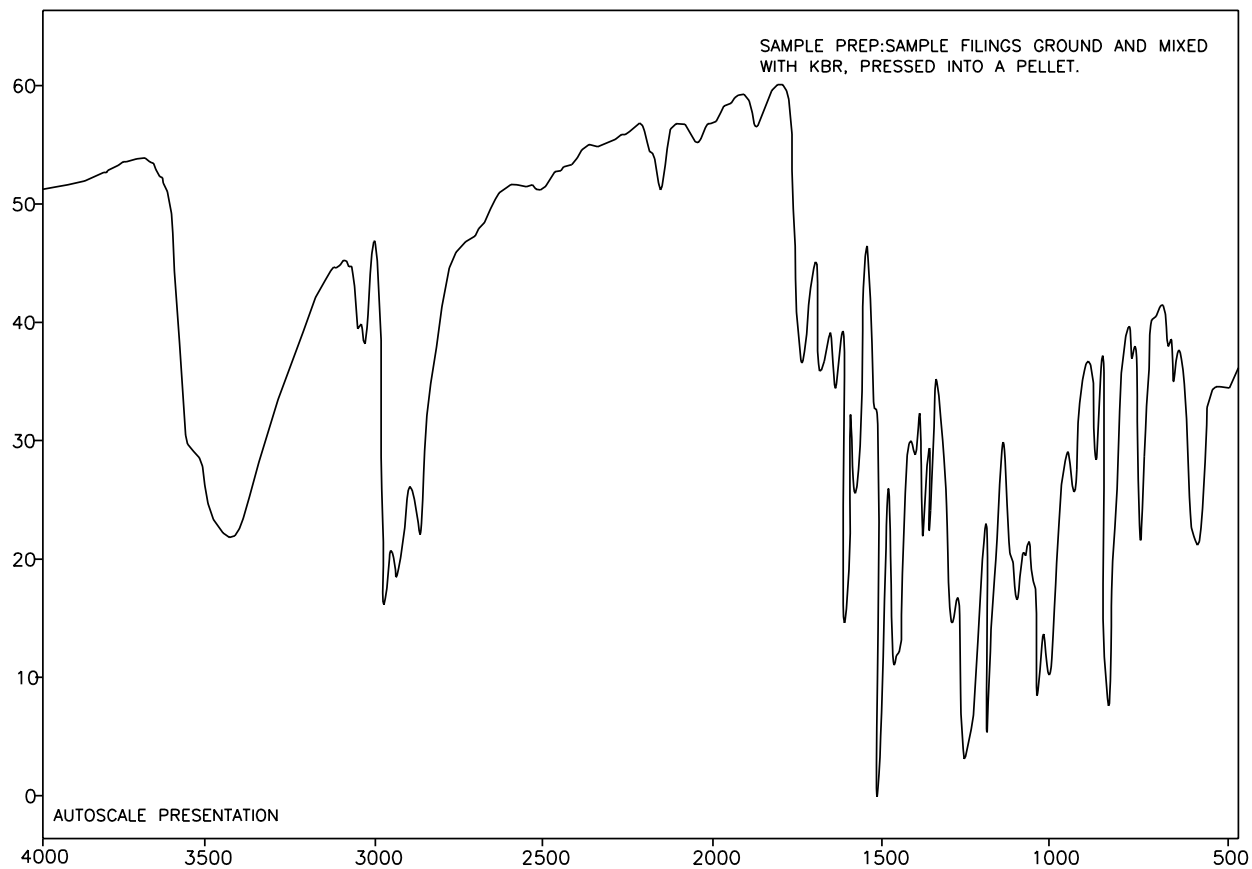
Revised Figure 6.15 effective February 7, 2004



S5147

Figure 6.16

Revised Figure 6.16 effective February 7, 2004



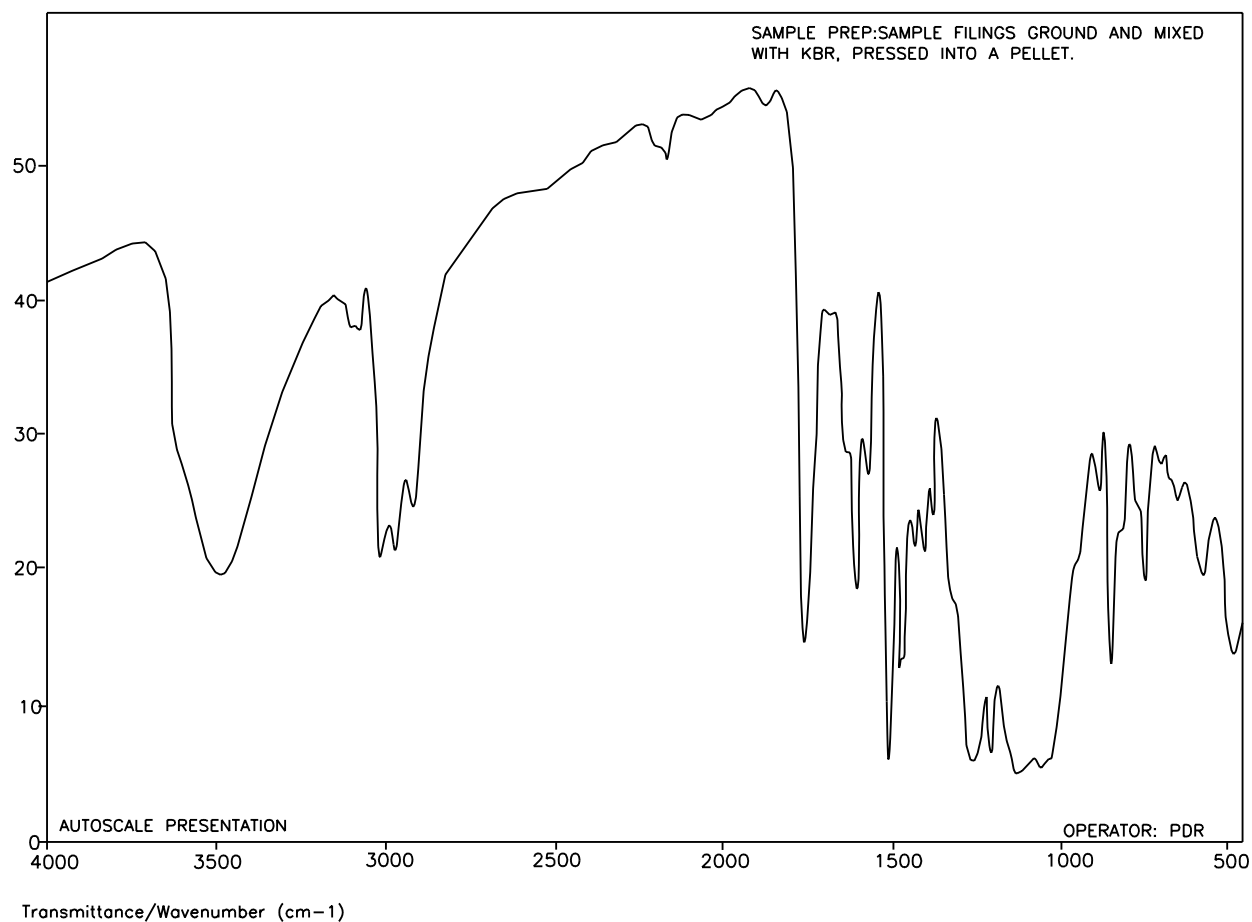
Transmittance/Wavenumber (cm-1)

