EA02025

TEXAS INSTRUMENTS, INC.'S

09/10/03 LETTER TO ODI

REQUEST 10

BOX 13

PART A – G

PART C

May 24, 1995

TEXAS INSTRUMENTS

FACSIMILE TRANSMITTAL

TO:	**Name:**	**Ed McKenzie**
	Location:	**DuPont High Performance Films**
	Mail Station:	
	Phone Number:	**614-474-0730** 0724
	FAX Number:	**614-474-0680**

FROM: **Keith Rosiello**

TEXAS INSTRUMENTS MS 12-29

Phone Number: **(508) 236-1284**

FAX Number: **(508) 236-3153**

- Tech support 800-237-4357

Total number of pages (including header page): 5

COMMENTS:

Ed,

I am a design engineer in Dave's group. He has given me the responsibility to finish off the Kapton spec. Basically I have put the spec, as discussed between yourself and Dave, on a TI print. Could you give it a once over, nothing has changed. I included a copy of the agreed upon spec for comparison. Please let me know if I may close this issue or if you want to discuss any further changes.

Thanks,
Keith

Texas Instruments Material Specification for Kapton® Film

1.0 SCOPE

This specification defines mechanical property, quality and inspection requirements for DuPont Type 300HN, 500HN and 500FN131 Kapton® and Teflon® laminated Kapton® film supplied to Texas Instruments. This specification applies when it is referenced on the print for the material or finished component.

2.0 TRACEABILITY

Material supplied to this specification must be traceable to the original mill roll. A mill roll is defined as a roll that is 50-60 inches wide and no longer than 10,000 feet. For the purpose of certifying strength and elongation, a new mill roll should be designated after any process changes that may affect the certified minimum strength and elongation values.

3.0 PROCESS CHANGES

Process changes that could affect the strength, ultimate elongation, or physical appearance of the film must have prior review and approval by Texas Instruments.

4.0 STRENGTH AND ELONGATION CERTIFICATION

4.1 Types 300HN and 500HN Kapton® Film

Tensile test specimens are to be taken from increments along the width of the roll including locations at both outer edges and the center. A minimum of 10 specimens are to be tested - 1 in the machine direction (MD) and 1 in the transverse direction (TD) from each of 5 locations across the width of the mill roll. The certified minimum strength is to be the minimum value recorded for all of the test specimens. Tensile testing is to be conducted upon start-up of a production run, then on every other mill roll. It is DuPont's responsibility to increase the frequency of inspection if there are process changes or other factors within a production run that may result in strength or elongation values that are lower than those certified by the test specimens.

Minimum Values	
Ultimate Tensile Strength	Type 300HN & 500HN
Machine Direction (MD)	24000 psi minimum
Transverse Direction (TD)	24000 psi minimum
Ultimate Elongation	
Machine Direction (MD)	50% minimum
Transverse Direction (TD)	50% minimum

Testing to be conducted per the latest revision of ASTM D882.

4.2 Type 500FN131 Teflon® laminated Kapton®

Tensile testing of 500FN131 film is not required provided the 300HN Kapton® substrate film has been tested and certified to meet the minimum strength and elongation values. The reasoning is that a.) the mechanical properties of the 500FN131 film are derived more from the 300HN substrate film rather than the Teflon® laminate and b.) the Teflon® laminating process according to DuPont does not negatively affect strength or elongation properties.

It is DuPont's responsibility to test Type 500FN131 film if either a.) the 300HN certification data is unavailable or b.) there is reason to believe the lamination process may have affected the certified minimum values of the 300HN substrate. In this case, it is acceptable to first remove the Teflon® film from the Kapton® substrate to get a more accurate and repeatable tensile test. The minimum strength and elongation values for the Type 300HN film shall apply.

5.0 DEFECTS (All film types)

Material supplied to this specification must be 100% inspected for defects including bubbles, pinholes and inclusions. The control plan must include a means for periodically verifying that the inspection equipment is capable of locating defects.

Criteria:

A. Inspection is required to detect holes and bubbles in all 300HN and 500HN film, as well as the 300HN used as the substrate for 500FN131 film using an on line camera inspection system. Holes of any size are not acceptable in finished product shipped to TI, and therefore needs to be addressed through appropriate Prevention controls in the manufacture of the film. As a practical Detection control, the system must be able to detect holes and bubbles of .025" or greater, and material found to have holes or bubbles of this size is not acceptable.

B. Inspection is required to detect inclusions of foreign matter in all 300HN and 500HN film, as well as the 300HN used as the substrate for 500FN131 film using an on line camera inspection system. Inclusions of .025" or greater must be detectable by the system and are not allowed in finished product shipped to TI.

6.0 CERTIFICATION AND DATA RETENTION

When the print specifies that material certification is required, the supplier certifies that the material was produced in accordance with this specification.

All strength test data and specimens are to be maintained by DuPont for a minimum of (5) years from the date of manufacture.

75951 SH.1

1.0 SCOPE
THIS SPECIFICATION DEFINES MECHANICAL PROPERTY, QUALITY AND INSPESTION REQUIREMENTS FOR DUPONT TYPE 300HN, 500HN AND 500FN131 KAPTON (R) AND TEFLON (R) LAMINATED KAPTON (R) FILM SUPPLIED TO TEXAS INSTRUMENTS. THIS SPECIFICATION APPLIES WHEN IT IS REFERENCED ON THE PRINT FOR THE MATERIAL OR FINISHED COMPONENT.

2.0 TRACEABILITY
MATERIAL SUPPLIED TO THIS SPECIFICATION MUST BE TRACEABLE TO THE ORIGINAL MILL ROLL. A MILL ROLL IS DEFINED AS A ROLL THAT IS 50 - 60 INCHES WIDE AND NO LONGER THAN 10,000 FEET. FOR THE PURPOSE OF CERTIFYING STRENGTH AND ELONGATION, A NEW MILL ROLL SHOULD BE DESIGNATED AFTER ANY PROCESS CHANGES THAT MAY AFFECT THE CERTIFIED MINIMUM STRENGTH AND ELONGATION VALUES.

3.0 PROCESS CHANGES
PROCESS CHANGES THAT COULD AFFECT THE STRENGTH, ULTIMATE ELONGATION, OR PHYSICAL APPEARANCE OF THE FILM MUST HAVE PRIOR REVIEW AND APPROVAL OF TEXAS INSTRUMENTS.

4.0 STRENGTH AND ELONGATION CERTIFICATION
4.1 TYPES 300HN AND 500HN KAPTON (R) FILM

TENSILE TEST SPECIMENS ARE TO BE TAKEN FROM INCREMENTS ALONG THE WIDTH OF THE ROLL INCLUDING LOCATIONS AT BOTH OUTER EDGES AND THE CENTER. A MINIMUM OF 10 SPECIMENS ARE TO BE TESTED - 1 IN THE MACHINE DIRECTION (MD) AND 1 IN THE TRANSVERSE DIRECTION (TD) FROM EACH OF 5 LOCATIONS ACROSS THE WIDTH OF THE MILL ROLL. THE CERTIFIED MINIMUM STRENGTH IS TO BE THE MINIMUM VALUE RECORDED FOR ALL OF THE TEST SPECIMENS. TENSILE TESTING IS TO BE CONDUCTED UPON START-UP OF A PRODUCTION RUN, THEN ON EVERY OTHER MILL ROLL. IT IS DUPONT'S RESPONSIBILITY TO INCREASE THE FREQUENCY OF INSPECTION IF THERE ARE PROCESS CHANGES OR OTHER FACTORS WITHIN A PRODUCTION RUN THAT MAY RESULT IN STRENGTH OR ELONGATION VALUES THAT ARE LOWER THAN THOSE CERTIFIED BY THE TEST SPECIMINES.

MINIMUM VALUES

ULTIMATE TENSIL STRENGTH	TYPE 300HN & 500HN
MACHINE DIRECTION (MD)	24000 PSI MINIMUM
TRANSVERSE DIRECTION (TD)	24000 PSI MINIMUM
ULTIMATE ELONGATION	
MACHINE DIRECTION (MD)	50% MINIMUM
TRANSVERSE DIRECTION (TD)	50% MINIMUM

TESTING TO BE CONDUCTED PER THE LATEST REVISION OF ASTM D882

A 1ST ISSUE 5-19-95, CMK22827 CFF
REV

75951 SH.2

4.2 TYPE 500FN131 TEFLON ® LAMINATED KAPTON ®
TENSILE TESTING 500FN131 FILM IS NOT REQUIRED PROVIDED THE 300HN KAPTON ® SUBSTRATE FILM HAS BEEN TESTED AND CERTIFIED TO MEET THE MINIMUM STRENGTH AND ELONGATION VALUES. THE REASONING IS THAT

A.) THE MECHANICAL PROPERTIES OF THE 500FN131 FILM ARE DERIVED MORE FROM THE 300HN SUBSTRATE FILM RATHER THAN THE TEFLON ® LAMINATE.

B.) THE TEFLON ® LAMINATING PROCESS ACCORDING TO DUPONT DOES NOT NEGATIVELY AFFECT STRENGTH OR ELONGATION PROPERTIES.

IT IS DUPONT'S RESPONSIBILITY TO TEST TYPE 500FN131 FILM IF EITHER

A.) THE 300HN CERTIFICATION DATA IS UNAVAILABLE OR

B.) THERE IS REASON TO BELIEVE THE LAMINATION PROCESS MAY HAVE AFFECTED THE CERTIFIED MINIMUM VALUES OF THE 300HN SUBSTRATE. IN THIS CASE IT IS ACCEPTABLE TO FIRST REMOVE THE TEFLON ® FILM FROM THE KAPTON ® SUBSTRATE TO GET A MORE ACCURATE AND REPEATABLE TENSILE TEST. THE MINIMUM STRENGTH AND ELONGATION VALUES FOR THE TYPE 300HN FILM SHALL APPLY.

5.0 DEFECTS (ALL FILM TYPES)
MATERIAL SUPPLIED TO THIS SPECIFICATION MUST BE 100% INSPECTED FOR DEFECTS INCLUDING BUBBLES, PINHOLES AND INCLUSIONS. THE CONTROL PLAN MUST INCLUDE A MEANS FOR PERIODICALLY VERIFING THAT THE INSPECTION EQUIPMENT IS CAPABLE OF LOCATING DEFECTS.

CRITERIA:

A. INSPECTION IS REQUIRED TO DETECT HOLES AND BUBBLES IN ALL 300HN AND 500HN FILM, AS WELL AS THE 300HN USED AS THE SUBSTRATE FOR 500FN131 FILM USING AN ON LINE CAMERA INSPECTION SYSTEM. HOLES OF ANY SIZE ARE NOT ACCEPTABLE IN FINISHED PRODUCT SHIPPED TO T.I., AND THEREFORE NEEDS TO BE ADDRESSED THROUGH APPROPRIATE PREVENTION CONTROLS IN THE MANUFACTURE OF THE FILM. AS A PRACTICAL DETECTION CONTROL, THE SYSTEM MUST BE ABLE TO DETECT HOLES AND BUBBLES OF .025" OR GREATER, AND MATERIAL FOUND TO HAVE HOLES OR BUBBLES OF THIS SIZE IS NOT ACCEPTABLE.

B. INSPECTION IS REQUIRED TO DETECT INCLUSIONS OF FOREIGN MATTER IN ALL 300HN AND 500HN FILM, AS WELL AS THE 300HN USED AS THE SUBSTRATE FOR 500FN131 FILM USING AN ON LINE CAMERA INSPECTION SYSTEM. INCLUSIONS OF .025" OR GREATER MUST BE DETECTABLE BY THE SYSTEM AND ARE NOT ALLOWED IN FINISHED PRODUCT SHIPPED TO T.I.

6.0 CERTIFICATION AND DATA RETENTION
WHEN THE PRINT SPECIFIES THAT MATERIAL CERTIFICATION IS REQUIRED, THE SUPPLIER CERTIFIES THAT THE MATERIAL WAS PRODUCED IN ACCORDANCE WITH THIS SPECIFICATION.

ALL STRENGTH TEST DATA AND SPECIMENS ARE TO BE MAINTAINED BY DUPONT FOR A MINIMUM OF (5) YEARS FROM THE DATE OF MANUFACTURE.

REV A 1ST ISSUE 5-19-95 (RN2262) OFF

1. Create an ECN to set-up a new drawing titled Texas Instruments Material Specification for Kapton ® Film.

2. Once it's on a TI print, send a (& before we sign it off in drafting) mark it "Preliminary" & fax to DuPont's Ed McKenzie for final look-over.

3. Make last changes & sign off drawing.

4. ~~On same~~ ~~Create another ECN to add~~

On same ECN, also request that a note be added to the 27225 Kapton strip spec:

"material supplied to this print must meet TI material Specification # (   )."

On the control board for the ECN, include Ethan Coulson & Scott O'Connell. — Btn Design & mfg engr; also ask Chris Wagner who to put on the board for purchasing.

52PS 27225-1 KAPTON STRIP SPEC
55PS -2 " "

89PS 75725-1

need a 5 mil Kapton spec
63PS 27225-4

ECN

(1) create Spec # ( )
(2) add Note 11 to 27225
must conform to spec ( )

CCB members:

[redacted]

Bryan - 3234

Mayer, Jon

From: Czarn David
To: Dague, Bryan
Cc: Mayer, Jon
Subject: DuPont visit - 7/24/95
Date: Monday, July 24, 1995 2:58PM

Bryan, Tom Clyde of DuPont called me this morning about their visit here Monday. It's my understanding that Tom heads up the High Performance Films Business Unit, with Ed McKenzie reporting to him. Tom called me because I had been in discussion with DuPont in the past about 1. helium permeability issues with AC switches and 2. the need for better hydrolytic stability for brake switch applications. In a recent customer survey I again pointed these out as 2 improvement areas.

Purpose of this message is to recommend a couple of things to discuss at the meeting. Currently, I don't plan to be there but can be if needed.

1. Al Amore did alot of He permeability testing with the current 500FN131 film, as well as some alternate materials supplied by DuPont. This was at the direct request of Harrison. In fact, it was Harrison who worked directly with DuPont (not with Ed McKenzie or Tom) to get the material we tested. The testing did not show significant improvement, and if I recall correctly the material was not very ductile so there was a concern about welding and diaphragm life. I think Al wrote a report on this or at least summarized the findings in a letter to GM. I think DuPont should be made aware of our results, and also be given a rough spec of what we're trying to meet in terms of leak rate with helium.

2. Relative to hydrolytic stability, several months ago DuPont sampled us with a few sheets of material from their Texas plant. I think they called it JP material; not sure why they developed it. The material was marginally better in terms of retained strength after exposure to hot water, I recall. I'm not sure if we ever did any testing. I'd recommend we look into what we've done (if anything); if it turns out we didn't do any testing, perhaps we can give then a time table of when we expect some results. I've made it clear to them whenever we get sample material that we need to satisfy the needs of our current programs first, so the experimental stuff has to take a back seat.

I'm not sure if the pressure switch diaphragm business is important enough to DuPont to put more efforts into coming up with a breakthrough in either of these areas. I think we have an opportunity to reinforce that these are important careabouts that would warrant a more focused effort on their part. So far, their approach has been to give us samples of materials they've developed for some other need.

Call if you want to discuss anything further.

Regards, Dave

RICHARD STANDER 8/4/95

WEEKLY UPDATE

1) Alternative Diaphram Mat'ls.

- Met with Dupont on Monday - meeting went very well, Several action items for Dupont.

- 36 Switches (150 PS) built & ready to test on cycler.
  - Kapton 500 FN 131 (control)
  - Kapton 500XP019
  - " " / 300 JP
  - PEEK (TALPA 2000) *

* PEEK Does have problems with crystallization changes w/ heat over time. (embrittlement possible?)

2) 150 PS Switches on cycler & running very well! Repaired air circulator on chamber & ordered replacement part 2-3 wks lead time.

3) 90 PS Switches have been plumbed & installed on cycler for first 150K run (running @ spec. pressure @ 2 Hz.

1A) I am continuing to investigate additional alternative films for increased diaphram life of switch.

27225-1/2

DuPont Films
U.S. Route [illegible] DuPont Road
P.O. Box [illegible]
[illegible], OH [illegible]
Tel. [illegible]

DUPONT

DuPont Films

July 31, 1995

John Meyer
Texas Instruments
34 Forest St.
Attleboro, MA 02703

Dear Mr. Meyer,

For many years, Kapton* Type FN films were used almost exclusively as electrical insulations for motors and cable. Over the past decade, use of type 500FN131 as a diaphragm material, primarily for the automotive industry, has steadily increased. As the requirements for these disparate end uses have been further defined, we feel it is necessary to differentiate between them and focus on the film characteristics important to each. This is especially apparent after review of the most recent version of the TI specification for Kapton* films.

As a result of many discussions with TI representatives over the past year, Du Pont is using the designation 500FN131L to identify internally product for TI's use in fabrication of automotive pressure switches. 500FN131L meets all the requirements of 500FN131, and features tighter specifications than film produced for electrical insulation. These specifications include bond strength between the Kapton* and Teflon* layers, and occurrence of defects such as holes, bubbles, or debris.

To assist us in this effort, we would ask Texas Instruments to begin ordering 5 mil FN laminate as:

Kapton* 500FN131L.

This name change will allow DuPont to fully integrate the product name in our systems, and install controls to completely segregate type FN131 laminates by the intended end use.

Please let me know if you have any questions, or if I can be of further assistance.

Sincerely,

Edward C. McKenzie

Edward C. McKenzie

* DuPont Registered Trademark

E.I. du Pont de Nemours and Company

Printed on Recycled Paper

TI-NHTSA 017696

DUPONT

FAX NO.: 508 699 3762.

CIRCLEVILLE PLANT

Date & Time 7/31/95 8:40

P.O. Box 89
Circleville, OH 43113

FACSIMILE TRANSMISSION COVER SHEET

ADDRESSEE(S):

Name	Company or Department	Location
JOHN MAYER	TEXAS INSTR.	ATTLEBORO

COPY:

SENDER:

Name	Business Sector	Location
ED McKENZIE	DUPONT	CIRCLEVILLE OH

*** 1 PAGE(S) TO FOLLOW THIS COVER SHEET ***

Special Instructions/Information to Recipient:
JOHN - PLEASE REVIEW THIS WITH EMMETT DURING HIS VISIT.
Thanks
Ed.

CIRCLEVILLE FAX NUMBER FOR THIS TRANSMISSION IS 1-800-679-4402. SHOULD PROBLEMS OCCUR WHILE SENDING, CONTACT 1-800-967-5607.

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(FAX.AB)

Charting a Course for Excellence

JUL-31-95 MON 08:47 TI PURCHASING ATTLE FAX NO. 5086993762 P.01

TI-NHTSA 017697

DU PONT

DuPont High Performance Films

Kapton® polyimide film

Table of Contents

Kapton® is used in applications such as the solar array and for thermal management in the United States space program.

General Information

Kapton® polyimide film possesses a unique combination of properties that make it ideal for a variety of applications in many different industries. The ability of Kapton® to maintain its excellent physical, electrical, and mechanical properties over a wide temperature range has opened new design and application areas to plastic films.

Kapton® is synthesized by polymerizing an aromatic dianhydride and an aromatic diamine. It has excellent chemical resistance; there are no known organic solvents for the film. Kapton® does not melt or burn as it has the highest UL-94 flammability rating: V-0. The outstanding properties of Kapton® permit it to be used at both high and low temperature extremes where other organic polymeric materials would not be functional.

Adhesives are available for bonding Kapton® to itself and to metals, various paper types, and other films.

Kapton® polyimide film can be used in a variety of electrical and electronic insulation applications: wire and cable tapes, formed coil insulation, substrates for flexible printed circuits, motor slot liners, magnet wire insulation, transformer and capacitor insulation, magnetic and pressure-sensitive tapes, and tubing. Many of these applications are based on the excellent balance of electrical, thermal, mechanical, physical, and chemical properties of Kapton® over a wide range of temperatures. It is this combination of useful properties at temperature extremes that makes Kapton® a unique industrial material.

Three types of Kapton® are described in this bulletin:

- Kapton® Type HN, all-polyimide film, has been used successfully in applications at temperatures as low as −269°C (−452°F) and as high as 400°C (752°F).

  Type HN film can be laminated, metallized, punched, formed, or adhesive coated. It is available as 7.5 µm (0.3 mil), 12.5 µm (0.5 mil), 19 µm (0.75 mil), 25 µm (1 mil), 50 µm (2 mil), 75 µm (3 mil), and 125 µm (5 mil) films.
- Kapton® Type VN, all-polyimide film with all of the properties of Type HN, plus superior dimensional stability. Type VN is available as 12.5 µm (0.5 mil), 19 µm (0.75 mil), 25 µm (1 mil), 50 µm (2 mil), 75 µm (3 mil), and 125 µm (5 mil) films.
- Kapton® Type FN, a Type HN film coated on one or both sides with Teflon® FEP fluoropolymer resin, imparts heat sealability, provides a moisture barrier, and enhances chemical resistance. Type FN is available in a number of combinations of polyimide and Teflon® FEP thicknesses (see **Table 16**).

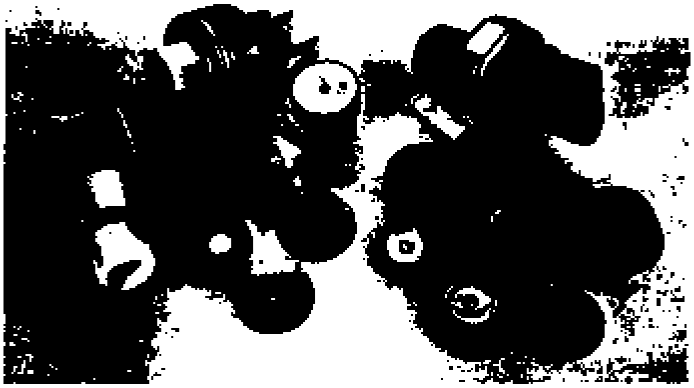
Note: In addition to these three types of Kapton®, films are available with the following attributes:

- antistat
- thermally conductive
- polyimides for fine line circuitry
- cryogenic insulation
- corona resistant
- pigmented for color
- conformable
- other films tailored to meet customers' needs

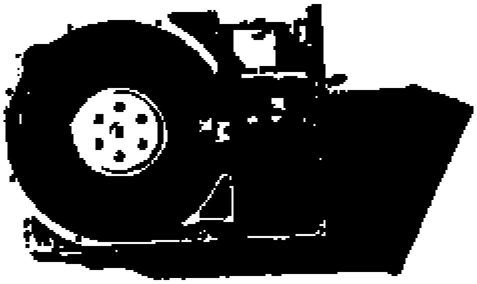
Data for these films are covered in separate product bulletins, which can be obtained from your DuPont representative.

The Chemical Abstracts Service Registry Number for Kapton® polyimide film is [25036-53-7].

TI-NHTSA 017700



Kapton[1] withstands the harsh chemical and physical demands on diaphragms used in automotive switches.



Kapton[1] is used in numerous electronic applications, including hard disk drives.

Physical and Thermal Properties

Kapton® polyimide films retain their physical properties over a wide temperature range. They have been used in field applications where the environmental temperatures were as low as −269°C (−452°F) and as high as 400°C (752°F). Complete data are not available at these extreme conditions, and the majority of technical data presented in this section falls in the 23 to 200°C (73 to 392°F) range.

Table 1
Physical Properties of Kapton® Type 100 HN Film, 25 μm (1 mil)

Physical Property	Typical Value at 23°C (73°F)	Typical Value at 200°C (392°F)	Test Method
Ultimate Tensile Strength, MPa (psi)	231 (33,500)	139 (20,000)	ASTM D-882-91, Method A*
Yield Point at 3%, MPa (psi)	69 (10,000)	41 (6000)	ASTM D-882-91
Stress to Produce 5% Elongation, MPa (psi)	90 (13,000)	61 (9000)	ASTM D-882-91
Ultimate Elongation, %	72	83	ASTM D-882-91
Tensile Modulus, GPa (psi)	2.5 (370,000)	2.0 (290,000)	ASTM D-882-91
Impact Strength, N·cm (ft·lb)	78 (0.58)		DuPont Pneumatic Impact Test
Folding Endurance (MIT), cycles	285,000		ASTM D-2176-89
Tear Strength—Propagating (Elmendorf), N (lbf)	0.07 (0.02)		ASTM D-1922-89
Tear Strength—Initial (Graves), N (lbf)	7.2 (1.6)		ASTM D-1004-90
Density, g/cc or g/mL	1.42		ASTM D-1505-90
Coefficient of Friction—Kinetic (Film-to-Film)	0.48		ASTM D-1894-90
Coefficient of Friction—Static (Film-to-Film)	0.63		ASTM D-1894-90
Refractive Index (Sodium D Line)	1.70		ASTM D-542-90
Poisson's Ratio	0.34		Avg. Three Samples Elongated at 5%, 7%, 10%
Low Temperature Flex Life	Pass		IPC TM 650, Method 2.6.18

*Specimen Size: 25 × 150 mm (1 × 6 in); Jaw Separation: 100 mm (4 in); Jaw Speed: 50 mm/min (2 in/min); Ultimate refers to the tensile strength and elongation measured at break.

Table 2
Thermal Properties of Kapton® Type 100 HN Film, 25 μm (1 mil)

Thermal Property	Typical Value	Test Condition	Test Method
Melting Point	None	None	ASTM E-794-85 (1989)
Thermal Coefficient of Linear Expansion	20 ppm/°C (11 ppm/°F)	−14 to 38°C (7 to 100°F)	ASTM D-696-91
Coefficient of Thermal Conductivity, W/m·K	0.12	296 K	ASTM F-433-77 (1987)[1]
$\frac{\text{cal}}{\text{cm} \cdot \text{sec} \cdot °\text{C}}$	2.87×10^{-4}	23°C	
Specific Heat, J/g·K (cal/g·°C)	1.09 (0.261)		Differential Calorimetry
Flammability	94V-0		UL-94 (2-8-85)
Shrinkage, %	0.17 1.25	30 min at 150°C 120 min at 400°C	IPC TM 650, Method 2.2.4A ASTM D-5214-91
Heat Sealability	Not Heat Sealable		
Limiting Oxygen Index, %	37		ASTM D-2863-87
Solder Float	Pass		IPC TM 650, Method 2.4.13A
Smoke Generation	DM = <1	NBS Smoke Chamber	NFPA-258
Glass Transition Temperature (T_g)	A second order transition occurs in Kapton® between 360°C (680°F) and 410°C (770°F) and is assumed to be the glass transition temperature. Different measurement techniques produce different results within the above temperature range.		

Table 3
Physical and Thermal Properties of Kapton Type VN Film

Property	Typical Value for Film Thickness 25 µm (1 mil)	50 µm (2 mil)	75 µm (3 mil)	125 µm (5 mil)	Test Method
Ultimate Tensile Strength, MPa (psi)	231 (33,500)	234 (34,000)	231 (33,500)	231 (33,500)	ASTM D-882-91
Ultimate Elongation, %	72	82	82	82	ASTM D-882-91
Tear Strength—Propagating (Elmendorf), N	0.07	0.21	0.38	0.58	ASTM D-1922-89
Tear Strength—Initial (Graves), N	7.2	16.3	26.3	46.9	ASTM D-1004-90
Folding Endurance (MIT), × 10^3 cycles	285	55	6	5	ASTM D-2176-89
Density, g/cc or g/mL	1.42	1.42	1.42	1.42	ASTM D-1505-90
Flammability	94V-0	94V-0	94V-0	94V-0	UL-94 (2-8-85)
Shrinkage, %, 30 min at 150°C (302°F)	0.03	0.03	0.03	0.03	IPC TM 650 Method 2.2.4A
Limiting Oxygen Index, %	37	43	46	45	ASTM D-2863-87

Table 4
Physical Properties of Kapton® Type FN Film*

Property	Typical Value for Film Type** 120FN616	150FN019	250FN029
Ultimate Tensile Strength, MPa (psi)			
23°C (73°F)	207 (30,000)	162 (23,500)	200 (29,000)
200°C (392°F)	121 (17,500)	89 (13,000)	115 (17,000)
Yield Point at 3%, MPa (psi)			
23°C (73°F)	61 (9000)	49 (7000)	58 (8500)
200°C (392°F)	42 (6000)	43 (6000)	36 (5000)
Stress at 5% Elongation, MPa (psi)			
23°C (73°F)	79 (11,500)	65 (9,500)	76 (11,000)
200°C (392°F)	53 (8000)	41 (6000)	48 (7000)
Ultimate Elongation, %			
23°C (73°F)	75	70	85
200°C (392°F)	80	75	110
Tensile Modulus, GPa (psi)			
23°C (73°F)	2.48 (360,000)	2.28 (330,000)	2.62 (380,000)
200°C (392°F)	1.62 (235,000)	1.14 (165,000)	1.38 (200,000)
Impact Strength at 23°C (73°F), N-cm (ft-lb)	78 (0.58)	68.6 (0.51)	156.8 (1.16)
Tear Strength—Propagating (Elmendorf), N (lbf)	0.09 (0.02)	0.47 (0.11)	0.57 (0.13)
Tear Strength—Initial (Graves), N (lbf)	11.8 (2.6)	11.5 (2.6)	17.8 (4.0)
Polyimide, wt%	80	57	73
FEP, wt%	20	43	27
Density, g/cc or g/mL	1.53	1.67	1.57

*Test methods for Table 4 are the same as for Table 1.

**Because a number of combinations of polyimide film and fluorocarbon coating add up to the same total gauge, it is necessary to distinguish among them. A three-digit system is used in which the middle digit represents the nominal thickness of the base Kapton® film in mils. The first and third digits represent the nominal thickness of the coating of Teflon® FEP fluoropolymer resin in mils. The symbol 9 is used to represent 13 µm (0.5 mil) and 6 to represent 2.5 µm (0.1 mil). Example: 120FN616 is a 120-gauge structure consisting of a 25 µm (1 mil) base film with a 2.5 µm (0.1 mil) coating of Teflon® on each side.

TI-NHTSA 017703

Mechanical Properties

The usual values of tensile strength, tensile modulus, and ultimate elongation at various temperatures can be obtained from the typical stress–strain curves shown in **Figures 1 and 2**. Such properties as tensile strength and modulus are inversely proportional to temperature, whereas elongation reaches a maximum value at about 300°C (570°F). Other factors, such as humidity, film thickness, and tensile elongation rates, were found to have only a negligible effect on the shape of the 23°C (73°F) curve.

Figure 1. Tensile Stress–Strain Curves, Type HN Film, 25 μm (1 mil)

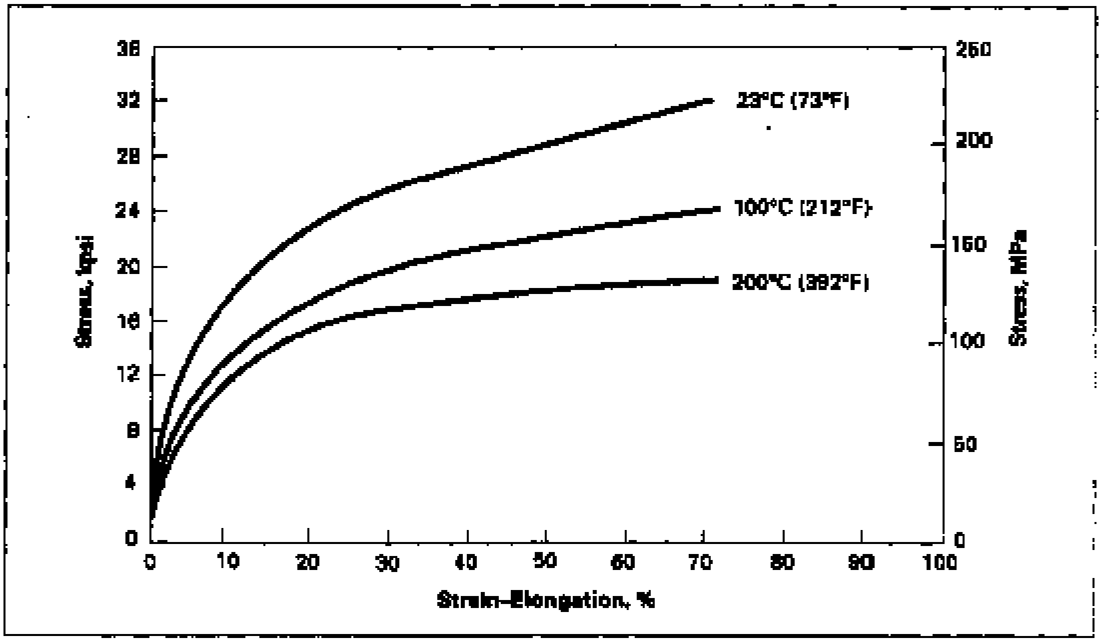
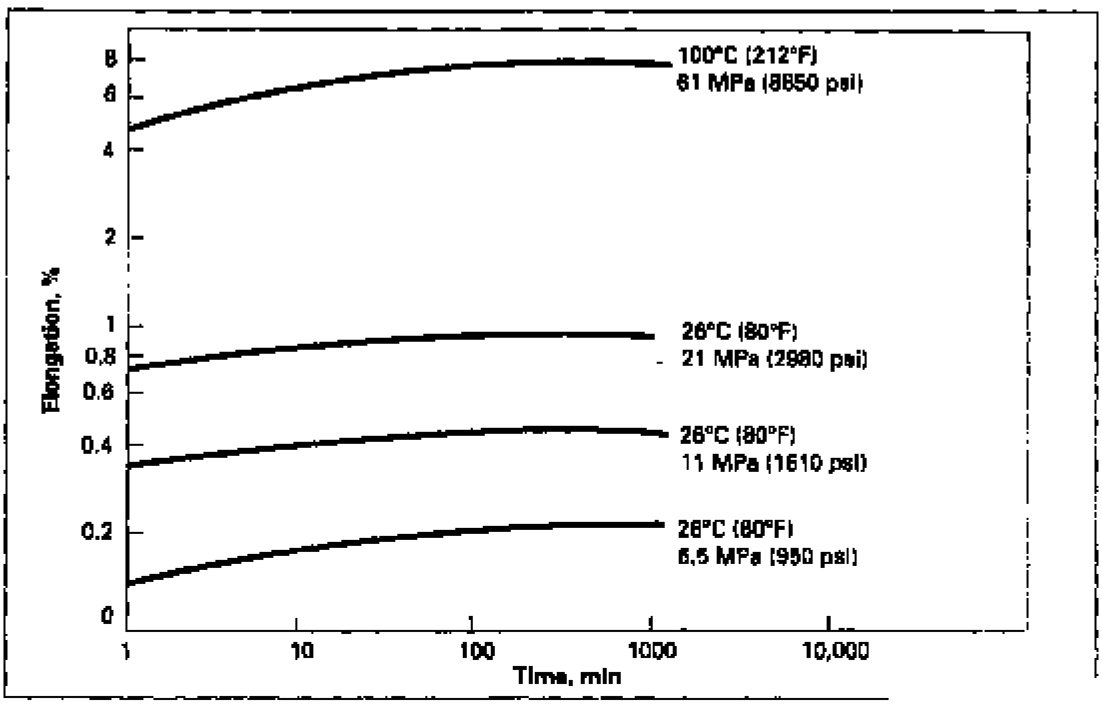


Figure 2. Tensile Creep Properties, Type HN Film, 25 μm (1 mil)

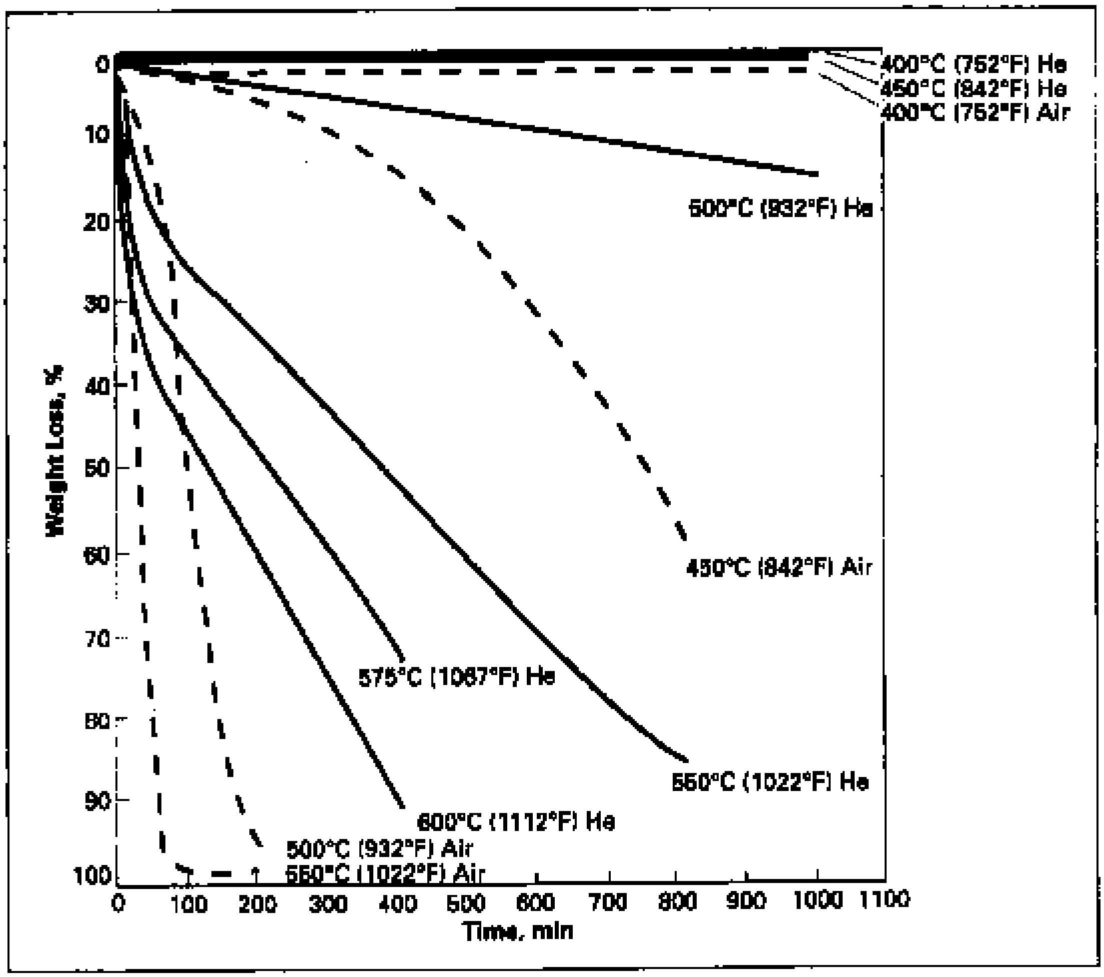


TI-NHTSA 017704

Table 6
Time Required for Reduction in Ultimate Elongation from 70% to 1%, Type HN Film, 25 μm (1 mil)

Temperature	Air Environment
450°C (840°F)	2 hours
425°C (800°F)	5 hours
400°C (750°F)	12 hours
375°C (710°F)	2 days
350°C (660°F)	6 days
325°C (620°F)	1 month
300°C (570°F)	3 months
275°C (530°F)	1 year
250°C (480°F)	8 years

Figure 10. Isothermal Weight Loss, Type HN Film, 25 μm (1 mil)



TI-NHTSA 017705

Electrical Properties

The most common electrical properties of Kapton® polyimide film of various gauges are shown in Tables 6 and 7. These values were measured at 23°C (73°F) and 50% relative humidity. The effect of such factors as humidity, temperature, and frequency on these basic values can be found in **Table 9** and **Figures 11–13**.

Table 7
Typical Electrical Properties of Kapton® Type HN and VN Films

Property Film Gauge	Typical Value		Test Condition	Test Method
Dielectric Strength	V/µm (kV/mm)	(V/mil)	60 Hz	ASTM D-149-91
25 µm (1 mil)	303	(7700)	1/4 in electrodes	
50 µm (2 mil)	240	(6100)	500 V/sec rise	
75 µm (3 mil)	205	(5200)		
125 µm (5 mil)	154	(3900)		
Dielectric Constant			1 kHz	ASTM D-150-92
25 µm (1 mil)	3.4			
50 µm (2 mil)	3.4			
75 µm (3 mil)	3.5			
125 µm (5 mil)	3.5			
Dissipation Factor			1 kHz	ASTM D-150-92
25 µm (1 mil)	0.0018			
50 µm (2 mil)	0.0020			
75 µm (3 mil)	0.0020			
125 µm (5 mil)	0.0026			
Volume Resistivity	Ω·cm			ASTM D-257-91
25 µm (1 mil)	1.5×10^{17}			
50 µm (2 mil)	1.5×10^{17}			
75 µm (3 mil)	1.4×10^{17}			
125 µm (5 mil)	1.0×10^{17}			

Table 8
Typical Electrical Properties of Kapton® Type FN Film

Property	120FN616	150FN019	250FN029
Dielectric Strength, V/µm (V/mil)	272 (6900)	197 (5000)	197 (5000)
Dielectric Constant	3.1	2.7	3.0
Dissipation Factor	0.0015	0.0013	0.0013
Volume Resistivity, Ω·cm			
at 23°C (73°F)	1.4×10^{17}	2.3×10^{17}	1.9×10^{17}
at 200°C (392°F)	4.4×10^{14}	3.6×10^{14}	3.7×10^{14}

Effect of Temperature

As Figures 14–17 indicate, extreme changes in temperature have relatively little effect on the excellent room temperature electrical properties of Kapton[1] polyimide film.

