Industry Specifications Bulletin MW-97-8

DuPont Films

High Performance Films

Kapton®

polyimide film

Motor and Magnet Wire Insulation

Introduction

DuPont Films manufactures and markets a variety of high-performance film products.

These specifications describe the values and tolerances for *Kapton*® polyimide film properties and characteristics known to be of significance in the motor and magnet wire industry.

Where necessary for thorough understanding, test methods and procedures have been included. Also, where necessary for clarity, there are separate tables in SI and English units.

Minimum and/or maximum values are provided as a guide to those requiring a better understanding of current product specification limits for design purposes. By providing these values, we recognize the potential that this data may be incorrectly interpreted as being representative of "actual/typical" values. If you require typical value data, please contact your DuPont Films marketing or technical representative.

Any aspects of the specifications requiring further interpretation or clarification should be discussed with your DuPont Films technical representative.

Types of *Kapton*® Film

The principal types of *Kapton*® used in motor insulation and to insulate magnet wire are HN, CR, WR, FN, FCR, and FWR.

Plain Kapton® *Films*

Kapton® HN Film

Kapton® HN is an aromatic polyimide film exhibiting an exceptional and unique balance of physical, chemical, and electrical properties over a wide temperature range, particularly at high temperatures. Chemically, it is the result of a polycondensation reaction between pyromellitic dianhydride and 4,4′-diaminodiphenylether.

Kapton® HN film is available in these standard thicknesses: 25, 50, 75, and 125 µm (1, 2, 3, and 5 mil). Additional thicknesses can be made available by special request. Please consult your DuPont Films marketing representative.

Kapton® CR Film

Corona-resistant *Kapton*® CR has been developed specifically to withstand the damaging effect of corona, which can cause ionization and eventual breakdown of an insulation material or system. *Kapton*® CR has a corona resistance or voltage endurance that is orders of magnitude better than standard *Kapton*® HN. Further, *Kapton*® CR provides a thermal conductivity that is more than twice that of standard *Kapton*® HN, allowing better dissipation of heat in motors.

Kapton® CR is available in the standard thicknesses: 25 and 125 µm (1 and 5 mil). Additional thicknesses can be made available by special request. Please contact your DuPont Films marketing representative.

Kapton® WR Film

Continuous exposure to hot water over time can affect the tensile strength, elongation, and dielectric strength of standard *Kapton*® HN. Water-resistant *Kapton*® WR was developed specifically to combat the effect of water on insulation systems and applications where hydrolytic stability is important.

Kapton® WR is available in the standard thickness 25 µm (1 mil). Additional thicknesses can be made available by special request. Please contact your DuPont Films marketing representative.

Table 1
Properties of Plain *Kapton*® Films

	Product Designation						
Property	**100HN**	**200HN**	**300HN**	**100CR**	**500CR**	**100WR**	**Method**
Minimum Machine Direction Ultimate Tensile Strength, MPa (kpsi)	179 (26)	179 (26)	179 (26)	110 (16)	79 (11.5)	179 (26)	ASTM D-882-91, Method A using an Instron Tensile Tester (specimen size: 13 × 150 mm [½ × 6 in]; jaw separation: 100 mm [4 in]; jaw speed: 50 mm [2 in] min.). Calculate the average of five specimens based on original measured thickness at 23°C (73°F).
Minimum Machine Direction Ultimate Elongation, %	55	55	55	35	23	65	Same as above method.
Maximum Machine Direction Shrinkage, %	2.5	2.5	2.5	2.5	2.5	2.5	MIL-P-46112B (MR). The percent shrinkage is obtained by using the average of three measurements before and after conditioning. Prior to measurement, the 215 × 280 mm (8½ × 11 in) specimen is conditioned by freely suspending for 2 hr in an oven controlled to 400 ±2°C (752 ±3.6°F).
Minimum Dielectric Strength, kV/mm (V/mil)	236 (6,000)	217 (5,500)	177 (4,500)	197 (5,000)	100 (2,550)	197 (5,000)	ASTM D-149-94. (Average of 10 specimens.) Flat sheets in air placed between 6.4 mm (¼ in) diameter brass electrodes with 0.8 mm (1/32 in) edge radius subjected to 60 cycles AC voltage at 500 V/sec rate of rise to the breakdown voltage.
Minimum Volume Resistivity, ohm·cm at 200°C (392°F)	10^{12}	10^{12}	10^{12}	10^{12}	10^{12}	10^{12}	ASTM D-257-93
Maximum Dielectric Constant	3.9	3.9	3.9	3.9	4.0	3.9	ASTM D-150-94. Use conducting silver paint electrodes, two terminal system of measurement at standard conditions. Results are based on an average of five tests using measured thickness of specimens. Measure at 1 kHz/sec.
Maximum Dissipation Factor	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	Same as above method.