File #1: NEMA0026

S5148

Figure 6.17

Revised Figure 6.17 effective February 7, 2004

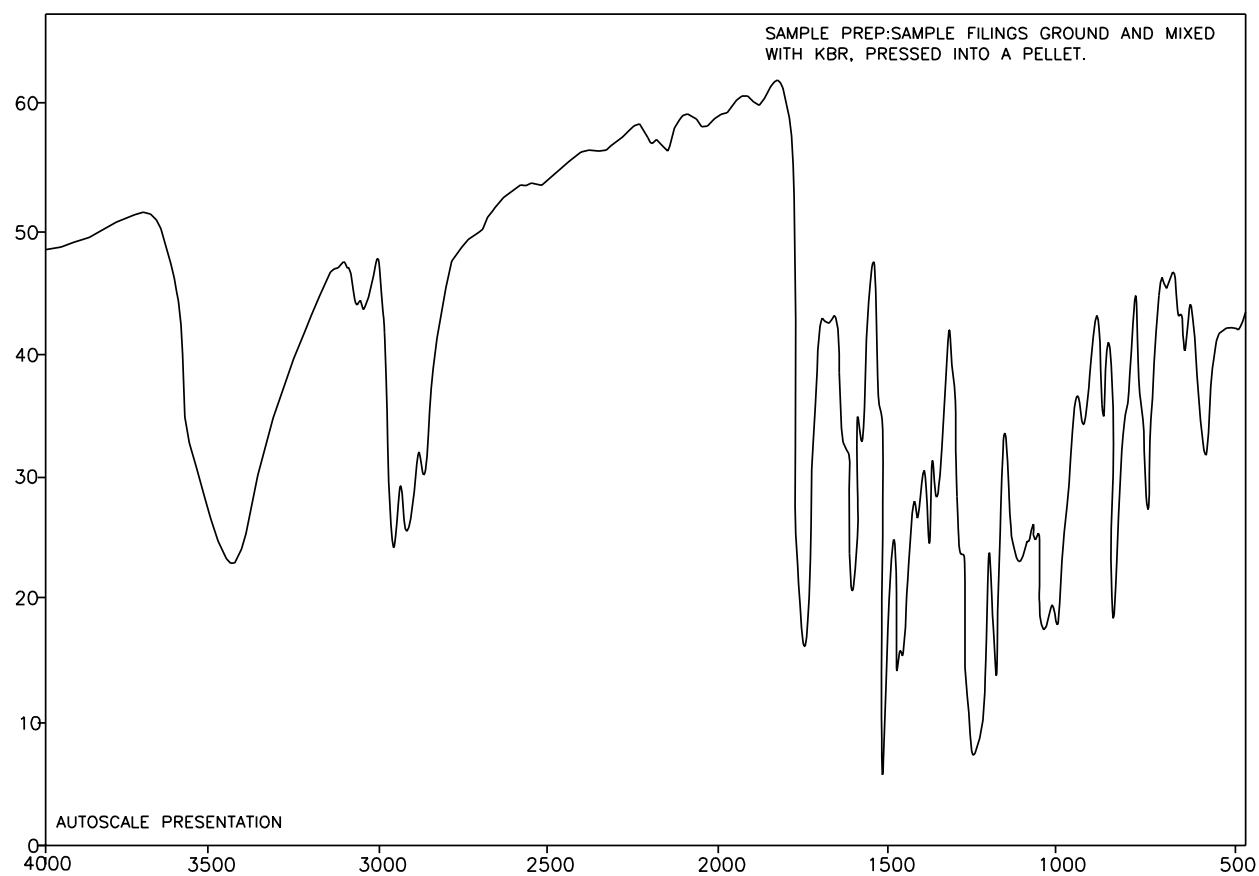


File#1: NEMA0028

S5149

Figure 6.18

Added Figure 6.18 effective February 7, 2004