Figure 14. AC Dielectric Strength vs. Temperature, Type HN Film, 25 μm (1 mil)

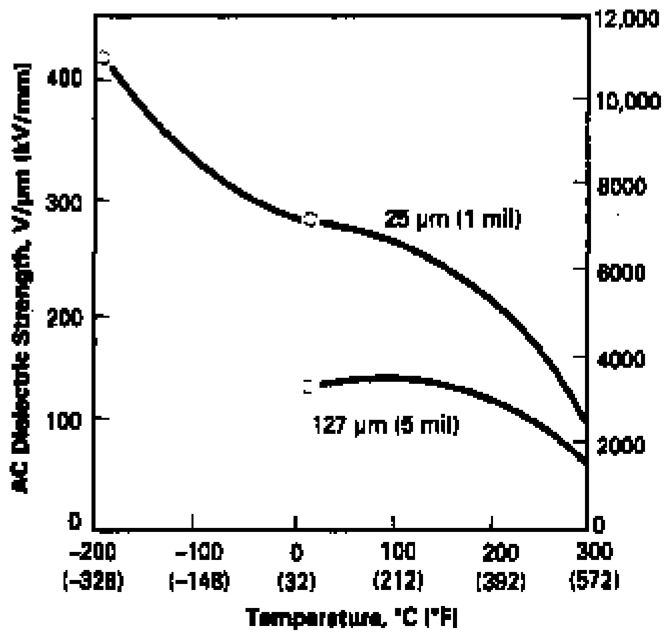


Figure 15. Dielectric Constant vs. Temperature, Type HN Film, 25 μm (1 mil)

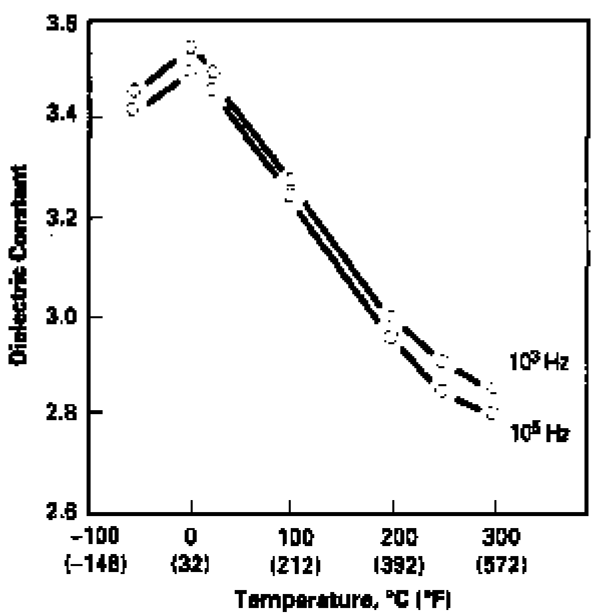


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Figure 16. Dissipation Factor vs. Temperature, Type HN Film, 25 μm (1 mil)

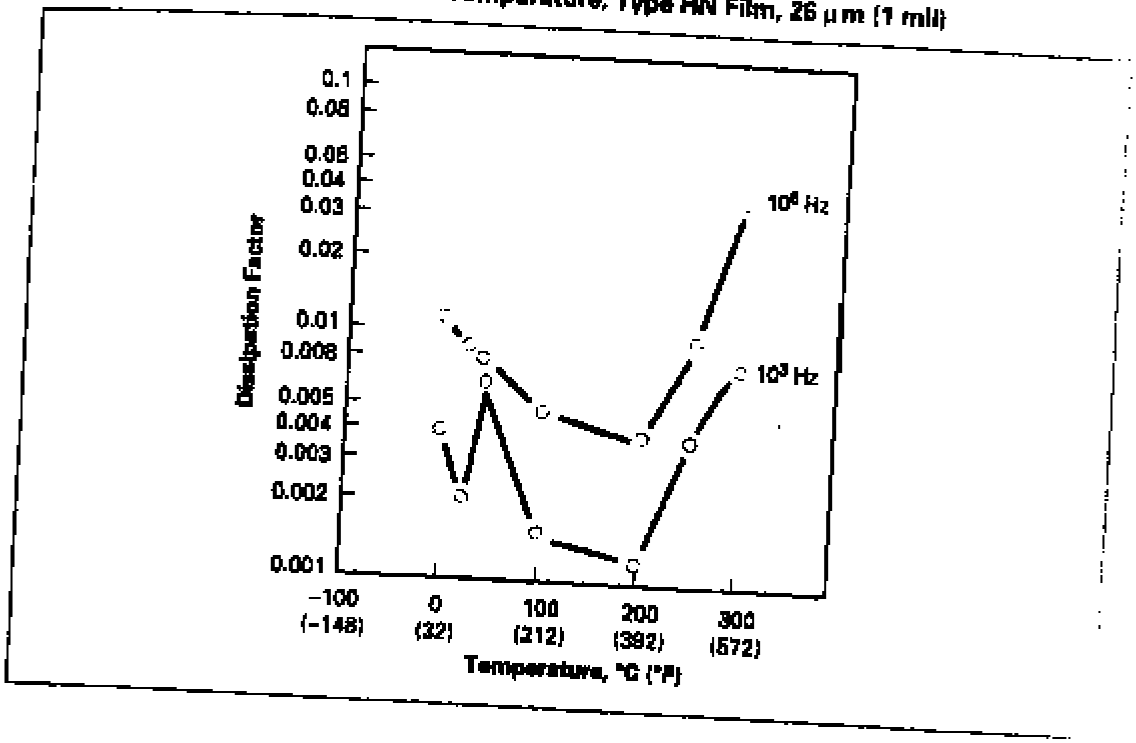
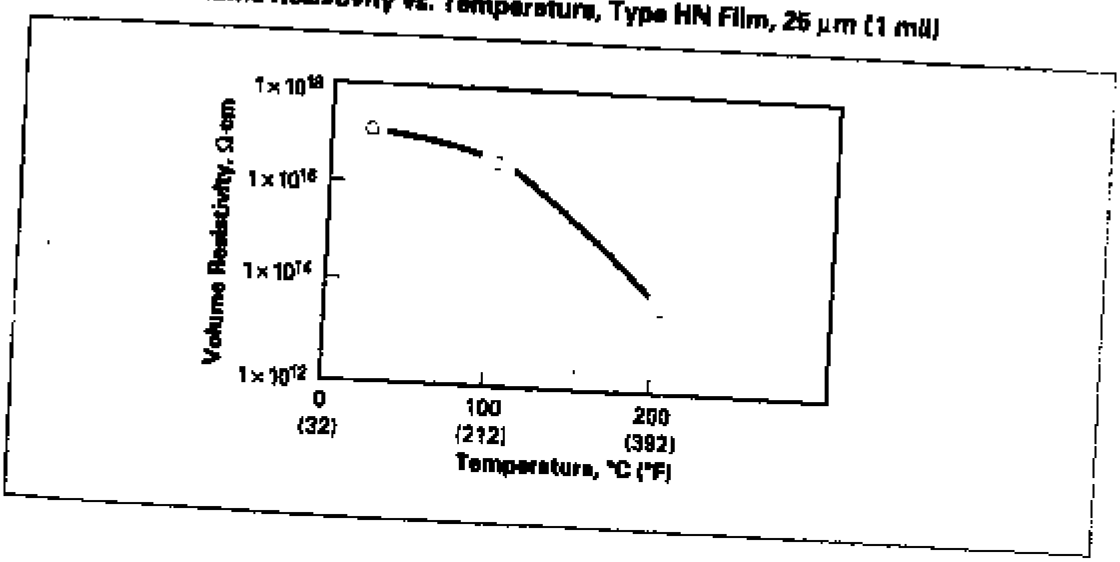


Figure 17. Volume Resistivity vs. Temperature, Type HN Film, 25 μm (1 mil)



Effect of Frequency

The effect of frequency on the values of the dielectric constant and dissipation factor at various isotherms are shown in **Figures 18** and **19** for Type HN film, 25 μm (1 mil), and in **Figures 20** and **21** for HN, 125 μm (5 mil).

Figure 18. Dielectric Constant vs. Frequency, Type HN Film, 25 μm (1 mil)

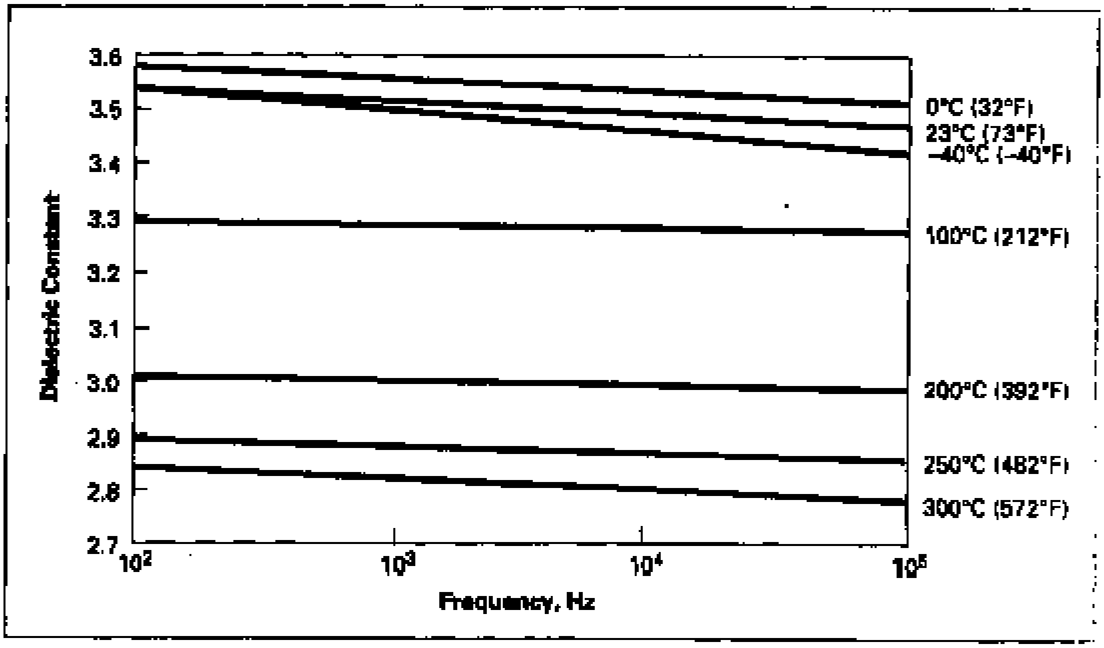


Figure 19. Dissipation Factor vs. Frequency, Type HN Film, 25 μm (1 mil)

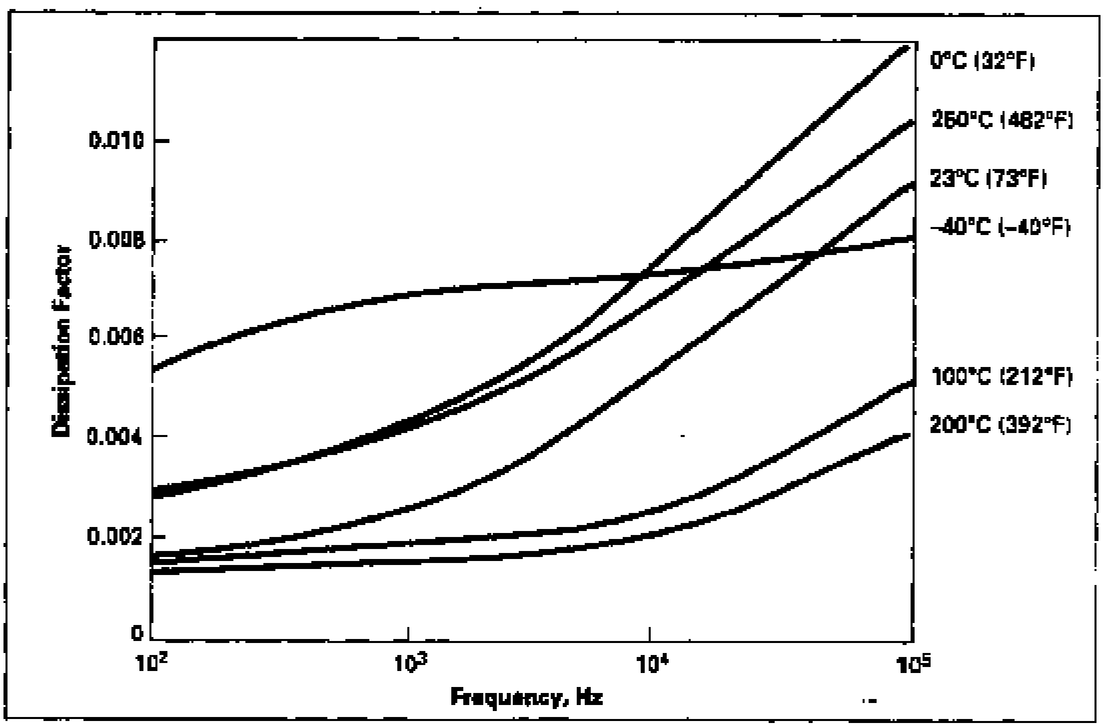


Figure 20. Dielectric Constant vs. Frequency, Type HN Film, 125 µm (5 mil)*

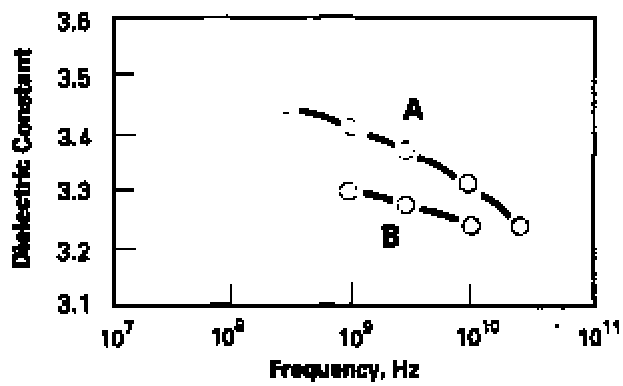
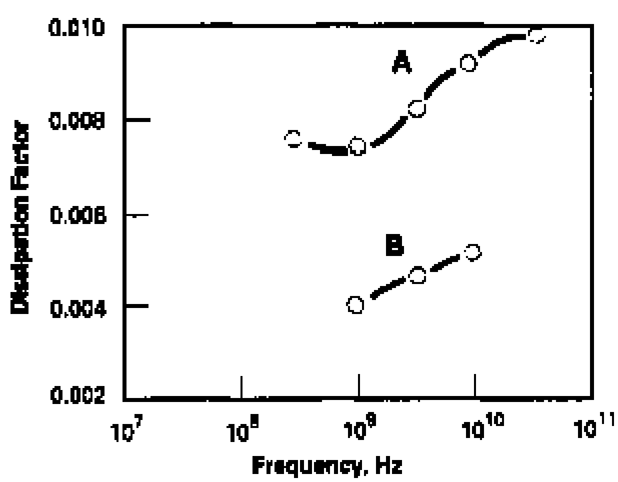


Figure 21. Dissipation Factor vs. Frequency, Type HN Film, 125 µm (5 mil)*



* Technical Report AFML-TR-72-39—Curve A is 500H Kapton* as received and measured at 25°C (77°F) and 45% RH with the electric field in the plane of the sheet. Curve B is the same measurement after conditioning the film at 100°C (212°F) for 48 h. Performance of 500HN is believed to be equivalent to 500H.

TI-NHTSA 017710

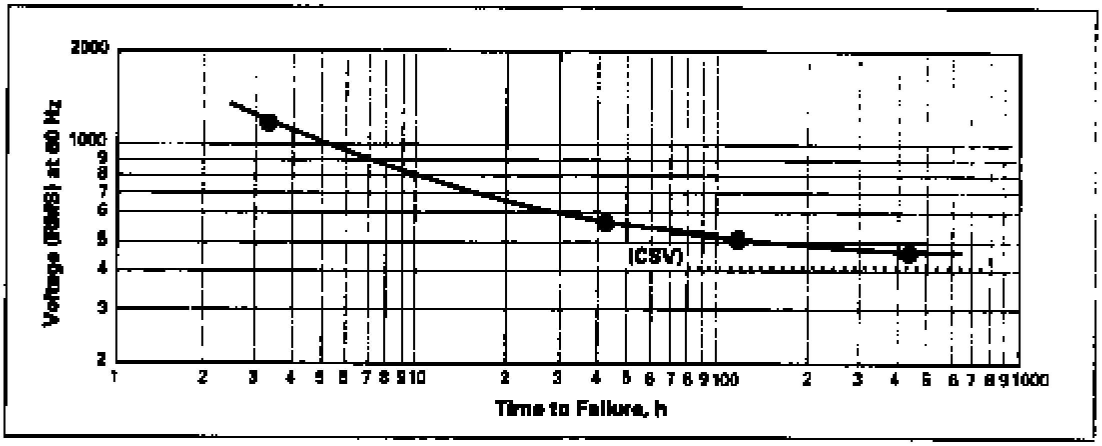
Corona Life

Like all organic materials, Kapton* is attacked by a corona discharge and when exposed continuously to it will ultimately fail dielectrically. At moderate levels of corona exposure, devices insulated with Kapton® have survived up to 3000 h, giving reasonable assurance that brief exposure to a corona will not significantly affect the life of a properly designed insulation system based on Kapton®.

Corona threshold voltage and intensity are functions of many parameters, including insulation thickness, air gap thickness, and device shape. Consult with a DuPont technical representative on the suitability of Kapton® for specific applications where a corona may be present.

Figure 22 shows the life for 25 µm (1 mil) Kapton® HN polyimide film as a function of voltage (RMS) at 60 Hz. As the corona starting level is approached, the Kapton® life curve flattens, indicating a long life. It should be emphasized that the superior thermal and moisture-proof capabilities of Kapton® insulated magnet wire, wrappers, and slot insulation can be utilized without fear of corona in properly designed systems. Kapton® can be used alone or in combination with other insulation materials.

Figure 22. Voltage Endurance of 100HN Kapton® Polyimide Film*



*Corona Starting Voltage (CSV) = 425 V

TI-NHTSA 017711

Chemical Properties

Typical chemical properties of Kapton® Types HN and FN films are given in Tables 10 and 11. The chemical properties of Type VN film are similar to those of Type HN.

Table 10
Chemical Properties of Kapton® Type HN Film, 25 μm (1 mil)

Property	Typical Value: Tensile Retained, %	Typical Value: Elongation Retained, %	Test Condition	Test Method
Chemical Resistance				
Isopropyl Alcohol	96	94	10 min at 23°C	IPC TM-650 Method 2.2.3B
Toluene	99	91		
Methyl Ethyl Ketone	98	90		
Methylene Chloride/ Trichloroethylene (1:1)	96	95		
2 N Hydrochloric Acid	98	99		
2 N Sodium Hydroxide	62	54		
Fungus Resistance	Nonnutrient			IPC TM-650 Method 2.6.1
Moisture Absorption	1.8% Types HN and VN		50% RH at 23°C	ASTM D-570-81 (1988)
	2.8% Types HN and VN		Immersion for 24 h at 23°C (73°F)	
Hygroscopic Coefficient of Expansion	22 ppm/% RH		23°C (73°F), 20–80% RH	
Permeability				
Gas	*mL/m² 24 h MPa*	*cc/(100 in² 24 h atm)*	23°C (73°F), 50% RH	ASTM D-1434-82 (1988)
Carbon Dioxide	6840	45		
Oxygen	3800	25		
Hydrogen	38,000	250		
Nitrogen	910	6		
Helium	63,000	415		
Vapor	*g/(m² 24 h)*	*g/(100 in² 24 h)*		ASTM E-96-92
Water	54	3.5		

Table 11
Chemical Properties of Kapton® Type FN Film

Property	120FN616	150FN019	400FN022
Moisture Absorption, %			
at 23°C (73°F), 50% RH	1.3	0.8	0.4
98% RH	2.5	1.7	1.2
Water Vapor Permeability,			
g/(m² 24 h)	17.5	9.6	2.4
g/(100 in² 24 h)	1.13	0.62	0.16

TI-NHTSA 017712

Kapton* is used as primary insulation for traction motors because of its outstanding combination of thermal, mechanical, and electrical properties.

Voice coils made with Kapton* possess superior high-frequency sound performance at operating temperatures.

Kapton Film Type Information

Table 15
Type and Thickness

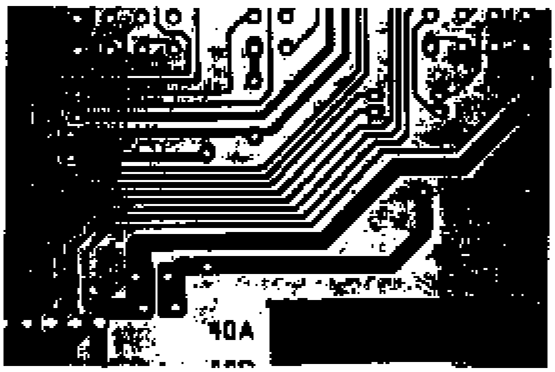
Type	Nominal Thickness µm	Nominal Thickness mil	Area Factor m²/kg	Area Factor ft²/lb
30HN	7.6	0.3	93	455
50HN	12.7	0.5	56	272
75HN	19.1	0.75	37	181
100HN	25.4	1.0	28	136
200HN	50.8	2.0	14	68
300HN	76.2	3.0	9.2	45
500HN	127	5.0	5.5	27
50VN	12.7	0.5	56	272
75VN	19.1	0.75	37	181
100VN	25.4	1.0	28	136
200VN	50.8	2.0	14	68
300VN	76.2	3.0	9.2	45
500VN	127	5.0	5.5	27
100FN099	25.4	1.0	23	110
120FN616	30.5	1.2	21	104
150FN999	38.1	1.5	14	69
150FN019	38.1	1.5	16	77
200FN011	50.8	2.0	11	54
200FN919	50.8	2.0	11	54
250FN029	63.5	2.5	10	49
300FN021	76.2	3.0	8.0	39
300FN929	76.2	3.0	8.0	39
400FN022	101.6	4.0	5.5	27
400FN031	101.6	4.0	6.1	30
500FN131	127	5.0	4.7	23
600FN051	152.4	6.0	4.3	21

Nominal Construction, Type FN

In the Kapton® Type FN order code of three digits, the middle digit represents the nominal thickness of the base Kapton® in mils. The first and third digits represent the nominal thickness of the coating of Teflon® FEP fluoropolymer resin in mils. The symbol 9 is used to represent 12.7 µm (0.5 mil) and 6 to represent 2.54 µm (0.1 mil). Example: 120FN616 is a 120-gauge structure consisting of a 25.4 µm (1 mil) base film with a 2.54 µm (0.1 mil) coating of Teflon® on each side. Illustrated in Table 16 are several examples of the many film types available.

Table 16
Type FN Film Constructions

	Construction					
	FEP		*HN*		*FEP*	
Type	*µm*	*mil*	*µm*	*mil*	*µm*	*mil*
100FN099			12.7	0.50	12.7	0.50
120FN616	2.54	0.10	25.4	1.00	2.54	0.10
150FN999	12.7	0.50	12.7	0.50	12.7	0.50
150FN019			25.4	1.00	12.7	0.50
200FN011			25.4	1.00	25.4	1.00
200FN919	12.7	0.50	25.4	1.00	12.7	0.50
250FN029			50.8	2.00	12.7	0.50
300FN021			50.8	2.00	25.4	1.00
300FN929	12.7	0.50	50.8	2.00	12.7	0.50
400FN022			50.8	2.00	50.8	2.00
400FN031			76.2	3.00	25.4	1.00
500FN131	25.4	1.00	76.2	3.00	25.4	1.00
600FN051			127	5.00	25.4	1.00



Kapton® bar code labels are used in the harsh environments PC boards are exposed to during soldering.

Kapton® is an excellent dielectric substrate that meets the stringent requirements of flexible circuitry.

Safety and Handling

Safe handling of Type HN and VN Kapton® polyimide films at high temperatures requires adequate ventilation. Meeting the requirements of OSHA (29 CFR 1910.1000) will provide adequate ventilation. If small quantities of Kapton® are involved, as is often the case, normal air circulation will be all that is needed in case of overheating. Whether or not existing ventilation is adequate will depend on the combined factors of film quantity, temperature, and exposure time. For additional information on the Teflon® FEP coating used on Type FN Kapton®, refer to the booklet "Guide to the Safe Handling of Fluoropolymer Resins" (H-48633).

Soldering and Hot Wire Stripping

Major uses for all types of Kapton® include electrical insulation for wire and cable and other electronic equipment. In virtually all of these applications, soldering is a routine fabricating procedure, as is the use of a heated element, to remove insulation. Soldering operations rarely produce off-gases to be of toxicological significance.

Welding and Flame Cutting

Direct application of welding arcs and torches can quickly destroy most plastics, including all types of Kapton® film. For practical reasons, therefore, it is best to remove all such parts from equipment to be welded. Where removal is not possible, such as in welding or cutting coated parts, mechanical ventilation should be provided. Because Kapton® can be used at very high temperatures, parts made from it may survive at locations close to the point of direct flame contact. Thus, some in-place welding operations can be done. Because the quantity of film heated is usually relatively small (less than 1 lb), ventilation requirements seldom exceed those for normal welding work. Because of the possibility of inadvertent overheating, the use of a small fan or elephant-trunk exhaust is advisable.

Scrap Disposal

Disposal of scrap Kapton® polyimide films presents no special problem to the user. Small amounts of scrap may be incinerated along with general plant refuse. The incinerator should have sufficient draft to exhaust all combustion products to the stack. Care should be taken to avoid breathing smoke and fumes from any fire. Because Kapton® is so difficult to burn, it is often best to dispose of scrap film in a landfill.

Fire Hazards

Whether in storage or use, Kapton® is unlikely to add appreciably to the hazards of fire. Bulk quantities of Kapton® (over 100 lb) should be stored away from flammable materials.

In the event of fire, personnel entering the area should use a fresh air supply or a respirator. All types of chemical extinguishers may be used to fight fires involving Kapton®. Large quantities of water also may be used to cool and extinguish a fire.

Static Electricity

The processing of Kapton® can generate a strong static charge. Unless this charge is bled off as it forms by using ionizing radiation or tinsel, it can build to many thousand of volts and discharge to people or metal equipment. In dust- or solvent-laden air, a flash fire or explosion could result. Precautions for static charges should also be taken when removing plastic films used as protective packaging for Kapton®.

For additional information, users should refer to the bulletin "Kapton® Polyimide Film—Products of Decomposition" (H-16512).

TI-NHTSA 017716

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DuPont High Performance Films

Properties Bulletin

DuPont Films

High Performance Films

Teflon® PFA

fluorocarbon film

Description

Teflon® PFA film is a transparent, thermoplastic film that can be heat sealed, thermoformed, vacuum formed, heat bonded, welded, metallized, laminated (combined with dozens of other materials), and used as an excellent hot-melt adhesive. This wide variety of fabrication possibilities combines with the following important properties to offer a unique balance of capabilities not available in any other plastic film.

Chemical Compatibility

Teflon® PFA film is chemically inert and solvent resistant to virtually all chemicals, except molten alkali metals, gaseous fluorine, and certain complex halogenated compounds, such as chlorine trifluoride at elevated temperatures and pressures.

- Teflon® is the most inert of all plastics.
- Low permeability to liquids, gases, moisture, and organic vapors

Electrical Reliability

- Superior reliability and retention of properties over large areas of film
- High dielectric strength, over 260 kV/mm for 0.025-mm film (6500 V/mil for 1-mil film)
- No electric tracking, nonwettable, and noncharring
- Very low power factor and dielectric constant, only slight change over wide ranges of temperature and frequency

Wide Thermal Range

- Continuous service temperature: –240 to 260°C (–400 to 500°F)
- Melting range: 300 to 310°C (572 to 590°F)
- Heat sealable

Mechanical Toughness

- Superior antistick and low frictional properties
- High resistance to impact and tearing
- Useful physical properties at cryogenic temperatures

Long Time Weatherability*

- Inert to outdoor exposure
- High transmittance of ultraviolet and all but far infrared

Reliability

- PFA film contains no plasticizers or other foreign materials.
- Conventional equipment and techniques can be used for processing; basic composition and properties will not be influenced.
- Rigid quality control by DuPont ensures uniform gauge, void-free film.

*Type C film not recommended for outdoor use.

The convenience of Teflon® fluorocarbon in easy-to-use film facilitates the design and fabrication of this low friction thermoplastic for all sorts of high-performance jobs. It is transparent and can be *heat sealed, thermoformed, welded,* and *heat bonded.* Superior antistick properties make it an ideal release film for many applications. A *cementable* type with an invisible surface treatment is available for bonding to one or both sides with adhesives. This versatility is augmented by the superior properties of a true melt-processible fluorocarbon and by the wide choice of product dimensions available from DuPont.

Table 1
Types and Gauges of DuPont Teflon® PFA Film

Gauge	50	100	200	500	750LP	1000	2000	3000	[illegible]	[illegible]	12500
Thickness											
mil	½	1	2	[illegible]	7.5	[illegible]	20	30	[illegible]	90	125
in	0.0005	0.001	0.002	[illegible]	0.0075	0.010	[illegible]	[illegible]	[illegible]	[illegible]	0.125
μm	12.5	25	50	125	187	250	500	750	1000	2300	3175
Approximate Area Factor											
ft²/lb	190	90	46	15	13.5	[illegible]	4.5	3	1.5	1	0.7
in²/lb	[illegible]	12,[illegible]	[illegible]	[illegible]	1,935	1,290	[illegible]	430	215	135	[illegible]
m²/kg	[illegible]	[illegible]	[illegible]	4	3	2	1	0.6	0.3	0.2	0.14
Type LP—General-Purpose	Available	Available	Available	Available	Available	Available	Available	Available	Available	Available	Available
Type CLP—One Side Cementable	—	Available	Available	Available	—	—	—	—	—	—	—

Films are available in the following widths: 50–500 gauge, ½ in to 60 in available; 750–12500 gauge, ½ in to 48 in available. See current price list for widths by specific gauge and type.

TI-NHTSA 017719

Table 2
Summary of Properties of Teflon® PFA Film

	Property	Test Method	Typical Value* SI Units	Typical Value* English Units
Mechanical	Tensile Strength at Break	ASTM D-882	21 N/mm^2	3000 psi
Mechanical	Elongation at Break	ASTM D-882	300%	
Mechanical	Yield Point	ASTM D-882	12 MPa	1700 psi
Mechanical	Elastic Modulus	ASTM D-882	480 MPa	70,000 psi
Mechanical	Impact Resistance	DuPont pneumatic impact tester	6.2×10^4	14 in·lb/mil
Mechanical	Folding Endurance (MIT)	ASTM D-2176	100,000 cycles	
Mechanical	Tear Strength—Initial (Graves)	ASTM D-1004	4.90 N	500 g
Mechanical	Tear Strength—Propagating (Elmendorf)	ASTM D-1922	0.74 N	75 g
Thermal	Melt Point	ASTM D-3418 (DTA)	302–310°C	576–590°F
Thermal	Thermal Conductivity	Cenco-Fitch	0.195 W/(m·K)	1.35 Btu·in/(h·ft^2·°F)
Thermal	Specific Heat	—	1172 J/(kg·K)	0.28 Btu/(lb·°F)
Thermal	Dimensional Stability	30 min at 150°C (302°F)	MD = 1% shrinkage TD = 1% shrinkage	
Thermal	Oxygen Index	ASTM D-2863	95%	
Electrical	Dielectric Strength, short-time, in air at 23°C (73°F), 6.35 mm (¼ in) diameter electrode, 0.79 mm (1/32 in) radius, 60 Hz, 500 V/s rate of rise: 0.025 mm (1 mil) film	ASTM D-149 Method A	260 kV/mm	6500 V/mil
Electrical	Dielectric Constant, 25°C (77°F), 100 Hz to 1 MHz	ASTM D-150	2.0	
Electrical	Dissipation Factor, 25°C (77°F), 100 Hz to 1 MHz	ASTM D-150	0.0002–0.0007	
Electrical	Volume Resistivity, −40 to 240°C (−40 to 464°F)	ASTM D-257	$>1 \times 10^{17}$ ohm·cm	
Chemical	Moisture Absorption	—	<0.02%	
Chemical	Permeability, Gas:	ASTM D-1434	$cm^3/(m^2$·24 h·atm)**	
Chemical	Carbon Dioxide		14×10^3	
Chemical	Nitrogen		2.0×10^3	
Chemical	Oxygen		6.7×10^3	
Chemical	Permeability, Vapors:	ASTM E-96	g/(m^2·d)	g/(100 in^2·24 h)
Chemical	Water		2	0.13
Chemical	Teflon® is chemically inert and solvent resistant to virtually all chemicals, except molten alkali metals, gaseous fluorine, and certain complex halogenated compounds, such as chlorine trifluoride at elevated temperatures and pressures.			
Misc.	Density	ASTM D-1505	2150 kg/m^3	134 lb/ft^3
Misc.	Coefficient of Friction Kinetic (Film-to-Steel)	ASTM D-1894	0.1–0.3	
Misc.	Refractive Index	ASTM D-542	1.350	
Misc.	Solar Transmission	ASTM E-424	96%	

*For 0.050-mm (2-mil) film at 25°C (77°F), unless otherwise specified

**To convert to $cm^3/(100\ in^2$·24 h·atm), multiply by 0.0645

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DuPont Films

DuPont Films

High Performance Films

Teflon® FEP

fluorocarbon film

Teflon® as Film

Teflon® FEP fluorocarbon film offers the outstanding properties of Teflon® in a convenient, easy-to-use form. It can be heat-sealed, thermoformed, welded, metallized, and laminated to many other materials or serve as a hot melt adhesive.

This combination of unique properties and easy-to-use form offers design and fabrication opportunities for a wide variety of end uses.

Teflon® is Unique Among Plastics

- Most chemically inert of all plastics
- Withstands both high- and low-temperature extremes
- Superior antistick/low friction properties
- Outstanding weather resistance
- Excellent optical characteristics
- Superior electrical properties
- Free of plasticizers or additives
- Excellent processibility with conventional thermoplastic methods

Teflon® FEP Film is Offered

- In thicknesses from 12.5–4750 µm (0.5–190 mil)
- In custom slit widths up to 1.2–1.6 m (46–63 in) depending on thickness
- In various size rolls wound on 7.6 cm or 15.2 cm (3 in or 6 in) cores

Teflon® film affords the engineer/designer a wide range of opportunities to take advantage of these properties with minimal and convenient fabrication techniques.

The ability of Teflon® FEP film to be easily cut, thermoformed, heat sealed, and welded permits ready application as diaphragms, gaskets, protective linings, or thermoformed pouches or containers, wherever high temperature and/or chemical resistance is required.

The excellent optical properties and resistance to weathering and ultraviolet degradation have led to the use of Teflon® FEP film in such varied applications as environmental growth chambers, solar energy collectors, and radome windows.

Its superior dielectic properties have been used in flexible, flat cable insulation, printed circuits, and electronic components for computers and aircraft.

The nonstick properties of Teflon® FEP have found use in conveyor belts, process roll covers, and as mold release films.

Special grades of Teflon® FEP film offer specific properties such as cementability or high stress crack resistance under extreme environmental conditions.

A complete listing of FEP film grades and their availability in different thicknesses is given in **Table 1**.

In addition to FEP, DuPont offers films of Teflon® PFA, for use at temperatures up to 260°C (500°F), and Tefzel® fluoropolymer for increased toughness and resistance to tear propagation.

Teflon® FEP film offers unique properties in a convenient form requiring minimal fabrication. Consider it for your next project.

For additional information, call (800) 237-4357.

Types and Gauges

Table 1
Types and Gauges of DuPont Teflon® FEP Fluorocarbon Film

Gauge	50	100	200	300	500	750	1000	1500	2000	3000	6000	9000	12500	19000
Thickness, mil	0.5	1	2	3	5	7.5	10	15	20	30	60	90	125	190
Thickness, µm	12.5	25	50	75	125	190	250	375	500	750	1500	2300	3125	4750
Approximate area factor, ft²/lb	180	90	45	30	18	12	9	6.0	4.5	3	1.5	1	0.72	0.47
Approximate area factor, m²/kg	36	18	9	6	4	2.5	2	1.2	1	0.6	0.3	0.2	0.14	0.09
Availability														
Type A—FEP, general-purpose	X	X	X	X	X	X	X	—	X	—	—	—	—	—
Type C—FEP, one side cementable	X	X	X	X	X	—	—	—	—	—	—	—	—	—
Type C-20—FEP, both sides cementable	X	X	X	—	X	—	—	—	—	—	—	—	—	—
Type L—FEP, high stress crack resistance in extreme environments	—	—	—	—	X	—	X	X	X	X	X	X	X	X

Note: Each roll of Teflon® film is clearly identified as to resin type, film thickness, and film type.

Teflon® FEP 500 C
Resin type
Film thickness, 500 gauge, 5 mil
Film type cementable one side

Mechanical and Thermal Properties

Teflon® FEP films perform well over a wide range of temperatures. Teflon® FEP has a continuous service temperature range from –240 to 205°C (–400 to 400°F), and it can be used in intermittent service at temperatures as high as 260°C (500°F). See Tables 2 and 3.

Tensile Properties

Figures 1–3 show how tensile properties of Teflon® FEP film vary with temperature. Teflon® films retain useful mechanical properties over a wide range from cryogenic to high temperatures.

Dimensional Stability

There are three components to the property of dimensional stability—hygroscopic expansion, residual shrinkage, and thermal expansion.

Hygroscopic Expansion

Because the moisture absorption of Teflon® FEP fluorocarbon film is less than 0.01% when totally immersed in water, changes in relative humidity have little effect on the film.

Figure 1. Tensile Stress vs. Elongation of Teflon® FEP Film

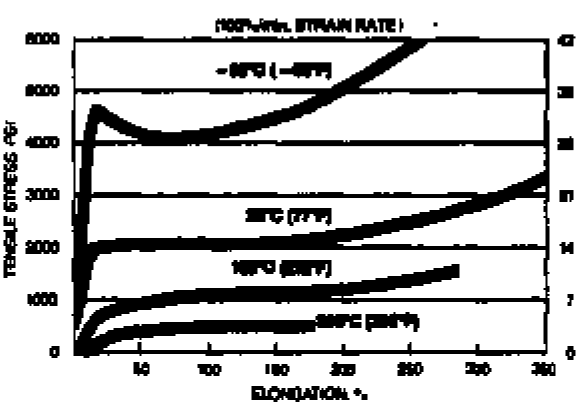

Figure 2. Tensile Properties of Teflon® FEP Film vs. Temperature

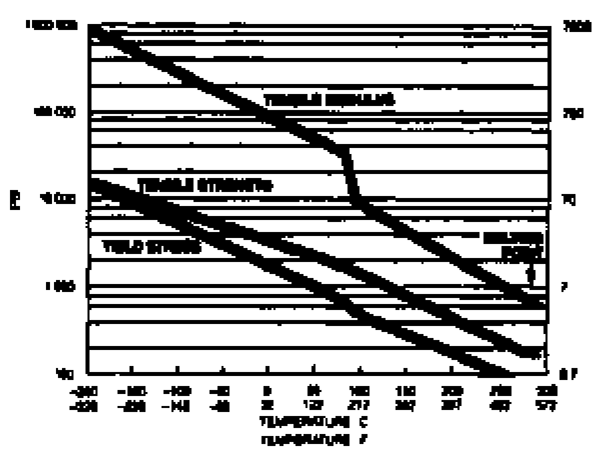

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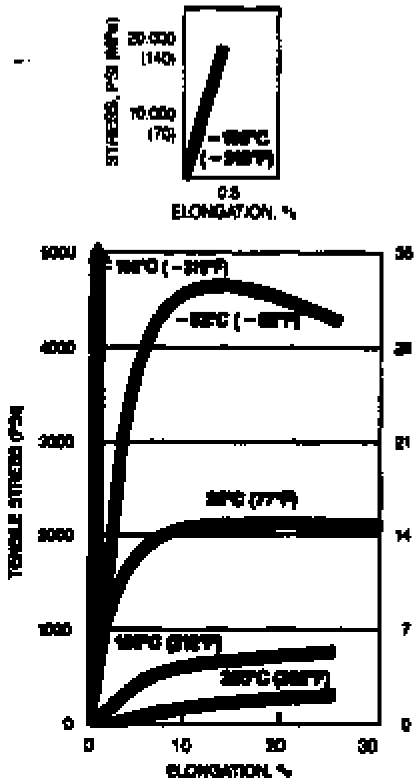
Figure 3. Tensile Stress vs. Elongation of Teflon® FEP Film



Residual Shrinkage

Stresses set up in the film during manufacturing or converting can cause shrinkage in unrestrained film when exposed to high temperatures.

Exposure of film to an elevated temperature, and the attendant shrinkage, will relieve this stress, and no further shrinkage will occur at lower temperatures.

Thermal Expansion

After residual shrinkage has been removed, Teflon® FEP film will expand and contract according to its normal coefficient of thermal expansion (see Figures 4 and 5). Note that this coefficient increases with temperature.

Figure 4. Shrinkage of Teflon® FEP 100A Film vs. Temperature

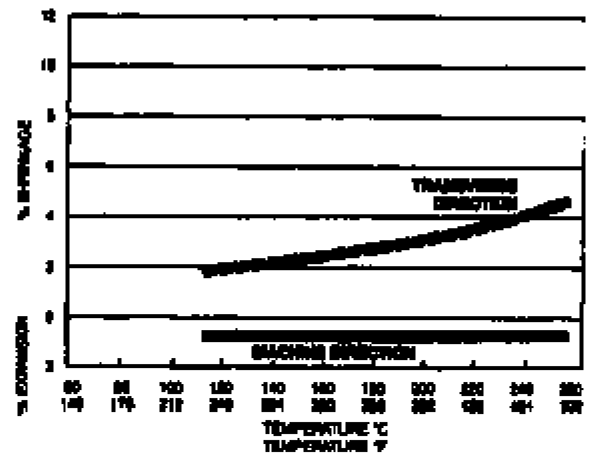


Table 2
Typical Mechanical Properties of Teflon® FEP Film*

Property	ASTM Method	SI Units	English Units
Tensile strength (at break)	D-882-81	21 MPa	3000 psi
Elongation at break	D-882-81	300%	300%
Elastic modulus	D-882-81	480 MPa	70 000 psi
Yield point	D-882-81	12 MPa	1700 psi
Stress to produce 5% strain	D-882-81	12 MPa	1700 psi
Folding endurance (MIT)	D-2176-69	10,000 cycles	10,000 cycles
Initial tear strength (Graves)	D-1004-66	5.3 N	1.2 lbf
Propagating tear strength (Elmendorf)	D-1922-67	2.5 N	250 g
Bursting strength**	D-774-67 (Mullen)	76 kPa	11 psi
Density	D-1505-68	2150 kg/m³	134 lb/ft³
Coefficient of friction kinetic (film to steel)	D-1894-61	0.3	0.3

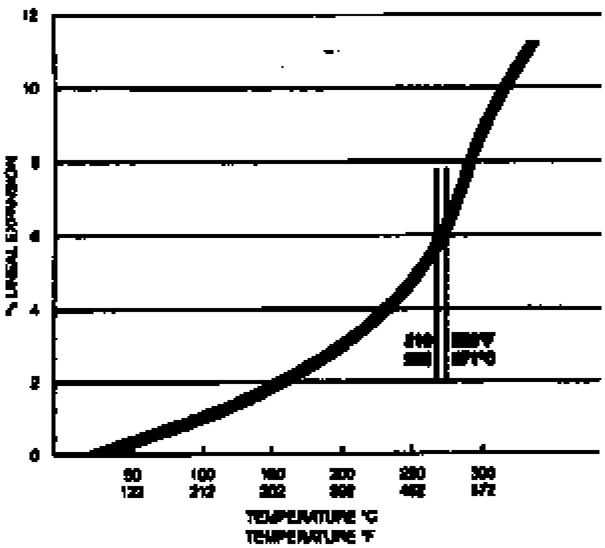
*200 gauge unless otherwise noted
**100 gauge film

Table 3
Typical Thermal Properties of Teflon® FEP Film*

Property	ASTM Method	SI Units	English Units
Melt point	D-3418 (DTA)	260–280°C	500–536°F
Maximum continuous service temperature		205°C	400°F
Zero strength** temperature	***	255°C	490°F
Specific heat		1172 J/kg·K	0.28 Btu/lb·°F
Coefficient of thermal conductivity		0.195 W/m·K	$1.35 \frac{Btu \cdot in}{h \cdot ft^2 \cdot °F}$
Coefficient of linear thermal expansion	D-696-79	$8.4 \times 10^{-5} \frac{mm}{mm \cdot °C}$	$8.4 \times 10^{-5} \frac{in}{in \cdot °F}$
Flammability classification	ANSI/UL-94	VTM-0	VTM-0
Oxygen index	D-2863-77	95%	95%
Dimensional stability MD	30 min at 150°C (302°F)	0.7% expansion	0.7% expansion
Dimensional stability TD	30 min at 150°C (302°F)	2.2% shrinkage	2.2% shrinkage

*200 gauge unless otherwise noted
**100 gauge film
***Temperature at which film supports a load of 0.14 MPa (20 psi) for 5 sec

Figure 5. Thermal Expansion of Teflon® FEP Film



Electrical Properties

Teflon® fluorocarbon films exhibit excellent electrical properties over a wide range of frequencies and temperatures. Table 4 shows how initial properties are retained even after long-term exposure to extreme environmental conditions.