Table 2
Properties of Heat-Sealable *Kapton®* Films

Property	Product Designation 120FN 616B	150FN 019	200FN 919	250FN 029	300FN 929	150FCR 019	150FWR 019	200FWR 919	Method
Minimum Machine Direction Ultimate Elongation, %	55	55	55	55	55	35	65	65	ASTM D-882-91, Method A using an Instron Tensile Tester (specimen size: 13 × 150 mm [½ × 6 in]; jaw separation: 100 mm [4 in]; jaw speed: 50 mm [2 in] min.). Calculate the average of five specimens based on original measured thickness at 23°C (73°F).
Minimum Dielectric Strength, kV/mm (V/mil)	197 (5,000)	157 (4,000)	130 (3,300)	110 (2,800)	108 (2,750)	130 (3,300)	157 (4,000)	130 (3,300)	ASTM D-149-94. (Average of 10 specimens.) Flat sheets in air placed between 6.4 mm (¼ in) diameter brass electrodes with 0.8 mm (1/32 in) edge radius subjected to 60 cycles AC voltage at 500 V/sec rate of rise to the breakdown voltage.
Minimum Heat Seal Peel Strength, N·cm (lb·in)									The heat seal peel strength between the coated and uncoated side of one-side coated *Kapton®* or the coated to coated side of one or two-sided coated *Kapton®*, or coated side to the untreated side of GT copper foil 25 µm (1 mil) is measured in the following manner. Seals are made in a jaw sealer at 350°C (662°F), 138 kPa (20 psi), 20 sec dwell time. After cooling, the seals are cut to 25 mm (1 in) wide strips using a Thwing-Albert JDC sample cutter or equivalent. The strength of the seal is measured with an Instron-type tensile tester. Seal strength is defined as the peak instantaneous strength occurring in each seal. Five specimen values are averaged.
Teflon® to *Teflon®*	2.3 (1.32)	NA	3.5 (1.98)	NA	3.5 (1.98)	NA	NA	3.5 (1.98)	
Teflon® to *Kapton®*	NA	2.3 (1.32)	NA	3.5 (1.98)	NA	2.1 (1.20)	2.3 (1.32)	NA	
Teflon® to Copper	2.3 (1.32)	2.9 (1.65)	3.5 (1.98)	3.5 (1.98)	3.5 (1.98)	2.7 (1.53)	2.9 (1.65)	3.5 (1.98)	
As-Received Seal Peel Strength, N·cm (lb·in)	Not Applicable	0.98 (0.55)	0.98 (0.55)	0.98 (0.55)	0.98 (0.55)	0.80 (0.45)	0.98 (0.55)	0.98 (0.55)	180° peel in an Instron-type tester at 23°C (73°F).

Heat-Sealable Kapton® *Films*

As primary insulation on magnet wire, it is often desired to seal film to the copper and to itself after the wire has been wrapped with the desired overlap. Because the polyimide has no true melting point, the film is coated with or laminated to *Teflon*® FEP fluoropolymer, which acts as a high-temperature glue. The heat-sealable films are designated as FN, FCR, and FWR. **Table 3** lists those combinations typically used in this industry. Other combinations can be made available. Please consult your DuPont Films marketing representative.