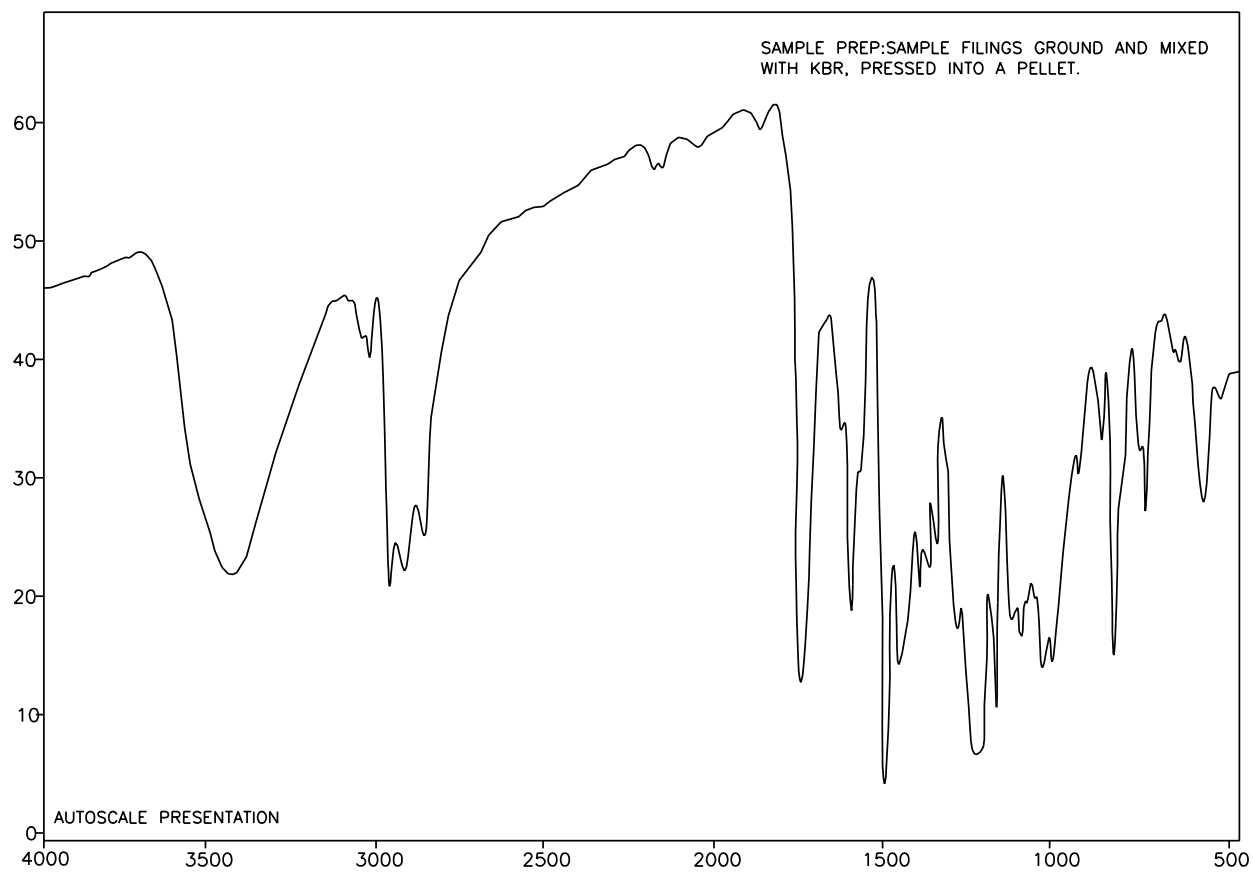
Transmittance/Wavenumber (cm⁻¹)

File #1: NEMA0030

S5150

Figure 6.19

Added Figure 6.19 effective February 7, 2004



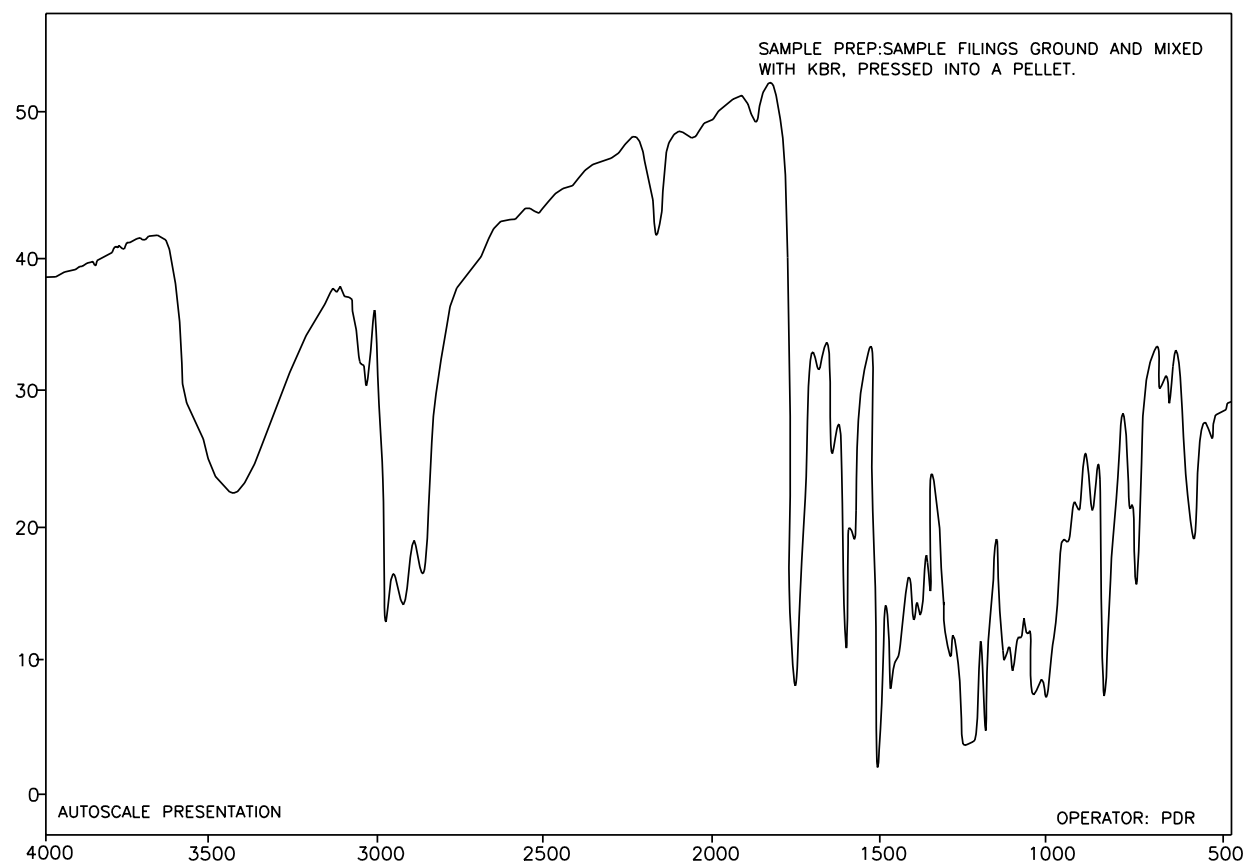
Transmittance/Wavenumber (cm-1)