Table 4
Typical Electrical Properties of Teflon® FEP Fluorocarbon Film 25 µm (1 mil) Thickness

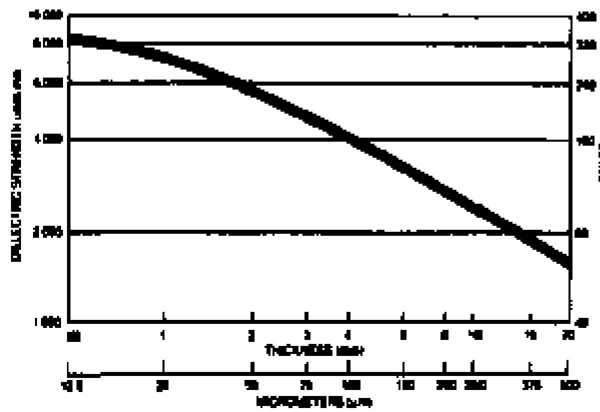
Property	ASTM Method	SI Units	English Units
Dielectric strength	D-149A-81 (6.4 mm (0.25 in) electrode in air, 60 Hz)	260 kV/mm	6500 V/mil
Dielectric constant	D-150-81 (1 kHz)	2.0	2.0
Dissipation factor	D-150-81 (1 kHz)	0.0002	0.0002
Volume resistivity	D-257-78	1 × 10[illegible] ohm-m	1 × 10[illegible] ohm-cm
Surface resistivity	D-257-78	1 × 10[illegible] ohm (per square)	1 × 10[illegible] ohm (per square)
Surface arc resistance	D-495-73	>165 s*	>165 s*

*Samples melted in arc did not track.

Dielectric Strength

Figure 6 shows how the dielectric strength of Teflon® FEP film is a function of film thickness; thinner films exhibit greater dielectric strength.

Figure 6. Dielectric Strength vs. Film Thickness of Teflon® FEP



Dielectric Constant

For Teflon® fluorocarbon film, dielectric constant is independent of film thickness. There is no difference between Type A and Type C films.

At a constant frequency, the dielectric constant of Teflon® FEP film decreases with rise in temperature due to thermal expansion (see Figure 7).

At a constant temperature, the dielectric constant falls slightly with an increase in frequency above 10^7 Hz (see Figure 8).

Figure 7. Dielectric Constant vs. Temperature of Teflon® FEP Film at 1 kHz and 100 kHz

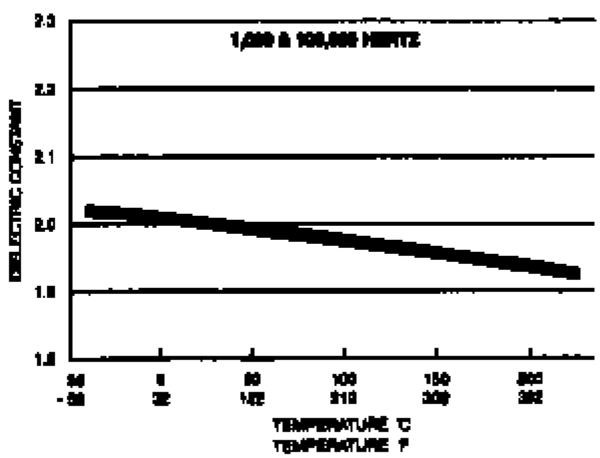
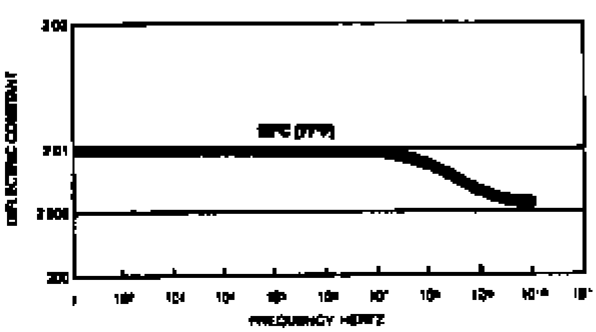


Figure 8. Dielectric Constant vs. Frequency



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Dissipation Factor

The consistently low value of the dissipation factor over a broad range of temperature and frequency makes Teflon® fluorocarbon film ideal in applications where electrical losses must be minimized (see **Figure 9**).

At a constant temperature, this dissipation factor of Teflon® films varies as noted in **Figure 10**. Absolute values remain low in comparison with many other dielectric materials.

Figure 9. Dissipation Factor vs. Temperature of Teflon® FEP Film

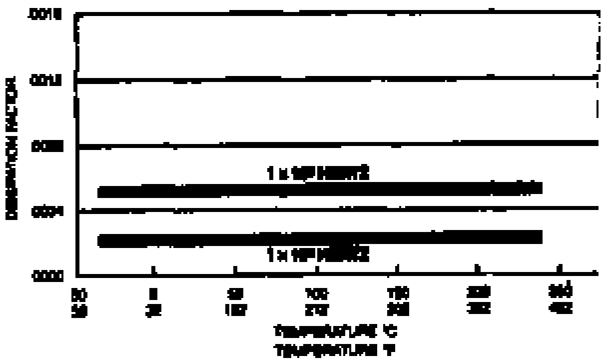
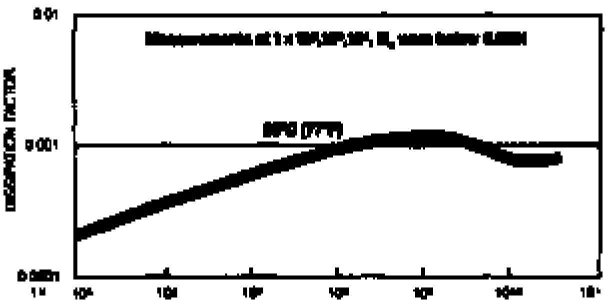


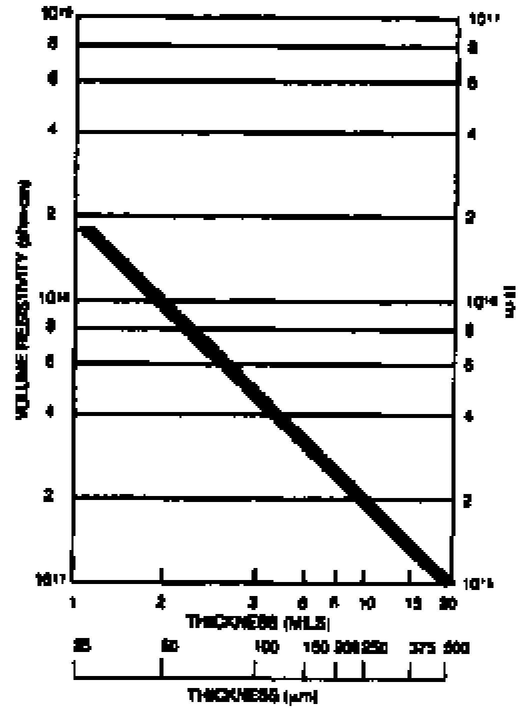
Figure 10. Dissipation Factor vs. Frequency of Teflon® FEP Film



Volume Resistivity

Volume resistivity of Teflon® fluorocarbon film decreases slightly as the film thickness increases (see **Figure 11**).

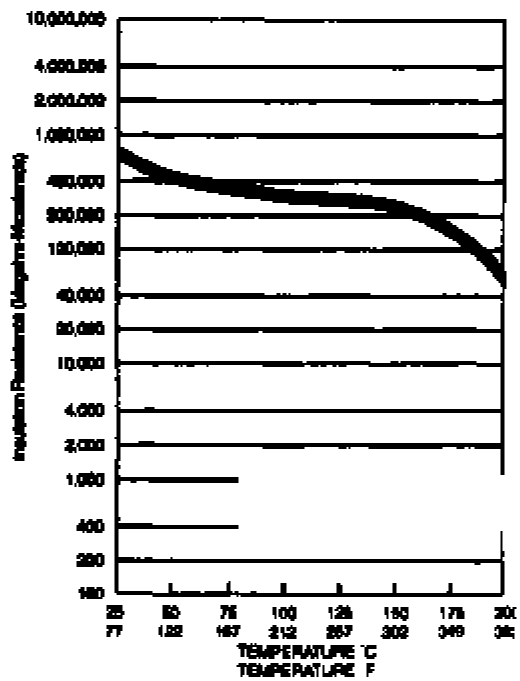
Figure 11. Volume Resistivity vs. Thickness (at 175°C [347°F])



Insulation Resistance

Even at 200°C (392°F), the insulation resistance of Teflon® film (65,000 megohm-microfarad) is higher than most conventional dielectric materials at room temperature (see **Figure 12**).

Figure 12. Insulation Resistance vs. Temperature
(125 μm/0.5 mil TEFLON FEP film)



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Chemical Properties

Teflon® FEP fluorocarbon film is chemically inert and solvent resistant to virtually all chemicals except molten alkali metals, fluorine at elevated temperatures, and certain complex halogenated compounds such as chlorine trifluoride at elevated temperatures and pressures.

In circumstances where end-use temperatures are close to the upper service limit 205°C (400°F), 80% sodium hydroxide, metal hydrides, aluminum chloride, ammonia, and certain amines ($R\text{-}NH_2$) may attack the film in a manner similar to molten alkali metals. Special testing is required when such extreme reducing or oxidizing conditions are evident.

With these exceptions noted, Teflon® FEP fluorocarbon films exhibit a very broad range of chemical and thermal serviceability.

Due to the many complex aspects of performance in severe environments, final selection should be based on functional evaluations or experience under actual end-use conditions.

The chemical substances listed in **Table 5** are representative of those with which Teflon® FEP film has been found to be nonreactive.

Table 5
Typical Chemicals with Which Teflon® FEP Film is Nonreactive*

Abietic acid	Cyclohexanone	Hydrofluoric acid	Phthalic acid
Acetic acid	Dibutyl phthalate	Hydrogen peroxide	Pinene
Acetic anhydride	Dibutyl sebacate	Lead	Piperidene
Acetone	Diethyl carbonate	Magnesium chloride	Polyacrylonitrile
Acetophenone	Diethyl ether	Mercury	Potassium acetate
Acrylic anhydride	Dimethyl formamide	Methyl ethyl ketone	Potassium hydroxide
Allyl acetate	Di-isobutyl adipate	Methacrylic acid	Potassium permanganate
Allyl methacrylate	Dimethylformamide	Methanol	Pyridine
Aluminum chloride	Dimethylhydrazine, unsymmetrical	Methyl methacrylate	Soap and detergents
Ammonia, liquid	Dioxane	Naphthalene	Sodium hydroxide
Ammonium chloride	Ethyl acetate	Naphthols	Sodium hypochlorite
Aniline	Ethyl alcohol	Nitric acid	Sodium peroxide
Benzonitrile	Ethyl ether	Nitrobenzene	Solvents, aliphatic and aromatic**
Benzoyl chloride	Ethyl hexoate	2-Nitro-butanol	Stannous chloride
Benzyl alcohol	Ethylene bromide	Nitromethane	Sulfur
Borax	Ethylene glycol	Nitrogen tetroxide	Sulfuric acid
Boric acid	Ferric chloride	2-Nitro-2-methyl propanol	Tetrabromoethane
Bromine	Ferric phosphate	n-Octadecyl alcohol	Tetrachlorethylene
n-Butyl amine	Fluoronaphthalene	Oils, animal and vegetable	Trichloracetic acid
Butyl acetate	Fluoronitrobenzene	Ozone	Trichlorethylene
Butyl methacrylate	Formaldehyde	Perchlorethylene	Tricresyl phosphate
Calcium chloride	Formic acid	Pentachloro-benzamide	Triethanolamine
Carbon disulfide	Furane	Perfluoroxylene	Vinyl methacrylate
Cetane	Gasoline	Phenol	Water
Chlorine	Hexachlorethane	Phosphoric acid	Xylene
Chloroform	Hexane	Phosphorus pentachloride	Zinc chloride
Chlorosulfonic acid	Hydrazine		
Chromic acid	Hydrochloric acid		
Cyclohexane			

*Based on experiments conducted up to the boiling points of the liquids listed. Teflon® FEP resins have normal service temperatures up to 205°C (400°F). Absence of a specific chemical does not mean that it is reactive with Teflon® FEP film.

**Some halogenated solvents may cause moderate swelling.

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Physical Properties

Absorption

Almost all plastics absorb small quantities of certain materials with which they come in contact. Submicroscopic voids between polymer molecules provide space for the material absorbed without chemical reaction. This phenomenon is usually marked by a slight weight increase and sometimes by discoloration.

Teflon® FEP fluorocarbon films have unusually low absorption compared with other thermoplastics. They absorb practically no common acids or bases at temperatures as high as 200°C (392°F) and exposures of up to one year. Even the absorption of solvents is extremely small. Weight increases are generally less than 1% when exposed at elevated temperatures for long periods. In general, aqueous solutions are absorbed very little by Teflon® FEP film. *Moisture absorption is typically less than 0.01% at ambient temperature and pressure.*

Permeability

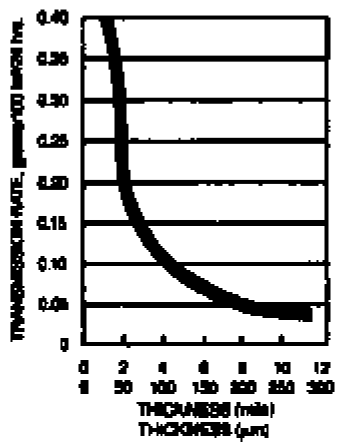
Many gases and vapors permeate Teflon® films at a much lower rate than for other thermoplastics (see Figure 13). In general, permeation increases with temperature, pressure, and surface contact area and decreases with increased film thickness. Table 6 lists rates at which various gases are transmitted through Teflon® FEP fluorocarbon film, while Table 7 lists rates of vapor permeability for some representative substances. Note that the pressure for each material is its vapor pressure at the indicated temperature.

Table 6
Typical Gas Permeability Rates of Teflon® FEP Fluorocarbon Film, 25 µm (1 mil) Thickness
(Test Method: ASTM D-1434 at 25°C [77°F])

Gas	Permeability Rate* $cm^3/(m^2 \cdot 24\ h \cdot atm)$
Carbon Dioxide	25.9×10^3
Hydrogen	34.1×10^3
Nitrogen	5.0×10^3
Oxygen	11.6×10^3

*To convert to $cm^3/(100\ in^2 \cdot 24\ h \cdot atm)$, multiply by 0.0645.

Figure 13. Water Vapor Transmission Rate of Teflon® FEP Film at 40°C (104°F) per ASTM E-96 (Modified)



Notes: Values are averages only and not for specification purposes. To convert the permeation values for 100 in² to those for 1 m², multiply by 15.5.

Table 7
Typical Vapors Transmission Rates of Teflon® FEP Fluorocarbon Film, 25 µm (1 mil) Thickness
(Test Method: Modified ASTM E-96)

Vapor	Temperature °C	Temperature °F	Vapor Transmission Rate SI Units (g/m²·d)	Vapor Transmission Rate English Units (g/100 in²·d)
Acetic Acid	35	95	6.3	0.41
Acetone	35	95	14.7	0.95
Benzene	35	95	9.9	0.64
Carbon Tetrachloride	35	95	4.8	0.31
Ethyl Acetate	35	95	11.7	0.76
Ethyl Alcohol	35	95	10.7	0.69
Freon® F-12	23	73	372.0	24.0
Hexane	35	95	8.7	0.56
Hydrochloric Acid	25	77	<0.2	<0.01
Nitric Acid (Red Fuming)	25	77	160.0	10.5
Sodium Hydroxide, 50%	25	77	<0.2	<0.01
Sulfuric Acid, 98%	25	77	2×10^{-4}	1×10^{-5}
Water	39.5	103	7.0	0.40

Optical Properties

Teflon® films transmit a high percentage of ultraviolet and visible light and are much more transparent to the infrared spectrum than glass (see Figures 14–16).

Other optical properties of Teflon® films of interest are:

	Teflon® FEP
Solar Transmission (ASTM E-424)	96%
Refractive Index (ASTM D-542)	1.341–1.347

Figure 14. Transmission Spectrum for Teflon® FEP Film

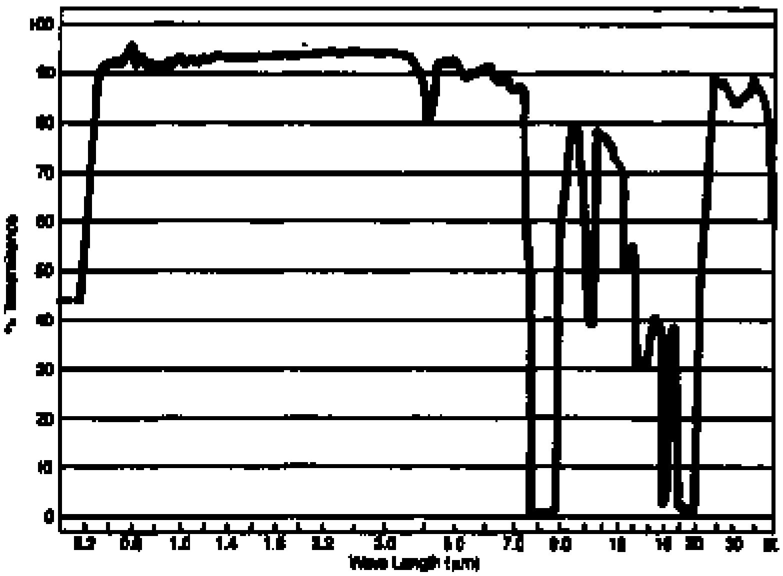


Figure 15. Transmittance at Normal Incidence of Solar Radiation through Teflon® FEP Films for Various Thicknesses

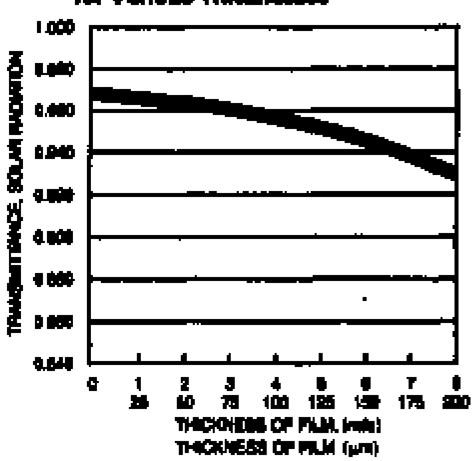
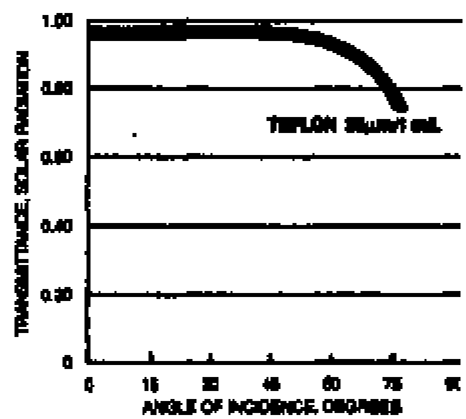


Figure 16. Transmittance of Solar Radiation through 25 µm (1 mil) Teflon® FEP Film for Various Angles of Incidence



Miscellaneous Properties

Cryogenic Service

Teflon® FEP has performed satisfactorily in cryogenic service at temperatures below that of liquid nitrogen. Teflon® fluorocarbon film is normally inert to liquid oxygen (LOX) when the film is free of contamination, pigmentation, or fillers for reinforcement.

FDA Compliance

Clear Teflon® FEP fluorocarbon film complies with Part 177 of Title 21 of the Food & Drug Administration regulations for safe use as articles or components of articles for producing, manufacturing, processing, preparing, treating, packaging, transporting, or holding food in accordance with Regulation 177.1550.

USDA Acceptance

Clear Teflon® FEP fluorocarbon film is acceptable as a component of materials for use in slaughtering, processing, transporting, or storage areas in direct contact with meat or poultry food product prepared under federal inspection.

Mildew (Fungus) Resistance

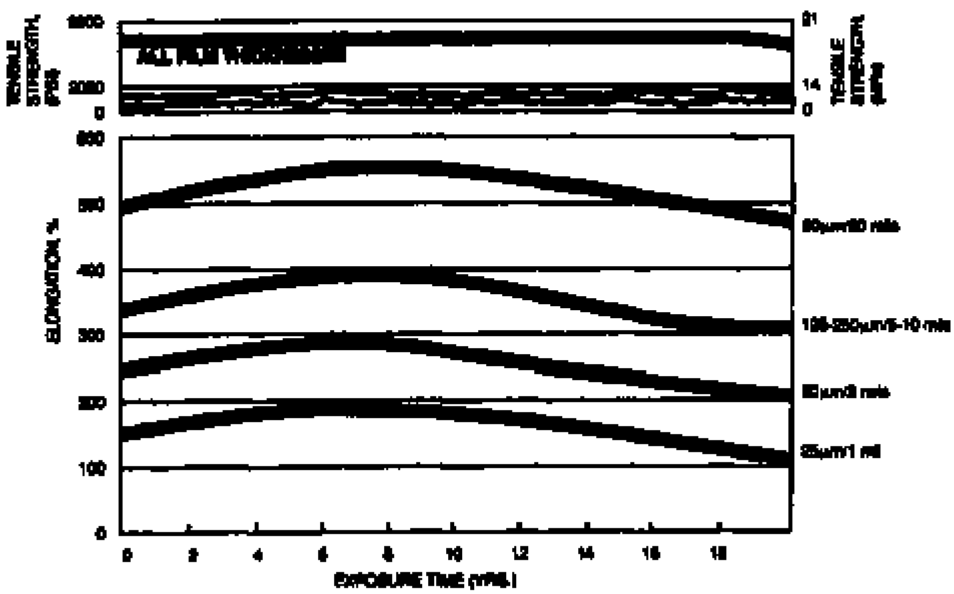
Teflon® FEP has been shown to be completely resistant to mildew growth by testing both in humidity chamber exposure inoculated with a mixed spore suspension and a soil burial test for three months.

Weatherability

In contrast to most other clear thermoplastic films, Teflon® film remains essentially unchanged after 20 years of outdoor exposure (see Figure 17). There is no evidence of discoloration, ultraviolet degradation, or strength loss. This outstanding performance is due to the structure of the polymer molecule and is not the result of chemical additives.

Types C and C-20 Teflon® film are not recommended for outdoor applications because ultraviolet radiation may adversely affect the treated surface.

Figure 17. The Effects of Florida Weathering on Teflon® FEP Film



Safety and Handling

Unheated Teflon® fluorocarbon is essentially inert. Animal tests indicate that Teflon® is nonirritating and nonsensitizing to the skin. Dust generated by cutting, grinding, or machining the unheated film should be avoided, as with any other nuisance dusts that are regulated by OSHA at 15 mg/m³ in air (29 CFR 1910:1000).

Care should be taken to avoid contamination of smoking tobacco or cigarettes with fluorocarbon resins.

Teflon® film can be processed and used at elevated temperatures without hazard if proper ventilation is used. Ventilation should be provided at processing temperatures of 275°C (525°F) or above.

Additional details on safety in handling and use are available in bulletin H-48633, "Guide to the Safe Handling of Fluoropolymer Resins," available from DuPont.

Other related literature available from DuPont:

Bulletin	Title
E-80413-1	Teflon® PFA Film—Specification Bulletin (T62-3)
H-55003-1	Teflon® FEP Film—Specification Bulletin (T62-1)
E-55008-1	Teflon® FEP Film—Properties Bulletin

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Caution: Do not use in medical applications involving permanent implantation in the human body. For other medical applications, see "DuPont Medical Caution Statement," H-50102.

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DuPont Films

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DuPont Films

High Performance Films

Teflon® FEP

fluorocarbon film

Teflon® as Film

Teflon® FEP fluorocarbon film offers the outstanding properties of Teflon® in a convenient, easy-to-use form. It can be heat-sealed, thermoformed, welded, metallized, and laminated to many other materials or serve as a hot melt adhesive.

This combination of unique properties and easy-to-use form offers design and fabrication opportunities for a wide variety of end uses.

Teflon® is Unique Among Plastics

- Most chemically inert of all plastics
- Withstands both high- and low-temperature extremes
- Superior antistick/low friction properties
- Outstanding weather resistance
- Excellent optical characteristics
- Superior electrical properties
- Free of plasticizers or additives
- Excellent processibility with conventional thermoplastic methods

Teflon® FEP Film is Offered

- In thicknesses from 12.5–4750 µm (0.5–190 mil)
- In custom slit widths up to 1.2–1.6 m (46–63 in) depending on thickness
- In various size rolls wound on 7.6 cm or 15.2 cm (3 in or 6 in) cores

Teflon® film affords the engineer/designer a wide range of opportunities to take advantage of these properties with minimal and convenient fabrication techniques.

The ability of Teflon® FEP film to be easily cut, thermoformed, heat sealed, and welded permits ready application as diaphragms, gaskets, protective linings, or thermoformed pouches or containers, wherever high temperature and/or chemical resistance is required.

The excellent optical properties and resistance to weathering and ultraviolet degradation have led to the use of Teflon® FEP film in such varied applications as environmental growth chambers, solar energy collectors, and radome windows.

Its superior dialectic properties have been used in flexible, flat cable insulation, printed circuits, and electronic components for computers and aircraft.

The nonstick properties of Teflon® FEP have found use in conveyor belts, process roll covers, and as mold release films.

Special grades of Teflon® FEP film offer specific properties such as cementability or high stress crack resistance under extreme environmental conditions.

A complete listing of FEP film grades and their availability in different thicknesses is given in Table 1.

In addition to FEP, DuPont offers films of Teflon® PFA, for use at temperatures up to 260°C (500°F), and Tefzel® fluoropolymer for increased toughness and resistance to tear propagation.

Teflon® FEP film offers unique properties in a convenient form requiring minimal fabrication. Consider it for your next project.

For additional information, call (800) 237-4357.

Types and Gauges

Table 1
Types and Gauges of DuPont Teflon® FEP Fluorocarbon Film

Gauge	50	100	200	300	500	750	1000	1500	2000	3000	6000	9000	12500	19000
Thickness, mil	0.5	1	2	3	5	7.5	10	15	20	30	60	90	125	190
Thickness, µm	12.5	25	50	75	125	190	250	375	500	750	1500	2300	3125	4750
Approximate area factor, ft²/lb	180	90	45	30	18	12	9	6.0	4.5	3	1.5	1	0.72	0.47
Approximate area factor, m²/kg	36	18	9	6	4	2.5	2	1.2	1	0.6	0.3	0.2	0.14	0.09
Availability														
Type A—FEP, general-purpose	X	X	X	X	X	X	X	—	X	—	—	—	—	—
Type C—FEP, one side cementable	X	X	X	X	X	—	—	—	—	—	—	—	—	—
Type C-20—FEP, both sides cementable	X	X	X	—	X	—	—	—	—	—	—	—	—	—
Type L—FEP, high stress crack resistance in extreme environments	—	—	—	—	X	—	X	X	X	X	X	X	X	X

Note: Each roll of Teflon® film is clearly identified as to resin type, film thickness, and film type.

Teflon® FEP 500 C
Resin type
Film thickness, 500 gauge, 5 mil
Film type cementable one side

Mechanical and Thermal Properties

Teflon® FEP films perform well over a wide range of temperatures. Teflon® FEP has a continuous service temperature range from –240 to 205°C (–400 to 400°F), and it can be used in intermittent service at temperatures as high as 260°C (500°F). See Tables 2 and 3.

Tensile Properties

Figures 1–3 show how tensile properties of Teflon® FEP film vary with temperature. Teflon® films retain useful mechanical properties over a wide range from cryogenic to high temperatures.

Dimensional Stability

There are three components to the property of dimensional stability—hygroscopic expansion, residual shrinkage, and thermal expansion.

Hygroscopic Expansion

Because the moisture absorption of Teflon® FEP fluorocarbon film is less than 0.01% when totally immersed in water, changes in relative humidity have little effect on the film.

Figure 1. Tensile Stress vs. Elongation of Teflon® FEP Film

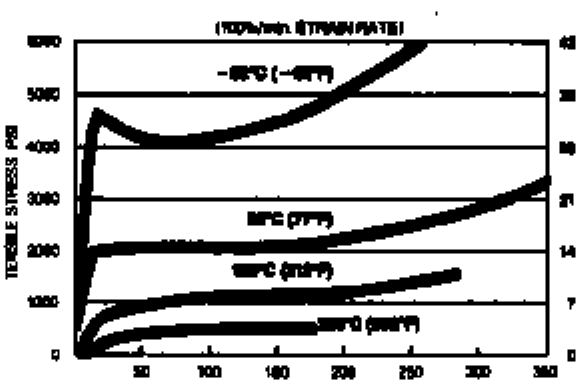

Figure 2. Tensile Properties of Teflon® FEP Film vs. Temperature

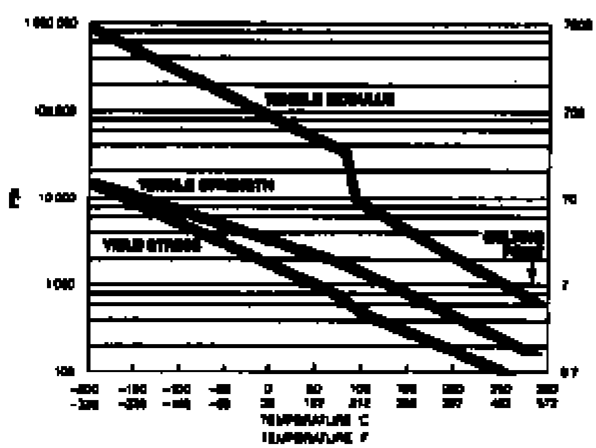

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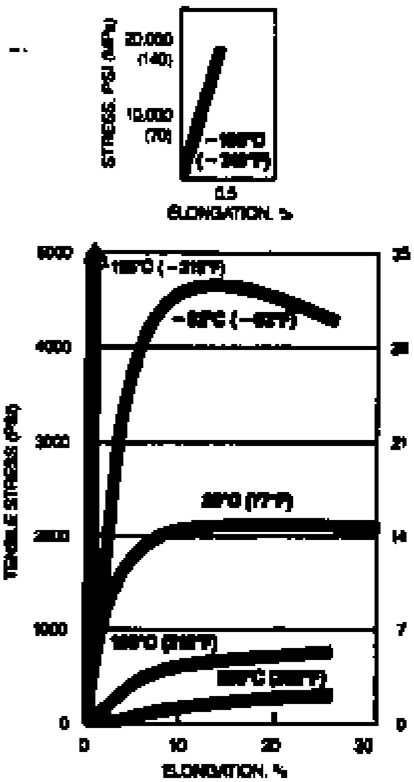
Figure 3. ...sile Stress vs. Elongation of Teflon* ... Film



Residual Shrinkage

Stresses set up in the film during manufacturing or converting can cause shrinkage in unrestrained film when exposed to high temperatures.

Exposure of film to an elevated temperature, and the attendant shrinkage, will relieve this stress, and no further shrinkage will occur at lower temperatures.

Thermal Expansion

After residual shrinkage has been removed, Teflon* FEP film will expand and contract according to its normal coefficient of thermal expansion (see **Figures 4 and 5**). Note that this coefficient increases with temperature.

Figure 4. Shrinkage of Teflon* FEP 100A Film vs. Temperature

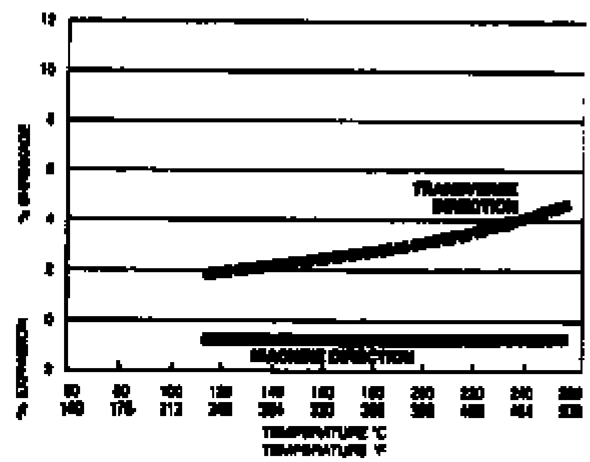


Table 2
Typical Mechanical Properties of Teflon* FEP Film*

Property	ASTM Method	SI Units	English Units
Tensile strength (at break)	D-882-81	21 MPa	3000 psi
Elongation at break	D-882-81	300%	300%
Elastic modulus	D-882-81	480 MPa	70 000 psi
Yield point	D-882-81	12 MPa	1700 psi
Stress to produce 5% strain	D-882-81	12 MPa	1700 psi
Folding endurance (MIT)	D-2176-69	10,000 cycles	10,000 cycles
Initial tear strength (Graves)	D-1004-66	5.3 N	1.2 lbf
Propagating tear strength (Elmendorf)	D-1922-67	2.5 N	250 g
Bursting strength**	D-774-67 (Mullen)	76 kPa	11 psi
Density	D-1505-68	2150 kg/m³	134 lb/ft³
Coefficient of friction kinetic (film to steel)	D-1894-61	0.3	0.3

*200 gauge unless otherwise noted

**100 gauge film

Table 3
Typical Thermal Properties of Teflon* FEP Film*

Property		ASTM Method	SI Units	English Units
Melt point		D-3418 (DTA)	260–280°C	500–536°F
Maximum continuous service temperature			205°C	400°F
Zero strength** temperature		***	255°C	490°F
Specific heat			1172 J/kg·K	0.28 Btu/lb·°F
Coefficient of thermal conductivity			0.195 W/m·K	1.35 $\frac{Btu \cdot in}{h \cdot ft^2 \cdot °F}$
Coefficient of linear thermal expansion		D-696-79	$9.4 \times 10^{-5} \frac{mm}{mm \cdot °C}$	$5.4 \times 10^{-5} \frac{in}{in \cdot °F}$
Flammability classification		ANSI/UL-94	VTM-0	VTM-0
Oxygen index		D-2863-77	95%	95%
Dimensional stability	MD	30 min at 150°C (302°F)	0.7% expansion	0.7% expansion
	TD		2.2% shrinkage	2.2% shrinkage

*200 gauge unless otherwise noted

**100 gauge film

***Temperature at which film supports a load of 0.14 MPa (20 psi) for 5 sec

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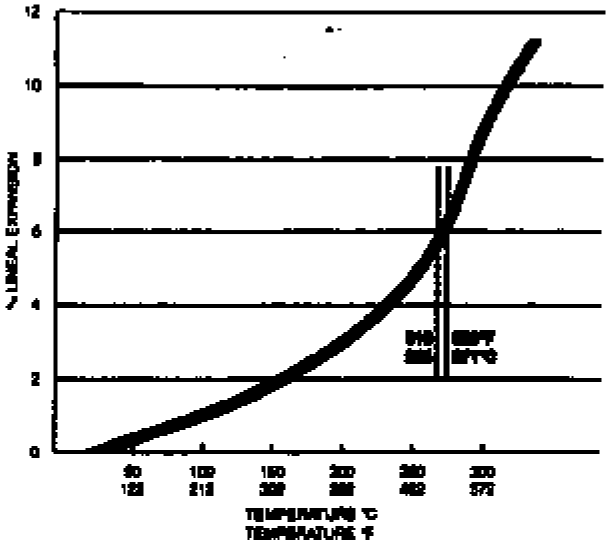
Figure 5. Thermal Expansion of Teflon® FEP Film



Electrical Properties

Teflon® fluorocarbon films exhibit excellent electrical properties over a wide range of frequencies and temperatures. Table 4 shows how initial properties are retained even after long-term exposure to extreme environmental conditions.

Table 4
Typical Electrical Properties of Teflon® FEP Fluorocarbon Film 25 μm (1 mil) Thickness

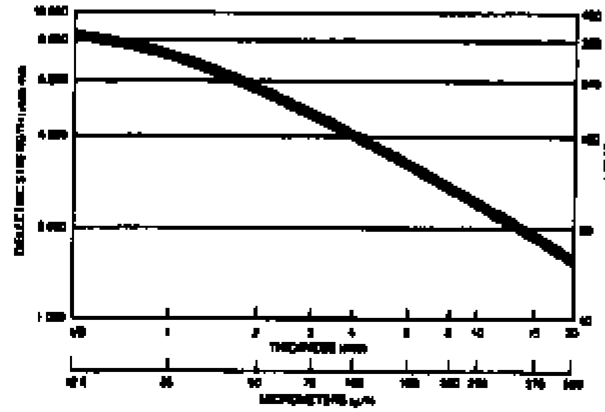
Property	ASTM Method	SI Units	English Units
Dielectric strength	D-149A-81 [6.4 mm (0.25 in) electrode in air, 60 Hz]	260 kV/mm	6500 V/mil
Dielectric constant	D-150-81 (1 kHz)	2.0	2.0
Dissipation factor	D-150-81 (1 kHz)	0.0002	0.0002
Volume resistivity	D-257-78	1×10^{16} ohm-m	1×10^{18} ohm-cm
Surface resistivity	D-257-78	1×10^{16} ohm (per square)	1×10^{16} ohm (per square)
Surface arc resistance	D-495-73	>165 s*	>165 s*

*Samples melted in arc did not track.

Dielectric Strength

Figure 6 shows how the dielectric strength of Teflon® FEP film is a function of film thickness; thinner films exhibit greater dielectric strength.

Figure 6. Dielectric Strength vs. Film Thickness of Teflon® FEP



Dielectric Constant

For Teflon® fluorocarbon film, dielectric constant is independent of film thickness. There is no difference between Type A and Type C films.

At a constant frequency, the dielectric constant of Teflon® FEP film decreases with rise in temperature due to thermal expansion (see Figure 7).

At a constant temperature, the dielectric constant falls slightly with an increase in frequency above 10^7 Hz (see Figure 8).

Figure 7. Dielectric Constant vs. Temperature of Teflon® FEP Film at 1 kHz and 100 kHz

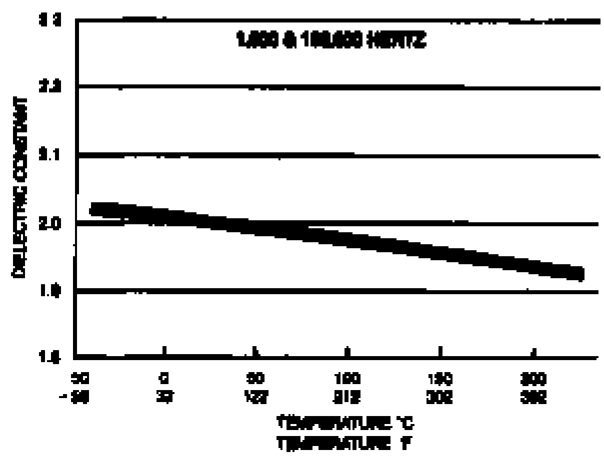
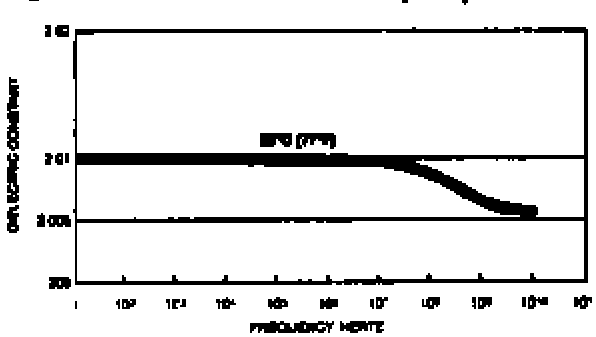


Figure 8. Dielectric Constant vs. Frequency



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Dissipation Fac

The consistently low value of the dissipation factor over a broad range of temperature and frequency makes Teflon® fluorocarbon film ideal in applications where electrical losses must be minimized (see **Figure 9**).

At a constant temperature, this dissipation factor of Teflon® films varies as noted in **Figure 10**. Absolute values remain low in comparison with many other dielectric materials.

Figure 9. Dissipation Factor vs. Temperature of Teflon® FEP Film

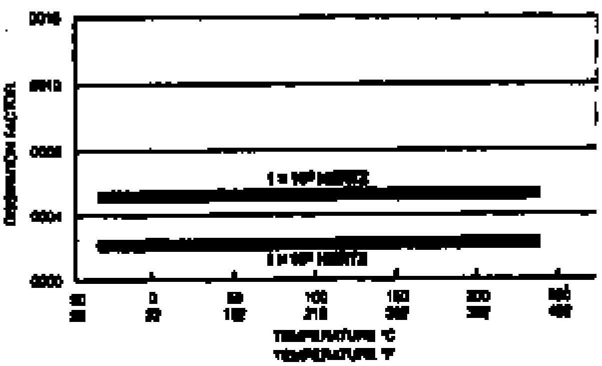
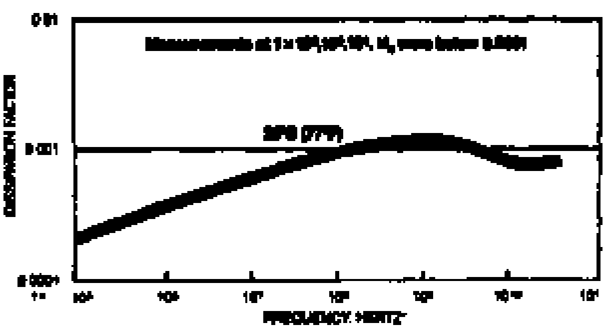


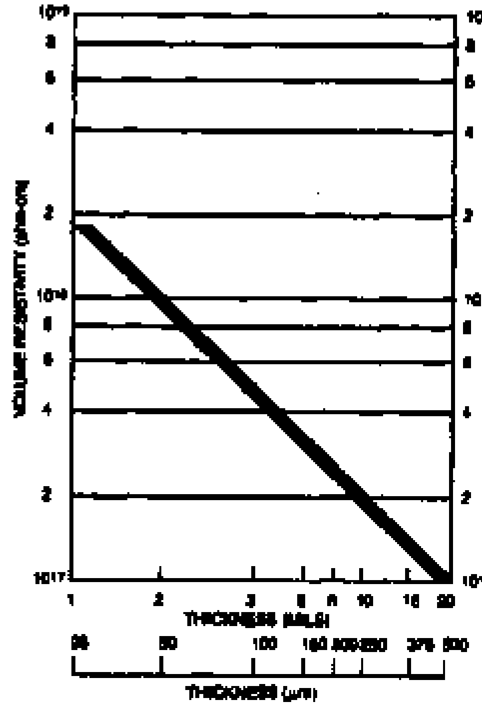
Figure 10. Dissipation Factor vs. Frequency of Teflon® FEP Film



Volume Resistivity

Volume resistivity of Teflon® fluorocarbon film decreases slightly as the film thickness increases (see **Figure 11**).

