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NEMA STANDARDS PUBLICATION

NEMA FI 3

CALENDERED ARAMID PAPERS USED FOR ELECTICAL INSULATION

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Calendered Aramid Papers Used for Electrical Insulation

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Foreword

This publication is a new standard for calendered aramid papers used for electrical insulation. Standard industry test methods are referenced herein, and the latest version of the appropriate standard should always be used. Since this is a new standard, it may not meet all industry needs, and suggestions and comments for future revisions are appreciated.

This document provides technical guidance similar to other NEMA standards and establishes minimum properties in accordance with ASTM or other commonly accepted tests. Users and other interested parties are invited to comment on this standard and suggest changes where they feel it does not meet their needs. Specifications on properties and characteristics not covered herein should be negotiated between buyer and seller, and test methods cited in this document may be used as the basis for those negotiations.

Metric tables for each of the constructions are included in this document. Where applicable, English units are accompanied by SI equivalents.

This Standards Publication was developed by the Flexible Insulation and Mica Section. Section approval of the standard does not necessarily imply that all section members voted for its approval or participated in its development. At the time it was approved, the Section was composed of the following members:

Bedford Materials Corp.—Bedford, PA
Dennison Manufacturing Company—Framingham, MA
EHV-Weidmann Industries, Inc.—St. Johnssbury, VT
E. I. DuPont de Nemours and Company, NOMEX® Products—Wilmington, DE
Essex Group, Inc. Macallen Mica—Newmarket, NH
Essex Group, Inc., U.S. Samica—Rutland, VT
Kirkwood Industries, Midwest Mica and Insulation—Cleveland, OH
Lydall, Inc., Manning Nonwovens Division—Troy, NY
Quin-T Corporation—Tilton, NH
VonRoll Isola/Insulating Materials, Inc.—Schenectady, NY

The Flexible Insulation and Mica Section of NEMA reviews these standards periodically for revisions necessary to keep them up to date. Proposed revisions or comments should be submitted to:

Manager, Engineering Department
National Electrical Manufacturers Association
1300 N. 17th St., Suite 1847
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Section 1
GENERAL

1.1 SCOPE

This Standards Publication is applicable to qualification and testing of calendered aramid papers in thicknesses up to 30 mils (0.76 mm) for use as electrical insulation. Methods and properties applicable to aramid pressboards, uncalendered aramid papers, and papers made of blends of aramid with other materials are substantially different and are not considered in this standard. Blends of aramid and mica are covered in NEMA Standard FI-1 (1996). For U.S. Government procurement purposes, this standard replaces Military Standard MIL-I-24204A.

1.2 DEFINITION OF ARAMID PAPER

As defined in the U.S. Federal Register (Volume 38, No. 237, December 11, 1973), an aramid is "a long-chain synthetic polyamide in which at least 85% of the amide linkages are attached directly to two aromatic rings." Aramid polymers can be processed into various forms, including resin, fiber, film, paper, or pressboard, but this standard applies only to a non-woven sheet made of 100% meta-aramid fibers, formed on wet-process paper machines, and calendered between rolls at high temperatures and pressures. Aramid paper covered by this standard is manufactured from a blend of two forms of fiber: (1) floc, which is short fiber cut from continuous filaments of drawn (stretched) aramid fiber, and (2) fibrids, which are microscopic particles of amorphous polymer. Up to 8% non-aramid additives are permitted, so long as such additives have a thermal capability at least equal to meta-aramid fiber.

1.3 REFERENCES

1.3.1 Mandatory Standard

Aramid paper products submitted for qualification under this NEMA standard must have been tested in accordance with the following standard and produced under contractual follow-up services of the issuer. Both mechanical and electrical properties must be "Recognized" for use at temperatures up to 220° Celsius. The following standard is, by reference, incorporated herein:

UL Standard 746B, *Polymeric Materials—Long Term Property Evaluations*

Copies of the above standard may be purchased by contacting:

Underwriters Laboratories
333 Pfingsten Road
Northbrook, IL 60062

In this publication, reference is made to the A.S.T.M. Standard Test Methods listed below. The most recent revision should normally be used:

ASTM D149	*Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies*
ASTM D150	*A-C Loss Characteristics and Permittivity (D.C.) of Solid Electrical Insulation*
ASTM D374	*Thickness of Solid Electrical Insulation*
ASTM D2275	*Voltage Endurance of Solid Electrical Insulation Subject to Partial Discharges (Corona) on the Surface*
ASTM D257	*D-C Resistance or Conductance of Insulating Materials*
ASTM D646	*Grammage of Paper and Paperboard (Weight per Unit Area)*

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ASTM D1004 *Initial Tear Resistance of Plastic Film and Sheeting*
ASTM D3394 *Sampling and Testing Electrical Insulating Board*
ASTM D2176 *Folding Endurance of Paper by the MIT Tester*
ASTM D828 *Tensile Breaking Strength of Paper and Paperboard*
ASTM D1830 *Thermal Endurance of Flexible Sheet Materials*
ASTM D3426 *Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials Using Impulse Waves*

Copies of the above standards may be purchased from:

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

Other relevant standards include the following IEC Documents:

IEC 216-1(1987), *Part 1: General procedures for the determination of thermal endurance properties, temperature indices and thermal endurance profiles*

IEC 819-3-3 (1991), *Specification for Non-Cellulosic Papers for Electrical Purposes*

Copies of the above standards may be purchased from:

Bureau Central de la Commission Electrotechnique Internationale
3, rue de Varembe
Geneva, Switzerland

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Section 2
TOLERANCES

2.1 TOLERANCE ON THICKNESS OF ARAMID PAPERS

The tolerances for the thickness of standard types and thicknesses of aramid papers are given in Section 7.

2.2 TOLERANCE ON WIDTH OF ARAMID PAPER TAPES

The tolerance in the width of aramid paper tapes from 3/8 to 1 1/2 inches (9.5 to 38.1 mm) wide shall be plus or minus 1/32 inch (0.8 mm).

2.3 TOLERANCES FOR DIMENSIONS OF NARROW ARAMID PAPER ROLLS

The tolerance in the width of rolls of aramid paper from 1.5 inches to 18 inches wide (38.1 mm to 457 mm) shall be plus or minus 1/4 inch (6.4 mm).

2.4 TOLERANCES FOR DIMENSIONS OF WIDE ARAMID PAPER ROLLS

The tolerance in the width of rolls of aramid paper from 18 inches to 72 inches wide (1828 mm) shall be plus or minus 1/2 inch (12.7 mm).

2.5 TOLERANCES FOR DIMENSIONS OF ARAMID PAPER SHEETS

The tolerances for the length and width of sheets shall be as follows:

2.5.1 In any dimension up to 18 inches (457 mm): plus or minus 1/4 inch (6.4 mm).

2.5.2 In any dimension 18 inches (457 mm) or larger: plus or minus 1/2 inch (12.7 mm).

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Section 3
CLASSIFICATION OF ARAMID PAPERS

3.1 DEFINITIONS OF DEFECTS

Any non-uniformity which reduces the physical or electrical properties of the paper shall be considered a defect. Such defects are permitted only within the following standards:

3.1.1 Defects Causing Reduced Insulation Strength

Defects which reduce the electrical insulating properties of the paper by more than 10% are permitted only when they are repaired by one piece of 1 mil (.025 mm) self-adhesive polyimide film tape no larger than 2" by 2" (51 mm by 51 mm) in size.

3.1.2 Holes

Holes larger than 3/8 inch (9.5 mm) are not allowed. Holes larger than 1/16 inch (1.6 mm) are permitted only when they are repaired with self-adhesive polyimide film tape sufficient to assure unreduced electrical breakdown resistance in or near the hole. Small, high-density translucent fiber particles may appear to be holes unless carefully examined. These do not reduce the performance of the sheet and are permitted.

3.1.3 Fractures

A fracture is defined as a break in the surface of the paper. Fractures larger than 1/2 inch (12.7 mm) are not permitted. Fractures larger than 1/16 inch (1.5 mm) are permitted only when they are permanently repaired with self-adhesive polyimide film tape sufficient to assure unreduced electrical breakdown resistance.