File #2: NEMA0031

S5151

Figure 6.20

Added Figure 6.20 effective February 7, 2004



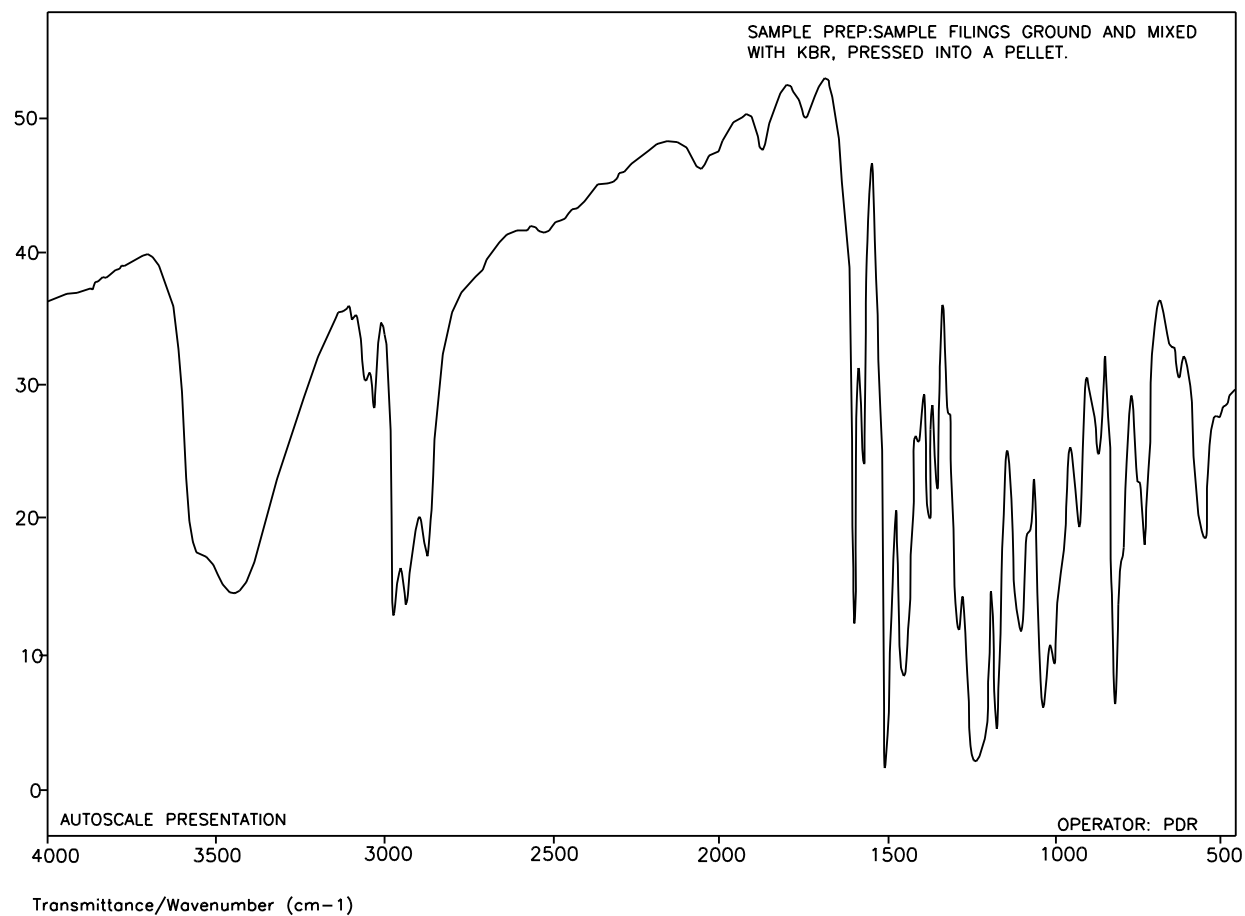
Transmittance/Wavenumber (cm-1)