Table 3
Constructions of Heat-Sealable *Kapton®* Types

	Film Constructions,* μm (mil)		
Film Designation	***Teflon®* FEP**	***Kapton®* HN**	***Teflon®* FEP**
120FN616B	3.8 (0.15)	25 (1.00)	3.8 (0.15)
150FN019		25 (1.00)	12.5 (0.50)
200FN919	12.5 (0.50)	25 (1.00)	12.5 (0.50)
250FN029		50 (2.00)	12.5 (0.50)
300FN929	12.5 (0.50)	50 (2.00)	12.5 (0.50)
	***Teflon®* FEP**	***Kapton®* CR**	***Teflon®* FEP**
150FCR019		25 (1.00)	12.5 (0.50)
	***Teflon®* FEP**	***Kapton®* WR**	***Teflon®* FEP**
150FWR019		25 (1.00)	12.5 (0.50)
200FWR919	12.5 (0.50)	25 (1.00)	12.5 (0.50)

* Commonly used in magnet wire and covered by specifications in this bulletin. See General Specification Bulletin for specifications of other Type FN films.

Applications

The unique properties of *Kapton*® allow it to be used extensively in the motor and magnet wire industry. In very thin sections, *Kapton*® conserves space for conductors, which ultimately yields more power without increasing motor size. *Kapton*® provides exceptional overload protection and long motor life, even in the most demanding application areas and/or environments. Additionally, *Kapton*® has superior chemical resistance to most solvents, hydrocarbons, and lubricants. *Kapton*® also carries the UL 94-V0 flammability rating and will not melt, ignite, or propagate flame.

Typical motor applications include: primary magnet wire insulation, turn-to-turn insulation, coil insulation, slot liners, and ground insulation.

In addition to being available as plain (Type HN, CR, or WR) and coated (Type FN, FCR, or FWR) film, *Kapton*® is routinely used in combination with other insulating materials as well as a pressure-sensitive adhesive tape.

Certification

Kapton® is certified to meet the requirements of the military specification MIL-P-46112B(MR) as well as the items listed in this specifications bulletin. Written confirmation is available with each delivery upon request.

Thermal Durability

The thermal durability of *Kapton*® polyimide film depends on the environmental conditions under which it is aged and tested, and lifetime depends on the criteria of failure. Films are routinely tested at the manufacturing site in the following manner.

Sheets of film 215 × 280 mm (8½ × 11 in) are freely suspended in an oven at 400°C (752°F). The temperature of the oven is monitored with a thermocouple to ensure a temperature accuracy of ±2°C (±3.6°F). Sheets are removed after 2 hr and tested on an Instron Tensile Tester as described in **Tables 1** and **2** under "Elongation." The elongation (at 23°C [73°F]) of the film should not be less than 10% after this aging at 400°C (752°F). This conforms to the "Elongation, %, after 2 hr 400°C (752°F)" requirement (**Table 1**) of MIL-P-46112B (MR).

Underwriters Laboratories, Inc. lists a thermal index of 200–220°C (392–428°F) (depending on gauge and type) for mechanical properties and 220–240°C (428–464°F) (depending on gauge and type) for electrical properties under their file no. E39505 for *Kapton*®.

Thickness

Test Method

Table 4 lists thickness of *Kapton*® films. Film is measured in accordance with ASTM D-374-94, Method A or C.

The average of ten randomly selected readings from a minimum area 77 cm^2 (12 in^2) is obtained and re-checked before rejecting any slit roll. Abnormal readings may occasionally result from dust particles or spot surface imperfections.

Table 4
Thickness of *Kapton*® Films

	Product Designation													
Thickness	100HN	200HN	300HN	120FN 616B	150FN 019	200FN 919	250FN 029	300FN 929	100CR	500CR	150FCR 019	100WR	150FWR 019	200FWR 919
Nominal, µm (mil)	25.4 (1.0)	50.8 (2.0)	76.2 (3.0)	33.0 (1.3)	38.1 (1.5)	50.8 (2.0)	63.5 (2.5)	76.2 (3.0)	25.4 (1.0)	127 (5.0)	38.1 (1.5)	25.4 (1.0)	38.1 (1.5)	50.8 (2.0)
Minimum, µm (mil)	22.8 (0.90)	47.0 (1.85)	69.8 (2.75)	31.0 (1.22)	34.3 (1.35)	45.7 (1.80)	60.4 (2.38)	69.8 (2.75)	22.8 (0.90)	117 (4.61)	34.3 (1.35)	22.8 (0.90)	34.3 (1.35)	45.7 (1.80)
Maximum, µm (mil)	28.7 (1.13)	55.9 (2.20)	82.6 (3.25)	34.8 (1.37)	41.9 (1.65)	55.9 (2.20)	66.5 (2.26)	82.6 (3.25)	28.7 (1.13)	137 (5.40)	41.9 (1.65)	28.7 (1.13)	41.9 (1.65)	55.9 (2.20)

General

Uniformity

Kapton® shall be free from defects that impair serviceability and/or appearance in usual applications.