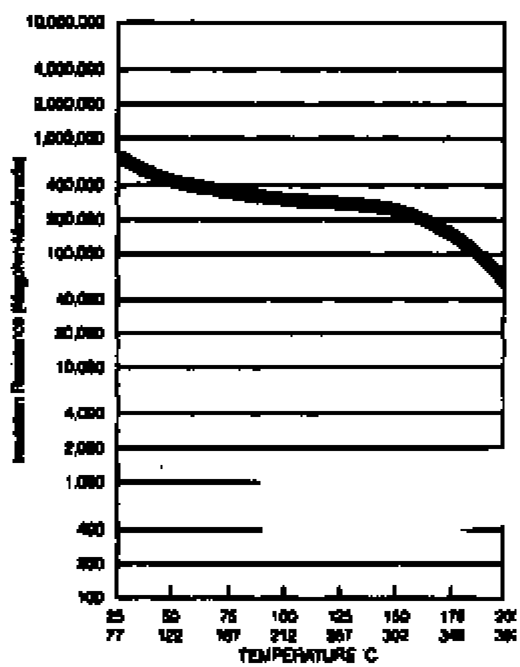
Figure 11. Volume Resistivity vs. Thickness (at 175°C [347°F])



Insulation Resistance

Even at 200°C (392°F), the insulation resistance of Teflon® film (65,000 megohm-microfarad) is higher than most conventional dielectric materials at room temperature (see **Figure 12**).

Figure 12. Insulation Resistance vs. Temperature
(125 µm/0.5 mil TEFLON FEP film)



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Chemical Properties

Teflon® FEP fluorocarbon film is chemically inert and solvent resistant to virtually all chemicals except molten alkali metals, fluorine at elevated temperatures, and certain complex halogenated compounds such as chlorine trifluoride at elevated temperatures and pressures.

In circumstances where end-use temperatures are close to the upper service limit 205°C (400°F), 80% sodium hydroxide, metal hydrides, aluminum chloride, ammonia, and certain amines ($R\text{-}NH_2$) may attack the film in a manner similar to molten alkali metals. Special testing is required when such extreme reducing or oxidizing conditions are evident.

With these exceptions noted, Teflon® FEP fluorocarbon films exhibit a very broad range of chemical and thermal serviceability.

Due to the many complex aspects of performance in severe environments, final selection should be based on functional evaluations or experience under actual end-use conditions.

The chemical substances listed in Table 5 are representative of those with which Teflon® FEP film has been found to be nonreactive.

Table 5
Typical Chemicals with Which Teflon® FEP Film is Nonreactive*

Abietic acid	Cyclohexanone	Hydrofluoric acid	Phthalic acid
Acetic acid	Dibutyl phthalate	Hydrogen peroxide	Pinene
Acetic anhydride	Dibutyl sebacate	Lead	Piperidene
Acetone	Diethyl carbonate	Magnesium chloride	Polyacrylonitrile
Acetophenone	Diethyl ether	Mercury	Potassium acetate
Acrylic anhydride	Dimethyl formamide	Methyl ethyl ketone	Potassium hydroxide
Allyl acetate	Di-isobutyl adipate	Methacrylic acid	Potassium permanganate
Allyl methacrylate	Dimethylformamide	Methanol	Pyridine
Aluminum chloride	Dimethylhydrazine, unsymmetrical	Methyl methacrylate	Soap and detergents
Ammonia, liquid	Dioxane	Naphthalene	Sodium hydroxide
Ammonium chloride	Ethyl acetate	Naphthols	Sodium hypochlorite
Aniline	Ethyl alcohol	Nitric acid	Sodium peroxide
Benzonitrile	Ethyl ether	Nitrobenzene	Solvents, aliphatic and aromatic**
Benzoyl chloride	Ethyl hexoate	2-Nitro-butanol	Stannous chloride
Benzyl alcohol	Ethylene bromide	Nitromethane	Sulfur
Borax	Ethylene glycol	Nitrogen tetroxide	Sulfuric acid
Boric acid	Ferric chloride	2-Nitro-2-methyl propanol	Tetrabromoethane
Bromine	Ferric phosphate	n-Octadecyl alcohol	Tetrachlorethylene
n-Butyl amine	Fluoronaphthalene	Oils, animal and vegetable	Trichloracetic acid
Butyl acetate	Fluoronitrobenzene	Ozone	Trichlorethylene
Butyl methacrylate	Formaldehyde	Perchlorethylene	Tricresyl phosphate
Calcium chloride	Formic acid	Pentachloro-benzamide	Triethanolamine
Carbon disulfide	Furane	Perfluoroxylene	Vinyl methacrylate
Cetane	Gasoline	Phenol	Water
Chlorine	Hexachloroethane	Phosphoric acid	Xylene
Chloroform	Hexane	Phosphorus pentachloride	Zinc chloride
Chlorosulfonic acid	Hydrazine		
Chromic acid	Hydrochloric acid		
Cyclohexane			

*Based on experiments conducted up to the boiling points of the liquids listed. Teflon® FEP resins have normal service temperatures up to 205°C (400°F). Absence of a specific chemical does not mean that it is reactive with Teflon® FEP film.

**Some halogenated solvents may cause moderate swelling.

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Physical Properties

Absorption

Almost all plastics absorb small quantities of certain materials with which they come in contact. Submicroscopic voids between polymer molecules provide space for the material absorbed without chemical reaction. This phenomenon is usually marked by a slight weight increase and sometimes by discoloration.

Teflon® FEP fluorocarbon films have unusually low absorption compared with other thermoplastics. They absorb practically no common acids or bases at temperatures as high as 200°C (392°F) and exposures of up to one year. Even the absorption of solvents is extremely small. Weight increases are generally less than 1% when exposed at elevated temperatures for long periods. In general, aqueous solutions are absorbed very little by Teflon® FEP film. *Moisture absorption is typically less than 0.01% at ambient temperature and pressure.*

Permeability

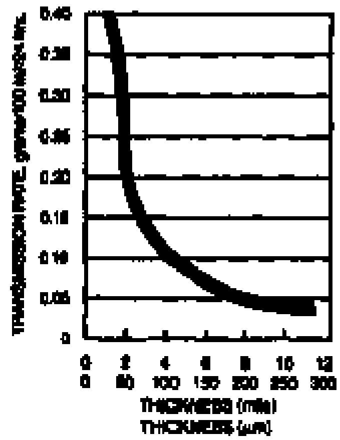
Many gases and vapors permeate Teflon® films at a much lower rate than for other thermoplastics (see **Figure 13**). In general, permeation increases with temperature, pressure, and surface contact area and decreases with increased film thickness. **Table 6** lists rates at which various gases are transmitted through Teflon® FEP fluorocarbon film, while **Table 7** lists rates of vapor permeability for some representative substances. Note that the pressure for each material is its vapor pressure at the indicated temperature.

Table 6
Typical Gas Permeability Rates of Teflon® FEP Fluorocarbon Film, 25 μm (1 mil) Thickness
(Test Method: ASTM D-1434 at 25°C (77°F))

Gas	Permeability Rate* $cm^3/(m^2 \cdot 24\ h \cdot atm)$
Carbon Dioxide	25.9×10^3
Hydrogen	34.1×10^3
Nitrogen	5.0×10^3
Oxygen	11.6×10^3

*To convert to $cm^3/(100\ in^2 \cdot 24\ h \cdot atm)$, multiply by 0.0646.

Figure 13. Water Vapor Transmission Rate of Teflon® FEP Film at 40°C (104°F) per ASTM E-96 (Modified)



Notes: Values are averages only and not for specification purposes. To convert the permeation values for 100 in² to those for 1 m², multiply by 15.5.

Table 7
Typical Vapors Transmission Rates of Teflon® FEP Fluorocarbon Film, 25 μm (1 mil) Thickness
(Test Method: Modified ASTM E-96)

Vapor	Temperature °C	Temperature °F	Vapor Transmission Rate SI Units $(g/m^2 \cdot d)$	Vapor Transmission Rate English Units $(g/100\ in^2 \cdot d)$
Acetic Acid	35	95	6.3	0.41
Acetone	35	95	14.7	0.95
Benzene	35	95	9.9	0.64
Carbon Tetrachloride	35	95	4.8	0.31
Ethyl Acetate	35	95	11.7	0.76
Ethyl Alcohol	35	95	10.7	0.69
Freon® F-12	23	73	372.0	24.0
Hexane	35	95	8.7	0.56
Hydrochloric Acid	25	77	<0.2	<0.01
Nitric Acid (Red Fuming)	25	77	160.0	10.5
Sodium Hydroxide, 50%	25	77	<0.2	<0.01
Sulfuric Acid, 98%	25	77	2×10^{-4}	1×10^{-4}
Water	39.5	103	7.0	0.40

Optical Properties

Teflon® films transmit a high percentage of ultraviolet and visible light and are much more transparent to the infrared spectrum than glass (see Figures 14–16).

Other optical properties of Teflon® films of interest are:

	Teflon® FEP
Solar Transmission (ASTM E-424)	96%
Refractive Index (ASTM D-542)	1.341–1.347

Figure 14. Transmission Spectrum for Teflon® FEP Film

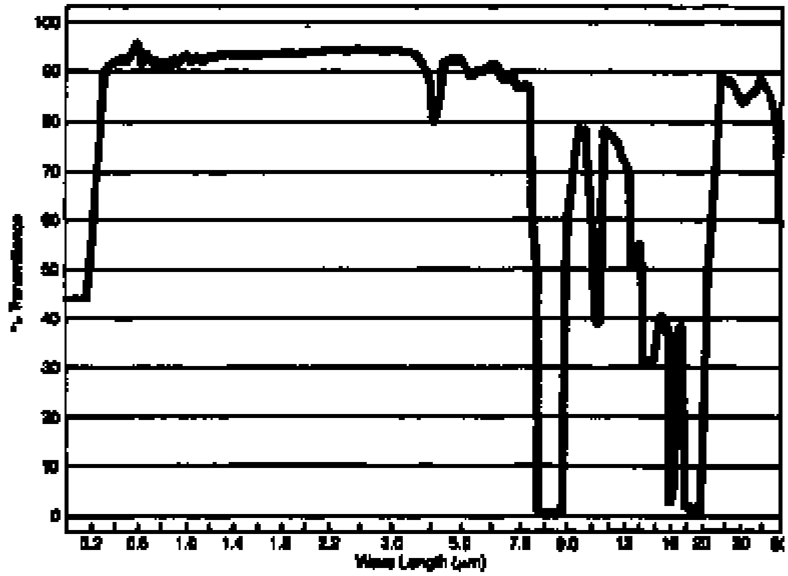


Figure 15. Transmittance at Normal Incidence of Solar Radiation through Teflon® FEP Films for Various Thicknesses

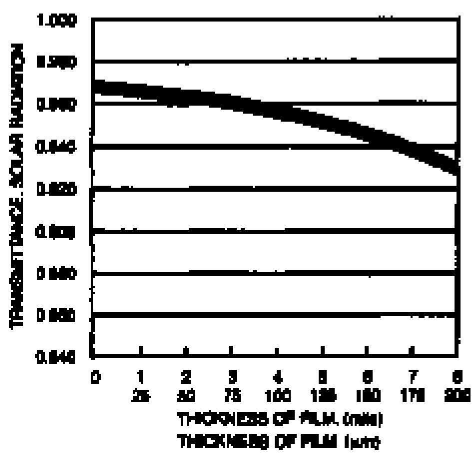
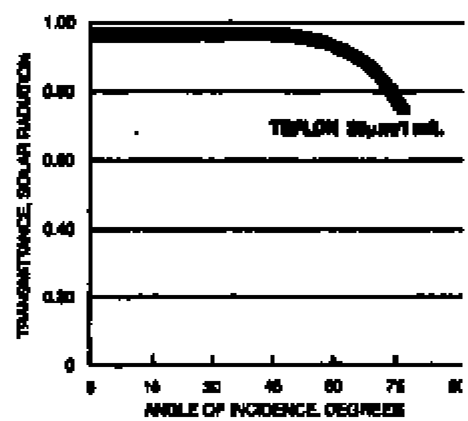


Figure 16. Transmittance of Solar Radiation through 25 µm (1 mil) Teflon® FEP Film for Various Angles of Incidence



Miscellaneous Properties

Cryogenic Service

Teflon® FEP has performed satisfactorily in cryogenic service at temperatures below that of liquid nitrogen. Teflon® fluorocarbon film is normally inert to liquid oxygen (LOX) when the film is free of contamination, pigmentation, or fillers for reinforcement.

FDA Compliance

Clear Teflon® FEP fluorocarbon film complies with Part 177 of Title 21 of the Food & Drug Administration regulations for safe use as articles or components of articles for producing, manufacturing, processing, preparing, treating, packaging, transporting, or holding food in accordance with Regulation 177.1550.

TI-NHTSA 017739

USDA Acceptance

Clear Teflon® FEP fluorocarbon film is acceptable as a component of materials for use in slaughtering, processing, transporting, or storage areas in direct contact with meat or poultry food product prepared under federal inspection.

Mildew (Fungus) Resistance

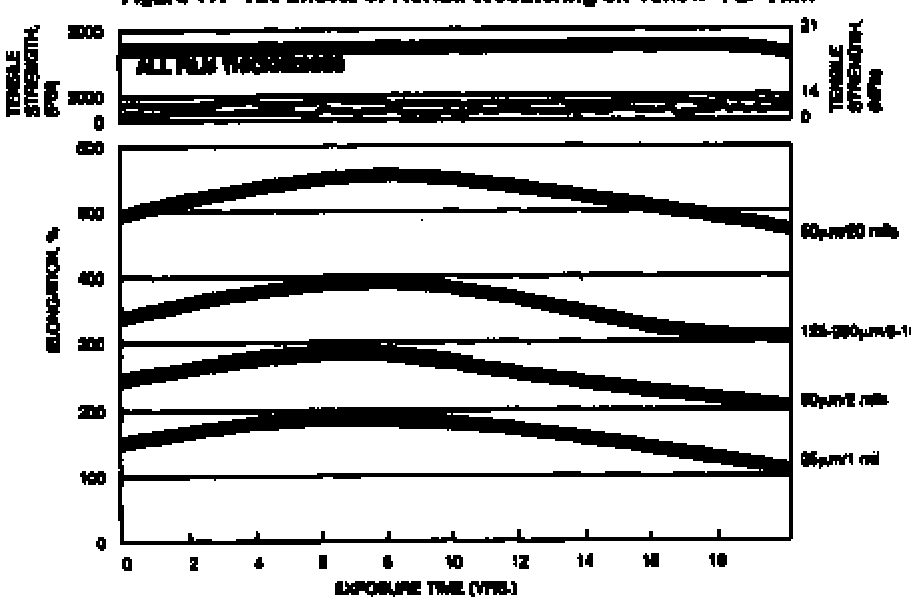
Teflon® FEP has been shown to be completely resistant to mildew growth by testing both in humidity chamber exposure inoculated with a mixed spore suspension and a soil burial test for three months.

Weatherability

In contrast to most other clear thermoplastic films, Teflon® film remains essentially unchanged after 20 years of outdoor exposure (see **Figure 17**). There is no evidence of discoloration, ultraviolet degradation, or strength loss. This outstanding performance is due to the structure of the polymer molecule and is not the result of chemical additives.

Types C and C-20 Teflon® film are not recommended for outdoor applications because ultraviolet radiation may adversely affect the treated surface.

Figure 17. The Effects of Florida Weathering on Teflon® FEP Film



Safety and Handling

Unheated Teflon® fluorocarbon is essentially inert. Animal tests indicate that Teflon® is nonirritating and nonsensitizing to the skin. Dust generated by cutting, grinding, or machining the unheated film should be avoided, as with any other nuisance dusts that are regulated by OSHA at 15 mg/m³ in air (29 CFR 1910:1000).

Care should be taken to avoid contamination of smoking tobacco or cigarettes with fluorocarbon resins.

Teflon® film can be processed and used at elevated temperatures without hazard if proper ventilation is used. Ventilation should be provided at processing temperatures of 275°C (525°F) or above.

Additional details on safety in handling and use are available in bulletin H-48633, "Guide to the Safe Handling of Fluoropolymer Resins," available from DuPont.

Other related literature available from DuPont:

Bulletin	Title
E-80413-1	Teflon® PFA Film—Specification Bulletin (T62-3)
H-55003-1	Teflon® FEP Film—Specification Bulletin (T62-1)
E-55008-1	Teflon® FEP Film—Properties Bulletin

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DuPont Films

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High Performance Films

Teflon® FEP

fluorocarbon film

Techniques for Fabricating Teflon® FEP

Introduction

Teflon® FEP fluorocarbon film offers the outstanding properties of Teflon® in a convenient, easy-to-use form. The film is used "as received" in a number of applications. However, in many instances, the film must be fabricated into a product suitable for a specific application. Some examples would be:

- Metallizing the film to produce a substrate for flexible printed circuits
- Sealing the film to produce a bag or pouch
- Melt bonding the film to a metal substrate
- Using the film as a melt adhesive to bond two pieces of copper tubing
- Adhesive bonding the film to vinyl sheeting (laminating)
- Thermoforming the film into useful shapes such as corrosion-resistant labware (funnels, beakers, etc.)

This brochure will describe the techniques employed in fabricating Teflon® FEP films. The following topics will be covered:

- Heat sealing
- Heat bonding
- Teflon® FEP film as an adhesive
- Adhesive laminating
- Metallizing
- Thermoforming

Note that all of the information in this brochure is related to techniques for the fabrication of Teflon® FEP films. The techniques for fabricating Teflon® PFA film are very similar to those for Teflon® FEP. The major difference is in the melting behavior of these films. Teflon® PFA film melts about 28–42°C (50–75°F) higher than Teflon® FEP. In all procedures requiring the film to be in the formable or melted state, equipment temperature should be modified accordingly. Procedures not requiring the Teflon® PFA films to be formable or melted would be the same as for Teflon® FEP films.

Heat Sealing Principles

In many areas of application, the heat sealability of Teflon® FEP fluorocarbon film will be of interest as a method of fabrication. This section discusses some of the methods that may be employed to obtain heat seals with Types A and L films.

General

Teflon® FEP film may be heat sealed by any method that heats the contacting surfaces of the film above the melt temperature of the polymer and, at the same time, provides intimate contact of those surfaces.

A fusion heat seal of Teflon® FEP film is a non-peeling type of seal, and a wide seal area is not necessary. Better appearing seals with minimum distortion and puckering of the film are obtained by localizing the heat applied to the film to as small an area as is practical. The use of hot bar or impulse sealing equipment necessitates bringing the entire thickness of film to the melting point of the polymer in order to accomplish a fusion temperature at the film interfaces. With relatively thin films, heat transfer time is sufficiently short to allow this method, although thinning out of the film adjacent to the seal occurs to a greater extent as film thickness increases. In continuous band sealing, this is accomplished by heating only the center portion of the band and by cooling the seal under pressure. Hot air sealing reduces thinning out by allowing the force of the air flow to act as the pressure medium and metal plates or guides to keep the majority of the film below the distortion temperature. Heat seals made with Type L Teflon® FEP and Type LP Teflon® PFA tend to be more durable.

Because molten Teflon® FEP fluorocarbon film has a tendency to stick to the jaws of a heat sealer, it is desirable to use a release agent in the sealing operation. Kapton® polyimide film may also be used as a release slip sheet.

Hot Bar Heat Sealing

The use of hot bar sealing equipment having a minimum temperature capability of 288°C (550°F) and a fast recovery rate will give a wide seal area and be limited to a straight seal. Because it is difficult to localize or isolate the film seal area, a degree of puckering takes place in thinner films. Thinning out will occur adjacent to the fusion area due to the jaw pressure when the film is in a fusion state. Because the equipment does not usually allow temperature cycling during the seal cycle, the film is taken from the jaws while in a molten state when film distortion is at a maximum.

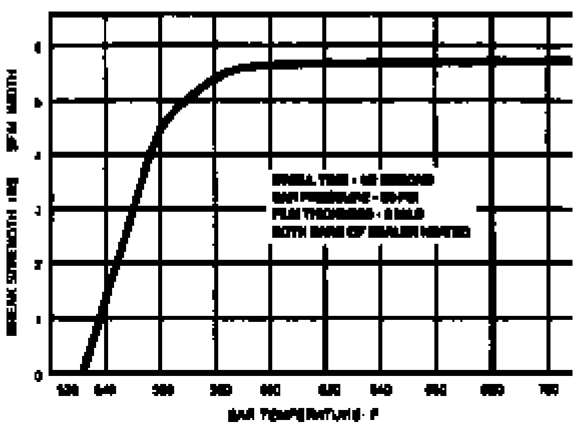
The following graphs illustrate the time/temperature/pressure relationships encountered in hot bar sealing. These general relationships hold true for other heat sealing methods as well.

Temperature

Figure 1 illustrates the effect of bar temperature upon the seal strength of 5-mil Teflon® FEP film at constant bar pressure and dwell time. Above a specific bar temperature (310°C [590°F] with this equipment) there is no significant change in the bond strength of the heat seal.

Figure 1. Effect of Bar Temperature Upon Seal Strength of Teflon® FEP Film

Pressure



In Figure 2, data are plotted for bar pressures of 30 psi and 60 psi with 2-mil film and a constant dwell time of ¼ sec. Pressure appears to have no significant effect upon the bond strength of the fusion heat seals. However, certain qualifications should be made. First, in thicker gauge film (5-mil and greater), pressure does affect the minimum temperature at which a fusion heat seal can be made. Higher pressures tend to yield a fusion heat seal at a slightly lower bar temperature, probably due to the fact that higher pressures can improve the rate of heat transfer from the heated bar to the film. At high pressures, however, cut through and thinning out occur. Teflon® FEP film possesses a relatively high melt viscosity, which is not nearly as much a problem as with lower melt viscosity thermoplastics.

Figure 2. Effect of Pressure Upon Seal Strength of Teflon® FEP Film

Time

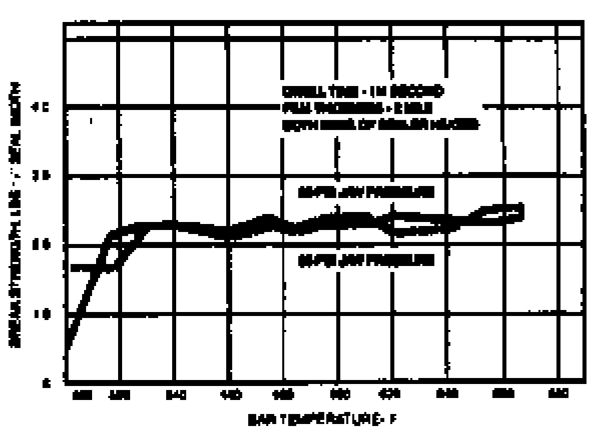


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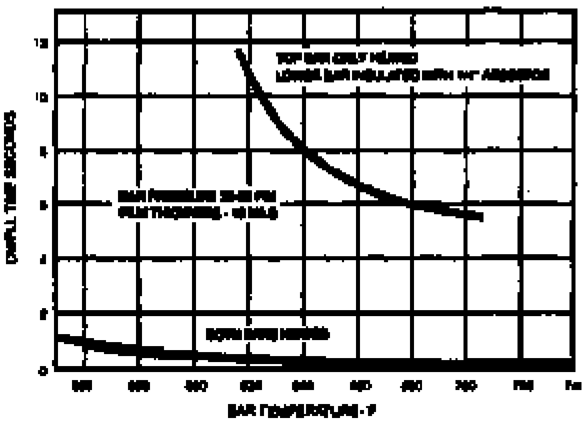
Figure 3 illustrates the considerable effect heating both bars vs. one bar of the sealer has upon the temperature-time relationship for obtaining a fusion heat seal. For example, at 338°C (640°F), it requires only 0.2 sec with two bars heated to obtain a fusion heat seal with 10-mil film, while with only one heated bar, 8.1 sec are required at this temperature. Theoretically, it should require four times as long to heat the film interfaces to the fusion temperature from one side as it should from both sides. However, lacking perfect insulation, heat losses to the surroundings and unheated bar increase this difference.

Figure 3. Effect of Bar Heating Upon Temperature-Time Relationship for Heat Sealing Teflon® FEP Film



Figures 4 and **5** summarize the data obtained for heated bar sealing of Teflon® FEP fluorocarbon film. **Figure 4** is for use when both bars are heated; **Figure 5** when only one bar is heated and the other one is insulated. In both figures, the selection of a temperature-dwell time combination above the indicated curve for a particular gauge film will result in a fusion heat seal of the selected gauge film.

In general, a selection of conditions just slightly in excess of the minimum indicated conditions should prove most satisfactory. This should minimize overheating and distortion of the film. The use of a different slip-sheet or different equipment may affect the selection of optimum temperature-dwell time conditions.

Figure 4. Temperature-Time Relationship for Obtaining Fusion Heat Seal with Teflon® FEP Film

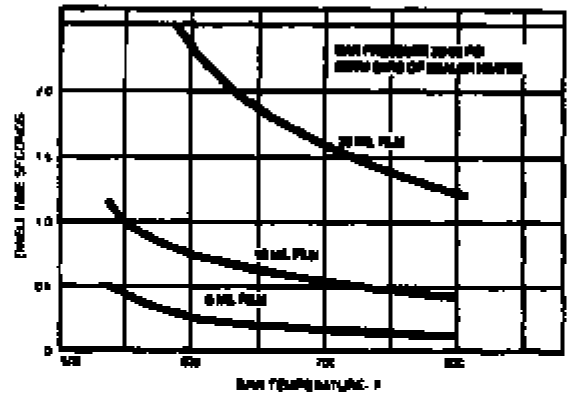
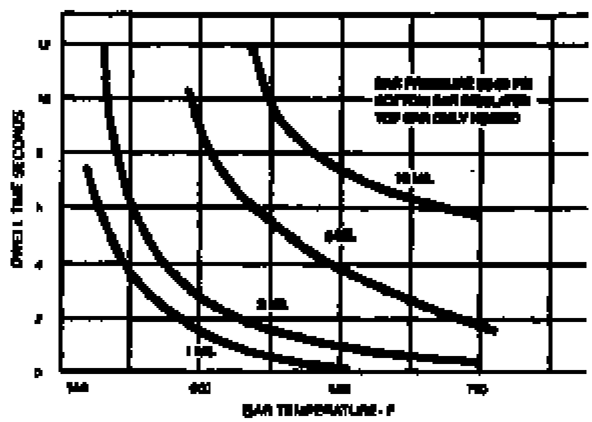


Figure 5. Temperature-Time Relationship for Obtaining Fusion Heat Seal with Teflon® FEP Film



Effect of Gauge on Heat Seals

Figure 6 indicates the heat seal strength obtainable with the various gauges of Teflon® FEP film. Because a Teflon® FEP film fusion heat seal does not peel, the indicated break strength and elongation is that of the weakest link—the film just adjacent to the sealed area. In general, this is approximately 80% of the tensile strength and ultimate elongation of the virgin film.

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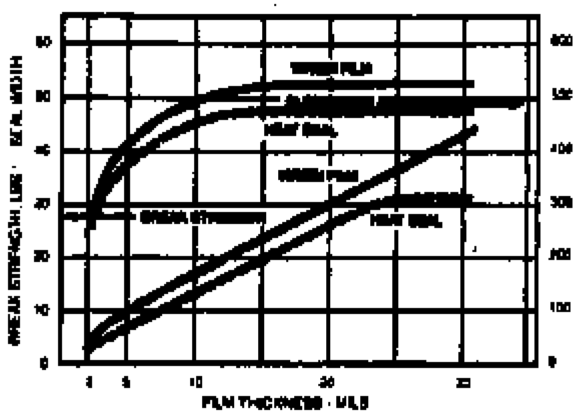
Figure 6. Heat Seal Strength and Elongation Obtainable with Teflon® FEP Film Compared to Virgin Film



Impulse Heat Sealing

Vertrod Corp.* impulse heat sealing equipment has been used for Teflon® FEP fluorocarbon film. The heat sealing is effected by a pulse of electrical current, which is passed through Nichrome** ribbons located in either top and/or bottom jaws. These ribbons transfer heat at a very high temperature for a short period of time. By varying the voltage and time of impulse with a jaw pressure of 10–25 psi, ½–20 mil Teflon® FEP film may be sealed. The heavier gauges will usually require equipment modification.

The seal area will be the width of the Nichrome ribbons and, as with the hot bar sealer, will be limited to a straight seal. Thinning out at the edge of the seal will occur due to the thickness of the Nichrome ribbons and the molten state of the entire thickness of film when at the seal temperature. Because the Nichrome ribbons supply heat for only a short period of time, by allowing the seal to remain in the jaws for several seconds after the impulse, the seal will be cooled below its maximum distortion temperature before being removed. Some puckering will generally occur with thinner films because the seal area is not entirely isolated from the remainder of the film.

Shaped Seal

Curved or irregular sealing configurations that are not possible with hot bar or impulse sealing equipment may be made by using a heated metal shape such as a ring. However, special sealers for irregular shapes are commercially available. The metal shape must be capable of a minimum of 288°C (550°F) and preferably capable of higher temperatures to allow a reasonably short seal cycle (considering the heat transfer time of the film and any slip sheet that may be used).

Care should be taken to ensure that the metal shape is not warped at the elevated sealing temperatures. Machining at these temperatures usually corrects this and allows for an even pressure and heating distribution.

In order to localize heat to the seal area only, cooled metal or nonmetal shapes may be placed in contact with the film area not being sealed. An insulation barrier should be placed between the heated and cooled shapes.

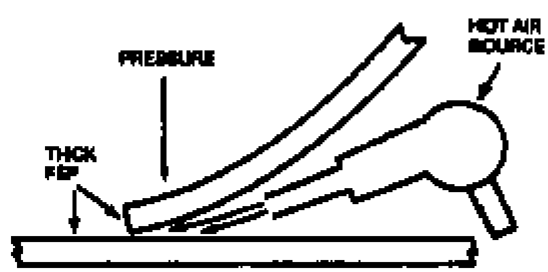
Sufficient contact time to allow the film interfaces to reach fusion temperature will depend upon the film thicknesses to be sealed and the temperature of the sealing mechanism. Heated metal shapes may be used on either one or both sides, both sides giving a faster heat transfer time and thus a shorter cycle.

A high-frequency generator may be used to heat, by induction techniques, a complex metal shape that cannot be heated by the use of conventional resistance type heater elements.

Hot Air Sealing

A hot air source may be used as a heat supply to seal Teflon® FEP film. For relatively thick films (greater than 20 mil), a hot air stream may be directed at the interfaces of the film to be sealed while applying minimal pressure to provide intimate contact of those surfaces. This method provides heat only to the surfaces to be sealed and keeps the major portion of the film below distortion temperature.

Illustration A. Hot Air Sealing of Thick Films



For thinner films where heat transfer time is sufficiently short, hot air may be applied to the outer surface of the film heating through the outer film layer to the interfaces and giving a fusion seal. If such a method is used, a metal guide should be

*Vertrod Corp., Brooklyn, NY

**Registered trademark of Driver Harris Company, Harrison, NJ

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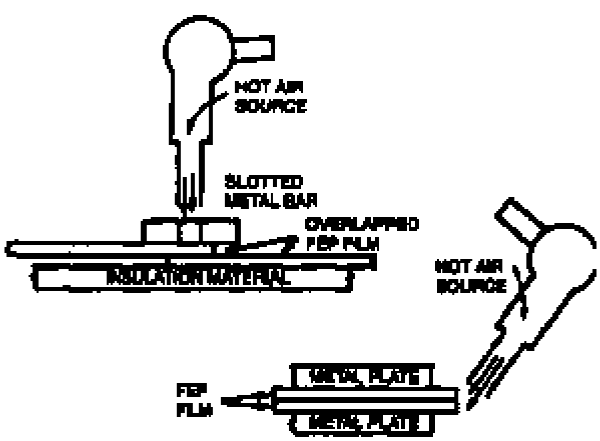
employed to keep the hot air stream directed to only the seal area, while the remainder of the film area is not exposed. A metal guide of complex shape will give a contour seal area.

Illustration B. Hot Air Sealing of Thin Films



Thermoplastic Welding

This information is for experienced operators with a knowledge of thermoplastic welding techniques and a general awareness of available welding tools and equipment.

Publications about welding and fabricating thermoplastic materials may serve as an additional resource.

Safety

Teflon® FEP fluorocarbon resin may undergo some decomposition at welding temperatures. Adequate ventilation must be provided with point-of-work exhaust hoods preferred. Individual fresh air masks may be necessary in some unavoidable enclosed spaces.

Further details regarding safety of Teflon® FEP resin are contained in the bulletin, H-48633, "Guide to the Safe Handling of Fluoropolymer Resins," available from DuPont.

Materials and Equipment

Welding Rods should be extruded virgin Teflon® FEP plastic, normally round, solid, and free of voids with a minimum diameter of 3/32 in and a maximum of 5/32 in.

Electrically Heated Welding Gun with at least a 750-W heating element capable of producing an air temperature of at least 427°C (800°F) when measured at a distance of ¼ in from the installed tip.

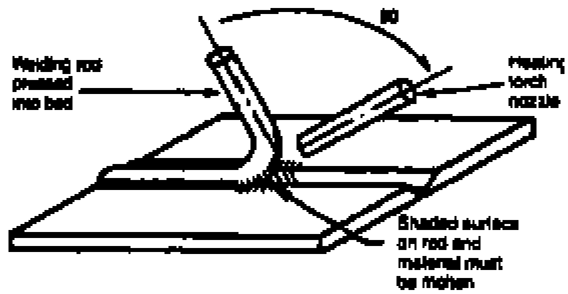
Inert Gas Supply and Pressure Regulator to provide 5–6 psig pressure at the tip of the welding tool.

Preparation

- Cleaning cannot be overemphasized. All surfaces, including welding rods and adjacent plastic for about 1 in beyond the joint, should be cleaned immediately prior to welding with a suitable solvent. **Do not use soap or detergents.**
- Bevelling of thermoplastic edges is essential to obtain a satisfactory weld. Mechanically guided power tools should be used for straighter edges. Use these bevel angle guidelines for Teflon® FEP sheet:
  - Butt Joints (single or double) 60°
  - Corners 60°
  - Fillets 45°
  - Laps Not required
- The joint must be kept in alignment during welding by mechanical clamping or tack welding with a maximum root gap of 1/32 in.

Welding

1) Start hot gas welder at 343°C (650°F).
2) Preheat starting edge of joint material and rod until both appear shiny and become slightly tacky. Hold welding tip about ¼ in from weld joint/rod intersection.
3) Cut the end of the welding rod at a 45° angle, hold it at a 90° angle to the joint, and move it up and down slightly in the heat until it sticks to the base material. During continuous welding, a slight uniform motion of the torch between the sheet and rod is required (the standard Pendulum Technique used by the industry).
4) Holding the rod at a 45° angle with the base material, apply downward pressure on the rod of about 3 lb force. Avoid tension stretching of the rod. See sketch below.



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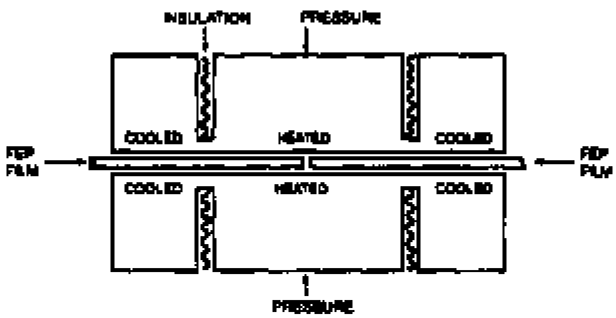
5) Continue welding at a steady and uniform rate of about ½–2 in/min.

6) Temperature, welding speed, rod pressure, and gas flow may be adjusted to vary from the indicated values as more skill and proficiency is achieved through experience.

Transparent Butt Seal

It has been demonstrated that an optically clear butt seal is possible by profile heating and cooling techniques (see Illustration C). By selectively heating and cooling a continuous metal surface in contact with the butt ends of Teflon® FEP fluorocarbon film, the film will flow and fuse to itself to give an optically clear seal. Heating the center portion of the metal where it is in contact with the butt ends and keeping the majority of the film on either side of the heated area cool restricts the thinning out and distortion of the film.

Illustration C. Transparent Butt Seal



Other Methods of Sealing

Induction Sealing

FEP film can be heat sealed by induction heating of metal or metal oxides at the bond interface.

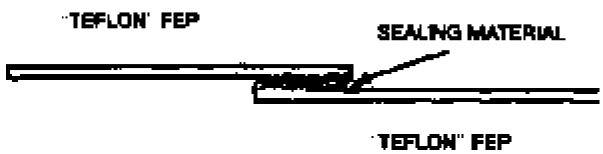
With induction heat sealing, metal or metal oxide is introduced at the bond interface. Heat is developed by energizing the magnetically excitable material with high-frequency induction generating equipment. The magnetic field passes through the films and generates heat at the bond interface. This eliminates the need for heat transfer through the thickness of the film.

Variables affecting the sealing rate are the type of metal used, its mass, and distance from the induction heating coil. Magnetic ferrous materials are best because of their intense hysteresis loss. Nonmagnetic metals like aluminum, copper, tantalum, and nickel have been induction heated, but higher power input and longer dwell time is required.

Blends or electromagnetic energy absorbing materials and a thermoplastic of the same composition as the materials to be bonded are commercially available in tape form or injection molded shapes.

The tape or shape is placed between the sections to be joined (see Figure 7) and magnetically excited. Coil designs provide the intense magnetic field needed. The actual weld is Teflon® FEP. If a low metal content is used, you can still obtain a true melt bond between the two FEP surfaces. This is extremely important for chemical applications.

Figure 7. Lap Weld Specimen



Heat Sealing Parameters		
	Induction	Impulse
Max. Film Thickness	0.500 in or more	0.020 in
Sealing Cycle	3 sec—60-mil	6 sec—20-mil
Appearance	No distortion	Some distortion and thinning*
Pressure	3–4 psi	20–40 psi

*Vertrod two-step impulse system gives smooth seal.

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Ultrasonic Sealing

Teflon® FEP fluorocarbon film may be ultrasonically sealed. Evaluation of any application for ultrasonic assembly must start with analysis of the part size, shape, and structure to determine ease of matching the ultrasonic tooling for efficient transfer of the sonic vibration without energy losses. Mastersonics* is one manufacturer of equipment that has been effective in ultrasonically sealing Teflon® FEP films.

Heat Bonding

Teflon® FEP Fluorocarbon Film to Various Substrates

Teflon® FEP fluorocarbon film is melt processible. Therefore, it can be heat bonded to many substrates (e.g., metals, glass cloth, and other high-temperature materials) without using adhesives. In this way, the unique properties of Teflon® FEP film expand the functionality of the substrate. The substrate material often adds strength and rigidity to the FEP film.

Laminates can be produced in a platen press or on continuous laminating equipment. The general-purpose Type A film or the cementable Type C film may be used. Bonding is accomplished above the melting point of FEP (approximately 271°C [520°F]).

Good bonding to any substrate requires intimate surface contact between the substrate and the FEP film. The molten FEP must flow into the substrate's surface. The substrate must be free from surface contaminants.

Surface Treatment of Metals

Teflon® FEP is quite viscous in the melt, which can impede intimate surface contact with the substrate. Methods of overcoming this are: raising the temperature of the melt to reduce viscosity or increasing laminating pressure to improve flow. However, the surface condition of a metal substrate can greatly influence bonding and dictate temperature and pressure conditions. Sandblasting, chemical etching, or rough grinding increases the effective surface area and "opens up" the surface. On a microscopic scale, a metal's surface is like a mountain range. These surface roughening treatments increase the distance between peaks or widen the valleys. Thus the surface is "open" to the viscous flow of the molten FEP, facilitating intimate contact. The increased surface area also enhances bond strength. These techniques usually remove loose oxides, which, although they may bond to the FEP, have poor bond strength to the metal itself. Many metals are processed using oily lubricants. For this reason, it is wise to degrease the metal surface with solvents. Certain metals (copper in particular) rapidly form oxides at the temperatures recommended for bonding. The use of surface-treated copper is recommended.

Some materials, such as nickel, gold, and aluminum, do not yield strong bonds to Type A FEP film at temperatures under 316°C (600°F). However, Type C FEP film does produce good bonds in that temperature range. Indeed, a few materials will not bond at all to Type A film, but bond well to the Type C surface. It is also possible to bond Type C film to some materials below the melt range of FEP.

Typical platen press conditions and substrate treatments are given in Table 1.

Teflon® FEP Fluorocarbon Dispersion Priming of Metals

Materials such as stainless steel or very thin foils may not respond readily to physical or chemical etching. Excellent bonds can be obtained by priming such surfaces with a thin coating of a fused Teflon® FEP fluorocarbon dispersion. When using the primers, the following procedures are recommended:

1. Spray a very light coating of a mixture of 50% TFE Primer—#850-line and 50% FEP Dispersion #120** on the clean metal surface.
2. Fuse the coating in a forced draft oven at 371°C (700°F) for 5–10 min depending upon the mass of metal involved.
3. Laminate Teflon® FEP fluorocarbon film to the primed surface at 288°C (550°F).

*Mastersonics, Granger, IN
**Available from the DuPont Company

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Table 1
Typical Platen Press Conditions

Substrate	Interface Temperature, °C (°F)	Pressure, psi	Dwell Time, min	Substrate Surface Preparation and Treatment
Aluminum	282 (540) 293 (560)	100 100	5 5	None, if Type C film is used Parker Bonderite 700 series*
Copper	282 (540)	100	3–5	Various treatments
Steel	293–304 (560–580)	100–300	5	Sandblast and degrease, phosphatized*
Stainless steel	360 (680) 293 (560)	300 300	5 5	None Dispersion primer of Teflon®—see paragraph above
Teflon® TFE	343 (650)	100	3–5	None
Nickel	282 (540)	100	5	None, if Type C film is used
Nickel Ceramics Nichrome	293 (560)	300	5	Dispersion primer of Teflon®
Nomex® nylon paper	282 (540)	100	5	Use Type C film Pre-dry Nomex® (at 121°C [250°F], 30 min)
Glass	296 (565)	10	10	Silane coupling agent**
Kapton® polyimide film	282 (540)	100	5	None, if Type C film is used

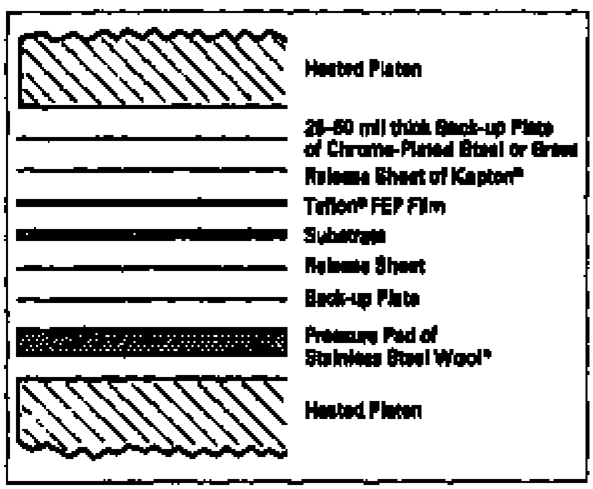
*Treating and phosphating chemicals are available from Oxy Metal Industries, 322 Main St., Morenci, MI 49058.
**Silane coupling agents are available from Union Carbide Corporation and Dow Corning.

Platen Press Laminating

Hot platen press laminating is the most common technique for bonding Teflon® FEP fluorocarbon film to other materials. There are a few fundamental considerations that contribute to good results with this technique. These are:

- Good platen temperature control and distribution (±5.5°C [±10°F] across the laminating area).
- Even pressure distribution across the laminating area. Use a pressure pad (see **Figure 5**).
- Compensating pressure control. (The selected laminating pressure should be maintained regardless of expansion or contraction of the materials being laminated.)
- Use the minimum temperature, time, and pressure combination that produce desired results.
- Cool laminate to at least 204°C (400°F) before releasing pressure. This may be done by quickly transferring laminate to a cold press or quenching it in cold water.