File #3: NEMA0038

S5152

Figure 6.21

Added Figure 6.21 effective February 7, 2004



File# 1: NEMA0044

S5153

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

Added Figure 6.22 relocated from 6.8 effective February 7, 2004

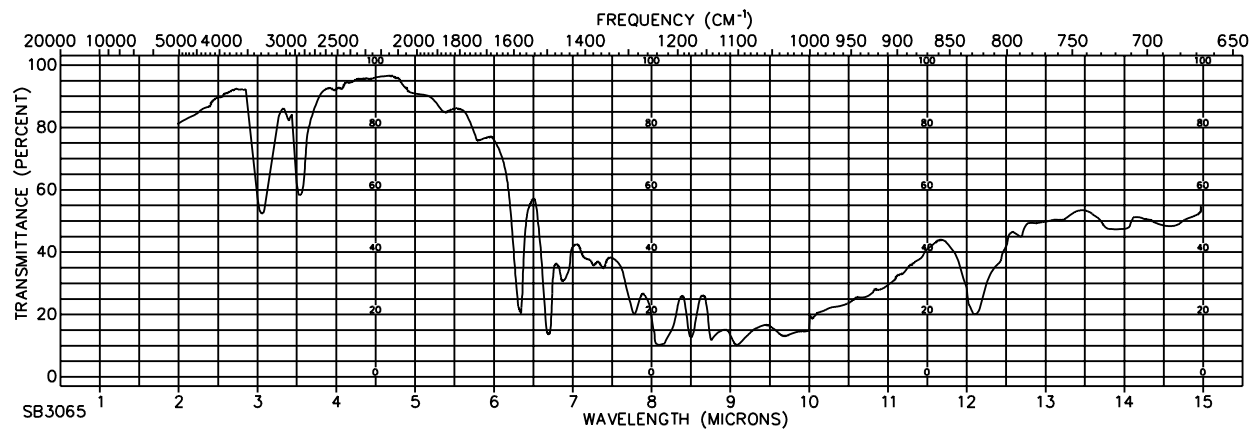


Figure 6.23
Typical IR spectrum for industrial laminates UL/ANSI Type FR-2

Added Figure 6.23 relocated from 6.9 effective February 7, 2004

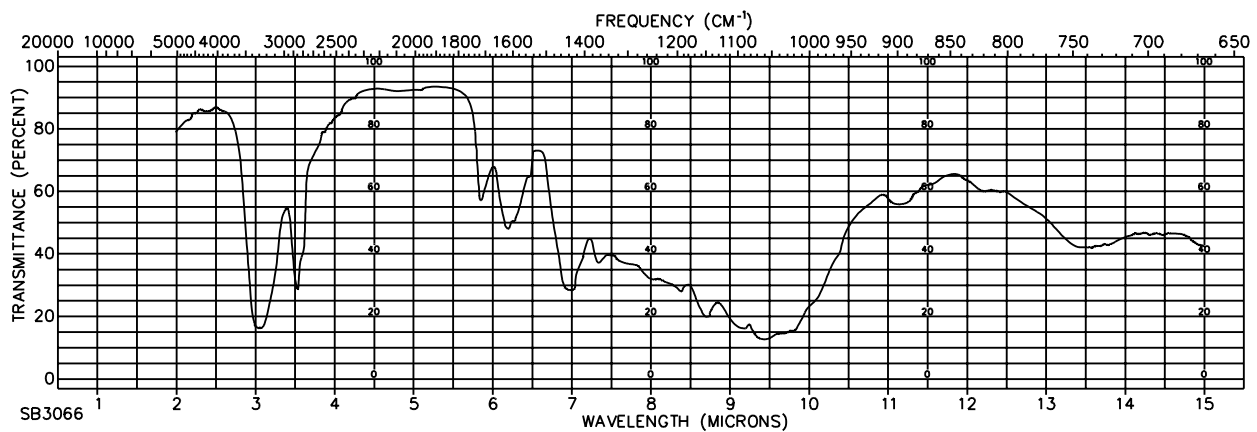


Figure 6.24
Typical IR spectrum for industrial laminates UL/ANSI Type FR-3

Added Figure 6.24 relocated from 6.10 effective February 7, 2004

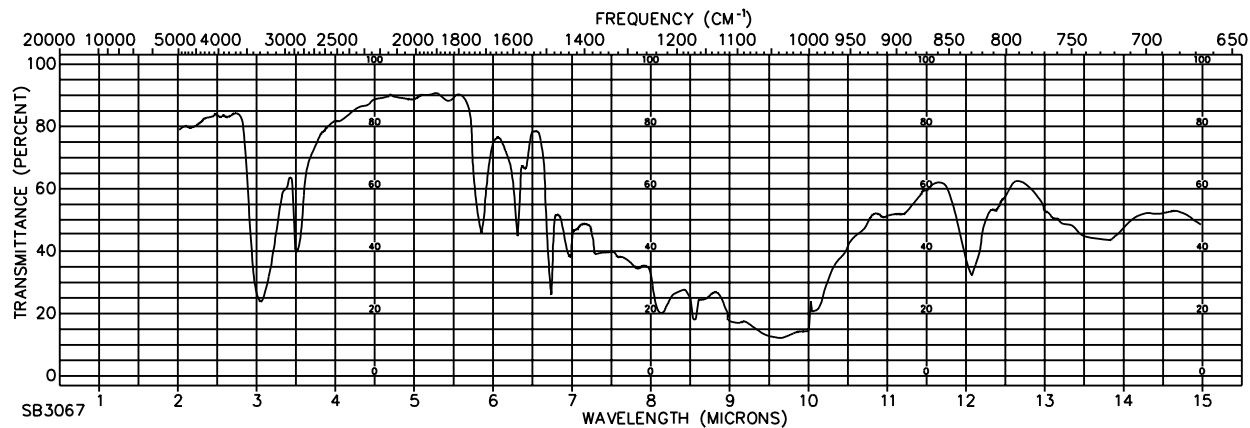


Figure 6.25
Typical IR spectrum for industrial laminates UL/ANSI Type G-3

Added Figure 6.25 relocated from 6.11 effective February 7, 2004

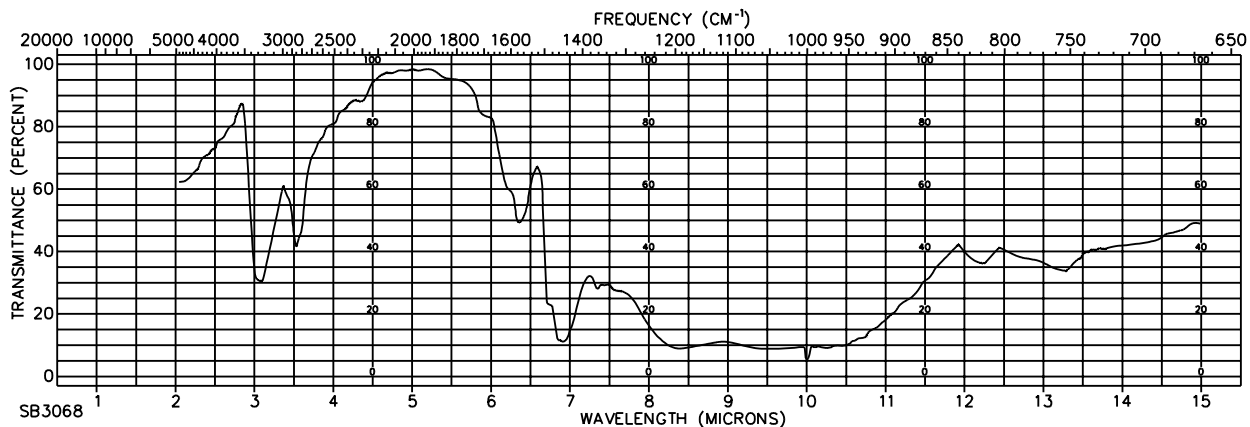


Figure 6.26
Typical IR spectrum for industrial laminates UL/ANSI Type CEM-1

Added Figure 6.26 relocated from 6.12 effective February 7, 2004

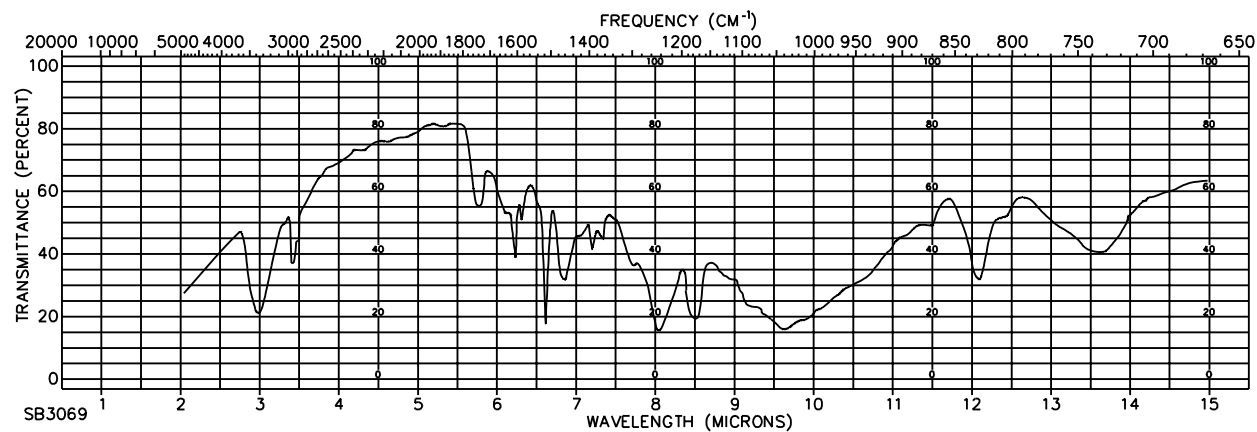


Figure 6.27
Typical IR spectrum for industrial laminates UL/ANSI Type CEM-3

Added Figure 6.27 relocated from 6.13 effective February 7, 2004