Cores

Cores shall be of sufficient strength to prevent collapsing during handling.

Core Type

	ID	Core Material
Pad	38 mm (1.5 in)	Plastic
	76 mm (3 in)	Paper or Plastic
	152 mm (6 in)	Paper or Plastic

	ID	Core Width	Core Material
Universal/ *Step-Pac*®	76 mm (3 in)	70 mm (2¾ in)	Paper
	76 mm (3 in)	111 mm (4⅜ in)	Paper

Core Width Tolerance

Roll Width	Tolerance
2 to 102 mm (5/64 to 4 in)	–0 to +0.8 mm (–0 to +1/32 in)
103 mm to max. (4 1/16 in to max.)	–0 to +1.6 mm (–0 to +1/16 in)

Film Width

The minimum width of film wound on pad is 9.5 mm (⅜ in). Universal winding is available for film widths from 3.2 mm (⅛ in) to 22.2 mm (⅞ in).

Step-Pac® is available for film widths from 3.2 mm (⅛ in) to 38.1 mm (1½ in).

The increments in width are 1.6 mm (1/16 in).

Width Tolerance

Slit Width Range	Tolerance
Pad Rolls	
<38 mm (1½ in)	± 0.18 mm (7 mil)
38 to 102 mm (1½–4 in)	± 0.76 mm (30 mil)
>102 mm (4 in)	± 1.52 mm (60 mil)
Universal	± 0.20 mm (8 mil)

Weight Tolerance

Weight Ordered	Tolerance
0.4536–4.536 kg (1–10 lb)	±20%
4.536–45.36 kg (10–100 lb)	±10%
>45.36 kg (>100 lb)	±5%

Roll Specifications

Kapton® polyimide film is supplied in three types of put-ups: *Step-Pac*®, universal wind, and pad wind, described below.

Step-Pac®

- Film shall be centered on the core to ±4.8 mm (±3/16 in).
- Film shall not project from the main body of the roll more than 3 mm (⅛ in).
- The outside and starting ends of the film shall be fastened in such a manner as to prevent unwinding.
- Roll face depression, the difference between the highest and lowest points unstressed, shall not exceed 4.8 mm (3/16 in).
- Width of traverse can be either 65 mm (2½ in) or 105 mm (4⅛ in).

Universal Wind

- Film shall be centered on the core to ±4.8 mm (±3⁄16 in).
- Film shall not project from the main body of the roll more than 3 mm (1⁄8 in).
- The outside and starting ends of the film shall be fastened in such a manner as to prevent unwinding.
- Roll face depression, the difference between the highest and lowest points unstressed, shall not exceed 4.8 mm (3⁄16 in).
- Width of traverse can be either 44 mm (1¾ in) or 100 mm (4 in).

Pad Wind

- Core width will be film width +3 mm (+1⁄8 in), –0 mm (–0 in).
- Core edges shall not project more than 1.6 mm (1⁄16 in) beyond roll face on either side.
- Core shall not be recessed on either side.
- The outside and starting ends of the film shall be fastened in such a manner as to prevent unwinding.
- "Dishing" or "cupping" may not exceed 1.6 mm (1⁄16 in), measured with a straight edge across the diameter of the roll.

Standard Put-Ups

Standard put-ups for different roll types are given in **Table 5**.

Table 5
Put-Ups for Different Roll Types

Roll Type	ID	OD
Step-Pac®	76 mm (3 in)	152 mm (6 in)*
	76 mm (3 in)	203 mm (8 in)*
	76 mm (3 in)	292 mm (11.5 in)*
Universal	76 mm (3 in)	152 mm (6 in)*
	76 mm (3 in)	203 mm (8 in)*
	76 mm (3 in)	292 mm (11.5 in)*
Pad	76 mm (3 in)	152 mm (6 in)
	76 mm (3 in)	241 mm (9.5 in)
	152 mm (6 in)	280 mm (11 in)

*depending on width

Other put-ups can be made available upon request. Please consult your DuPont Films marketing representative.