Figure 5. Platen Press Laminating



*Available from the International Steel Wool Corp.

TI-NHTSA 017749

Teflon® FEP Fluorocarbon Film as an Adhesive

Teflon®-FEP fluorocarbon film is thought of usually as a release or antistick material. It is thought of occasionally as an inert thermoplastic from which various parts and shapes of pure Teflon® can be formed. Rarely is it thought of as an adhesive—yet its performance in all three of these areas is equally outstanding. It may be surprising to know that, when melted, Teflon® film actually becomes an excellent adhesive for bonding many materials—metals and nonmetallics as well.

Few adhesives can match the broad capabilities of Teflon® film. Its excellent resistance to both chemicals and high temperatures makes possible bonded structures suitable for service in applications where ordinary adhesives may not be equal to the task. Teflon® film is a flexible adhesive that permits laminated structures to be post-formed. It is the ideal adhesive for Teflon® TFE and produces strong bonds between two surfaces of PTFE or between PTFE and other substrates that can withstand temperatures greater than 332°C (630°F) (above the PTFE melt temperature). Because it is available in film form, on a roll, and in a range of thicknesses from ½–190 mil, Teflon® film is more convenient in handling and storing than many other adhesives.

Adhesive Laminating

Teflon® FEP fluorocarbon film extends the DuPont family of films to those applications requiring high temperature resistance, antisticking surfaces, low coefficient of friction, and resistance to chemical attack. Teflon® FEP film, Type C, has a specially treated surface that permits it to be used with conventional adhesives. Type A film is not as modified, and most adhesives will not adhere to it. However, the Type A film surface may be chemically etched to promote adhesion.

Teflon® FEP film, Type C or etched, can be laminated to many heat-sensitive substrates (elastomers, fabrics, wood, plastics, and papers) using conventional laminating equipment. Irregular shapes can be fabricated using adhesive laminations of Teflon® FEP film and post-forming techniques.

Many materials, by virtue of their adhesive character, may be combined with Teflon® FEP film by casting or molding directly to the etched surface. Included in this category are most epoxy compounds, elastomers, urethane foam, uncured rubber, and some vinyl plastisols.

In most cases, the bond may be enhanced by a pretreatment of the substrate, although in the case of fabrics, wood, and other porous materials, this is unnecessary. The specific type of treatment required varies with the substrate used: thus, while metals may be treated with chemical etches or sandblasting, certain plastics may require only a solvent wash to remove surface contamination or plasticizer.

As mentioned above, Teflon® FEP fluorocarbon film, Type C, manufactured by DuPont is modified with a proprietary surface treatment that allows it to be bonded using most commercial adhesives. Prolonged exposure of this specially treated surface to ultraviolet radiation, moisture, or elevated temperature will adversely affect cementability of the film.

Cementability tests have been carried out on unopened archive sample rolls of treated films. The results of these tests suggest that the adverse effect on cementability can be minimized by keeping the film in its original package or otherwise effectively protecting the film from ultraviolet light. For best results, it is advisable to carry out cementability tests on film prior to its use.

Laminating technique varies with the substrate and adhesive system employed. Most adhesive suppliers are familiar with the condition employed when bonding Teflon® film to various substrates and will have specific recommendations. When contacting adhesive suppliers for specific recommendations for a specific end-use application, it is suggested that the following information be supplied in the initial inquiry:

Process Limitations

- Maximum laminating temperature available.
- Maximum laminating pressure.
- Maximum time, heat, and pressure that can be applied to the laminate (drying tunnel, roll storage).
- Speed of laminator (if continuous process).
- Whether aqueous or organic solvent systems are preferred.
- Type of substrate.
- Type of adhesive applicator (reverse roll, gravure, flexographic).

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End-use Conditions

- Maximum continuous use temperature.
- Maximum intermittent temperature.
- Degree of flexibility or formability needed.
- Bond strength needed (peel or shear).
- Type of atmosphere (chemical, humidity, outdoor).

Metallizing

Teflon® FEP fluorocarbon film makes an excellent substrate for vacuum metallization—by either thermal evaporation or magnetron sputtering. Key properties are:

- Negligible moisture content
- Absence of additives and oligomers to outgas under vacuum and processing temperatures
- Inert to chemical reaction while in the metallizer
- Uniform film web thickness
- Good dimensional stability (low shrinkage)
- Resistance to degradation at metallizer temperature and pressure

As in the case for laminating, the film surface may have to be treated (Type C or sodium etched) to improve surface energy and enhance adhesion of the deposited metal particles. Untreated, general-purpose FEP film may be vacuum metallized for some applications depending upon the specific metal and deposition process used. Copper, aluminum, silver, gold, and some metallic oxides have been applied to Teflon® FEP film through vacuum metallization.

Thermoforming of Teflon® FEP Fluorocarbon Film

Introduction

Teflon® FEP fluorocarbon film is a true thermoplastic material that is readily formable in either vacuum or pressure-forming equipment. Because it is available in thicknesses of ½–190 mil, Teflon® FEP film can be used in a wide variety of applications from surfacing to completely self-supported structures. Its formability combined with its release properties, chemical inertness, and high service temperature make Teflon® FEP film ideal for use in various antistick and corrosion-resistant surfacing applications.

Cementable film (treated or etched) may be adversely affected by thermoforming due to large area increases (stretched) and prolonged heat.

Vacuum Forming

Straight vacuum forming is adequate for most applications using ½-, 1-, 2-, and 5-mil films. It can also be used for thicker films where the mold is not too intricate. Modified vacuum forming techniques such as drape forming, use of a heated plug assist, and snapback forming are applicable. The heating time depends upon the distance of the film from the heaters and the complexity of the shape to be formed. As shown in Table 2, using a heater located 4 in above the film, a 10-sec heating time is optimum for forming 5-mil film in a 7 in × 12 in × 2 in female mold.

A radiant heater having a watt density of at least 3.5 kW/ft² is required to heat the film to the temperature where it can be formed. Most commercial equipment is supplied with heating elements of 1.7–2.5 kW/ft².

Molds for vacuum forming 10- and 20-mil Teflon® FEP film should be heated to 93–149°C (200–300°F) in order to keep the film from cooling before it has been completely formed. In some cases, heated molds are helpful for forming thinner films also.

Table 2
Optimum Conditions for Vacuum Forming

Film Gauge, mil	Heat Density, kW/ft²	Time, sec	Remarks
1	1.9	32	Only with rested heater
1	3.7	8	
2	3.7	10	
5	3.7	12	
10	3.7	20	Thick portion at point of initial contact with mold

Note: The mold used for this first set of data is a vertical cylinder 1½ in high and 3 in diameter. It represents a 200% area increase.

Film Gauge, mil	Heat Density, kW/ft²	Time, sec	Remarks
2	3.7	8	
5	3.7	10	
10	3.7	—	Heated in formed piece throughout time range. Heated mold necessary.
20	3.7	—	

Note: This mold is a pan-shaped cavity 7 in × 12 in × 2 in. It represents an area increase of 90%.

Pressure Formin

Pressure forming involves heating the clamped film with a contact platen mounted over the mold, then evacuating the mold cavity and simultaneously applying air pressure of 20–100 psi or greater to the upper side of the film.

Good conformity and detail are achieved with 1- to 20-mil Teflon® FEP fluorocarbon film in such pressure forming equipment. Optimum platen temperatures range from 246°C (475°F) for 1-mil film to 254°C (490°F) for 5-, 10-, and 20-mil films. Above 257°C (495°F) the film tends to stick to the heater platen. At these temperatures, pressure requirements vary from 60–120 psi depending upon the thickness of the film.

Molds heated to 93–177°C (200–350°F) are required for pressure forming 10- and 20-mil Teflon® FEP film. With 1-, 2-, and 5-mil films, the use of heated molds widens the forming temperature range from ±2.7 to 5.5°C (±5 to 10°F).

As shown in Table 3, a heating time of 10 sec is adequate for 1- to 20-mil film, although shorter heating time can be used with thinner films. The dwell time after forming is not critical, provided it is long enough to cool the film so that it can be removed from the mold without distortion.

Table 3
Optimum Conditions for Pressure Forming

Film Gauge, mil	Temp., °C (°F)	Heat Time, sec	Dwell Time, sec	Pressure, psi	Remarks
1	246 (475)	10	6	60	
2	252 (485)	10	6	60	
5	254 (490)	10	6	60	
10	254 (490)	10	7	80	Holes
20	254 (490)	10	6	100	

Note: The mold for the first set of data is a group of nine 3-in square pouches, 1 in deep. It represents an area increase of about 130% in each pouch. This mold has no heating.

Film Gauge, mil	Heat Temp., °C (°F)	Mold Temp., °C (°F)	Heat Time, sec	Dwell Time, sec	Pressure, psi
5	254 (490)	121 (250)	10	6	60
10	254 (490)	121 (250)	10	6	80
20	254 (490)	149 (300)	10	6	100

Note: The need for a heated mold is proved by the use of a disk shaped mold 4½ in diameter and 1 in deep heated with strap heater. Area increase is 87%.

Summary of Important Points

Thermoformable?

Yes—Teflon® FEP is a true thermoplastic material that is readily formable.

Problems?

The major problem is when someone has difficulty in thermoforming FEP film, most of the time sufficient heat is not available (or if it's available, it's not made available long enough) to bring the film up to forming temperature.

What does it take?

It takes 3–3.5 kW/ft² watt density of radiant heat.

Teflon® FEP film is very transparent to infrared energy and doesn't readily absorb the energy from radiant heaters. Ceramic heating elements have been successful in adequately heating Teflon® FEP film for thermoforming.

The temperature of the heaters is usually above 649°C (1200°F) just to effectively heat the film to 260–288°C (500–550°F).

What does the FEP film do?

If there is sufficient heat intensity, the FEP film first wrinkles, buckles upward (against gravity, thermo-expansion, and relieving of stresses) and then tends to straighten out and finally free downward and continues to sag.

The FEP film will sag considerably and become crystal clear at the point when it should be formed, which is easily seen in 5-mil and above.

Minor wrinkles may occur at the first part of the heating cycle, but should even themselves out during sag.

One test of sufficient heat availability is that if heat is left on the FEP film, it will continue to sag indefinitely until it breaks from thinning out or touches something beneath it.

If it sags to a point and continued heating doesn't cause it to sag further, heat intensity is marginal.

Deep Draws

In deep draws, take advantage of the sag of the film. For instance, if you are forming a dome or cylinder, either form into a female mold or up over a male mold. Forming down over a male mold is more difficult (but not impossible) because you must turn the sag of the film inside-out.

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Detailed Draws

Very good detail in the formed part is possible with Teflon® FEP fluorocarbon film. To do so, the FEP film must be pulled tight against the mold while still hot (crystal clear).

Shrinkage

If the formed shape is stripped from the mold while hot, upon cooling some of the residual shrinkage will be removed. Thus, it will have less chance of fitting the mold again than if it was completely cooled while on the mold.

Webbing

Webbing can take place as the film is formed. It is related to mold design and caused by excess material not having a place to go; so it folds over on itself. This is most common with male molds in deep draws.

By placing a ring around the mold or small shapes at the points of webbing to take up the excess film, this foldover can generally be kept from occurring in the formed shape.

Mold Materials

Metals, Teflon® TFE, and glass are the most frequently used mold materials. Plaster, wood, and lower temperature plastics may be used for several formed parts, if they are masked from the heating cycle, but may char under continued use.

Notes on Thermoforming

As in a molding operation, after cooling to room temperature, there will be shrinkage of the formed piece. The amount of the shrinkage will depend upon its temperature at the time of forming. A shrinkage allowance must be built into the mold. In the case of Teflon® FEP film, the allowance will be 6–8% depending on expected temperatures of the film.

There will also be variable stresses in the piece due to the elongation of the film during the forming operation. These are not usually apparent until an unrestrained piece is exposed to an elevated temperature, at which time stress relieving may distort the piece. This elongation stress can vary in amount in different sections of a formed piece and can also vary with different films used on the same mold. The film temperature/yield stress relationship will also have an effect. They can be "normalized" by using pressure-forming techniques at a temperature above that to which the restrained piece will be exposed.

Excessive thinning of film, at times to the point of rupture, can be experienced when forming in molds with a high ratio of depth to width of draw. A radius on the edges of the mold will help the film accommodate itself to the draw by making it easier to "flow" over a corner. Thickness of original film, its temperature, and rate of draw are also important.

An insulator such as TFE, glass, or wood (vs. a conductor such as metal) may offer some advantages in surface appearance. Many times a metal will give a finish with optical distortion in it, while TFE or wood will give less distortion to the part.

Mold Design

If the formed part has straight sides, try to design the mold so the formed part may be easily removed.

Forming into a female mold may offer advantages in removal vs. the tight fit of a formed shape over a male mold without tapered sides.

Vacuum Holes

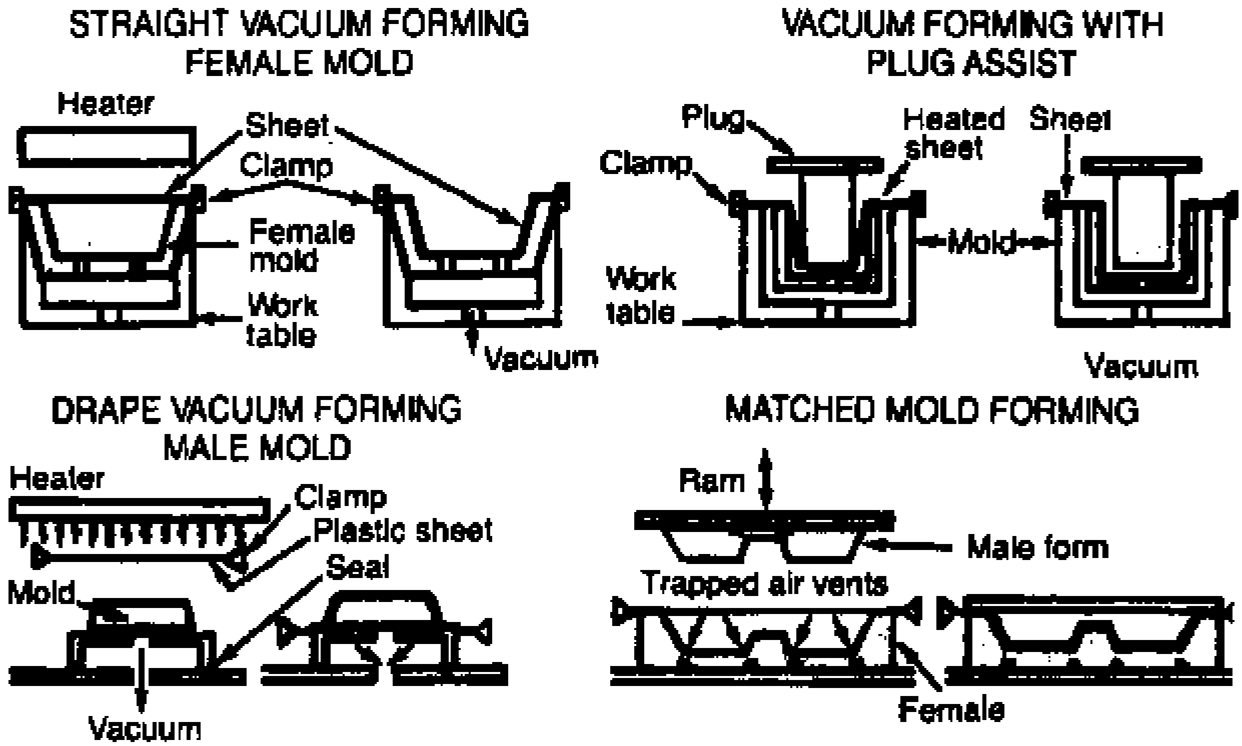
Vacuum holes should be as small as practical: 1/32 in maximum, 1/64 in preferable.

Mold design may allow vacuum to be drawn through slits, a preferable method for gaining detail.

Vacuum holes should be located at strategic spots to pull the film in all crevices. Not every low spot or crevice must have a vacuum hole, but a sufficient number should be located to prevent any bridging of the film between high areas of the mold.

TI-NHTSA 017753

Most Commonly Used Forming Techniques



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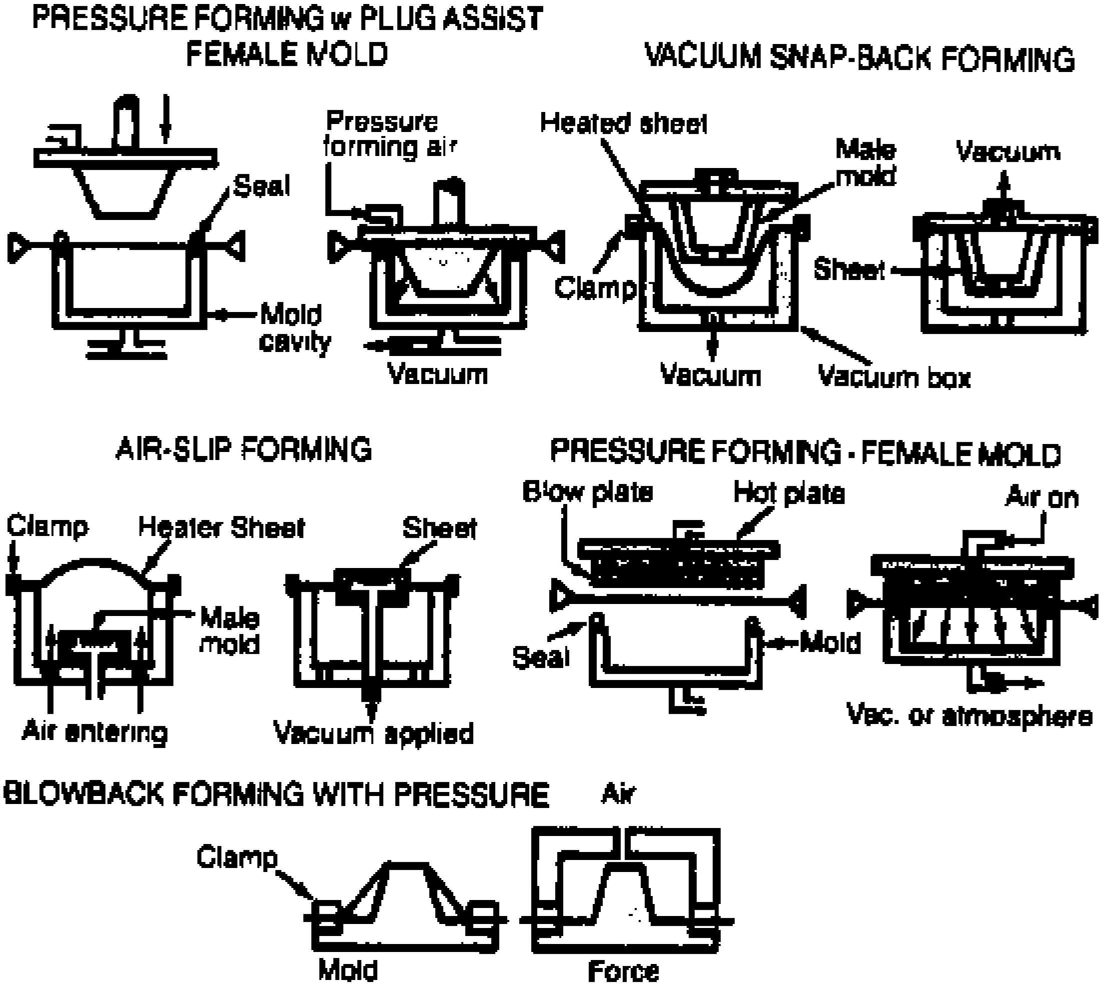

TI-NHTSA 017766

United States
DuPont High Performance Films
P.O. Box 89
Route 23 South and DuPont Road
Circleville, OH 43113
Ordering Information:
800-967-5607
Product Information:
800-237-4357
Fax: 800-879-4481

Canada
DuPont Canada, Inc.
P.O. Box 2200, Streetsville
Mississauga, Ontario, Canada
L5M 2H3
Inquiries: 905-821-5603
Customer Service: 800-263-2742
Fax: 905-821-5230

Latin America
Argentina
DuPont Argentina
Av. Mitre y Calle 5
CP 1884, Berazategui, Argentina
Pcia de Buenos Aires
54-1-256-2435
Fax: 54-1-319-4451

Brazil
DuPont do Brasil
Al. Itapecuru, 506
06454-080, Alphaville
Barueri, Sao Paulo
55-11-421-8689
Fax: 55-11-421-8686

Mexico
DuPont S.A. de C.V.
Homero 206
Col. Chapultepec Morales
Mexico, D.F. 11570
525-722-1184
Fax: 525-722-1370

Venezuela
DuPont Venezuela
Edificio "Los Frailes"
Calle la Guarita
Urbanization Chuao
CP 1060, Caracas, Venezuela
58-2-92-8547
Fax: 58-2-91-5638

Europe
DuPont de Nemours
(Luxembourg) S.A.
Contern
L-2984 Luxembourg
Grand Duchy of Luxembourg
352-3666-5575
Fax: 352-3666-5000

Asia Pacific
Japan
DuPont Kabushiki Kaisha
Arco Tower
8-1, Shimomeguro 1-chome
Meguro-ku, Tokyo 153
Japan
81-3-5434-6139
Fax: 81-3-5434-6193

ASEAN
DuPont Singapore PTE Ltd.
1 Maritime Square
#07-01 World Trade Centre
Singapore 099253
65-279-3434
Fax: 65-279-3456

Hong Kong/China
DuPont China Ltd.
1122 New World Office Bldg.
East Wing
Salisbury Road, Kowloon
Hong Kong
852-2734-5401
Fax: 852-2721-4117

India
DuPont South Asia Ltd.
503-505, Madhava
Bandra Kurla Commercial Complex
Bandra (E)
Bombay 400 051
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91-22-6438255/6438256
Fax: 91-22-6438297

Korea
DuPont Korea Ltd.
4/5th Floor, Asia Tower
#726, Yeoksam-dong, Kangnam-ku
Seoul 135-082, Korea
82-2-222-5398
Fax: 82-2-222-5476

Taiwan
DuPont Taiwan Ltd.
7, Tzu-Chiang 1st Road
Chungli, Taoyuan
Taiwan, ROC
886-3-4549204
Fax: 886-3-4620676

Caution: Do not use in medical applications involving permanent implantation in the human body. For other medical applications, see "DuPont Medical Caution Statement," H-50102.

[illegible] [illegible] Printed in U.S.A.
(Replaces H-[illegible])
Reorder No.: H-[illegible]-1

DuPont Films

DuPont Polymers

MSDS

KAP002 Revised 14-FEB-1994 Printed 7-MAY-1996

"KAPTON" POLYIMIDE FILM, FLUOROCARBON-COATED (EXCLUDING TIO2-FILLED TYPES)

CHEMICAL PRODUCT/COMPANY IDENTIFICATION

Material Identification
Kapton is a registered trademark of DuPont.

Corporate MSDS Number DU005414

Tradenames and Synonyms
"KAPTON" F, FN
"KAPTON" HRN
"KAPTON" HRN616ES
"KAPTON" XP
"KAPTON" ZN
"KAPTON" 1100FC051-5

Company Identification
MANUFACTURER/DISTRIBUTOR
DuPont
"Kapton"/"Teflon" Customer Service
P.O. Box 89
Circleville, OH 43113

PHONE NUMBERS

Product Information	1-800-237-4357
Transport Emergency	1-800-424-9300
Medical Emergency	1-800-441-3637

COMPOSITION/INFORMATION ON INGREDIENTS

Components

Material	CAS Number	%
INERT POLYIMIDE FILM		100
Coated or laminated with:		
POLYFLUOROCARBON	25067-11-2	

(Continued)

compounds can cause severe eye, skin and respiratory tract irritation. Inhalation can cause shortness of breath and other respiratory effects and symptoms may be delayed.

Carcinogenicity Information

None of the components present in this material at concentrations equal to or greater than 0.1% are listed by IARC, NTP, OSHA or ACGIH as a carcinogen.

FIRST AID MEASURES

First Aid

INHALATION

If exposed to fumes from overheating or combustion, move to fresh air. Consult a physician if symptoms persist.

SKIN CONTACT

Wash with soap and water after handling. If skin irritation develops, consult a physician.

EYE CONTACT

Flush eyes with plenty of water. Consult a physician if symptoms persist.

INGESTION

Not a probable route of exposure for films.

FIRE FIGHTING MEASURES

Flammable Properties

Not a fire or explosion hazard.

The flammability characteristic of polyimide film is reported as "self-extinguishing".

"Kapton" chars but does not burn in air. Coated types of "Kapton" will burn in an atmosphere of 96% oxygen when an ignition source is present. Combustion products include carbon monoxide, hydrogen fluoride, carbonyl fluoride and possibly perfluoroisobutylene.

The processing of "Kapton" polyimide films can cause the generation of static charge. Precautions for static charges should also be taken when removing plastic films used as protective packaging for "Kapton".

(Continued)

EXPOSURE CONTROLS/PERSONAL PROTECTION (Continued)

Exposure Guidelines

Applicable Exposure Limits

POLYFLUOROCARBON

PEL (OSHA)	None Established
TLV (ACGIH)	None Established
AEL * (DuPont)	10 mg/m3, 8 Hr. TWA, total dust 5 mg/m3, 8 Hr. TWA, respirable dust

DIMETHYL ACETAMIDE (residual in film)

PEL (OSHA)	10 ppm, 35 mg/m3, 8 Hr. TWA, Skin
TLV (ACGIH)	10 ppm, 36 mg/m3, 8 Hr. TWA, Skin Notice of Intended Changes (1995-1996) A4
AEL * (DuPont)	10 ppm, 8 & 12 Hr. TWA, Skin

POLYIMIDE POLYMER (as nuisance dust)

PEL (OSHA)	None Established
TLV (ACGIH)	None Established
AEL * (DuPont)	10 mg/m3, 8 Hr. TWA, total dust 5 mg/m3, 8 Hr. TWA, respirable dust

* AEL is DuPont's Acceptable Exposure Limit. Where governmentally imposed occupational exposure limits which are lower than the AEL are in effect, such limits shall take precedence.

PHYSICAL AND CHEMICAL PROPERTIES

Physical Data

Melting Point	None
% Volatiles	1% max
Solubility in Water	Insoluble
Odor	No odor
Form	Transparent film
Color	Light amber
Specific Gravity	>1.4

STABILITY AND REACTIVITY

Chemical Stability

Stable at normal temperatures and storage conditions.

Fluorocarbon coatings react with finely divided metal powders and fluorine and related compounds (e.g. chlorine trifluoride).

Decomposition

"Kapton" flurocarbon coatings may degrade at temperatures >350 deg C producing hydrogen fluoride and carbonyl fluorides.

(Continued)

The data in this Material Safety Data Sheet relates only to the specific material designated herein and does not relate to use in combination with any other material or in any process.

Responsibility for MSDS	"Kapton" Customer Service
Address	DuPont Circleville, OH
Telephone	800-237-4357

End of MSDS

508 - 236-3131

TEXAS INSTRUMENT

DuPont Order No. EHNP38218 DuPont Item No. N/A.

Customer Order No. 500142114 Gauge & Type 500MN

Kapton* polyimide shipped on this order is certified to conform to DuPont General Specifications Bulletin GS-88-7. This material is also certified to meet the requirements of Military Specification MIL-P-46112B(MR).

Date 09-30-96

Signed Dail Curtiss

*DuPont registered trademark
:CDC

Edward C. McKenzie
DuPont High Performance Films
U.S. Route 23 & DuPont Road
P.O. Box 89
Circleville, OH 43113
Tel. (614) 474-67[illegible]
Fax (614) 474-[illegible]

DuPont High Performance Films

Date: 10/17/96

To: AL AMORE

AL - ENCLOSED ARE 2 SHEET SAMPLES EA, OF 200HN KAPTON® FILM'S WITH 350Å & 700Å OF TITANIUM SPUTTER METALLIZED ON ONE SIDE.

PLEASE CALL IF QUESTIONS

REGARDS,
ED.

DuPont Circleville

Mr. Alan Amore
Texas Instruments Inc.
34 Forest Street, MS 12-29
Attleboro, MA 02703-0964

November 12, 1996

Dear Al,

Thank you for your continued interest in Dupont products. Enclosed are samples of 1, 2, 3 and 5 mil Kapton* that have been aluminized on one side by Dunmore Corporation. Dupont does not provide metallization services. However, I have enclosed a list of referrals should you need production quantities of metallized Kapton* in the future. Please keep me informed as you evaluate the effectiveness of these samples in reducing the helium permeability through Kapton* films.

If any other questions arise, please do not hesitate to give me a call.

Sincerely,
Khadijah Fladger

Khadijah Fladger
Senior Marketing Rep.

* Registered Trademark of Dupont

Kapton® Metallizers

Acton Technologies-Jim Rusnock
Pittson, PA
717-654-2810

Courtaulds-Skip Cox
Martinsville, VA
703-629-1711

Dunmore Corporation-Terry Carroll
Newtown, PA
215-968-0442

Metallized Products-Jeff Sturges
Winchester, MA
617-729-8300

National Metallizing-Jack Wilson
Cranberry, NJ
609-655-4004

Sheldahl-Terry Shepler
Northfield, MN
507-663-8000

Southwall Technologies-Bob D'Aquisto
Palo Alto, CA
415-962-9115

Teflon

High Performance Films

DuPont FEP

fluorocarbon film

Types A, C, C-20, and L

Introduction

This specification covers FEP fluorocarbon film sold by DuPont Films.

Film types included in this specification meet requirements of fluorocarbon film specified by ASTM D-3368 as follows:

ASTM D-3368	
Type I	FEP Type A
Type II, Grade 1	FEP Type C
Type II, Grade 2	FEP Type C-20
Type III	FEP Type L

Where minimum or maximum tolerances are given, these represent limiting conditions approached by only a small portion of the film. A majority of the film will have properties falling within a range narrower than that specified.

Current product availability is shown in Table 1.

Manufacturing

Material

Copolymer of tetrafluoroethylene and hexafluoropropylene in the form of a film.

Color

The color of the film is uniform and ranges from clear to translucent depending on the thickness.

Defects

The material shall be uniform in appearance and shall be sufficiently free of contamination, wrinkles, holes, scratches, and other imperfections so as to be functionally acceptable.

Cores

Shall be of sufficient strength to prevent collapsing on handling. Sizes 3 in (76.2 mm) or 6 in (152.4 mm) I.D. should be specified on orders.

Order Tolerance

The tolerance for under or overrun on pounds ordered is ±10%.

Splices

Description

Splices for all gauges are butt type and are made with yellow pressure-sensitive tape. One strip is applied to each side of the splice and shall be 2 in (50.8 mm) wide for 200 gauge and above and 1 in (25.4 mm) wide for below 200 gauge.

Frequency

See Table 2.

Thickness and Coverage

The average thickness is determined by measurement of the average weight of the film. The average unit weight will meet the specifications as shown in Table 3, Section A. In addition, no single point will fall outside the minimum and maximum thickness as shown in Table 3, Section B. Point thickness is determined through at least ten measurements across the width of the film in accordance with ASTM D-374 Method A or C.

Width

The maximum variation in film width from that required on the order varies with the gauge and width of film and is shown in Table 4.

General

Packaging

DuPont FEP fluorocarbon film is wound on 3-in (76.2-mm) or 6-in (152.4-mm) cores and is overwrapped in polyethylene. The film is then boxed to prevent loss of contents or damage during shipment. Each container is labeled with DuPont and customer's name, purchase order number, film thickness, type, mill roll number, and shipping date.

A label containing similar information is also affixed to the core for roll widths 2⅛ in (54 mm) and above; for rolls less than 2⅛ in (54 mm) wide, the core label is in the package.

Assurance

Statistical sampling techniques are used to ensure specified properties in the following tables are met.

Table 1
Availability of DuPont FEP Fluorocarbon Film

Type	Gauge 50	100	175	200	300	500	750	1000	1500	2000	3000	4500	6000	7500	9000	12500	18000
A	*	*	*	*	*	*	*	*	—	*	—	—	—	—	—	—	—
C	*	*	*	*	*	*	—	*	—	—	—	—	—	—	—	—	—
C-20	—	—	—	*	—	*	—	—	—	—	—	—	—	—	—	—	—
L	—	—	—	—	—	*	—	*	*	*	*	*	*	*	*	*	*

*Available
Note: Specifications apply to gauges and type available as indicated.

Table 2
Maximum Allowable Splices/Roll

Types: A, C, and C-20

	Put-Up, O.D., in						
	3-in Cores				6-in Cores		
Gauge	6	<7½	7½	9½	<9½	9½	11
50	—	—	—	—	3	4	7
100	2	2	3	4	2	3	4
200	1	1	2	3	1	2	3
300	1	1	2	3	1	2	3
500	1	1	2	3	1	2	3
750	1	1	2	3	1	2	3
1000	—	—	—	—	1	1	3
2000	—	—	—	—	1	1	2

Note: Minimum distance between splices or between a splice and the end or start of a slit roll shall not be less than 100 ft for film under 2000 gauge and 50 ft for 2000 gauge.

Type: L

	Roll, in	
Gauge	3 × 9½	3 × 11
500	3	3
1000	—	3
1500	—	3
2000	—	2
3000	—	2
4500	—	2
6000	—	1
7500	—	1
9000	—	1

Note: Minimum distance between the end of a splice and the end or start of a slit roll shall not be less than 100 ft for 500L, 50 ft for 1000L, 50 ft for 2000L and 3000L, 30 ft for 6000L, and 14 ft for 9000L.

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Table 7
Property Value, Type L

Property	Film Gauge										Method
	500	1000	1500	2000	3000	4500	6000	7500	9000	12500	
Tensile Strength, psi, 25°C	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	ASTM D-882 for ≤10 mil thickness. ASTM D-638 for >10 mil thickness. 2 in/min testing speed.
Elongation, %, Min.	250	250	250	250	250	250	250	250	250	250	Same as above method.
Shrinkage, %, Max. at 200°C											Average of five measurements on room temperature samples before and after each test. Each specimen, 4 in x 4 in freely suspended in an oven controlled to 200°C ±1°C. Exposure time 0.5 hr.
MD	±2	±2	±2	±2	±4	±4	±4	±4	±5	±5	
TD	±2	±2	±2	±2	±4	±4	±4	±4	±5	±5	
Melt Temperature, Melting Endotherm Peak, °C	260–280										ASTM D-3418 (DTA).
Density, g/cm³, 23°C	2.13–2.17										ASTM D-1505.

Table 3
DuPont FEP Fluorocarbon Film Thickness Tolerance

Nominal Gauge	Nominal Thickness, in	A: Average Thickness Unit Weight, g/m²				B: Single Point Thickness*		C: Area Factor, ft²/lb		
		Nom.	Min.	Max.	% Var.	Min.	Max.	Nom.	Min.	Max.
Types: A, C, and C-20										
50	0.0005	27.28	24.55	30.01	±10	0.00035	0.00065	178.97	162.70	196.87
100	0.0010	54.56	49.10	60.02	±10	0.00070	0.00130	89.49	81.35	98.43
175	0.0017	95.48	85.93	105.03	±10	0.00130	0.00220	51.14	46.00	56.25
200	0.0020	109.12	98.20	120.03	±10	0.00150	0.00250	44.74	40.67	49.72
300	0.0030	163.68	147.31	180.05	±10	0.00225	0.00375	29.83	27.11	33.14
500	0.0050	272.80	253.70	291.90	±7	0.00400	0.00600	17.90	16.72	19.25
750	0.0075	409.20	380.55	437.84	±7	0.00622	0.00877	11.93	11.15	12.83
1000	0.0100	545.60	507.40	583.79	±7	0.00850	0.01150	8.95	8.36	9.62
2000	0.0200	1091.20	1014.82	1167.58	±7	0.01700	0.02300	4.47	4.18	4.81
Type: L										
500	0.0050	272.80	245.52	300.08	±10	0.0040	0.0060	17.90	16.27	19.89
1000	0.0010	545.60	491.04	600.16	±10	0.0085	0.0115	8.95	8.13	9.94
1500	0.0015	818.40	736.56	900.24	±10	0.0128	0.0173	5.97	5.42	6.63
2000	0.0200	1091.20	982.08	1200.32	±10	0.0170	0.0230	4.47	4.06	4.97
3000	0.0300	1636.80	1473.12	1800.48	±10	0.0255	0.0345	2.98	2.71	3.31
4500	0.0400	2455.20	2209.68	2700.72	±10	0.0383	0.0518	1.99	1.80	2.20
6000	0.0600	3273.60	2946.24	3600.24	±10	0.0540	0.0660	1.49	1.35	1.66
7500	0.0750	4092.00	368.28	4501.20	±10	0.0638	0.0863	1.19	1.07	1.31
9000	0.0900	4910.40	4419.36	5401.44	±10	0.0810	0.0990	0.99	0.90	1.10
12500	0.125	6820.00	6480.00	7160.00	±10	0.106	0.144	0.72	0.68	0.76
19000	0.190	10366.00	9885.00	10847.00	±10	0.161	0.218	0.47	0.45	0.49

Determined by using lowest and highest thickness readings of ten measurements across the film per ASTM D-374 Method A or C.

Table 4
Roll Width Tolerance, in

Gauge	Web Width, in: 1/2–15/16	1–6	Over 6
50 and 100	±1/16	±1/16	±1/16
200 through 400	±1/16	±1/16	±1/16
500 through 1500	±1/16	±1/32	±1/16
2000	±1/16	±1/16	±1/16
Over 2000	±1/8	±1/8	±1/8

Note: Variation in film width shall not exceed these limits.

Table 5
Property Value, Types A, C, C-20, and L

Property	Film Gauge									Method
	50	100	200	300	500	750	1000	1500	2000	
Dielectric Strength, V/mil, AC	4000	4000	3500	3000	2500	2000	1800	1500	1400	Average of ten samples tested per ASTM D-149 Method A. Flat sheets in air placed between ¼ in diameter brass electrodes with $\frac{1}{32}$ in edge radius and subjected to 60 Hz AC voltage rise at 500 V/sec to the break-down voltage.
Dielectric Constant (at 25°C, 1000 Hz) Max.	2.15									ASTM D-150. Result is average of five tests using measured sample thickness.
Dissipation Factor (at 25°C, 1000 Hz) Max.	0.0003									ASTM D-150, same as above.
Volume Resistivity, ohm-cm at 170°C, Min.	1×10^{17}									ASTM D-257.
Surface Resistivity, ohm (per sq.) at 23°C, 35% RH, Min.	1×10^{15}									ASTM D-257.

Table 6
Property Value, Types A, C, and C-20

Property	Film Gauge								Method
	50	100	200	300	500	750	1000	2000	
Tensile Strength, psi, 25°C, Min.	2000	2500	2500	2500	2500	2500	2500	2500	ASTM D-882 for ≤10 mil thickness. ASTM D-638 for >10 mil thickness. 2 in/min testing speed.
Elongation at Break, %, Min.	175	200	250	250	250	250	250	250	Same as above method.
Shrinkage, %, Max. at 200°C									Average of five measurements on room temperature samples before and after each test. Each specimen, 4 in × 4 in freely suspended in an oven controlled to 200°C ±1°C. Exposure time 0.5 hr.
MD	±5	±5	±3	±2	±2	±2	±2	±2	
TD	±5	±5	±3	±2	±2	±2	±2	±2	
Cementability (Type C film only), Min. peel strength in g/in of width	170	300	750	900	2000	2000	3000	—	Use DuPont adhesive #68040 on Aldine #1200 aluminum sheet (0.019 in thickness). Peel Test at 180° angle at peel rate 12 in/min.
Melt Temperature, Melting Endotherm Peak, °C	260–280								ASTM D-3418 (DTA).
Density, g/cm³, 23°C	2.13–2.17								ASTM D-1505.

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Table 7
Property Value, Type I.

Property	Film Gauge 500	1000	1500	2000	3000	4500	6000	7500	9000	12500	Method
Tensile Strength, psi, 25°C	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	ASTM D-882 for ≤10 mil thickness. ASTM D-638 for >10 mil thickness. 2 in/min testing speed.
Elongation, %, Min.	250	250	250	250	250	250	250	250	250	250	Same as above method.
Shrinkage, %, Max. at 200°C											Average of five measurements on room temperature samples before and after each test. Each specimen, 4 in × 4 in freely suspended in an oven controlled to 200°C ±1°C. Exposure time 0.5 hr.
MD	±2	±2	±2	±2	±4	±4	±4	±4	±5	±5	
TD	±2	±2	±2	±2	±4	±4	±4	±4	±5	±5	
Melt Temperature, Melting Endotherm Peak, °C	260–280										ASTM D-3418 (DTA).
Density, g/cm³, 23°C	2.13–2.17										ASTM D-1505.

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Caution: Do not use in medical applications involving permanent implantation in the human body. For other medical applications, see "DuPont Medical Caution Statement," H-50102.

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(Replaces: H-[illegible]-1)
Reorder No.: H-[illegible]-2

DuPont Films

DUPONT: PFA laminated Kaptons (Data From Ed McKenzie Jan. '97)

Test Properties of Kapton 500 PN 131 v.s. Kapton 500 PA 131:

PN Designates PFA laminated Kapton HN (Solvent Cast onto Heated Drum)
Circleville, Ohio

PA Designates PFA laminated Kapton HA (Same Chemistry, Solvent Cast onto Polished Stainless Steel Belt - Different Curing Process)
Bayport, Texas

Property	Units	500 PN 131	500 PA 131
Elongation	%		
MD		97	98
TD		100	105
Tensile Strength	KPSI		
MD		24.2	19.9
TD		24.3	17.6
Thickness	Mils	4.85	4.85
Dielectric Strength	Volts/Mil	3,763	3,529
Cold Peel	Grams/Inch		
side 1 average		534	381
side 2 average		494	381

Note:

- Kapton FN Cold Peel Specification is Minimum 250 Grams/inch

- Typical FN Cold Peels: 250-350 Grams/Inch

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Table 1 Typical Properties of "Torelina" and Other Films

Table 1 compares the major properties of "Torelina" with other films.