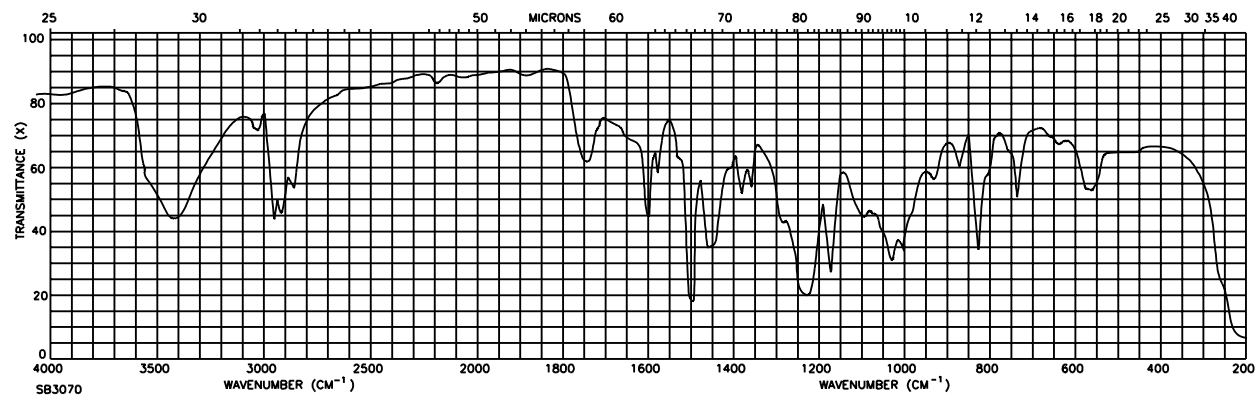


Figure 6.28
Typical IR spectrum for industrial laminates UL/ANSI Type GPO-2

Added Figure 6.28 relocated from 6.14 effective February 7, 2004

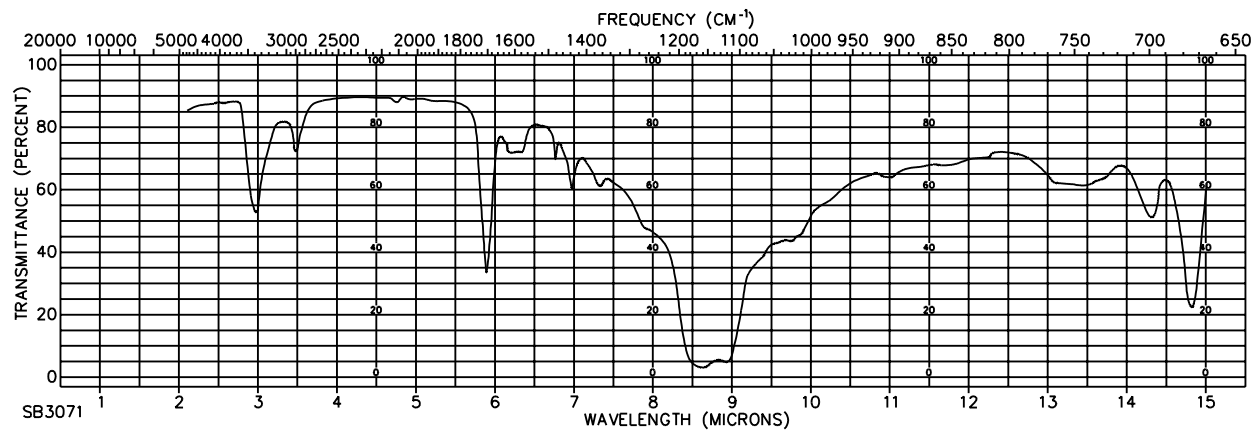


Figure 6.29
Typical IR spectrum for industrial laminates UL/ANSI Type GPO-3

Added Figure 6.29 relocated from 6.15 effective February 7, 2004

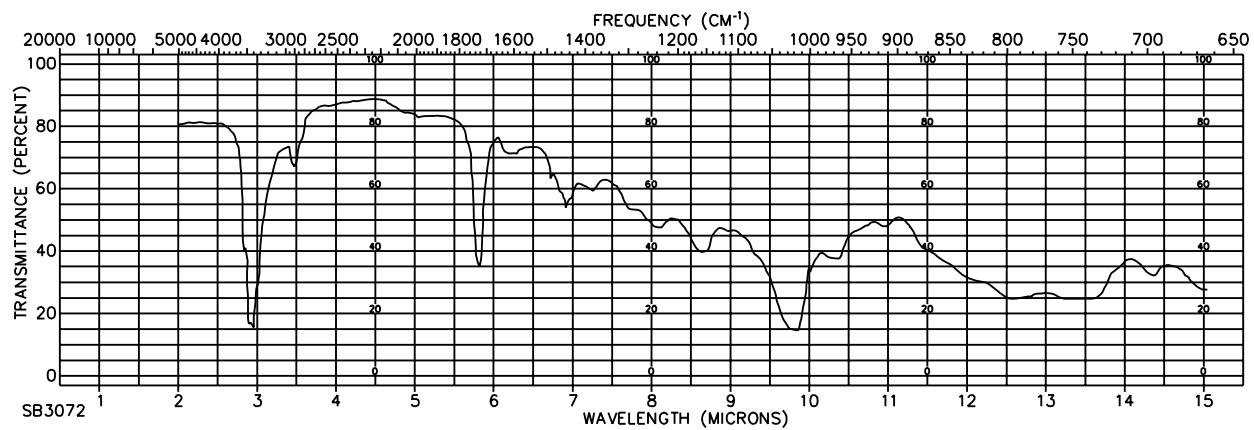


Figure 6.30
Typical IR spectrum for industrial laminates UL/ANSI Type GPY

Added Figure 6.30 relocated from 6.16 effective February 7, 2004

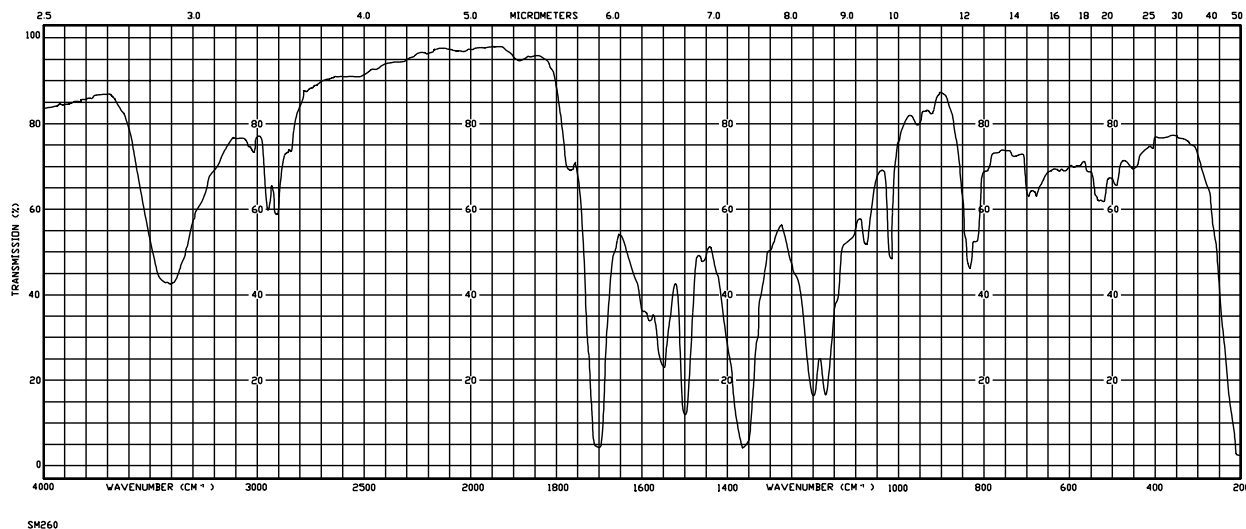
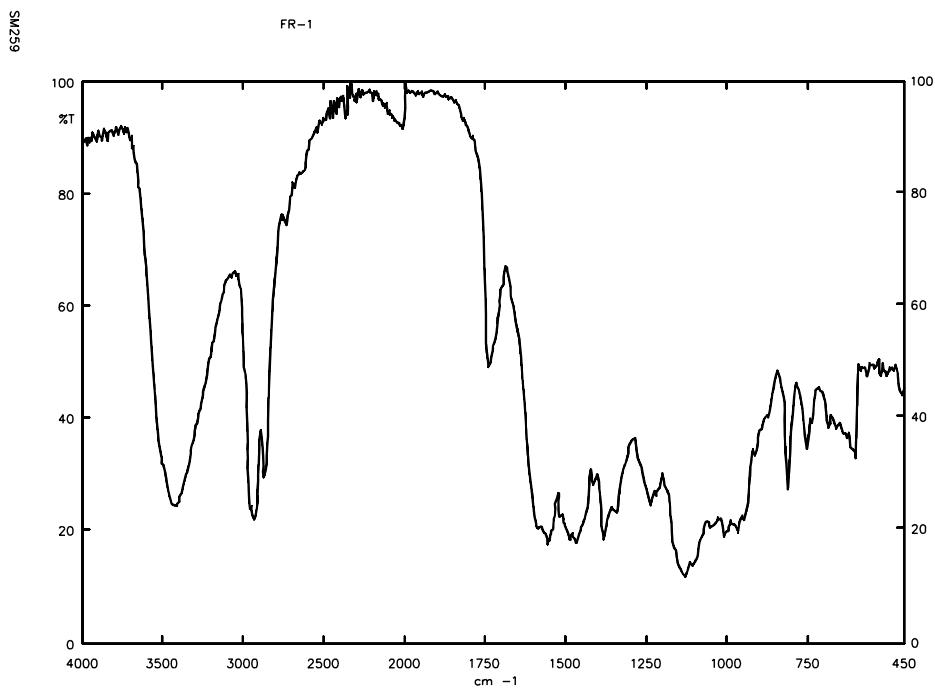


Figure 6.31
Typical IR spectrum for industrial laminates UL/ANSI Type FR-1

Added Figure 6.31 relocated from 6.17 effective February 7, 2004



7 Full Test Program

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

7.1 revised November 28, 2001

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

Table 7.1
Rigid industrial laminate full test program and specimen requirements

Table 7.1 revised November 28, 2001

The specimens are to be in the machine (grain) direction. They are to be prepared by completely etching a metal clad sheet, where applicable.