Splice Specifications

A variety of splices are available: heat seal (limited to 305 mm [12 in] width or less), *Kapton®* polyimide film-based pressure-sensitive tape, or *Mylar®* polyester film-based pressure-sensitive tape.

The minimum average distance between splices is shown in **Tables 6** and **7**. To calculate the maximum number of splices in a roll, divide the roll length by the minimum average length and subtract one.

Table 6
Minimum Average Splice Free Length for *Kapton®* Films

			Product Designation		
Roll Type / Meters	Core ID, mm	Roll OD, mm	100HN 100CR 100WR	150FN 150FCR 150FWR	200FN 200FWR
Step-Pac®	76	152	610	610	304
		203	610	610	304
		305	610	610	304
Universal	76	152	610	610	304
		203	610	610	304
		305	610	610	304
Pad	76	152	154	50	61
		240	195	107	102
Feet	**in**	**in**			
Step-Pac®	3	6	2,000	2,000	1,000
		8	2,000	2,000	1,000
		12	2,000	2,000	1,000
Universal	3	6	2,000	2,000	1,000
		8	2,000	2,000	1,000
		12	2,000	2,000	1,000
Pad	3	6	505	165	200
		9½	640	350	335

Table 7
Minimum Length Between Splices and/or Beginning and End of Roll for *Kapton®* Films

Roll Type / Meters	Core ID, mm	Roll OD, mm	Product Designation: 100HN 100CR 100WR	150FN 150FCR 150FWR	200FN 200FWR
Step-Pac®	76	152	30	46	46
		203	30	46	46
		305	30	46	46
Universal	76	152	30	46	46
		203	30	46	46
		305	30	46	46
Pad	76	152	30	30	30
		240	30	30	30
Feet	**in**	**in**			
Step-Pac®	3	6	100	150	150
		8	100	150	150
		12	100	150	150
Universal	3	6	100	150	150
		8	100	150	150
		12	100	150	150
Pad	3	6	100	100	100
		9½	100	100	100

Heat seal splices are made as follows: On all films but *Kapton*® 250FN029, the splice is an overlap splice a minimum of 10 mm (⅜ in) long. On 250FN029, a butt splice is made using *Kapton*®120FN616 as the joining tape applied on the FEP surface.

- Overlap heat seal splices are oriented with the leading edge of the new film on the bottom for universal and pad rolls for two-sided FEP structures. Pad rolls of one-sided FEP composites have the leading edge on the top.
- The 250FN029 butt splice is oriented with the 120FN616 tape on the top of the film as it unwinds from universal or *Step-Pac*® rolls and on the bottom as it unwinds from pad rolls.

Pressure-sensitive splices are made as follows: A butt splice is made with the film ends covered on both sides with splice tape. For all films, a 50 mm (2 in) wide pressure-sensitive tape will be used.

Splices will be sufficiently smooth and wrinkle-free, so that adjacent layers of film are not disturbed and approximately centered to ±6 mm (±¼ in).

No splices will be made after the roll has reached minimum OD.

Packaging

Kapton® shall be adequately packed to prevent loss of contents or damage during shipment.

All film will be wrapped with a non-fibrous material.

Marking

Kapton® is identified as described in **Table 8** to allow complete traceability back to the raw materials and processing conditions.

Table 8
Information Contained on Labels

	Container	Shipping Package	Core Label*
Scheduled Date	X	X	X
Customer Order Number	X	X	X**
DuPont Order Number	X	X	X
Gauge	X	X	X
Type	X	X	X
Width	X	X	X
No. of Rolls per Container	X	X	
Net Weight	X	X	
Footage			X
Mill Roll Number	X	X	
ID and OD***	X	X	

*Affixed to the core on all cores, 57 mm (2¼ in) wide and over; include with the package on all cores less than 57 mm (2¼ in) wide.

**Available for up to 12 characters.

***Inside diameter of core and nominal outside diameter of roll.

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(10/97) 300869A Printed in U.S.A.
[Replaces: H-24923]
Reorder No.: H-24923-1

DuPont Films