Property	Units	"Torelina" 25µm	Polyimide film 25µm
Crystallinity		Crystalline	Crystalline
Film-making process		Melt extrusion, biaxial orientation	Solution, non-orientation
Density	g/cm^3	1.35	1.42
Mechanical*			
Tensile strength	kg/mm^2	30/25	18/18
Ultimate elongation	%	60/60	70/70
Tensile modulus	kg/mm^2	400/400	300/300
Initial tear-strength	kg	19	17
Tear-strength propagation	g/mm	300	310
Impact strength	kg·cm/mm	600	—
Physical and Thermal			
Melting point	°C	285	None (no melting)
Glass transition temperature	°C	92	None
Thermal expansion coefficient	$°C^{-1}$	30×10^{-6}	20×10^{-6}
Thermal conductivity	cal/cm·sec·°C	3.1×10^{-4}	3.7×10^{-4}
Long-term service temperature (UL 746B)			
Mechanical (approved thickness range)	°C	160 (12µm or thicker)	200 (75µm or thicker)
Electrical (approved thickness range)	°C	200 (12µm or thicker)	240 (75µm or thicker)
Flammability		Self-extinguishing	Self-extinguishing
UL 94 (approved thickness range)		V-0 (25µm or thicker)	V-0 (75µm or thicker)
Chemical			
Moisture absorption	%/75%RH	0.05	2.2
Hygroscopic expansion coefficient	$\%RH^{-1}$	1.5×10^{-6}	22×10^{-6}
Chemical resistance			
Acid		Excellent	Excellent
Base		Excellent	Weak to strong base
Organic solvent		Excellent	Excellent
Electrical			
Dielectric strength (AC)	kV/mm	280	275
Volume resistivity	Ω·cm	5×10^{17}	10^{18}
Dielectric constant			
1 kHz, 25°C		3.0	3.5
1 MHz, 25°C		3.0	3.4
1 GHz, 25°C		3.0	—
Dissipation factor			
1 kHz, 25°C		0.0005	0.003
1 MHz, 25°C		0.0015	0.010
1 GHz, 25°C		0.0015	—

* Lengthwise/widthwise

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Physical and Thermal Properties

This chapter describes some of the basic characteristics of Fortron® PPS and its thermal capability. The thermal properties discussed here, and shown in Table 1, are due to short-term testing. Long-term thermal properties, such as time–temperature effects both without load (heat aging) and with a load (creep modulus), are discussed in Chapter 3.

The reader is encouraged to review sections of this manual that deal with the thermal stability of Fortron® PPS products, as well as sections that show how dimensional accuracy depends on thermal changes. Finally, a general review of Chapter 4 of *Designing with Plastic: The Fundamentals* (TDM-1) may help the designer deal with the thermal requirements of an application.

Table 1 Thermal and physical properties of Fortron® PPS

Property	Units	40% Glass	65% Mineral/ Glass	Unfilled
Specific Gravity		1.64	[illegible]	1.35
Melt Specific Heat	J/g°C	[illegible]	1.0	[illegible]
Glass Transition Temperature	°C	[illegible]	[illegible]	[illegible]
Crystallization Temperature (Peak)	°C	[illegible]	125	[illegible]
Melt Recrystallization Temperature (Peak)	°C	[illegible]	[illegible]	[illegible]*
Melt Temperature	°C	[illegible]	[illegible]	[illegible]
Heat Deflection Temperature, @ 264 psi	°C	[illegible]+	[illegible]+	[illegible]
Thermal Conductivity	W/m°K			
@ 35°C		[illegible]	[illegible]	
@ 125°C		[illegible]	[illegible]	
@ 220°C		[illegible]	[illegible]	
@ 300°C		[illegible]	[illegible]	[illegible]

* Please note that this range represents the values for a number of different polymers, not a range for one polymer.

Crystallinity

Fortron® PPS is a semicrystalline polymer that consists of both amorphous and crystalline regions. The crystalline regions of neat Fortron® PPS account for 60–65% of the polymer. With the combination of a high degree of crystallinity and its aromatic structure, Fortron® PPS exhibits a high melt temperature of 285°C (545°F). The polymer crystallizes rapidly above the T_g, as indicated by an exothermic crystallization peak at 120–130°C, as seen in Table 1. From the melt, recrystallization also occurs rapidly at 215–220°C, also seen in Table 1.

Glass Transition Temperature (T_g)

The glass transition temperature, T_g, is the temperature at which the amorphous regions of the polymer become mobile. The significance of this value is that above T_g (about 90°C for Fortron® PPS products), the load-bearing capability is reduced. This is illustrated by the results from a dynamic mechanical thermal analysis (DMTA), a powerful technique used to indicate the stiffness of a molded part as a function of temperature and load. Results from the DMTA cover a range of loads and temperatures.

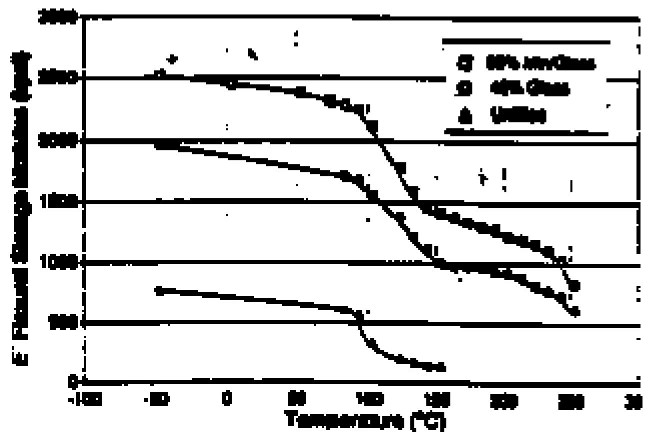


Figure 1 Flexural storage modulus vs. temperature for Fortron® PPS

The flexural storage modulus (E') is one such curve generated by a DMTA for evaluating the load-bearing capability of a material. Figure 1 illustrates the change in stiffness of Fortron® PPS at temperatures both below and above the T_g.

Thermal Degradation via Thermogravimetric Analysis (TGA)

Thermogravimetric analysis is a technique used to evaluate a material's thermal stability. In this test the material is heated until it is melted completely and finally degraded. During the heating process, the weight of the sample is measured at various exposure temperatures. The curve seen in Figure 2 shows that thermal oxidation of 40% glass-reinforced Fortron® PPS occurs well after the melt temperature.

1. Mechanical Properties

1-1 Tensile Properties

Table M1 shows the tensile properties of "Torelina" in comparison with other films. "Torelina's" figures for tensile strength and tensile modulus are comparable with those of biaxially-oriented polyester film and are among the highest of all types of films. Its ultimate elongation is in the mid degree.

Table M1 Tensile Properties of Various Films (25μm thick, lengthwise)

	Tensile strength (MPa)	Ultimate elongation (%)	Tensile modulus (MPa)
"Torelina" (Biaxially oriented)	300	60	4,000
Polyester (Biaxially oriented)	250	130	4,000
Polypropylene (Biaxially oriented)	190	170	2,000
Polycarbonate (Uniaxially oriented)	100	150	1,100
Polyvinylidene fluoride (Biaxially oriented)	170	170	1,400
Polyimide (Non-oriented)	180	70	3,000
Polyether-imide (Non-oriented)	110	100	3,000
Polysulfone (Non-oriented)	80	200	2,400

Fig. M1 shows variations of "Torelina's" stress-strain (S-S) curve by temperature.

Fig. M1 Variations of S-S Curve by Temperature

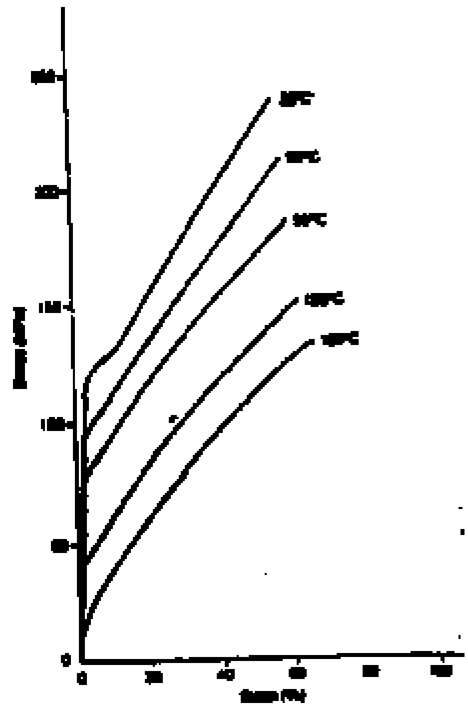


Fig. M2 displays the temperature dependence of tensile strength in "Torelina."

Fig. M2 Tensile Strength vs. Temperature

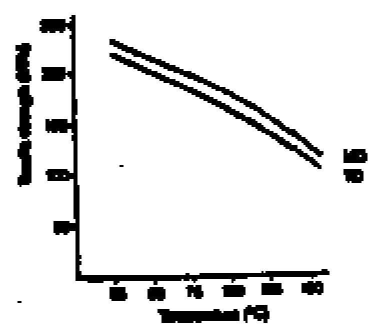
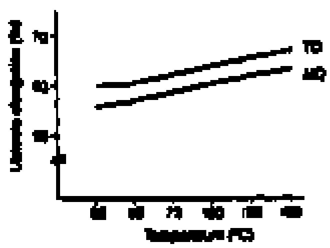


Fig. M3 shows the temperature dependence of "Torelina's" ultimate elongation. At 150°C, "Torelina" has a tensile strength nearly 50% of its tensile strength at room temperature, with its ultimate elongation virtually unchanged over temperature variations.

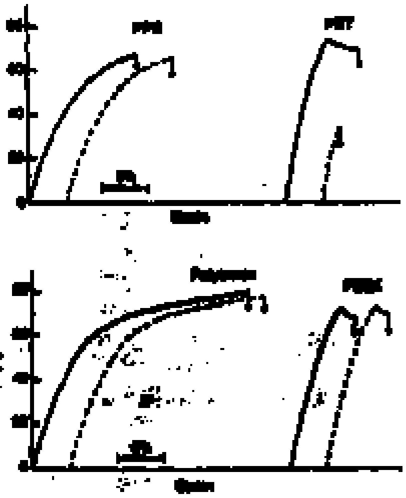
Fig. M3 Ultimate Elongation vs. Temperature



1-2 Tensile Properties at Low Temperatures

Fig. M4 shows the comparison of the stress-strain (S-S) curve of "Torelina" with those of other films at 77K (−196°C). "Torelina" boasts superior strength and flexibility even at low temperatures, thus proving ideal for insulation of equipment exposed to low temperatures.

Fig. M4 S-S Curves of Various Films at 77K



——— : Unirradiated

- - - - : Measured after being irradiated by a reactor (reactor irradiation by a γ-ray dose of 7.8MGy and fast neutron fluence of 4.4×10^{24} n/m²)

(Data courtesy of Yamada and Miyata, Journal of Nuclear Materials 133 & 134 (1985), Fig. 1)

1-3 Tensile Modulus

Fig. M5 shows the temperature dependence of "Torelina's" dynamic tensile modulus measured at 110Hz using a VIBRON.

Fig. M5 Dynamic Tensile Modulus vs. Temperature

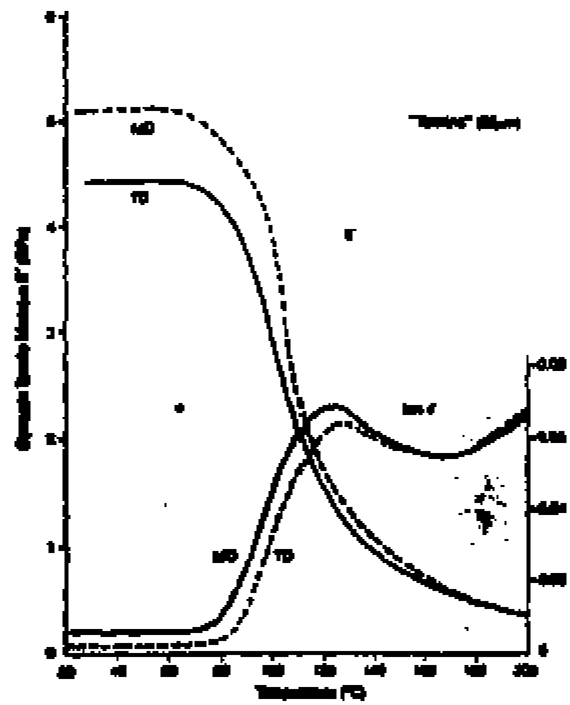


Fig. M6 compares the creep characteristics of "Torelina" with polyester films. In comparison with other films, "Torelina" exhibits a lower dimensional change even after being subject to stress for long periods of time.

Fig. M6 Creep Characteristics of "Torelina"

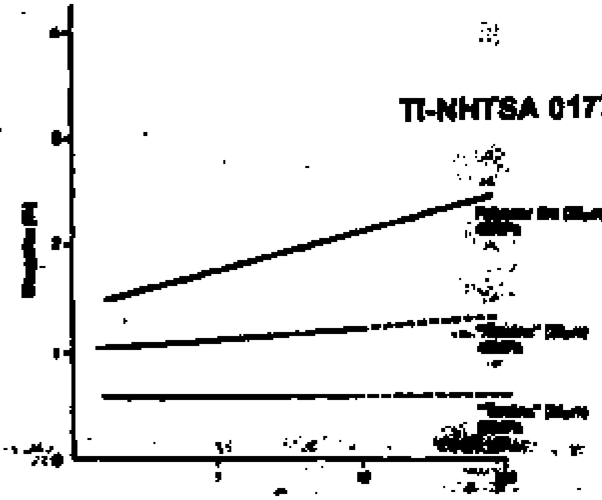
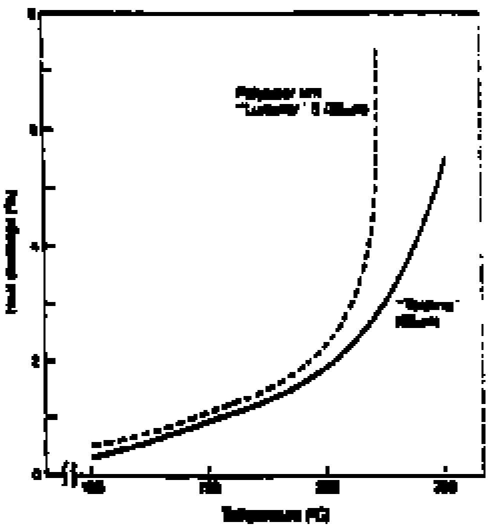


Fig. P2 Heat Shrinkage vs. Heating Temperature (Film Lengthwise)



2-3 Dimensional Stability

Fig. P3 shows "Toraline's" dimensional change by humidity (hygroscopic expansion) and Fig. P4 illustrates its dimensional change by temperature (thermal expansion). The hygroscopic expansion coefficient of "Toraline" is nearly 1/6th of polyester film, one of the lowest among all films. On the other hand, its thermal expansion coefficient is approximately 50% higher than that of polyester film.

Fig. P3 Hygroscopic Expansion of "Toraline" and Polyester Film

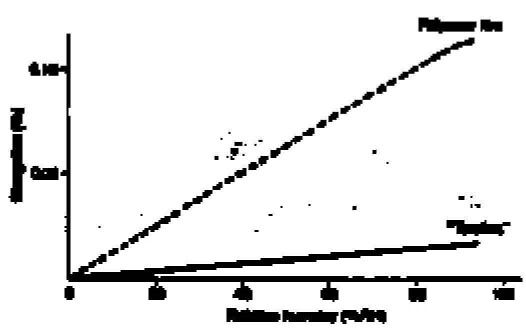
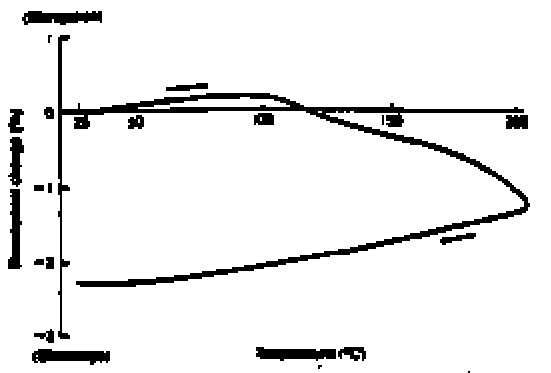


Fig. P4 Dimensional Change of "Toraline" with Heating (Film Lengthwise)



2-4 Stress Crack Resistance

Non-oriented films made of noncrystalline (amorphous) polymer such as polyether-imide film may generate stress cracks on the film surface if subjected to bending or wrapping stress and also exposed to heat. This is true even during short periods of time and at relatively low temperatures.

As a biaxially-oriented highly crystalline polymer film, "Toraline" totally eliminates this problem, as shown in Table P2.

Table P2 Stress Crack Characteristics of "Toraline"

1. Testing method:
   (1) Specimens
   "Toraline" (75µm thick)
   Polyether-imide film (75µm thick)
   (2) Testing conditions
   A 10mm-wide specimen wound onto a 5mm-diameter steel rod with 25% overlapped is aged under the following conditions, and then their mechanical properties and dielectric strength are measured.
   Aging conditions: One cycle represents heating at 180°C for 1 hour and then cooling to room temperature.
2. Test results

Aging cycle	"Toraline" Mechanical properties: Strength (kg/mm²)	"Toraline" Mechanical properties: Elongation (%)	"Toraline" Dielectric breakdown voltage (kV, AC)	Polyether-imide film Mechanical properties: Strength (kg/mm²)	Polyether-imide film Mechanical properties: Elongation (%)	Polyether-imide film Dielectric breakdown voltage (kV, AC)
Initial values	28	65	12.5	11	[illegible]	12.0
1	24	61	—	0	0	—
2	24	60	—	0	0	—
3	22	60	12.0	0	0	1.2

TI-NHTSA 017779

Warpage

Anisotropic effects on dimensions (warping) can be caused by a number of factors, including the following:

- Mold temperature.
- Nonuniform part thickness.
- Nonuniform cooling.
- Filler type/level.
- Orientation of filler.
- Location of dimensions with respect to the gate.
- Molded-in stresses.
- Gate size.

To describe the effects of anisotropy in geometrically complex parts, a sample part containing a variety of shapes was designed. Figure 2.7 shows the specifications for this warpage sample. Figure 2.8 shows the measured points used to obtain the data shown in Figures 2.9 - 2.12, which compare the largest dimensional differences of 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS products with respect to flatness (Figure 2.9), roundness of a cylinder (Figure 2.10), roundness of a hole (Figure 2.11), and bowing angle (Figure 2.12).

From these figures it can be seen that 65% mineral/glass-reinforced Fortron® PPS has the least warpage, due to the fact that this material uses less glass than the 40% glass-reinforced material, and that mineral filler has a smaller aspect ratio than glass fibers.

Annealing

When processed at a mold temperature of 275°F(130°C) or greater, parts molded of Fortron® PPS are able to fully crystallize, and therefore, show very little continued shrinkage when exposed to temperatures as high as 450°F (232°C) for 24 hr. A study of the effects of annealing Fortron® PPS products showed the following additional shrinkage values for the flow direction, using 1/8-in. thick samples:

40% Glass-Reinforced:

- 0.0009 in./in. after 2 hr. annealing.
- 0.001 in./in. after 24 hr. annealing.

65% Mineral/Glass-Reinforced:

- 0.001 in./in. after 2 hr. annealing.
- 0.0012 in./in. after 24 hr. annealing.

Thus, there is very little advantage in annealing a sample molded at or above 275°F (130°C) for more than 2 hr. to obtain further shrinkage.

Fortron® PPS can be molded at lower mold temperatures at the expense of reduced thermal/load properties, i.e., heat distortion temperature. Annealing parts that have been molded at lower temperatures less than 275°F (130°C) will increase the load-bearing capabilities of those parts, but such practice may cause warpage; thus, strict care (e.g., fixturing the part) should be taken with parts requiring critical tolerances.

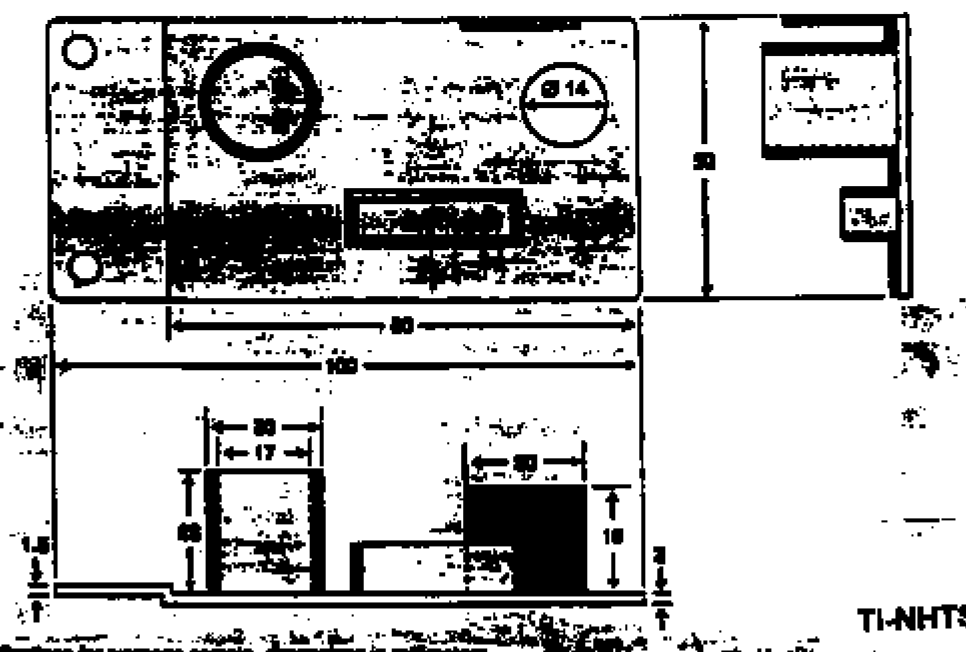


Figure 2.7 Specifications for warpage sample, dimensions in millimeters

TI-NHTSA 017780

In addition to gasoline and other fuel oils, "Toreline" also features a superb durability against gasohol, the gasoline-alcohol mixture which is now receiving attention as a substitute for gasoline. (See Table C2.)

Table C2 Gasohol Resistance of "Toreline"

Gasohol	"Toreline" 100μm		Polyester film "Lumirror" S10 100μm	
	Tensile strength retained (%)	Ultimate elongation retained (%)	Tensile strength retained (%)	Ultimate elongation retained (%)
FUEL-C isooctane (50%)/toluene (50%)	87	80	95	90
FUEL-C (90%)/methanol (10%)	80	76	96	78
FUEL-C (80%)/ethanol (20%)	82	75	90	65
FUEL-C/lauryl peroxide (2.5%)	81	70	91	66
FUEL-C/triethanolamine (2.5%)/dioctyl phthalate (2.5%)	81	75	68	35

Testing conditions: 60°C, 500 hours

As shown in Table C3, "Toreline" has a high resistance to Freon, the substance used as a refrigerant in air conditioners, etc., and the amount of extract is very small.

Table C3 Freon Resistance of "Toreline"

1. Testing conditions
   (1) "Toreline": 125μm
   (2) Freon: R-22 (120ml)
   (3) Temperature: 170°C (vapor phase)
   (4) Pressure: 16 ~ 20kg/cm²

2. Test results

Film	Property	After 400 hr.	After 1000 hr.
"Toreline" (125μm)	Strength retained (%)	88	84
	Elongation retained (%)	86	80
Polyester film (250μm)	Strength retained (%)	27	Unmeasurable
	Elongation retained (%)	Below 5	Unmeasurable

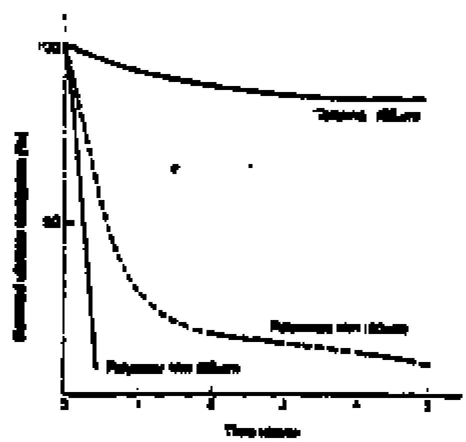
Note: Percentage of tensile strength and elongation retained
Percentage retained (%) = Value after aging/initial value × 100

3-2 Hydrolysis Resistance

PPS is a polymer which shows virtually no hydrolysis. Accordingly, "Toreline" features outstanding resistance to hydrolysis.

Fig. C1 shows the decrease of ultimate elongation of various thin films when placed in saturated water vapor at 155°C. In absolutely dry conditions polyimide film boasts better thermal resistance than "Toreline." In water vapor, however, it deteriorates much more rapidly.

Fig. C1 Hydrolysis Resistance of Various Films (Decrease of ultimate elongation in saturated water vapor at 155°C)



Gas Permeability and Moisture Absorption

Gas:	PI (Kapton HN)	PPS	Units
Helium	63,080	6,434 *	ml/m2 * 24 h * Mpa/0.1mm
Oxygen	3,800	503 *	
Nitrogen	910	81 *	
Carbon Dioxide	6,840	2,299 *	
Hydrogen	38,000	N/A	

Moisture Absorption:	PI (Kapton HN)	PPS
50% RH	1.8%	
75% RH	2.2%*	0.05%*
100% RH	2.8%	

* Toray Torelina Data

Table 1 Chemical resistance of 40% glass-reinforced Fortron® PPS

Reagent (Conc.*)	Temp. (°C)	Time (days)	Tens. Elong.	Tens. Str.	Weight	Length	Thick-ness
Acids:							
Hydrochloric Acid (10%)	23	40	A	A	A		
Hydrochloric Acid (10%)	80	42	—	C	C	A	—
Nitric Acid (10%)	23	40	A	A	A	—	—
Sulfuric Acid (10%)	23	40	A	A	A	—	—
Sulfuric Acid (30%)	60	90	A	A	—	—	—
Alcohols:							
1-Butanol	80	180	A	A	—	—	—
Ethanol (5%)	80	180	A	A	C	A	C
Methanol	60	180	B	A	A	A	B
Methanol (80%)	55	180	A	A	A	A	A
Methanol (15%)	65	180	A	A	A	A	A
Ethylene Glycol (Antifreeze)	120	180	B	A	A	A	A
Bases:							
Sodium Hydroxide (10%)	23	40	A	A	A	A	B
Sodium Hydroxide (30%)	80	180	A	A	* —	—	—
Hydrocarbons:							
Brake Fluid	80	42	—	A	A	A	A
Diesel Fuel	80	180	A	A	A	A	A
95% Fuel A/5% Ethanol	80	180	A	A	C	A	C
85% Fuel B/15% Methanol	65	180	A	A	A	A	A
40% Fuel C/60% Methanol	55	180	A	A	A	A	A
Gasoline (Regular)	80	125	A	A	—	—	—
Gear Oil (75W-90)	150	142	A	A	A	A	—
Kerosene	40	40	A	A	A	—	—
Lubricating Oil	60	40	A	A	A	—	—
Mineral Oil (Sat.)	120	30	A	A	A	—	—
Motor Oil	80	42	—	A	A	A	A
Refrigeration Oil	100	60	—	—	A	—	—
Toluene	60	30	—	B	—	—	—
Transmission Fluid	150	42	A	A	A	—	—
Xylene	80	180	B	A	B	A	C
Inorganics:							
Calcium Chloride (Sat.)	80	42	—	A	A	A	A
Potassium Chromate (30%)	80	42	A	A	—	—	—
Zinc Chloride (Sat.)	80	42	—	A	A	A	A
Sodium Hypochlorite (5%)	80	30	B	B	—	—	—
Deionized Water	23	180	A	A	—	—	—
Deionized Water	100	180	C	C	A	A	A

TI-NHTSA 017783

What's New

Thermal insulation and radiant heat shielding in one

Bisco Products, a subsidiary of Dow Corning, introduces its RF-120 composite, a material that integrates a reflective, aluminized scrim substrate with a layer of high-temperature silicone foam. The composite, which offers both radiant heat shielding and insulation from a single component, already has been designed into automotive and military applications. One military vehicle manufacturer uses RF-120 to line a vehicle's firewall to protect the air conditioning lines from an exhaust system that had previously rendered the A/C ineffective.

Bisco's multi-purpose composite.

What's Info No. 2[illegible]

HDPE liners replace paper in adhesive transfer films

Coating Sciences Inc. introduces a new line of high-performance adhesive transfer films that are self wound on HDPE liners. Ultrafilm provides improved processing efficiency during diecutting and end-use assembly; improved matrix separation, which eliminates tearing upon removal of the liner; and elimination of the dust associated with paper liners. Typical applications include sound attenuation and vibration dampening.

What's Info No. 201

Itan converts motor-end laminates to nylon

In a recent application for United Technologies Motor Systems, Itan Industries has chosen to use injection molded Stanyl TW341 for end laminates. Itan chose Stanyl due to its high temperature resistance (short-term temp. performance to over 200°C, U.L. electrical temp. index of 150°C) and flexibility for installation. The laminates will be used in both small-frame and large-frame motors in place of vulcanized fiber or an epoxy dip process.

What's Info No. 202

Pilot launches new line of fuel-line quick connectors

Pilot Industries announces the development of five new fuel-line quick connectors made of Phillips Chemical Co.'s Ryton polyphenylene sulfide (PPS) instead of the nylon, stainless steel or plated carbon steel typically used. Costing about the same as nylon, PPS is superior due to its electrical conductivity, addressing concerns about electrostatic discharge, says Pilot. The Dexter, MI, company says the connectors, which link the fuel lines to the engine and to the fuel pump, will be available for use by the Big Three by late 1996.

What's Info No. 204

[illegible]

Acura selects Crystal Clad for 1997 interior accents

Acura chooses Crystal Clad interior laminates from Avery Dennison to accent the instrument panel and doors in its 1997 CL Coupe. The laminates offer a luxurious "water clear" high-gloss surface and a Florentine burl wood-grain pattern. Through the use of the gravure printing process, Avery is able to produce a more consistent reproduction than with lithography or "dip" process, says the company. The top coat is applied to a dimensionally stable, very clear polyester film, and the burl design is reverse-printed on the back. The film then is laminated to a thermoplastic backing to be thermoformed.

What's Info No. 2[illegible]

Delphi replaces steel with linear PPS in brakes

Delphi achieves a seven-fold weight reduction by replacing cold-rolled steel air valves in its braking systems with plastic, the first load-bearing application for plastic in a brake system. Molded from Hoechst Technical Polymers' Fortron linear polyphenylene sulfide (PPS), the parts carry a 15,900 psi compressive load from -40° to +250°F and withstand the harshness of braking fluid. Compared to the 132g weight of the steel part, the PPS component weighs only 18g and matches the original part in price despite being made from a higher-cost material.

What's Info No. 2[illegible]

High plunge CV joint reduces noise for Jeep

GKN of Auburn Hills, MI, introduces a newly designed constant velocity (CV) joint with the highest plunging capability ever, on current model year Jeep Cherokees. The CV joint provides 48 mm plunge capability compared to the conventional 22 to 25 mm, and noise is reduced because the driven shaft is given a constant speed rather than the pulsating, variable speed of the single- and double-cardan joints they replace. Weight is also reduced by eliminating the splines required by cardan joints, because they don't plunge.

What's Info No. 207

HP offers transient-mode engine test solution

Hewlett-Packard Co. introduces a closed-loop control card for VXI systems that enables auto manufacturers to do transient testing and to produce performance curves that show how an engine runs at a variety of torque loads and rpm. The HP E1415A card handles loop control independent of the test system computer; traditional systems require the system computer to control multiple closed loops and acquire many channels of data. It can handle a single loop at rates up to 2.5 K per loop and up to 32 loops at slower rates.

What's Info No.

New CBN abrasives cut power consumption

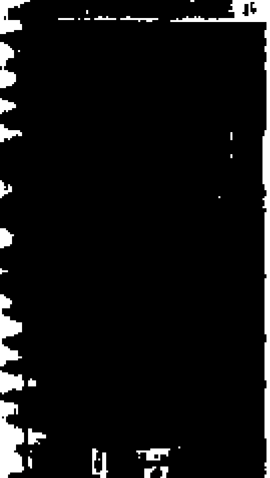
GE Superabrasives announces development of an entirely new form of monocrystalline cubic boron nitride (CBN) superabrasive characterized by higher strength, smoother faces and sharper, more durable cutting edges than previous CBN crystals. Targeted at grinding applications in aerospace, automotive and other industries, Borazon CBN 400 series provides longer wheel life at lower power consumption, higher grinding efficiency and material removal and shorter cycle times. This results in lower cost-per-part.

What's Info No.

[illegible]-amp automotive lamp switching relay

[illegible] Zettler Inc. introduces the new AZ972 and AZ97[illegible] [illegible] automotive lamp switching relays designed to accommodate the high momentary current of up to 80 amps associated with [illegible] VDC lamps. The relays feature quick-connect terminals and Class F insulation. The low [illegible] lamp relays have a life of [illegible] of 100,000 operations [illegible]-rated load.

What's Info No. [illegible]



[illegible]ays for 12 VDC lamp[illegible]

TI-NHTSA 017784

TEXAS INSTRUMENTS INC. | MATERIALS & CONTROLS GROUP | PREC SITE

PARTS LIST | PROJECT | PART NUMBER: 92PSL2-1 | REV LTR: B CLS: 490
EXPLOSION | NUM: 3520 | DWG PFX: NUM:92PSL2-1 | ECN INC.DT: 97/02/03

TITLE: PRESSURE SWITCH (HYDRAULIC-POWER STEERING)

LV	CNT	QTY/UM	BITM	PART/DRAWING NUMBER	RV	NOMENCLATURE/PARM DATA
01	1	REF		37486-1		FINAL ASSEMBLY
				37486-1		
01	2	1	3	37485-1		CRIMP ASM
				37485SH1		
02	3	1	2	37484-1		SWITCH ASM
				37484SH1		
03	4	1	2	37441-1		HEX BODY (BRASS)
				37441		
03	5	1	3	28733-1		GASKET (VITON)
				28733		
05	6	1	4	28814-1		DIAPHRAGM
				28814		
04	7	AR	2	27225-3		KAPTON STRIP SPEC (.170 LBS/K)
				27225		

03	8	1	5	28714-2		WASHER
				28714		
03	9	1	6	28792-1		DISC SEAT
				28792		
05	10	1	7	28780-1		CONVERTER
				28780		
05	11	1	8	37525-1		DISC (PRESSURE SET)
				37525SH2		
03	12	1	9	46652-1		BASE (FORTRON-BLACK)
				46652		
01	13	1	4	75725-1		O RING (EXTERNAL)
				75725		
01	14	AR	6	76096-1		SILICONE SEAL (.235 LBS/K)
				76096		

| NOTES, REV.DATA,DISTRIBUTION,OPERATING CHARACTERISTICS,SPECIAL REQUIREMENTS |

REV DESC: CHG DISC P/N,SET UP DISC DWG | CCB APPROVAL DATE: 97/01/29

DFTG WORK GROUP: PRECISION CONTROLS | ECN ORIGINATOR: STANLEY Q HOWAL

NOTES:
1 - FF ACTUATION PRESSURE----------- 350 - 450 PSIG AT 18 - 28 DEGREES C

TI-NHTSA 017785

DuPont High Performance Films
U.S. Route 23 & DuPont Road
P.O. Box 89
Circleville, OH 43113
Tel (614) 474-0721
Fax 614 474-0680

DuPont Films

May 1, 1997

Dear Valued Customer:

For more than 30 years, we have had a clear vision for our polyimide businesses: technology leadership, industry leadership, and sustainable business health. Our focus in these areas has remained unchanged, and has served as a foundation for unprecedented growth in recent years to the industries we serve. Over the last decade, our industry leadership and technology leadership have been driven through extensive process, product and market research and development. Sustainable business health has resulted from cost stewardship, improving manufacturing efficiencies and investing in technology and capacity enhancements.

While aggressive cost stewardship strategies have allowed us to maintain relative price stability since the early 1990's, raw material price increases, the need to underwrite new capacity through investments totaling more than $175 million, and inflationary pressures have caused ongoing strategies for sustainable business health to be inadequate.

As a result, effective June 1, 1997, prices for Kapton) polyimide films will be increased globally five percent. Further details will be available through your Marketing or Customer Service Representative. As we stated in our customer satisfaction survey brochure, a number of initiatives have helped fuel an already vigorous demand for Kapton). We believe the investment made possible with this increase will enable us to continue to expand our manufacturing and technological capabilities to meet this demand, thereby protecting the health and flexibility of both of our businesses.

We greatly value your business and our relationship with you. We believe this price increase will help us continue creating the technology and value-added products that strengthen the health and longevity of our respective organizations. We look forward to sustaining our mutually profitable growth opportunities well into the next century.

Sincerely,

F. Tim Reese

F. Tim Reese
Worldwide Business Director/Plant Manager
High Performance Films

ROUTE TO______

TEXAS INSTRUMENTS
ATTLEBORO, MASSACHUSETTS 02703

REPORT OF DISCREPANT IN-PROCESS MATERIAL

No. 031089

[redacted] | REV. | INSPECTOR 809589 | DATE 9/5/97 | Mfg. Supervision Review:

SOURCE Dupont | DEVICE | PROD. CODE 60 | QUANTITY 3 rolls

ITEM	ATTRIBUTE/REQUIREMENT	ACTUAL (1148)	#INSP	AC	RE	#DEF
	~~core out of rou~~					
	center round	core out of round	3	0	3	3
	no wrinkles	Kapton wrinkled	3	0	3	3

SAMPLES MUST BE RETAINED FOR DISPUTES

MAT'L/PROD. CONTROL

☐ CHECK INVENTORY AT (LOCATION)
☐ PARTS/MATERIAL IN SHORT SUPPLY

HOLD AT / REJECT

PRIORITY ☐1 ☐2 ☒3

COMMENTS:

PLANNER: SIGNATURE DATE

MRB ENGINEERING DISPOSITION

☒ RETURN TO SUPPLIER
☐ REWORK AT TI
☐ SORT AT TI
☐ SCRAP
☐ DEVIATE (J A B)

COMMENTS:

NOTE — IF DISP. OTHER THAN RTS - MRB CORRECTIVE ACTION MUST BE COMPLETED

MRB SIGNATURES		DATE
PURCHASING	[signature]	9/16/97
MFG ENG	[signature]	9/...
QRA ENG	[signature]	9/...
MS MGR		
DE MGR		
QRA MGR		

REWORK PROCEDURE: (MFG./ENG.)

PO 50083039
Supplier 171011
Buyer 5070

Pcode 060
Def Code 2E
MH811623

ESTIMATED TIME______

REWORK COMPLETE ON / BY / ACTUAL STD. HOURS / GOOD PCS. REMAINING

INSPECTION AFTER REWORK | #INSP | AC | RE | #DEF | INSPECTOR | DATE | QRA ENG. (Signature required if AC)

MRB CORRECTIVE ACTION

TI
— CHANGE DRAWING/SPEC (DRAWING MUST BE ATTACHED) ☐
— USE ENCLOSED SAMPLES AS ACCEPTABLE VISUAL STANDARDS ☐
— OTHER (EXPLAIN) ☐

SUPPLIER
— PROVIDE CORRECTIVE ACTION WITH FORMAL RESPONSE ☒
— SUBMIT INSPECTION DATA WITH FUTURE SHIPMENTS ☐
— CONDUCT CAPABILITY STUDY AND SUBMIT TO ENGINEERING ☐
— OTHER (EXPLAIN) ☐

COMMENTS:

RECEIVING INSPECTION

RI SEQUENCE NO.	DISP. CODE	AREA	LOCATION
9598	RTS	M	B-16

REJECT VALIDATION INITIAL DO DATE 9-22-97

SUPPLIER NOTIFIED INITIAL DATE

ACTION TAKEN TO PREVENT RECURRENCE:

PROCUREMENT ASSURANCE

DO NOT WRITE BELOW THIS LINE

☐ FOR INFO ONLY - SUPPLIER
☒ EXTERNAL C.A.R.
☐ FOR INFO ONLY - INTERNAL
☐ INTERNAL C.A.R.

[signature] SIGNATURE DATE

9/25

FORM

TI-NHTSA 017787

- Heat staking used just to keep layers together for assembly

Visit on Thurs (Ed Metenzie) 9:00 AM
10/3/97 B12

Tackiness of Teflon surfaces varies with handling - abrasion, cleanliness, heat may degrade
→ can tell from surface activity
(beading vs wetting of std fluid (dyne level) (dyne pens))

Dupont tests

Teflon / Teflon
Teflon to other Kapton (top layer)
Teflon to Kapton
Teflon to Copper

→ Mechanical changes to Kapton with heat
Sensitive to U.V. or moisture ?

→ ultrasonic / friction weld of teflon surfaces

X → Call John Brennan on Kapton
Fatigue strength after exposure to heat

3/97

Ewart] McKenzie — E. Lee, Stan Howe, Steve Price, John Wasp, John Haynes

Dupont Circleville, OH (614) 474-0730

tel con .0005 - Teflon
.0015 Kapton ∴ .0025 thick
.0005 - Teflon

delamination problem @ Teflon / Kapton interface

- Impact of Heat Staking

→ Teflon - 560 - 580°F melt pt
Teflon to Teflon joining good at these temps

Temp cycling ~ 135°C / 150°C std spec testing

Heat Staking Temp

- Kapton → additional heat improves bond strength
Teflon — No pressure / 250°C / Time

"C" Surface — increases bonding of Teflon / Tegion layer

Corona treat

Lot to lot variation occurs in Dupont process

Teflon on one side - Not a standard product → $

Teflon FEP used now

→ see bulletin

Can use PFA for higher strength, but more $

TI-NHTSA 017790

From:	Amatruda, Andy
Sent:	Thursday, November 06, 1997 2:06 PM
To:	Boswell, Daniel; Wezowicz, John; Sellers, Matthew; Verros, George; Prolo, Stephen; Cutler, Dorrin; Haynes, John; Hodge, Michael; Lee, Steven
Cc:	Pechonis, John; Hornot, Stan
Subject:	Dupont visit to discuss Kapton issues

The direct addresses met with Ed McKenzie, Technical Specialist from Dupont. We reviewed the our Kapton application in the Pressure Switch as well as our Kapton Heat Staking process. This discussion led to our perceived mode of Kapton failure and an inspection of Kapton diaphragms from various stages in our assembly process. We arrived at several key observations which I have summarized below:

1) We are using 2 pieces of a .0005"/.002"/.0005" Teflon/Kapton/Teflon product. As far as we know this relatively low gauge Kapton product is not used on other Pressure Switches. A .001"/.003"/.001" product in used as 1 or more layers is typical.

2) The critical test where we observe failure (cracking/leaking) of the Kapton is a 250K cycle test held at an elevated temperature of 150C and cycled between 0 and 1500 psi. In this test devices with 2 piece diaphragms which were Heat Staked together had failed. What we also found during this discussion was that in some cases the Kapton diaphragms with no Heat Staking failed as well. When the diaphragms were pulled apart for either case delamination between the adjacent Teflon layers were noted.

3) The initiation of the delamination appears to have a favored orientation; perpendicular to the machine direction. Kapton is anisotropic and can be weaker in the transverse direction, however Ed felt the differences in strength were small. Our application of Kapton in "circular flexing" application is not typical and thus Dupont does not have a lot of information on typical failure modes for this loading. The idea of potentially strengthening the overall diaphragm by orienting the 2 Kapton diaphragms 90 degrees to each other was discussed, but was not felt to be a key contributor to the problem.

4) The melting point of Teflon ranges from 495 to 525F. This lends itself well to our Heat Staking process where pressure and 520F heat Staking Ribs are used.

5) The center of the Kapton diaphragm gets as hot as 400F for 5 seconds. Dupont's expectation is that this exposure to temperature and time is not detrimental to the physical properties of the Kapton and does not enhance the surface activity of the Teflon surface. In fact Dupont's experience suggests that exposure to heat would actually degrade the surface activity of the Teflon while increasing the bond strength between the Teflon/Kapton layers. Examination of the Heat Staked and blanked diaphragms before assembly into the device show no tendency of the Teflon layers bonding to each other outside of the immediate staked zone.

6) The individual layers of Kapton and Teflon are "Corona" treated to activate their surfaces before laminating. This is required to achieve the desired cold peel strength values between the Kapton and the Teflon. However, if both sides of the Teflon layer are treated it also facilitates bonding of the Teflon surfaces to each other. Ultimately the Teflon/Teflon bond is stronger than Teflon/Kapton bond if exposed to the same conditions.