3.1.4 Solid Tactile Defects

Clumps of fibers and similar solid tactile defects over 2 inches (51 mm) in the longest dimension are not permitted. Such defects over 3/8 inch (9.5 mm), but less than 2 inches in the longest dimension, are permitted; discolored (brown or black) defects shall be permanently reinforced with self-adhesive polyimide film tape sufficient in strength and area to assure proper physical integrity of the paper.

3.1.5 Hollow Tactile Defects (Blisters)

Hollow tactile defects (blisters) over 1 inch (25.4 mm) in the longest dimension are not permitted. Blisters over 1/8 inch (3.2 mm) are permitted only when permanently reinforced with self-adhesive polyimide film tape sufficient to assure unreduced electrical breakdown resistance.

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3.1.6 Stains and Discolorations

Stains and discolorations over 2 inches (51 mm) in the longest dimension are not permitted. Such discolored areas over 1 inch (25.4 mm), but less than 2 inches (51 mm) in the maximum dimension, shall be permanently repaired with self-adhesive polyimide film tape sufficient in strength and area to assure that the physical strength of the sheet is not impaired.

3.1.7 Splices

Splices shall have parallel edges with a maximum gap no wider than 1/8 inch (3.2 mm). Splicing tapes will be applied to one surface only unless otherwise specified. Splicing materials to be used are:

3.1.7.1 Papers Up to 5 mils (0.13 mm) Thick

Paper up to 5 mils (.13 mm) thick shall be spliced with self-adhesive polyimide film tape 3 inches (76 mm) wide to assure acceptable physical, thermal, and electrical integrity in all applications suited to the unspliced material.

3.1.7.2 Papers Thicker than 5 mils (0.13mm)

Paper thicker than 5 mils shall be spliced with self-adhesive polyester film tape 3 inches (76 mm) wide to assure unimpaired physical strength of the sheet.

NOTE—Because polyester film deteriorates more rapidly than aramid paper, aramid paper spliced with this tape shall not be used in equipment unless the splicing tape is separately approved for use in the equipment.

3.2 SAMPLING FOR TESTING

A lot to be sampled for compliance with this standard may consist of one or more rolls of a given type and thickness of paper, provided that all rolls in the lot came from the same master roll and are so identified by the producer's package labels. Samples may be taken from any of the rolls shipped, and those samples may be aggregated to meet or exceed requirements of the ASTM test procedure insofar as the number of samples is concerned.

3.2.1 Samples from Rolls

A sample section shall be cut completely across the roll at any point chosen. The required number of specimens shall be cut from the sample, preferably by die cutting, at intervals across the sheet so as to represent the full width of the paper.

3.2.2 Samples from Sheets

Samples shall be cut from one or more sheets. The specimens shall be cut, preferably by die cutting, at intervals across the cross-direction of the sheet, if known, or in both directions of the sheet if the sheet is not marked for directions.

3.3 METHOD OF CALCULATION

Calculations and reporting must conform to that specified in the relevant test method. See Sections 1 and 4 for recommended test methods.

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Section 4
METHODS OF MEASUREMENT

4.1 METHODS OF MEASURING THICKNESS

4.1.1 Sheets

Ten measurements of the thickness shall be taken at substantially equal intervals over the width of the sheet, in accordance with Method C or D given in ASTM D374, using anvil pressure of 23 to 27 psi (1.6 to 1.9 kPa). Method A or B given in ASTM D374 may also be used, but Method C or D shall constitute the referee methods. An individual measurement is a single reading, and the average of the ten individual measurements shall constitute the average thickness of the sheet or plate.

4.1.2 Tapes

A roll shall be selected at random from any lot. Test the product in accordance with Method C or D given in ASTM D374, modified so that the anvil pressure will be 23 to 27 psi (1.6 to 1.9 kPa). Ten measurements of the thickness shall be taken at equal intervals along the sample.

Should Method A or B given in ASTM D374 be used, the tape sample shall be folded so that it will form five layers of tape, each approximately 4 feet (1.22 meters) long. Ten measurements of the thickness of the five layers shall be taken at equal intervals over the entire length of the tape in accordance with Method A or B given in ASTM D374. An individual measurement is a single reading taken on five layers of tape and divided by 5.