I Tests

1. Short term (UL 746A)

- a) Infrared analysis^a
- b) Flexural strength^a
- c) Ash content (if applicable)^a
- d) Flammability tests^a
- e) High current arcing ignition (HAI)
- f) Hot wire ignition (HWI)
- g) Deleted
- h) High voltage arc tracking (HVTR)
- i) Dielectric strength
- j) Arc resistance in accordance with ASTM D495 (1994)^d
- k) Comparative track index (CTI)
- l) Volume resistivity
- m) Thermogravimetric analysis (TGA)^a
- n) Water absorption and immersion

2. Long term thermal aging (UL 746B)

- a) 1- or 2-point thermal aging of the industrial laminate to 50 percent retention of initial flexural strength property level. (Dielectric Strength for G-7, GPO-2, and GPO-3 materials). See Table 7.2 for temperature/ time. If a control is to be used in accordance with 7.3, an industrial laminate of the same general UL/ANSI grade is to be aged and tested concurrently with the laminate.
- b) The temperature, times, and samples required for a 4-point thermal aging shall be determined in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

II Specimens (Does not include samples needed for a 4-point thermal aging program)

Table 7.1 Continued on Next Page

Table 7.1 Continued

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

^a Not required if previously determined under the abbreviated program described in Section 5, General.

^b Includes 1- point thermal aging program samples.

^c Includes 2- point thermal aging program samples.

^d Standard Test Method For High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation.

^e Samples provided in the 1.6 mm (0.062 inch) thickness may be built up to a thickness of 3.2 mm (0.125 inch).

Table 7.2
1 and 2 temperature point thermal aging program

Table 7.2 revised February 7, 2001

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

Table 7.2 Continued on Next Page

Table 7.2 Continued

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

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

7.3 revised November 28, 2001

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

7.3.1 revised November 28, 2001

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

7.4 revised November 28, 2001

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

7.5 revised November 28, 2001