7) Processing of the Kapton material tends to deactivate the Corona Treated "C Surface" on the Teflon surface layers. Depending on the amount of processing the surface activity can degrade different degrees.

8) It is feasible that a Teflon "C Surface" which has not been significantly degraded could Bond with another Teflon "C Surface" at a temperature well below the Teflon Melting point provided sufficient pressure was applied. The cycle test is run at 150C with a 1500 psi peak, but in the area of the Transfer Pin local pressures far exceed this value. Dupont has no experience with "laminating" pressures that high so can not comment on how likely it is that the Teflon surfaces of the 2 diaphragms are bonding at this temperature and pressure.

9) There is no process to "deactivate" a C Surface, however not both sides of the Teflon need to have this treatment. Dupont can and does produce Teflon/Kapton/Teflon laminates where the outer Teflon surfaces are not Corona treated. In fact the very successful .001"/003"/001" material used for most other Pressure Switches in multiple layers does not have this surface treatment on the outer Teflon surfaces! This was confirmed by a simple ink marker

wettability test.

Conclusions

The Heat Staking may have little to no impact on the life of the Kapton diaphragms. It appears that the possibility of the 2 adjacent Teflon layers bonding under temperature and time is more likely. This could occur due to the more active surface on this product relative to what we have used historically. With the adjacent Teflon surface bonded the diaphragm could act like a single .005" diaphragm with 2 week areas, namely the 2 Kapton/Teflon interfaces. Sufficient fatigue due to cycling could cause the delamination of these layers, leading to ultimate diaphragm failure.

The random variation in surface activity due to mechanical handling of the Kapton could be responsible for the somewhat inconsistent results achieved in systematic tests.

Actions

Based on the above information the Team decided to investigate the influence of untreated outer Teflon surfaces on diaphragm life by

A) Evaluating standard .001"/.001"/.001" Teflon/Kapton/Teflon material (no Corona treatment)
B) Evaluate sample platen made .0005"/.002"/.0005" material with no Corona treatment

Samples of these materials will be sent to me and I will contact the appropriate people to conduct he tests. I expect to receive these samples early next week. I will also be receiving Kapton technical literature and will make copies of the Teflon information Ed left for us.

Regards....Andy

Dague, Bryan

From: Charboneau, Tom
Sent: Friday, November 07, 1997 9:07 AM
To: Dague, Bryan; Amatruda, Andy
Subject: FW: Dupont visit to discuss Kapton issues

Andy, excellent detective work and a valuable summary of the issue. Thanks!

Bryan, let's make sure Andy's message gets into the Data Library so we'll have some background on this teflon activiation process. I'm not sure this is the cause, but it's something I wasn't aware of and may be critically important. In fact we will want to include in our material specs if this turns out to be significant.

Tom

From: Pechonis, John
Sent: Friday, November 07, 1997 7:35 AM
To: Charboneau, Thomas
Subject: FW: Dupont visit to discuss Kapton issues

TC, for your info. We are trying to drive this issue to closure so we can get the right process in place.

From:	Amatrudo, Andy
Sent:	Thursday, November 06, 1997 2:08 PM
To:	Boswell, Daniel; Wesowicz, John; Sellers, Matthew; Verros, George; Prota, Stephen; Cutler, Darrin; Haynes, John; Hodge, Michael; Lee, Steven
Cc:	Pechonis, John; Homol, Stan
Subject:	Dupont visit to discuss Kapton issues

The direct addressees met with Ed McKenzie, Technical Specialist from Dupont. We reviewed the our Kapton application in the Pressure Switch as well as our Kapton Heat Staking process. This discussion led to our perceived mode of Kapton failure and an inspection of Kapton diaphragms from various stages in our assembly process. We arrived at several key observations which I have summarized below:

1) We are using 2 pieces of a .0005"/.002"/.0005" Teflon/Kapton/Teflon product. As far as we know this relatively low gauge Kapton product is not used on other Pressure Switches. A .001"/.003"/.001" product in used as 1 or more layers is typical.

2) The critical test where we observe failure (cracking/leaking) of the Kapton is a 250K cycle test held at an elevated temperature of 150C and cycled between 0 and 1500 psi. In this test devices with 2 piece diaphragms which were Heat Staked together had failed. What we also found during this discussion was that in some cases the Kapton diaphragms with no Heat Staking failed as well. When the diaphragms were pulled apart for either case delamination between the adjacent Teflon layers were noted.

3) The initiation of the delamination appears to have a favored orientation; perpendicular to the machine direction. Kapton is anisotropic and can be weaker in the transverse direction, however Ed felt the differences in strength were small. Our application of Kapton in "circular flexing" application is not typical and thus Dupont does not have a lot of information on typical failure modes for this loading. The idea of potentially strengthening the overall diaphragm by orienting the 2 Kapton diaphragms 90 degrees to each other was discussed, but was not felt to be a key contributor to the problem.

4) The melting point of Teflon ranges from 495 to 525F. This lends itself well to our Heat Staking process where pressure and 520F heat Staking Ribs are used.

5) The center of the Kapton diaphragm gets as hot as 400F for 5 seconds. Dupont's expectation is that this exposure to temperature and time is not detrimental to the physical properties of the Kapton and does not enhance the surface activity of the Teflon surface. In fact Dupont's experience suggests that exposure to heat would actually degrade the surface activity of the Teflon while increasing the bond strength between the Teflon/Kapton layers. Examination of the Heat Staked and blanked diaphragms before assembly into the device show no tendency of the Teflon layers bonding to each other outside of the immediate staked zone.

6) The individual layers of Kapton and Teflon are "Corona" treated to activate their surfaces before laminating. This is required to achieve the desired cold peel strength values between the Kapton and the Teflon. However, if both sides of the Teflon layer are treated it also facilitates bonding of the Teflon surfaces to each other. Ultimately the Teflon/Teflon bond is stronger than Teflon/Kapton bond if exposed to the same conditions.

7) Processing of the Kapton material tends to deactivate the Corona Treated "C Surface" on the Teflon surface layers. Depending on the amount of processing the surface activity can degrade different degrees.

8) It is feasible that a Teflon "C Surface" which has not been significantly degraded could Bond with another Teflon "C Surface" at a temperature well below the Teflon Melting point provided sufficient pressure was applied. The cycle test is run at 150C with a 1500 psi peak, but in the area of the Transfer Pin local pressures far exceed this value. Dupont has no experience with "laminating" pressures that high so can not comment on how likely it is that the Teflon surfaces of the 2 diaphragms are bonding at this temperature and pressure.

9) There is no process to "deactivate" a C Surface, however not both sides of the Teflon need to have this treatment. Dupont can and does produce Teflon/Kapton/Teflon laminates where the outer Teflon surfaces are not Corona treated. In fact the very successful .001"/003"/001" material used for most other Pressure Switches in multiple layers

does not have this surface treatment on the outer Teflon surfaces! This was confirmed by a simple ink marker wettibility test.

Conclusions

The Heat Staking may have little to no impact on the life of the Kapton diaphragms. It appears that the possibility of the 2 adjacent Teflon layers bonding under temperature and time is more likely. This could occur due to the more active surface on this product relative to what we have used historically. With the adjacent Teflon surface bonded the diaphragm could act like a single .005" diaphragm with 2 weak areas, namely the 2 Kapton/Teflon interfaces. Sufficient fatigue due to cycling could cause the delamination of these layers, leading to ultimate diaphragm failure.

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Samples of these materials will be sent to me and I will contact the appropriate people to conduct he tests. I expect to receive these samples early next week. I will also be receiving Kapton technical literature and will make copies of the Teflon information Ed left for us.

Regards....Andy

Dague, Bryan

From: Ichiro_Nishimura@nts.toray.co.jp[SMTP:Ichiro_Nishimura@nts.toray.co.jp]
Sent: Tuesday, November 04, 1997 8:55 PM
To: edulac@email.mc.ti.com
Cc: bdague@email.mc.ti_com
Subject: Re: Reels for rolled Material

```
Ichiro Nishimura @ TORAY
97/11/05 10:55

1. We received your reel(core) samples and are meeting with core supplier
this week  to obtain cost information . The material of core looks like ABS
which is very expensive. Can we use 1 size of core for all the different
film widths to minimize  the cost? If we can, please let me know desirable
core size(width).
```

Ed McKenzie

11/6/97

- Heat Stake Ribs – 520°F

- 250 K cycles @ elevated temp, 150°C
  ☆ → the test we currently fail

Melt pt of Telfon → could be as low as 495°F
high as 525°F

No evidence of full face delam after heat staking → only after heat stake and 300°F

"convertable"

C surface + Pressure @ 150°C & to get Teflon bond (upto 0 to 1500 psi)

→ Etching teflon, like "Corona" treatment
only lasts about 10 minutes in air

• Plasma treatment done in special atmosphere

- done on both sides of Telfon (and each layer)

- usually heat after laminating Tef/Kap/Tef product degrades the activity of the Teflon surface

- Kapton is also corona treated as well to get cold peel strength

Ed McKenzie

11/6/97 ①

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"commentable"

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→ ~~[illegible]~~

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Materials & Controls
Supplier Corrective Action Request

NOTE: YOUR CORRECTIVE ACTIVE RESPONSE IS DUE 15 WORKDAYS AFTER RECEIPT OF THIS REQUEST AT YOUR FACILITY.	RECEIVED NOV 07 1997 PROCUREMENT ASSURANCE	**RETURN TO:** Lorraine Heroux MS: 11-11 Texas Instruments Incorporated 34 Forest St. P.O. Box 2964 Attleboro, Ma. 027030964

PREPARATION DATE: SEPTEMBER 24, 1997

a

SUPPLIER:	E I DUPONT DE NEMOURS & CO	PART NUMBER:	27225-1
ATTENTION:	EDWARD C. MCKENIZE	QNM OR RDM#	031089

PLEASE ADDRESS APPROPRIATE CATEGORIES BELOW: ◆ INDICATES SUPPLIER TO ADDRESS

1. A.) TEXAS INSTRUMENTS INCORPORATED MRB MEMBERS & APPROPRIATE MANAGERS

BUYER: [redacted] MS: 23-04 ◆ ______ MS:
◆ [redacted] MS: [illegible] ◆ ______ MS:
◆ [redacted] MS: [illegible] ◆ ______ MS:

* 1. b.) SUPPLIER IDENTIFIED SUB-TIER SUPPLIERS: (WRITED NONE, IF NONE

NAME: Solvco (CoreService) ADDRESS (IF APPLICABLE): ______

*2. **DESCRIPTION OF NONCONFORMANCE**:

MANUFACTURING DATE: ______ LOT NUMBER (IF APPLICABLE): ______

ATTRIBUTE SPECIFICATION ______ +/- ______ ACTUAL: ______

OTHER: ABS PLASTIC USED FOR CORES IS "OUT OF ROUND"

*3. **CONTAINMENT**: SHORT TERM FIX PROBLEM, ISOLATE PRODUCT & DATE

NOT APPLICABLE DAMAGE OCCURS DUE TO HANDLING AND SHIPPING.

*4. **DEFINE AND VERIFY ROOT CAUSE**: ANALYZE AND PROPOSE SOLUTION

INADEQUATE STRENGTH OF PLASTIC CORES CALLED OUT IN TI SPEC.

DUPONT HAS PROPOSED NEW CORES ON SEVERAL OCCASIONS. TWICE WE HAVE SENT SAMPLE MATERIAL ON NEW CORES AND ARE AWAITING TI RESPONSE. SEE RDM# 025109, 030653, 030657

*5. **PERMANENT CORRECTIVE ACTION**: SOLUTION THAT ADDRESSES CORRECTIVE ACTION, DATE TO BE IMPLEMENTED, AND DATE CORRECTED PART TO BE SHIPPED OR PROCESS TO BE FOLLOWED.

NEW TYPE CORES SAMPLES SUBMITTED TO TI - AWAITING RESPONSE.

*6. **VERIFICATION**: DEFINE TEST / ANALYSIS OF ROOT CAUSE TO ENSURE CORRECTIVE ACTION

N/A

*7. **CONTROL**: ENSURE CORRECTIVE ACTION REMAINS IN EFFECT (MONITOR PROCESS)

N/A

*8. **PREVENTION**: EXPLAIN ACTIONS TAKEN TO PREVENT REOCCURANCE

AWAITING TI RESPONSE. IF DUPONT PROPOSAL NOT ACCEPTABLE, WE WILL NEED TO REVISIT SPECIFICATION W/ TI

SUPPLIER'S AGENT: E.C. McKenzie TITLE: TECHNICAL SPECIALIST

AGENT'S SIGNATURE: DATE COMPLETED: 11/7/97

TEXAS INSTRUMENTS INCORPORATED PQA & MRB REVIEW:

☐ *THIS SUPPLIER CORRECTIVE ACTION RESPONSE HAS BEEN APPROVED BY PROCUREMENT QUALITY ASSURANCE, AND HAS BEEN DISTRIBUTED TO ALL IDENTIFIED IN SECTION 1.a*

Congratulations to all participants for this accomplishment!

PQA INITIALS & DATE:

☐ THIS SUPPLIER CORRECTIVE ACTION RESPONSE HAS NOT BEEN APPROVED BY PROCUREMENT QUALITY ASSURANCE, BECAUSE:

☐ A SECOND RESPONSE HAS BEEN REQUESTED ON:

☐ THE MRB DOES NOT ACCEPT THIS CORRECTIVE ACTION AND HEREBY REQUEST THAT PROCUREMENT QUALITY ASSURANCE ISSUE AN ADDITIONAL REQUEST FOR CORRECTIVE ACTION.

REQUESTED BY:

☐ THE MRB IS HEREBY ALERTED TO A LESS THAN 100% EFFECTIVE CORRECTIVE ACTION, AND MAY REQUEST AN ADDITIONAL SUPPLIER RESPONSE THROUGH THE APPROPRIATE BUYER.

Materials & Controls
Supplier Corrective Action Request

NOTE: YOUR CORRECTIVE ACTIVE RESPONSE IS DUE 15 WORKDAYS AFTER RECEIPT OF THIS REQUEST AT YOUR FACILITY.

RECEIVED

NOV 07 1997

PROCUREMENT ASSURANCE

RETURN TO:
Lorraine Heroux MS: 11-11
Texas Instruments Incorporated
34 Forest St. P.O. Box 2964
Attleboro, Ma.
027030964

PREPARATION DATE: SEPTEMBER 24 , 1997

SUPPLIER:	E I DUPONT DE NEMOURS & CO	PART NUMBER:	27225-1
ATTENTION:	EDWARD C. MCKENIZE	QN# OR RD/M#	031089

PLEASE ADDRESS APPROPRIATE CATEGORIES BELOW: * INDICATES SUPPLIER TO ADDRESS

1. A.) TEXAS INSTRUMENTS INCORPORATED MRB MEMBERS & APPROPRIATE MANAGERS

BUYER: [redacted] MS: 23-04 ◆ ______ MS:

◆ ______ [redacted] MS:

◆ ______ MS:

* 1. b.) SUPPLIE

NAME: ______ ______

*2. DESCRIPT

MANUFACTUR ______

ATTRIBUTE SP ______

OTHER: ______

*3. **CONTAINMENT**: SHORT TERM FIX PROBLEM, ISOLATE PRODUCT & DATE

*4. **DEFINE AND VERIFY ROOT CAUSE**: ANALYZE AND PROPOSE SOLUTION

TI FORM NO. PQA 123 REV. C.

TI-NHTSA 017800

DuPont Films

Memo

To: Lorraine Heroux, Texas Instruments

From: Ed McKenzie, DuPont

CC: John Haynes TI, Khadijah Fledger, DuPont

Date: November 7, 1997

Re: Corrective Actions for Out Of Round Cores

Attached is our Corrective Action for RDM # 031089. Over the past 2 years or so, we have seen similar complaints for cores being out of round. DuPont has suggested replacement cores on several occasions, and we have submitted test rolls on the new cores free of charge to TI for evaluation twice. As the existing cores are not strong enough to maintain their shape 100% of the time, we will continue to have rejections like this on occasion. While they are infrequent, it is time consuming and costly for TI and DuPont to keep filling out CA's for the same issue.

I hope TI can either approve the new type cores quickly, or we can come to agreement the occasional core will be out of round, and returned to DuPont for rework, without the need for corrective action and additional paperwork.

Thank you for your business and continued interest in DuPont High Performance Films.

Ed

TI-NHTSA 017801

Materials & Controls
Supplier Corrective Action Request

NOTE: YOUR CORRECTIVE ACTIVE RESPONSE IS DUE 15 WORKDAYS AFTER RECEIPT OF THIS REQUEST AT YOUR FACILITY.

RETURN TO:
Lorraine [illegible] MS: 11-11
Texas Instruments Incorporated
34 Forest St. P.O. Box 2964
Attleboro, Ma.
027030964

PREPARATION DATE: SEPTEMBER 24, 1997

SUPPLIER:	E I DUPONT DE NEMOURS & CO	PART NUMBER:	27225-1
ATTENTION:	EDWARD C MCKENIZE	SUPPLIER NUMBER:	031089

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1. A.) TEXAS INSTRUMENTS INCORPORATED MRB MEMBERS & APPROPRIATE MANAGERS

BUYER: DARLENE SANVILLE MS: 23-04 ◆ ______ MS:
◆ ______ MS: ◆ ______ MS:
◆ ______ MS: ◆ ______ MS:

* 1. b.) SUPPLIER IDENTIFIED SUB-TIER SUPPLIERS: (WRITE NONE, IF NONE

NAME: SONOCO (CORE SUPPLIER) ADDRESS (IF APPLICABLE): ______

*2. **DESCRIPTION OF NONCONFORMANCE:**

MANUFACTURING DATE: ______ LOT NUMBER (IF APPLICABLE): ______

ATTRIBUTE SPECIFICATION ______ +/- ______ ACTUAL: ______

OTHER: ABS PLASTIC USED FOR CORES IS "OUT OF ROUND"

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NEW TYPE CORES. SAMPLES SUBMITTED TO TI - AWAITING RESPONSE.

*6. **VERIFICATION**: DEFINE TEST / ANALYSIS OF ROOT CAUSE TO ENSURE CORRECTIVE ACTION

N/A

*7. **CONTROL**: ENSURE CORRECTIVE ACTION REMAINS IN EFFECT (MONITOR PROCESS)

N/A

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☐ THE MRB DOES NOT ACCEPT THIS CORRECTIVE ACTION AND HEREBY REQUEST THAT PROCUREMENT QUALITY ASSURANCE ISSUE AN ADDITIONAL REQUEST FOR CORRECTIVE ACTION.

REQUESTED BY: ______

☐ THE MRB IS HEREBY ALERTED TO A LESS THAN 100% EFFECTIVE CORRECTIVE ACTION, AND MAY REQUEST AN ADDITIONAL SUPPLIER RESPONSE THROUGH THE APPROPRIATE BUYER.

11/06/97 16:58 :05/05 NO:852

TEXAS INSTRUMENTS
ATTLEBORO, MASSACHUSETTS

REPORT OF DISCREPANT IN-PROCESS MATERIAL

No. 031089

[redacted]

Dupont

GO

3 rolls

ITEM	ATTRIBUTE/REQUIREMENT	ACTUAL				
	~~core out of ro~~					
	center found	core out of round	3	0	3	3
	no wrinkles	Kapton wrinkled	3	0	1	3

MATL/PROD. CONTROL

SAMPLES MUST BE RETAINED FOR DISPUTES

COMMENTS:

MRB ENGINEERING DISPOSITION

☒ RETURN TO SUPPLIER

☐ REWORK AT TI

☐ SORT AT TI

☐ SCRAP

☐ USE AS IS

COMMENTS:

REWORK PROCEDURE (MFG./ENG.)

P0 5208300039

Supplier 171011

Buyer 5070

Pcode 060

Def code 2E

MH811628

MRB CORRECTIVE ACTION

COMMENTS:

RECEIVING INSPECTION

9598 RTS M B-16

DO 9-22-97

PROCUREMENT ASSURANCE

9-22-97

9/25

TI-NHTSA 017804

UNDERWRITERS LABORATORIES INC.

CERTIFICATE OF REGISTRATION

E.I. du Pont de Nemours and Company

Kapton - Teflon® Plant
P.O. Box 89
Circleville, OH 43113

Underwriters Laboratories Inc.® (UL) issues this certificate to the Firm named above, after assessing the Firm's quality system and finding it in compliance with

ISO 9002:1994

EN ISO 9002:1994; BS EN ISO 9002:1994; ANSI/ASQC Q9002:1994

for the following scope of registration

2821 (US) : Plastics Materials, Synthetic Resins and Nonvulcanizable Elastomers

The manufacture of a range of polyimide and fluorocarbon resin films marketed under the trade names KAPTON and TEFLON including laminates of the above.

This quality system registration is included in UL's Directory of Registered Firms and applies to the provision of goods and/or services as specified in the scope of registration from the address(es) shown above. By issuance of this certificate the firm represents that it will maintain its registration in accordance with the applicable requirements. This certificate is not transferable and remains the property of Underwriters Laboratories Inc. ©.

File Number: A2174
Volume: 1
Issue Date: November 29, 1991
Revision Date: December 5, 1996
Renewal Date: November 29, 1997

S. Joe Bhatia
Vice President
Follow-Up Services

Accredited by Raad voor Accreditatie

UL REGISTERED FIRM

[illegible] High Performance Films
[illegible] Route 23 & DuPont Road
[illegible] Box 89
[illegible] OH 43113
Tel (614) 474-0724
Fax (614) 474-0680

DuPont Films

May 1, 1997

Dear Valued Customer:

For more than 30 years, we have had a clear vision for our polyimide businesses: technology leadership, industry leadership, and sustainable business health. Our focus in these areas has remained unchanged, and has served as a foundation for unprecedented growth in recent years to the industries we serve. Over the last decade, our industry leadership and technology leadership have been driven through extensive process, product and market research and development. Sustainable business health has resulted from cost stewardship, improving manufacturing efficiencies and investing in technology and capacity enhancements.

While aggressive cost stewardship strategies have allowed us to maintain relative price stability since the early 1990's, raw material price increases, the need to underwrite new capacity through investments totaling more than $175 million, and inflationary pressures have caused ongoing strategies for sustainable business health to be inadequate.

As a result, effective June 1, 1997, prices for Kapton) polyimide films will be increased globally five percent. Further details will be available through your Marketing or Customer Service Representative. As we stated in our customer satisfaction survey brochure, a number of initiatives have helped fuel an already vigorous demand for Kapton). We believe the investment made possible with this increase will enable us to continue to expand our manufacturing and technological capabilities to meet this demand, thereby protecting the health and flexibility of both of our businesses.

We greatly value your business and our relationship with you. We believe this price increase will help us continue creating the technology and value-added products that strengthen the health and longevity of our respective organizations. We look forward to sustaining our mutually profitable growth opportunities well into the next century.

Sincerely,

F. Tim Reese

F. Tim Reese
Worldwide Business Director/Plant Manager
High Performance Films

TI-NHTSA 017806

KAPTON® Film
General Specifications Bulletin GS-92-6

Du Pont Electron[illegible]

High Performance Films

August 1992

INTRODUCTION

Du Pont Electronics manufactures and sells a variety of high-quality plastic film products.

These specifications describe the values and tolerances for film properties and characteristics of KAPTON® film. Where necessary for thorough understanding, test methods and procedures have been included.

Any aspects of the specifications that require further interpretation or clarification should be discussed with representatives of Du Pont Electronics.

TYPES OF KAPTON POLYIMIDE FILM

Du Pont makes several types of KAPTON film. Types HN, FN, and VN are used most commonly.

Types H, F, and V are alternative, special versions of these standard types. The specifications in this bulletin apply to them as well. In addition, Du Pont manufactures other, more specialized types such as FPC, PST, TAB, and films containing various fillers. For information on these types, please contact your Du Pont Electronics representative or the customer service office nearest you.

Type HN Film

KAPTON Type HN is a tough, aromatic polyimide film, exhibiting an excellent balance of physical, chemical, and electrical properties over a wide temperature range, particularly at unusually high temperatures. Chemically, its polyimide polymer makeup is the result of a polycondensation reaction between pyromellitic dianhydride and 4,4'diaminodiphenylether. KAPTON HN is available in 30, 50, 100, 200, 300, and 500 gauges. Other gauges, such as 75 and 400, are available by special request.

Type FN Film

KAPTON Type FN film is a heat sealable grade that retains the unique balance of properties of KAPTON Type HN over a wide temperature range. This is achieved by combining Type HN with Du Pont TEFLON® FEP fluorocarbon resin in a composite structure. Table I lists the combinations that are commercially available at this time. Other combinations are available. Consult your Du Pont Electronics marketing representative for further information.

Type VN Film

KAPTON Type VN is the same toug polyimide film as Type HN Film, exhibiting an excellent balance of physical, chemical, and electrical properties over a wide temperature range, with superior dimensional stability at elevated temperatures. T product is available in 50, 75, 100, 2(300, and 500 gauges.

Certification

KAPTON is certified to meet the requirements of the military specification MIL-P-46112 B (MR-2) in addition to the items covered by this specifications bulletin. Written confirmation is available with each delivery upon request.

Table I. KAPTON FN Film Types

	Construction (mils)		
Designation	FEP	HN	FE
120FN616	0.10	1.00	0.1
120FN616B	0.15	1.00	0.1
100FN099		0.50	0.5
150FN999	0.50	0.50	0.5
150FN019		1.00	0.5
200FN919	0.50	1.00	0.5
200FN011		1.00	1.0
250FN029		2.00	0.5
300FN021		2.00	1.0
300FN111	1.00	1.00	1.0
300FN929	0.50	2.00	0.5
400FN022		2.00	2.0
400FN031		3.00	1.0
400FN121	1.00	2.00	1.0
500FN131	1.00	3.00	1.0
600FN051		5.00	1.0

TI-NHTSA 017807

DUPONT

PROPERTIES OF TYPE HN FILM

Table II. Mechanical Properties of HN Film

Property	Property Value Film Thickness (mils) 0.30	0.50*	1.00*	2.00*	3.00*	5.00*	Method
Tensile Strength psi, at 23°C. Machine Direction (MD) and, Transverse Direction (TD), (Minimum)	16,000	20,000	24,000	24,000	24,000	24,000	ASTM D-882-88, Method A using an Instron Tensile Tester (specimen size: ½" × 6", jaw separation: 4", jaw speed: 2"/min). Calculate the average of five specimens based on original measured thickness.
Elongation, % MD and TD (Minimum)	25	35	40	45	50	50	Same as above.
Shrinkage, % MD and TD at 400°C (Maximum)	4.0	4.0	2.5	2.5	2.5	2.5	MIL-P-46112B (MR-2). The percent shrinkage is obtained for either the MD or TD using the average of three measurements in either direction before and after conditioning. Prior to measurement, the 8½" × 11" specimen is conditioned by freely suspending it for two hours† in an oven controlled to 400°C.
Moisture absorption, % (Maximum)	4.0	4.0	4.0	4.0	4.0	4.0	ASTM D-570-81, using 24-hour immersion at 23°C. Average of three specimens.

* Also applies to Type VN

† 1 hour for 30 and 50 gauge film

Table III. Electrical Properties of HN Film

Property	Property Value Film Thickness (mils) 0.30	0.50*	1.00*	2.00*	3.00*	5.00*	Method
Dielectric Strength, AC volts/mil, (Minimum)	3,000	3,000	6,000	5,000	4,600	3,000	ASTM D-149-81. (Average of ten specimens.) Flat sheets in air placed between ¼" diameter brass electrodes with 1/32" edge radius subjected to 60 cycles AC voltage at 500 volts/sec rate of rise to the breakdown voltage.
Volume Resistivity, ohm-cm at 200°C (Minimum)	10^{12}	10^{12}	10^{12}	10^{12}	10^{12}	10^{12}	ASTM D-257-78
Dielectric constant at 1 kHz (Maximum)	4.0	4.0	3.9	3.9	3.9	3.9	ASTM D-150-81. 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.
Dissipation factor at 1 kHz (Maximum)	0.0070	0.0050	0.0036	0.0036	0.0036	0.0036	Same as above.

* Also applies to Type VN

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THERMAL DURABILITY

The thermal durability of KAPTON® film depends on the environmental conditions under which it is aged and tested. Its lifetime depends on the criterion of failure. KAPTON is routinely tested at the manufacturing site in the following manner:

Sheets of film 8.5" × 11" are freely suspended in an oven at a temperature of 400° C ±2° C, monitored with a thermocouple to ensure accuracy. Sheets are removed after two hours (one hour for 30 and 50 gauge film) and tested on an Instron Tensile Tester as described in the Mechanical Properties chart for Type HN. The elongation of the film at 23.5° C should not be less than 10% after this aging at 400° C. This conforms to MIL-P-46112B (MR) "Elongation After Aging at 400° C" test (paragraph 4.4.5) and "Elongation, Percent, After Two Hour 400° C" requirement (Table II).

Underwriters Laboratories, Inc. lists a thermal index of 200° C to 220° C (depending on gauge and type) for mechanical properties, and 220° C to 240° C (depending on gauge and type) for electrical properties, under their file number E39505 for KAPTON polyimide film.

PROPERTIES OF TYPE FN FILM

Heat Seal Strength

Film-to-Film Seals

The peel strength of heat seals between the coated and uncoated sides of one-side-coated KAPTON, or between the coated sides of both one- and two-side-coated KAPTON is determined as follows.

Seals are made in a jaw sealer at 350° C, 20 psi, with a 20-second dwell time. After cooling, the seals are cut into 1-inch (25 mm) wide strips using a Thwing-Albert JDC sample cutter or its equivalent. The seal strength 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.

The minimum peel strength between the coated sides of one- or two-side coated KAPTON film will be 600 g/in except for 120FN616, which will be 450 g/in. The minimum peel strength between the coated and uncoated side of one-side coated KAPTON will be 450 g/in.

Film-to-Copper Seals

The ability of FEP film to adhere to copper is measured using the same heat seal peel strength technique as described in "Film-to-Film Seals."

The peel strength is measured with 120FN616 sealed to the untreated side of 1 mil (25 μm), ¾ oz GT copper foil; it will be a minimum of 250 g/in.

As-Received Strength (Cold peel) of Bonds Between KAPTON Type HN and TEFLON Layers

The bond between the KAPTON Type HN and TEFLON® fluorocarbon resin layers on all type FN products except 120FN616 will have a minimum peel strength of 225 g/in, measured using an Instron-type tensile tester and a 180-degree peel.

Table IV. Dielectric Strength of Type FN Films

Gauge Construction	Minimum Breakdown (volts/mil)
120FN616	4000
120FN616B	4000
100FN099	3000
150FN099	3000
150FN019	3500
200FN919	3000
200FN011	3000
250FN029	2500
300FN021	2500
300FN111	2000
300FN929	2500
400FN022	2000
400FN031	2700
400FN121	2500
500FN131	2200
600FN051	2100

Test Method

Average of ten specimens tested per ASTM D-149-61. Flat sheets in air placed between ¼" (6 mm) diameter brass electrodes with 1/32" (0.8 mm) edge radius subjected to 60 cycles AC voltage. Rise is 500 volts/sec to the breakdown voltage.

PROPERTIES OF TYPE VN FILM

Table V. Mechanical Properties of VN Film

	Property Value Film Thickness (mils)					
Property	**0.50**	**0.75**	**1.00**	**2.00**	**3.00**	**5.00**
Shrinkage, % MD and TD at 200°C (Maximum)	0.10	0.10	0.10	0.10	0.10	0.10

Test Method

The percent shrinkage obtained for either the MD or TD by using the average of three measurements in either direction before and after conditioning. Temperature exposure 200° ±2°C for one hour. Measurements must be made at the same temperature and humidity conditions before and after conditioning. To assure sample/ambient equilibrium before and after conditioning, specimens should be exposed for three hours.

GENERAL

Materials

KAPTON* Type HN and Type VN films are polyimide polymers in the form of a film.

KAPTON Type FN film is a combination of Type HN film with TEFLON® FEP fluorocarbon resin on one or both sides.

Uniformity

Material shall be uniform in composition and free from defects that impair serviceability and/or appearance in proven applications.

Cores

Cores shall be of sufficient strength to prevent collapsing from handling. Standard core internal diameters are nominally 3 inches and 6 inches (76mm and 152 mm) with the following specifications:

3" I.D. = 3.032" ±0.008" (77.01 ±0.2 mm)

6" I.D. = 6.028" ±0.010" (153.11 ±0.25 mm)

Core material will be plastic for 3" I.D. cores less than 5/8" (16 mm) wide.

Core material will be fiber for 3" I.D. cores wider than 5/8" (16 mm) and for 6" I.D. cores. A split 3" I.D. fiber core is standard for all universal and Step-Pac™ rolls.

If these cores are not suitable, further information on other options may be obtained from your Du Pont Electronics representative.

Width Tolerance

The maximum variation in film width from that specified on the order shall be as follows:

Slit Width Range	Tolerance
7/8" (22 mm) or less Universal or Step-Pac™	±7 mils (0.18 mm)
1" (25 mm) or less Pad Rolls	±15 mils (0.38 mm)
1 1/16" (27 mm) to 4" (102 mm) Pad Rolls	±30 mils (0.76 mm)
4 1/16" or wider Pad Rolls	±60 mils (1.5 mm)

Outside Diameter Tolerance

±½" (13 mm)

Table VI. KAPTON® Film Specifications

Type	Nominal Thickness		Width Range Minimum		Width Range Maximum		Area Factor	
	mils	μm	in.	(mm)	in.	(cm)	ft²/lb	(m²/kg)
30HN	0.3	8	3/16	4.8	50	127	463	94
50HN	0.5	13	3/16	4.8	52	132	272	56
100HN	1.0	25	3/16	4.8	60	152	136	28
200HN	2.0	50	3/16	4.8	60	152	68	14
300HN	3.0	76	3/16	4.8	60	152	45	9.2
500HN	5.0	125	3/16	4.8	60	152	27	5.5
50VN	0.5	13	7/8	22	52	132	272	56
75VN	0.75	19	7/8	22	60	152	181	37
100VN	1.0	25	7/8	22	60	152	136	28
200VN	2.0	50	7/8	22	60	152	68	14
300VN	3.0	75	7/8	22	60	152	45	9.2
500VN	5.0	125	7/8	22	60	152	27	5.5
100FN089	1.0	25	1/8	3.2	36	91	110	22
120FN616	1.2	30	1/8	3.2	36	91	104	21
120FN616B	1.3	33	1/8	3.2	36	91		
150FN999	1.5	38	1/8	3.2	36	91	68	14
150FN019	1.5	38	1/8	3.2	36	91	77	16
200FN011	2.0	50	3/16	4.8	36	91	54	11
200FN919	2.0	50	3/16	4.8	36	91	54	11
250FN029	2.5	63	1/8	3.2	36	91	49	10
300FN021	3.0	75	3/16	4.8	36	91	39	8.0
300FN111	3.0	75	3/16	4.8	36	91		
300FN929	3.0	75	3/16	4.8	36	91	39	8.0
400FN022	4.0	100	3/16	4.8	36	91	27	5.5
400FN031	4.0	100	3/16	4.8	36	91	30	6.1
400FN121	4.0	100	3/16	4.8	36	91		
500FN131	5.0	125	3/16	4.8	36	91	23	4.7
600FN051	6.0	150	1/2	13	36	91	21	4.3

The usual dimensions of pad rolls are 3" I.D. by 6" or 9" O.D for widths up to 4". For wider rolls, the usual dimensions are 6" I.D. by 9½" or 11" O.D. For Universal and Step-Pac™ rolls, the dimensions are 3" I.D. by 6", 9", or 12" O.D. If these dimensions are not suitable, information on other options is available from your Du Pont Electronics technical or customer service representative.

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Roll Types
KAPTON* film is supplied in three types of rolls: pad, universal, and Step-Pac™ wind.

Pad Roll Specifications

1. Core width will be the film width +⅛" (+3.2 mm), –0.
2. Core edges shall not project more than 1/16" (1.6 mm) beyond the roll face on either side.
3. Core shall not be recessed on either side.
4. The outside and starting ends of the film shall be fastened in a manner to prevent unwinding.
5. "Dishing" or "cupping" may not exceed 1/16" (1.6 mm), measured with a straightedge across the diameter of the roll.

Universal and Step-Pac™ Roll Specifications

1. The difference between the lengths of the projecting core on each side shall not exceed 3/16" (4.8 mm).
2. Film shall not project from the main body of the roll more than ⅛" (3.2 mm).
3. The outside and starting ends of the film shall be fastened in a manner to prevent unwinding.
4. Roll face depression, the difference between the highest and lowest points of the roll, unstressed, shall not exceed 3/16" (4.8 mm).

Splices
Description
Three types of splice are available.

1. MYLAR* polyester film-based yellow tape (standard).
2. KAPTON* polyimide film-based tape (special requirements only).
3. Heat seal splice, 12" (305 mm) or less in width (Type FN).

Splices will be centered on the joint to ±¼" (±6 mm). They will be smooth and wrinkle-free to avoid distortion of the adjacent film layers in the roll.

Tape Splices
Tape splices are standard on all gauges of HN and VN film and on all gauges of FN film more than 12" (305 mm) wide.

Tape splices are made with the butt edges of the film covered on both sides with pressure-sensitive adhesive tape. Two-inch wide splicing tape is used.

Heat Seal Splices
Heat seal splices are made on all films, except 250FN029, with an overlap that is a minimum of ⅜" (9.5 mm) wide.

On 250FN029, a butt splice is ma using 120FN616 as the joining ta applied on the FEP surface. The splice is oriented with the 120FN tape on the top of the film as it unwinds from a universal put-up, on the bottom as it unwinds from pad.

Overlap heat seal splices for two- FEP composites are oriented with leading edge of the new film on th bottom for universal put-ups and put-ups. Pad put-ups of one-side F composites have the leading edge the top.

Splice Placement
Table VII shows the minimum len between splices, and the minimum length to a splice from the beginn and the end of a roll, for most rolls However, no splice is allowed afte roll has reached the minimum out diameter.

Maximum Splices Per Slit Roll
To calculate the maximum numbe splices in a roll, divide the nomina per roll by the minimum average length between splices and subtra one.

Table VII. Splice Data—KAPTON* Polyimide Film

Core I.D. (in.)	Roll O.D. (in.)	Roll	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			Minimum Average Splice-free Length (Feet)																
3 6	6 9¼	Pad	300	500	600	505	380	750	160	750	185	250	250	250	200	165	185	150	12
3 6	9¼ 11	Pad	—	—	600	640	425	340	280	425	350	365	375	310	305	280/245	205	185	17
3	8 12	Universal**	—	—	—	800	510	—	—	510	360	465	465**	410	335	420/340	250	170	—
			Minimum Length Between Splices or Beginning and End of a Roll (Feet)																
3 6	6 9¼	Pad	—	100	100	100	100	100	—	100	100	100	100	100	100	100	100/75	75	—
3 6	9¼ 11	Pad	—	—	100	100	100	100	75	—	100	—	100	100	100	100	100/75	75	7
3	8 12	Universal	—	—	—	100	100	100	75	150	150	150	150	150	150	—	—	—	—

Notes:

* To 50" (1270 mm) wide for 30HN, 52" (1321 mm) wide for 50HN

† 60" (1524 mm) wide

‡ To 6" (152 mm) wide

§ To 18" (457 mm) wide. For widths greater than 18" to the maximum, the minimum average footage will be one-half that shown in the table.

** ⅛" to ⅞" (3.2 to 22 mm) wide

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Average Thickness Tolerances (Unit Weight)

Test Method and Sampling Procedure

Cut test specimens that are equal to the width of the slit roll and not less than 0.5 meter long. Weigh the specimens to the nearest 0.10 gram on a torsion balance.

To confirm the average thickness tolerances, sample a minimum of one specimen from each of several randomly selected slit rolls as follows:

Slit Roll Width	Minimum Number of Slit Rolls to be Sampled
Under 6" (152 mm)	26 divided by slit roll width (in.)
6" (152 mm) and Over	Four

Table VIII.

Type HN Film Thickness (mils)	Unit Weight (g/m²) Minimum	Maximum
0.30	7.6	14.0
0.50*	14.0	26.0
0.75*	21.8	32.6
1.00*	32.7	39.7
2.00*	66.9	77.9
3.00*	101.9	116.4
5.00*	169.5	192.5

* Applies to Type VN films also.

Table IX.

Type FN Film Gauge & Construction	Unit Weight (g/m²) Minimum	Maximum
120FN616	41	58
120FN616B	47	54
100FN099	37	55
150FN099	61	65
150FN019	53	74
200FN919	77	104
200FN011	77	104
250FN029	97	113
300FN021	111	142
300FN111	134	156
300FN929	111	142
400FN022	163	200
400FN031	146	179
400FN121	163	200
500FN131	195	239
600FN051	211	258

Micrometer Thickness

Thickness tolerances are based on a statistical analysis of routine process control data.

Test Method

Make the following measurements to confirm that film from a single slit roll meets the micrometer tolerances:

1. Measure in accordance with ASTM D-374-88, Method A, C, or D.
2. Obtain the average of ten randomly selected readings from a minimum area of 12 in.² (7.7 m²). Recheck before rejecting any slit roll. Abnormal readings may occasionally result from dust particles or spot surface imperfections. Discard such readings, as they will adversely affect the accuracy of average measurements.

Table X.

Type HN Gauge	Nominal Thickness (mils)	Thickness Tolerances (mils) Minimum	Maximum
30	0.30	0.24	0.36
50*	0.50	0.35	0.65
75*	0.75	0.60	0.90
100*	1.00	0.85	1.15
200*	2.00	1.75	2.25
300*	3.00	2.72	3.28
500*	5.00	4.65	5.35

*Applies to Type VN films also.

Table XI.

Type FN Gauge	Nominal Thickness (mils)	Thickness Tolerances (mils) Minimum	Maximum
120FN616	1.20	1.10	1.40
120FN616B	1.30	1.20	1.50
100FN099	1.00	0.75	1.25
150FN099	1.50	1.20	1.80
150FN019	1.50	1.25	1.75
200FN919	2.00	1.70	2.30
200FN011	2.00	1.70	2.30
250FN029	2.50	2.38	2.63
300FN021	3.00	2.60	3.40
300FN111	3.00	2.30	3.70
300FN929	3.00	2.60	3.40
400FN022	4.00	3.30	4.70
400FN031	4.00	3.60	4.40
400FN121	4.00	3.30	4.70
500FN131	5.00	4.50	5.50
600FN051	6.00	5.40	6.60

Gauge Depression

To reduce web handling difficulties, which would occur if film representing thickness extremes were shipped in the same roll, a gauge depression standard is applied.

Roll depression is the difference in diameter between the hardest and softest part of the roll or the difference between the undepressed and depressed (finger pressure) diameter at the softest part, whichever is greater.

Table XII lists the maximum allowable depression for most pad rolls. There is no gauge depression standard for universal wind since that roll is limited to a maximum of ⅞" (22 mm) wide.