The average of the ten individual measurements shall constitute the average thickness of the tape.

4.2 METHODS OF MEASURING ELECTRIC STRENGTH

4.2.1 Sheets and Tapes

The electric strength of sheets and tapes shall be measured in accordance with ASTM D149, with the following specifications:

a. Size of electrodes—Two-inch electrodes shall be used. For materials where one dimension is not great enough to prevent flashover in air (such as tapes), 1/4-inch (6.35-mm) electrodes shall be used as specified in Section 45 of ASTM D295.
b. Conditioning—Samples should be conditioned to 23°C and 50% R.H. for 24 hours prior to testing.
c. Medium—All electric strength tests specified in this standard must be performed in air. Tests in other environments are possible if needed, but are not considered in this standard.
d. Electric strength—The average electric strength shall be the average of 10 electric breakdowns divided by the average thickness of the specimens and shall be reported as volts or kilovolts per unit thickness.

4.3 METHOD OF DETERMINING MOISTURE CONTENT

4.3.1 Purpose

The purpose of this test is to ascertain the percentage of moisture present in aramid paper. Moisture content, though not specified in this document, is an important property in certain uses.

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4.3.2 Apparatus

The apparatus shall consist of the following:

a. An electrically heated, forced-air oven which will provide a temperature of 150 °C ± 5 °C (302 °F ± 9 °F).
b. Dishes of aluminum, or other materials not affected by the test conditions.
c. An analytical balance having an accuracy of at least 0.001 gram.

4.3.3 Test Specimen

The specimen(s) to be tested should weigh not less than 5 grams.

4.3.4 Procedure

a. Weigh a clean dish to the nearest .001 gram (weight C).
b. Weigh the test specimen in the tared dish to the nearest .001 gram (weight E).
c. Place the dish with the specimen in the oven at 150°C ± 5 °C (302°F ± 9°F) for not less than 60 minutes.
d. Cool in a desiccator and weigh the dried sample in the dish (weight H).

4.3.5 Report

The report shall determine the percent moisture, as follows:

$$\frac{\text{Weight E} - \text{Weight H}}{\text{Weight E} - \text{Weight C}} \times 100 = \text{Percent Moisture}$$

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Section 5
TYPES OF ARAMID PAPER

Depending on manufacturing methods, aramid paper products may have markedly different properties. Because of the wide range of possible properties, only two common types, primarily used for electrical insulation, are covered herein. They are identified as Type 1 and Type 2 and may be characterized as follows:

a. Type 1—Has a relatively hard, smooth, non-porous surface. Both electrical and physical properties are relatively high, and it is used in many of the most important applications.

b. Type 2—Surface is more fibrous, more absorbent, and more flexible than Type 1. Most electrical and mechanical properties are similar to but slightly lower than Type 1. Tear properties may be preferred over those of Type 1.

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Section 6
SPECIFICATIONS BY TYPE AND THICKNESS

TYPE I

NOMINAL THICKNESS OF EACH GRADE											
mils	2	3	5	7	10	12	15	20	24	29	30
mm	0.05	0.08	0.13	0.18	0.25	0.30	0.38	0.51	0.61	0.74	0.76
MINIMUM VALUES ARE GIVEN FOR THE FOLLOWING PROPERTIES											
Thickness											
mils	1.9	2.7	4.7	6.5	9.1	11	14	19	23	26	27
mm	0.048	0.069	0.12	0.17	0.23	0.28	0.35	0.47	0.58	0.66	0.69
Basis Weight											
oz/sq. yard	1.06	1.69	3.19	4.78	6.77	8.50	10.9	15.3	19.6	23.4	23.2
g/m2	35.9	57.3	108	162	230	288	371	519	665	793	787
Density (g/cc)	0.61	0.68	0.76	0.86	0.87	0.90	0.93	0.97	1.05	1.08	0.99
Diel. Strength											
V/mil	330	460	538	714	700	720	695	690	655	570	520
kV/mm	13.0	18.1	21.2	28.1	27.6	28.3	27.4	27.2	25.8	22.4	20.5
Tensile Brk Str. (MD)											
lb/in	19	32	66	105	140	180	230	290	375	416	418
N/cm	32	56	115	183	245	314	402	507	655	727	730
Tensile Brk Str. (XD)											
lb/in	7.2	15	30	55	67	95	125	165	240	289	260
N/cm	13	26	52	96	117	166	218	288	419	505	454
Brk Elong.											
MD %	5.7	6.9	10.7	13.7	12.0	15.0	14.3	14.0	11.8	13.3	13.3
XD %	4.2	5.0	7.0	9.7	10.0	11.0	11.7	10.3	9.8	8.3	10.7
Tear Str (MD)											
lb	1.7	1.8	4.9	8.2	13	15	21	30	32	36	44
N	7.6	8.0	22	37	57	67	95	133	141	162	194
Tear Str (XD)											
lb	0.60	1.1	2.4	3.6	7.6	7.4	11.6	19.2	26.5	31.7	34.6
N	2.7	4.9	10.7	16.0	33.8	32.9	51.6	85.4	118	141	154

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TYPE 2

	NOMINAL THICKNESS OF EACH GRADE				
Thickness (mils)	3.4	7	10	12	15
Thickness (mm)	0.09	0.18	0.25	0.30	0.38
MINIMUM VALUES ARE GIVEN FOR FOLLOWING PROPERTIES					
Thickness (mils)	3.3	6.94	9.4	11.5	14.5
Thickness (mm)	0.084	0.176	0.24	0.29	0.37
Basis Weight					
oz/sq. yard	2.2	4.9	7	8	11
g/m2	74	162	238	278	361
Density (g/cc)	0.71	0.84	0.86	0.83	0.85
Diel. Strength					
V/mil	375	600	615	610	610
kV/mm	14.8	23.6	24.2	24.0	24.0
Tensile Brk Str. (MD)					
lb/in	24	72	102	125	160
N/cm	42	126	178	218	280
Tensile Brk Str. (XD)					
lb/in	10	35	50	67	83
N/cm	17	61	87	117	145
Brk Elong.					
MD %	4.8	8.8	8.5	10	8.0
XD %	6.0	10	11	13	11
Tear Str (MD)					
lb	2.9	9.2	13	17	20
N	13	41	59	73	87
Tear Str (XD)					
lb	1.1	3.0	5.4	7.4	10
N	4.9	13	24	33	43

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Section 7
ELECTRICAL PROPERTIES—TYPE TESTS

The following data are average electrical properties measured on aramid papers meeting specifications in Section 7 of this standard. These properties are not routinely tested and should not be relied upon as specifications. The tests were performed per ASTM Standards D-149 and D-150 specified in Section 1.

Permittivity measured at 23°C, 50% Relative Humidity												
Nominal Thickness												
mils	2	3	3.4	5	7	10	12	15	20	24	29	30
mm	0.05	0.08	0.09	0.13	0.18	0.25	0.30	0.38	0.51	0.61	0.74	0.76
Typical Value (60 Hz)												
Type I	1.6	1.6	–	2.4	2.7	2.7	2.9	3.2	3.4	3.7	3.7	3.7
Type 2	–	–	1.7	–	2.5	2.7	2.8	2.9	–	–	–	–

Dissipation Factor measured at 23°C, 50% Relative Humidity, at 60 Hz												
Nominal Thickness												
mils	2	3	3.4	5	7	10	12	15	20	24	29	30
mm	0.05	0.08	0.09	0.13	0.18	0.25	0.30	0.38	0.51	0.61	0.74	0.76
Typical Value (60 Hz)												
Type I	0.004	0.005		0.006	0.006	0.006	0.007	0.007	0.007	0.007	0.007	0.007
Type 2			0.005		0.008	0.008	0.008	0.009				

Volume Resistivity (Types 1 and 2, all thicknesses)	
Type 1	Typical value measured at 23°C, 50% Relative Humidity: 10^{15} ohm-cm
Type 2	Typical value measured at 23°C, 96% Relative Humidity: 10^{14} ohm-cm

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