Table XII. KAPTON® Polyimide Film Gauge Depression Standards—Pad Rolls

Put-Up I.D. (in.)	Put-Up O.D. (in.)	Maximum allowable depression in 1/32" increments (× 0.79 = mm) — Roll Widths (inches): ½–1	1–5 15/16	6–7 15/16	8–8 15/16	9–12 15/16	13–13 15/16	14–15 15/16	16–17 15/16	18–19 15/16	20–20 15/16	21–21 15/16	22–22 15/16	23 & Wider
3 6	6 8½	3	3	3	5	5	5	7	7	7	7	9	9	9
3 6	9½ 11	5	7	9	9	9	9	9	11	11	13	13	13	15
3 6	13 14	–	9	9	9	11	11	13	13	15	15	15	17	17

PACKAGING AND MARKING

Packaging

KAPTON® film 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 shown in Table XIII, to allow complete traceability back to the raw materials and processing conditions.

Arrangements for special markings can be made (such as part or specification number). Consult with your Du Pont Electronics technical or customer service representative for details.

Table XIII. Package Marking

	Shipping Container	Package	Core Label*
Scheduled Date	X	X	X
Customer Order Number	X	X	X‡
Du Pont Order Number	X	X	X
Gauge	X	X	X
Type	X	X	X
Width	X	X	X
Number of Rolls per Container	X	X	
Net Weight	X	X	
Actual Footage			X
Mill Roll Number	X	X	X
I.D. and O.D.†	X	X	

Notes:

* Affixed to the core on all cores, 2.25" (57 mm) wide and over. Included with the package on all cores less than 2.25" (57 mm) wide.

† Inside diameter of core and nominal outside diameter of roll

‡ Available for up to 12 characters.

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DuPont Polymers

"KAPTON" POLYIMIDE FILM, FLUOROCARBON-COATED (EXCLUDING TI02-FILLED TYPES)

CHEMICAL PRODUCT/COMPANY IDENTIFICATION

Material Identification

Kapton is a registered trademark of DuPont.

Corporate MSDS Number DU005414

Tradenames and Synonyms

"KAPTON" F, FN
"KAPTON" HRN
"KAPTON" HRN616ES
"KAPTON" XP
"KAPTON" ZN
"KAPTON" 1100FC051-6

Company Identification

MANUFACTURER/DISTRIBUTOR

DuPont
"Kapton"/"Teflon" Customer Service
P.O. Box 89
Circleville, OH 43113

PHONE NUMBERS

Product Information	1-800-237-4357
Transport Emergency	1-800-424-9300
Medical Emergency	1-800-441-3637

COMPOSITION/INFORMATION ON INGREDIENTS

Components

Material	CAS Number	%
INERT POLYIMIDE FILM		100
Coated or laminated with:		
POLYFLUOROCARBON	25067-11-2	

(Continued)

compounds can cause severe eye, skin and respiratory tract irritation. Inhalation can cause shortness of breath and other respiratory effects and symptoms may be delayed.

Carcinogenicity Information

None of the components present in this material at concentrations equal to or greater than 0.1% are listed by IARC, NTP, OSHA or ACGIH as a carcinogen.

FIRST AID MEASURES

First Aid

INHALATION

If exposed to fumes from overheating or combustion, move to fresh air. Consult a physician if symptoms persist.

SKIN CONTACT

Wash with soap and water after handling. If skin irritation develops, consult a physician.

EYE CONTACT

Flush eyes with plenty of water. Consult a physician if symptoms persist.

INGESTION

Not a probable route of exposure for films.

FIRE FIGHTING MEASURES

Flammable Properties

Not a fire or explosion hazard.

The flammability characteristic of polyimide film is reported as "self-extinguishing".

"Kapton" chars but does not burn in air. Coated types of "Kapton" will burn in an atmosphere of 95% oxygen when an ignition source is present. Combustion products include carbon monoxide, hydrogen fluoride, carbonyl fluoride and possibly perfluoroisobutylene.

The processing of "Kapton" polyimide films can cause the generation of static charge. Precautions for static charges should also be taken when removing plastic films used as protective packaging for "Kapton".

(Continued)

EXPOSURE CONTROLS/PERSONAL PROTECTION (Continued)

Exposure Guidelines
Applicable Exposure Limits

POLYFLUOROCARBON		
PEL	(OSHA)	None Established
TLV	(ACGIH)	None Established
AEL *	(DuPont)	10 mg/m3, 8 Hr. TWA, total dust 5 mg/m3, 8 Hr. TWA, respirable dust
DIMETHYL ACETAMIDE (residual in film)		
PEL	(OSHA)	10 ppm, 35 mg/m3, 8 Hr. TWA, Skin
TLV	(ACGIH)	10 ppm, 36 mg/m3, 8 Hr. TWA, Skin Notice of Intended Changes (1995-1996) A4
AEL *	(DuPont)	10 ppm, 8 & 12 Hr. TWA, Skin
POLYIMIDE POLYMER (as nuisance dust)		
PEL	(OSHA)	None Established
TLV	(ACGIH)	None Established
AEL *	(DuPont)	10 mg/m3, 8 Hr. TWA, total dust 5 mg/m3, 8 Hr. TWA, respirable dust

* AEL is DuPont's Acceptable Exposure Limit. Where governmentally imposed occupational exposure limits which are lower than the AEL are in effect, such limits shall take precedence.

PHYSICAL AND CHEMICAL PROPERTIES

Physical Data

Melting Point	None
% Volatiles	1% max
Solubility in Water	Insoluble
Odor	No odor
Form	Transparent film
Color	Light amber
Specific Gravity	>1.4

STABILITY AND REACTIVITY

Chemical Stability
Stable at normal temperatures and storage conditions.

Fluorocarbon coatings react with finely divided metal powders and fluorine and related compounds (e.g. chlorine trifluoride).

Decomposition
"Kapton" flurocarbon coatings may degrade at temperatures >350 deg C producing hydrogen fluoride and carbonyl fluorides.

(Continued)

The data in this Material Safety Data Sheet relates only to the specific material designated herein and does not relate to use in combination with any other material or in any process.

Responsibility for MSDS	"Kapton" Customer Service
Address	DuPont Circleville, OH
Telephone	800-237-4357

End of MSDS

DuPont

Engineering Polymers
Elastomers
Fluoroproducts
Packaging & Industrial Products

Dear Customer:

Enclosed are DuPont's Material Safety Data Sheets for the products you have purchased or inquired about.

Our Material Safety Data Sheets (MSDS) communicate important information about the safe handling of DuPont products, recommended protective measures, and health hazard information in compliance with the Occupational Safety & Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200), and status under certain Federal, State, and foreign regulations.

Our MSDS also includes the TSCA inventory status of product ingredients and lists ingredients that are on the Toxic Chemical List, and the concentrations at which they are present in compliance with the Superfund Amendments & Reauthorization Act of 1986, Title III (SARA), Section 313.

As part of DuPont's longstanding commitment to product safety, we provide MSDSs for all products, both hazardous and nonhazardous. An MSDS is sent to all customers with their initial order of a product, and with their next order after a MSDS is revised with significant new information. If you do not purchase directly from DuPont, your supplier should provide the MSDS to you.

You should provide the information contained in the enclosed MSDS to your employees, agents, contractors, distributors, and customers who handle, use, purchase, or otherwise may be exposed to the DuPont products described.

If you have questions regarding this Material Safety Data Sheet, please contact the person named on the last page of the MSDS. If you need a MSDS for other DuPont polymer products, please contact our MSDS Coordinator.

Sincerely,

DuPont Polymers
MSDS Coordinator
302-999-4586
P. O. BOX 80713
Wilmington, DE 19880-0713

Enclosure
12/93

Dulao, Erin

From: Dulao, Erin
Sent: Friday, December 05, 1997 10:45AM
To: Haynes, John
Subject: Dupont Price Hike

John, below is my call to arms, informing whoever you deem necessary of the severity of this price increase and maybe lighting a fire under some butts to get things done. What do you think?
Erin

Friends, Romans and Countrymen,
This is war...

The phone message that we received from Dupont will actualize itself as a huge price increase. Here is the damage report:

200FHN- from $59.88 to $64.64 per pound an 8% increase to the penny. This material goes into part # 74224-1 which goes into 57PSs, 77PSs and 87PSs to the tune of about 600 lbs a year. Translation, $2,874 increase.

[redacted] from $59.88 to $64.64 per pound an 8% increase to the penny. This material goes into part #27225-4 which goes into a lot of PSM devices (65, 66, 67 and 68), to the tune of about [redacted] a year. Translation, $8,143 increase.

600HND- from $59.88 to $65.64 per pound an 10% increase to the penny. This material goes into part #27225-5 which goes into the 59PS family at a thankfully small tune of about [illegible] lbs per year. Translation, $1,497.50 increase.

75.01
300FN929 - from $78.0? to $81.09 per pound an 4% increase. This material goes into part #27225-3 which goes into 91PSs, 92PSs, and 93PSs to the ever growing tune of about 50lbs per year. Translation, $151 increase.
300.50
[redacted] from $90.28 to $97.50 per pound an 8% increase to the penny. This material goes into part #27225-1 and 27225-2 which go into everything to the tune of [redacted] per year. Translation, $48,374 increase.

I saved the best for last. The final damage per year is close to $61,039.50. This does not include the price increases that we will surely be receiving from Insulfab who buys from Dupont and then gives us already cut parts.

TI Holland - 300FN929 - 441 lbs/yr $2,950.91
$2,951. increase

Insulfab us 200HN - 1,000 lbs/yr
Terry 500131 100 lbs/yr

2,874.00
1497.50
300.50
48,374.00
52,046.00

TI-NHTSA 017819

[redacted]

Effective January 1, 1998

DuPont

DuPont High Performance Films

Kapton® Polyimide Film
General

Kapton polyimide film is an exceptionally strong, heat resistant film with an excellent combination of mechanical and electrical properties. Kapton has been used successfully in various applications at temperatures from -269°C to 400°C. It is flame resistant, does not melt, resists effects of organic solvents and has a very high resistance to high-energy radiation.

Type HN: An all-purpose, uncoated film, with toughness and dielectric integrity at very high and very low temperatures.

Type HPP-ST: A special-purpose, uncoated film with all the properties of Type HN, surface treated for superior adhesion.

Type VN: An all-purpose, uncoated film with all the properties of Type HN, plus superior dimensional stability.

Type MT: A special-purpose uncoated film with thermal conductivity 2X that of standard Kapton.

Type FN: A Type HN film coated on one or both sides with Teflon® FEP fluorocarbon resin to impart heat sealability, provide a moisture barrier, and enhance chemical resistance.

Type XP: A Type HN film coated on one or both sides with Teflon PFA fluorocarbon resin to impart heat sealability, provide a moisture barrier, and enhance chemical resistance. The PFA coating is especially suited for applications requiring high bond strengths at elevated temperatures.

Please direct all inquiries and orders to:
Customer Service [illegible] or Product Information [illegible]

Pricing and Yield Information

Type	Gauge & Type	Nominal Thickness (mils)	Price [illegible]	Price [illegible]	Maximum Width (inches)	Standard Length [illegible]	Approximate Yield [illegible]
HN	30 HN	0.3	$ [illegible]	$ 1.[illegible]	[illegible]	N/A	[illegible]
	75 HN	[illegible]	$ 1[illegible]	$ 1.[illegible]	[illegible]	N/A	[illegible]
	100 HN	1.0	$ 71.50	$ 0.[illegible]	[illegible]	[illegible]	[illegible]
	200 HN	2.0	$ 71.50	$ 1.[illegible]	[illegible]	[illegible]	[illegible]
	300 HN	3.0	$ 71.50	$ 1.[illegible]	[illegible]	[illegible]	45
	500 HN	5.0	$ 73.[illegible]	$ 2.[illegible]	[illegible]	[illegible]	27
HPP-ST	100 HPP-ST	1.0	$ [illegible]	$ 0.[illegible]	[illegible]	[illegible]	136
	200 HPP-ST	2.0	$ [illegible]	$ 1.[illegible]	[illegible]	2500	[illegible]
	300 HPP-ST	3.0	$ 72.[illegible]	$ 1.[illegible]	[illegible]	1670	45
	500 HPP-ST	5.0	$ [illegible]	$ 2.[illegible]	[illegible]	1000	27
	400 HPP-ST	[illegible]	$ 1[illegible]	$ [illegible]	[illegible]	[illegible]	[illegible]
	700 HPP-ST	7.0	$ 1[illegible]	$ [illegible]	[illegible]	[illegible]	[illegible]
VN	100 VN	1.0	$ [illegible]	$ 0.[illegible]	[illegible]	[illegible]	136
	200 VN	2.0	$ 76.[illegible]	$ 1.11[illegible]	[illegible]	[illegible]	[illegible]
	300 VN	3.0	$ 76.[illegible]	$ 1.7[illegible]	[illegible]	1670	45
	500 VN	5.0	$ 81.[illegible]	$ [illegible]	[illegible]	[illegible]	27
MT	100 MT	1.0	$ [illegible]	$ 1.[illegible]	[illegible]	N/A	[illegible]
	150 MT	1.5	$ [illegible]	$ 1.[illegible]	[illegible]	N/A	72
	200 MT	2.0	$ [illegible]	$ 1.[illegible]	[illegible]	N/A	54
	300 MT	3.0	$ [illegible]	$ 2.[illegible]	[illegible]	N/A	36
FN	120 FN[illegible]	1.2	$ [illegible]	$ 0.[illegible]	44	[illegible]	[illegible]
	150 FN[illegible]	1.5	$ [illegible]	$ 1.31[illegible]	44	[illegible]	[illegible]
	200 FN[illegible]	2.0	$ [illegible]	$ 1.7[illegible]	44	[illegible]	[illegible]
	[illegible] FN[illegible]	2.0	$ [illegible]	$ 1.7[illegible]	44	[illegible]	[illegible]
	250 FN[illegible]	2.5	$ [illegible]	$ 1.[illegible]	44	2100	[illegible]
	300 FN[illegible]	3.0	$ [illegible]	$ 2.[illegible]	44	1670	[illegible]
	300 FN[illegible]	3.0	$ [illegible]	$ [illegible]	44	1670	[illegible]
	400 FN[illegible]	4.0	$ [illegible]	$ [illegible]	44	[illegible]	[illegible]
	400 FN[illegible]	4.0	$ 11[illegible]	$ [illegible]	44	[illegible]	[illegible]
	500 FN[illegible]	5.0	$ 11[illegible]	$ [illegible]	44	[illegible]	[illegible]
XP	150 XP[illegible]	1.5	$ 97.[illegible]	$ 1.[illegible]	44	[illegible]	77
	200 XP[illegible]	2.0	$ 97.[illegible]	$ 1.7[illegible]	44	[illegible]	54
	[illegible] XP[illegible]	[illegible]	$ 97.[illegible]	$ 1.[illegible]	44	[illegible]	[illegible]

* A 5% discount from the price applies to [illegible] films [illegible] less than [illegible] inches wide.
* Since a number of combinations of polyimide film and fluorocarbon coating add up to the same total gauge, it is necessary to distinguish among them. A three-digit system is used in which the middle digit represents the nominal thickness of the base Kapton film in mils. The first and third digits represent the nominal thickness of the coating of Teflon FEP or PFA fluorocarbon resin in mils. The symbol 9 is used to represent 1/2-mil, and 6 to represent 1/10-mil. Example: [illegible] is a 3-mil structure consisting of a 2-mil base film with 1 mil of Teflon on one side. [illegible] is a [illegible]-gauge structure consisting of a [illegible]-mil coating of Teflon on each side.

Kapton Polyimide Film General

Ordering Guide

Please specify quantity (either by length, area, number of rolls or weight), gauge, width and putup. A 10% premium will be added for nonstandard orders.

Standard Putups:	3/8-10 inches (13-254 mm) wide and standard length 10-1/16 inches (256 mm) to maximum width and 1x, 2x, or 4x standard length
Minimum Order:	• 30 and 50 gauge, 5 lbs. <5 lbs, $300/item setup charge • All other gauges, 50 lbs. <50 lbs, $300/item setup charge
Minimum Length:	1/4 standard length
Splices:	There may be 1 splice per standard length. Splice-free is available.
Minimum Width:	3/8 inch (9.5 mm). Narrower widths available upon request.
Width Increments:	For rolls 3/8 inches (9.5 mm): 1/64 inch (0.5 mm) For rolls 13/32-4 inches (10-102 mm): 1/32 inch (1 mm) For rolls 4-1/16 inches (103 mm) to maximum width: 1/16 inch (2 mm)
Width Tolerance:	For rolls 3/8-1-1/2 inches (9.5-38 mm) wide: 0.005 inch (0.125 mm) For rolls 1-17/32-4 inches (39-102 mm) wide: 1/32 inch (1 mm) For rolls 4-1/16 inches (103 mm) to maximum width: 1/16 inch (2 mm)
Area/Length Tolerance:	-0% to +5%
Weight Tolerance:	1-10 lbs, ± 20% 10.01-100 lbs, ± 10% > 100 lbs, ± 5%
Core Type:	6 inch (152 mm) ID paper or plastic is standard 3 inch (76 mm) paper is available but not recommended
Core Width Tolerance:	For rolls 3/8-4 inches (9.5-102 mm): -0 to +1/32 inch For rolls 4-1/16 inches (103 mm) to maximum width: -0 to +1/16 inch
Certification:	General grades of Kapton polyimide film are certified to meet the requirements of ASTM D-5213. Written confirmation is available upon request.
Terms:	All orders accepted subject to and sales made in accordance with our standard conditions of sale which are printed on the back of the invoice and order acknowledgment forms. Net 30 days from date of invoice. No discount for prior payment.
Payment:	Please send remittance with invoice number(s) and customer code to DuPont at the address shown at the bottom of the invoice. Invoices not paid when due are subject to a late payment service charge of 1-1/2% per month or the maximum allowable by law, whichever is lower.
Conditions:	Shipments are made F.O.B. destination, except Alaska, from our plants near Circleville, Ohio or Bayport, Texas. Orders already prepared are not subject to cancellation, alteration or deferment of shipment. All prices subject to change without notice. Orders will be billed at prices in effect on the date of shipment.

United States
DuPont High Performance Films
P.O. Box 89
Route 23 South and DuPont Road
Circleville, OH 43113
Customer Service: 800-967-5607
Product Information: 800-237-4357
Fax: 800-879-4481

Canada
DuPont Canada, Inc.
P.O. Box 2300, Streetsville
Mississauga, Ontario, Canada
L5M 2J3
Inquiries: (905) 821-5693
Customer Service: 800-363-6742
Fax: (905) 821-5230

Caution: Do not use in medical applications involving permanent implantation in the human body. For other medical applications, see "DuPont Medical Caution Statement," H-50102.

(6/97) [illegible]

DuPont High Performance Films

Kapton® polyimide film

TI-NHTSA 017823

Kapton® polyimide film possesses a unique combination of properties which make it ideal for a variety of applications in many different industries. The ability of Kapton® to maintain its excellent physical, electrical, and mechanical properties over a wide temperature range has opened new design and application areas to plastic films.

Kapton® is synthesized by polymerizing an aromatic dianhydride and an aromatic diamine. It has excellent chemical resistance; there are no known organic solvents for the film. Kapton® does not melt or burn as it has the highest UL-94 flammability rating: V-0. The outstanding properties of Kapton® permit it to be used at both high and low temperature extremes where other organic polymeric materials would not be functional.

Adhesives are available for bonding Kapton® to itself and to metals, various paper types, and other films.

Kapton® polyimide film can be used in a variety of electrical and electronic insulation applications: wire and cable tapes, formed coil insulation, substrates for flexible printed circuits, motor slot liners, magnet wire insulation, transformer and capacitor insulation, magnetic and pressure-sensitive tapes, and tubing. Many of these applications are based on the excellent balance of electrical, thermal, mechanical, physical, and chemical properties of Kapton® over a wide range of temperatures. It is this combination of useful properties at temperature extremes that makes Kapton® a unique industrial material.

Three types of Kapton® are described in this bulletin:

- Kapton® Type HN, all-polyimide film has been used successfully in applications at temperatures as low as −269°C (−452°F) and as high as 400°C (752°F). Type HN film can be laminated, metallized, punched, formed, or adhesive coated. It is available as 7.5 µm (0.3 mil), 12.5 µm (0.5 mil), 19 µm (0.75 mil), 25 µm (1 mil), 50 µm (2 mil), 75 µm (3 mil), and 125 µm (5 mil) films.
- Kapton® Type VN, all-polyimide film with all of the properties of Type HN, plus superior dimensional stability. Type VN is available as 12.5 µm (0.5 mil), 19 µm (0.75 mil), 25 µm (1 mil), 50 µm (2 mil), 75 µm (3 mil), and 125 µm (5 mil) films.
- Kapton® Type FN, a Type HN film coated on one or both sides with Teflon® FEP fluoropolymer resin, imparts heat sealability, provides a moisture barrier, and enhances chemical resistance. Type FN is available in a number of combinations of polyimide and Teflon® FEP thicknesses (see Table 16).

Note: In addition to these three types of Kapton®, films are available with the following attributes:

- antistat
- thermally conductive
- polyimides for fine line circuitry
- cryogenic insulation
- corona resistant
- pigmented for color
- conformable
- other films tailored to meet customers' needs

Data for these films are covered in separate product bulletins, which can be obtained from your DuPont representative.

The Chemical Abstracts Service Registry Number for Kapton® polyimide film is [25036-53-7].

TI-NHTSA 017824

Kapton® polyimide films retain their physical properties over a wide temperature range. They have been used in field applications where the environmental temperatures were as low as −269°C (−452°F) and as high as 400°C (752°F). Complete data are not available at these extreme conditions, and the majority of technical data presented in this section falls in the 23° to 200°C (73° to 392°F) range.

Table 1
Physical Properties of Kapton® Type 100 HN Film, 25 μm (1 mil)

Physical Property	Typical Value at 23°C (73°F)	Typical Value at 200°C (392°F)	Test Method
Ultimate Tensile Strength, MPa (psi)	231 (33,500)	139 (20,000)	ASTM D-882-91, Method A*
Yield Point at 3%, MPa (psi)	69 (10,000)	41 (6,000)	ASTM D-882-91
Stress to Produce 5% Elongation, MPa (psi)	90 (13,000)	61 (9,000)	ASTM D-882-91
Ultimate Elongation, %	72	83	ASTM D-882-91
Tensile Modulus, GPa (psi)	2.5 (370,000)	2.0 (290,000)	ASTM D-882-91
Impact Strength, N·cm (ft·lb)	78 (0.58)		DuPont Pneumatic Impact Test
Folding Endurance (MIT), cycles	285,000		ASTM D-2176-89
Tear Strength—Propagating (Elmendorf), N (lbf)	0.07 (0.02)		ASTM D-1922-89
Tear Strength—Initial (Graves), N (lbf)	7.2 (1.6)		ASTM D-1004-90
Density, g/cc or g/mL	1.42		ASTM D-1505-90
Coefficient of Friction—Kinetic (Film-to-Film)	0.48		ASTM D-1894-90
Coefficient of Friction—Static (Film-to-Film)	0.63		ASTM D-1894-90
Refractive Index (Sodium D Line)	1.70		ASTM D-542-90
Poisson's Ratio	0.34		Avg. Three Samples Elongated at 5%, 7%, 10%
Low Temperature Flex Life	Pass		IPC TM 650, Method 2.6.18

*Specimen Size: 25 × 150 mm (1 × 6 in); Jaw Separation: 100 mm (4 in); Jaw Speed: 50 mm/min (2 in/min); Ultimate refers to the tensile strength and elongation measured at break.

Table 2
Thermal Properties of Kapton® Type 100 HN Film, 25 μm (1 mil)

Thermal Property	Typical Value	Test Condition	Test Method
Melting Point	None	None	ASTM E-794-85 (1989)
Thermal Coefficient of Linear Expansion	20 ppm/°C (11 ppm/°F)	−14 to 38°C (7 to 100°F)	ASTM D-696-91
Coefficient of Thermal Conductivity, W/m·K	0.12	296 K	ASTM F-433-77 (1987)
$\frac{cal}{cm \cdot sec \cdot °C}$	2.87 × 10⁻⁴	23°C	
Specific Heat, J/g·K (cal/g·°C)	1.09 (0.261)		Differential Calorimetry
Flammability	94V-0		UL-94 (2-8-85)
Shrinkage, %	0.17 1.25	30 min at 150°C 120 min at 400°C	IPC TM 650, Method 2.2.4A ASTM D-5214-91
Heat Sealability	Not Heat Sealable		
Limiting Oxygen Index, %	37		ASTM D-2863-87
Solder Float	Pass		IPC TM 650, Method 2.4.13A
Smoke Generation	DM = <1	NBS Smoke Chamber	NFPA-258
Glass Transition Temperature (T_g)	A second order transition occurs in Kapton® between 360°C (680°F) and 410°C (770°F) and is assumed to be the glass transition temperature. Different measurement techniques produce different results within the above temperature range.		

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Table 3
Physical and Thermal Properties of Kapton® Type VN Film

Property	Typical Value for Film Thickness 25 µm (1 mil)	50 µm (2 mil)	75 µm (3 mil)	125 µm (5 mil)	Test Method
Ultimate Tensile Strength, MPa (psi)	231 (33,500)	234 (34,000)	231 (33,500)	231 (33,500)	ASTM D-882-91
Ultimate Elongation, %	72	82	82	82	ASTM D-882-91
Tear Strength—Propagating (Elmendorf), N	0.07	0.21	0.38	0.58	ASTM D-1922-89
Tear Strength—Initial (Graves), N	7.2	16.3	26.3	46.9	ASTM D-1004-90
Folding Endurance (MIT), × 10³ cycles	285	55	6	5	ASTM D-2176-89
Density, g/cc or g/mL	1.42	1.42	1.42	1.42	ASTM D-1505-90
Flammability	94V-0	94V-0	94V-0	94V-0	UL-94 (2-8-85)
Shrinkage, %, 30 min at 150°C (302°F)	0.03	0.03	0.03	0.03	IPC TM 650 Method 2.2.4A
Limiting Oxygen Index, %	37	43	46	45	ASTM D-2863-87

Table 4
Physical Properties of Kapton® Type FN Film*

Property	Typical Value for Film Type** 120FN616	150FN019	250FN029
Ultimate Tensile Strength, MPa (psi)			
23°C (73°F)	207 (30,000)	162 (23,500)	200 (29,000)
200°C (392°F)	121 (17,500)	89 (13,000)	115 (17,000)
Yield Point at 3%, MPa (psi)			
23°C (73°F)	61 (9,000)	49 (7,000)	59 (8,500)
200°C (392°F)	41 (6,000)	43 (6,000)	35 (5,000)
Stress at 5% Elongation, MPa (psi)			
23°C (73°F)	79 (11,500)	65 (9,500)	78 (11,000)
200°C (392°F)	55 (8,000)	41 (6,000)	48 (7,000)
Ultimate Elongation, %			
23°C (73°F)	75	70	85
200°C (392°F)	80	75	110
Tensile Modulus, GPa (psi)			
23°C (73°F)	2.48 (360,000)	2.21 (320,000)	2.62 (380,000)
200°C (392°F)	1.62 (235,000)	1.14 (165,000)	1.38 (200,000)
Impact Strength at 23°C (73°F), N·cm (ft·lb)	78 (0.58)	68.6 (0.51)	156.8 (1.16)
Tear Strength—Propagating (Elmendorf), N (lbf)	0.08 (0.02)	0.47 (0.11)	0.57 (0.13)
Tear Strength—Initial (Graves), N (lbf)	11.5 (2.6)	11.5 (2.6)	17.8 (4.0)
Polyimide, wt %	80	57	73
FEP, wt %	20	43	27
Density, g/cc or g/mL	1.53	1.67	1.57

* Test methods for Table 4 are the same as for Table 1.

** Because a number of combinations of polyimide film and fluorocarbon coating add up to the same total gauge, it is necessary to distinguish among them. A three-digit system is used in which the middle digit represents the nominal thickness of the base Kapton® film in mils. The first and third digits represent the nominal thickness of the coating of Teflon® FEP fluoropolymer resin in mils. The symbol 9 is used to represent 13 µm (0.5 mil) and 6 to represent 2.5 µm (0.1 mil). Example: 120FN616 is a 120-gauge structure consisting of a 25 µm (1 mil) base film with a 2.5 µm (0.1 mil) coating of Teflon® on each side.

TI-NHTSA 017827

The usual values of tensile strength, tensile modulus, and ultimate elongation at various temperatures can be obtained from the typical stress–strain curves shown in Figures 1 and 2. Such properties as tensile strength and modulus are inversely proportional to temperature, whereas elongation reaches a maximum value at about 300°C (570°F). Other factors, such as humidity, film thickness, and tensile elongation rates were found to have only a negligible effect on the shape of the 23°C (73°F) curve.

Figure 1. Tensile Stress–Strain Curves, Type HN Film, 25 µm (1 mil)

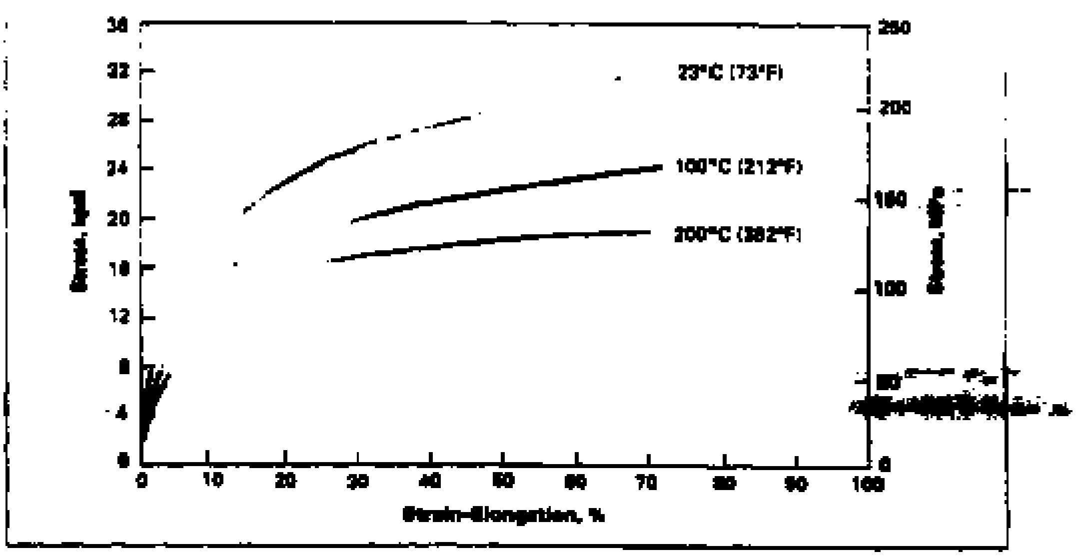
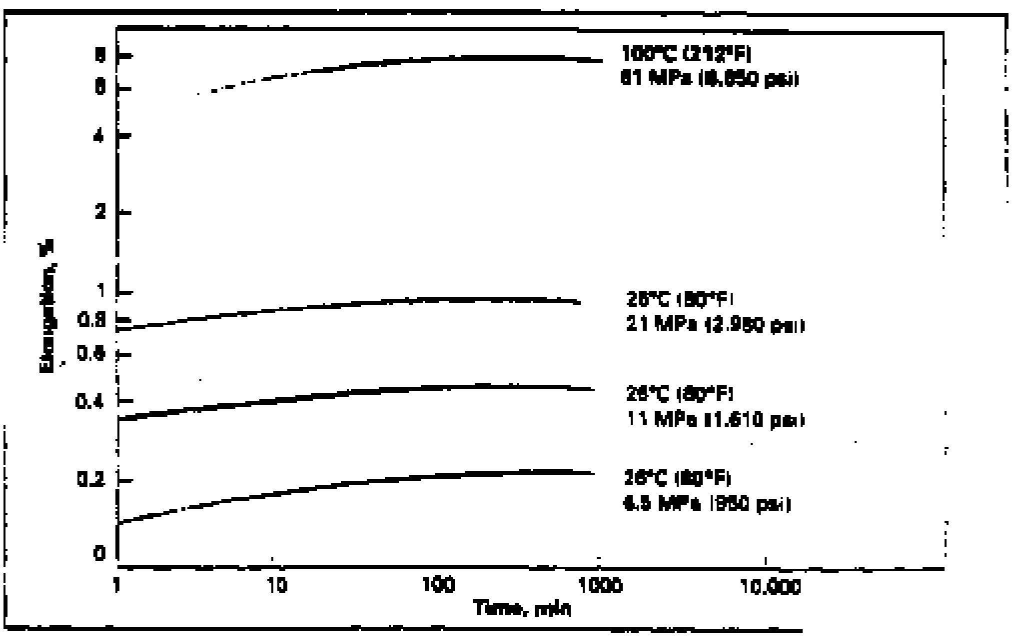


Figure 2. Tensile Creep Properties, Type HN Film, 25 µm (1 mil)



TI-NHTSA 017828

Kapton polyimide film is made by a condensation reaction; therefore, its properties are affected by water. Although long-term exposure to boiling water, as shown in the curves in Figures 3 and 4, will reduce the level of film properties, sufficient tensile and elongation remain to ensure good mechanical performance. A decrease in the temperature and the water content will reduce the rate of Kapton property reduction, whereas higher temperature and pressure will increase it.

Figure 3. Tensile Strength After Exposure to 100°C (212°F) Water, Type HN Film, 25 μm (1 mil)

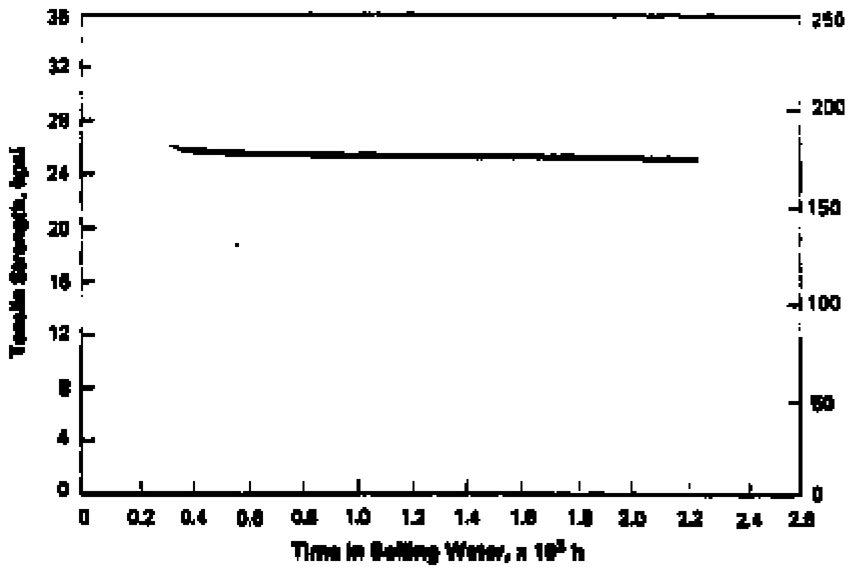
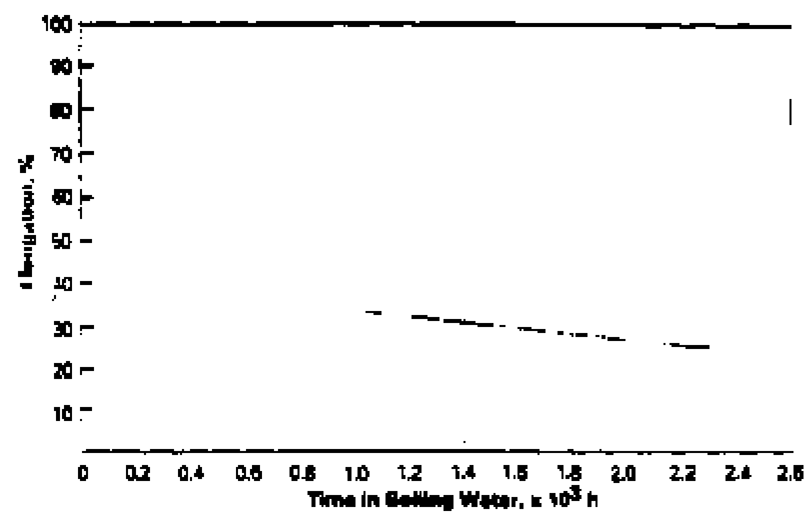


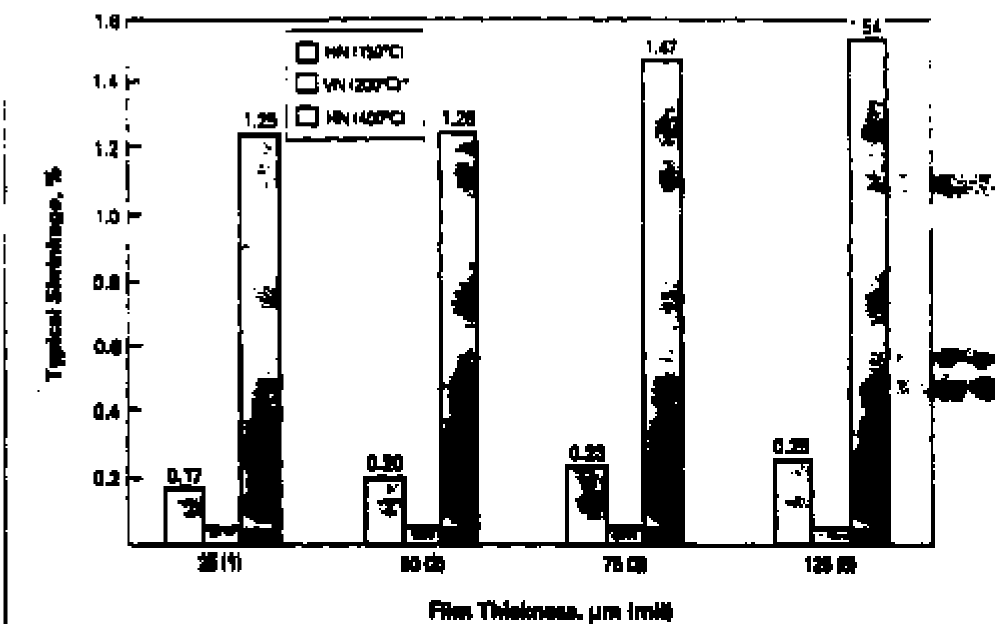
Figure 4. Ultimate Elongation After Exposure to 100°C (212°F) Water, Type HN Film, 25 μm (1 mil)



TI-NHTSA 017829

The dimensional stability of Kapton® polyimide film depends on two factors—the normal coefficient of thermal expansion and the residual stresses placed in the film during manufacture. The latter causes Kapton® to shrink on its first exposure to elevated temperatures as indicated in the bar graph in Figure 5. Once the film has been exposed, the normal values for the thermal coefficient of linear expansion as shown in Table 5 can be expected.

Figure 6. Residual Shrinkage vs. Exposure Temperature and Thickness, Type HN and VN Films



*Type VN shrinkage is 0.03% for all thicknesses.

Table 5
Thermal Coefficient of Expansion
Type HN Film, 25 µm (1 mil)
Thermally Exposed

Temperature Range, °C (°F)	ppm/°C
23–100 (73–212)	16
100–200 (212–392)	31
200–300 (392–572)	48
300–400 (572–752)	78
23–400 (73–752)	45

TI-NHTSA 017630

The useful life of Kapton* polyimide film is a function of both temperature and oxygen concentration. In accordance with UL-746B test procedures, the thermal life of Kapton* was determined at various temperatures. At time zero and 325°C (617°F), the tensile strength is 234 MPa (34,000 psi) and the elongation is 67%. The results are shown in Figures 6–8

Figure 6. Tensile Strength vs. Aging in Air at 325°C (617°F), Type HN Film, 25 µm (1 mil)

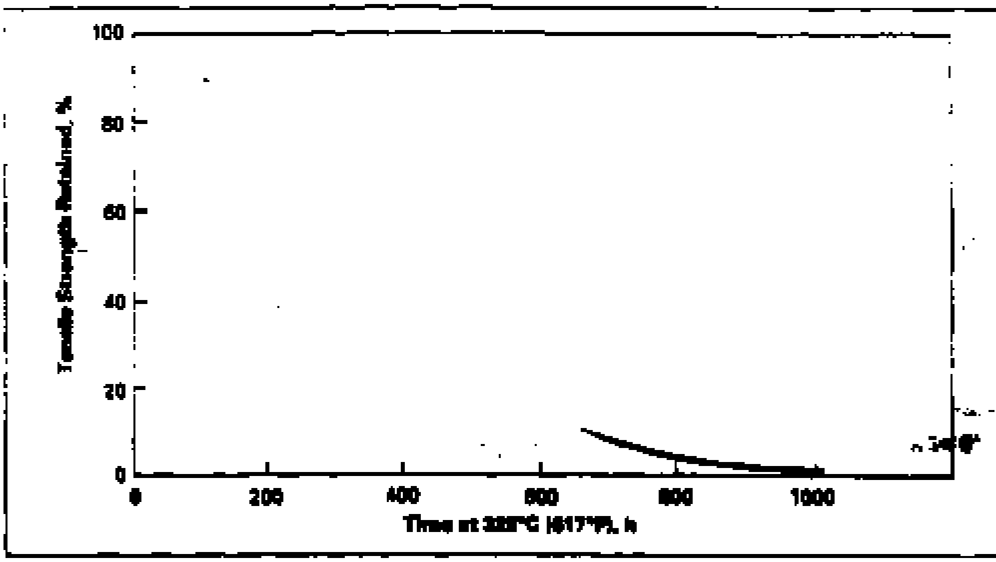


Figure 7. Ultimate Elongation vs. Aging in Air at 325°C (617°F), Type HN Film, 25 µm (1 mil)

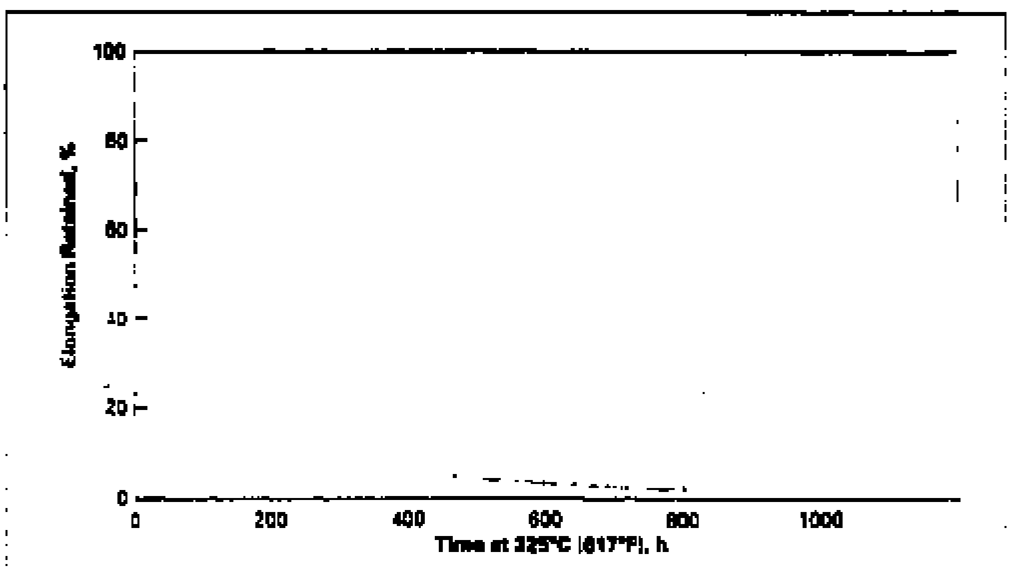


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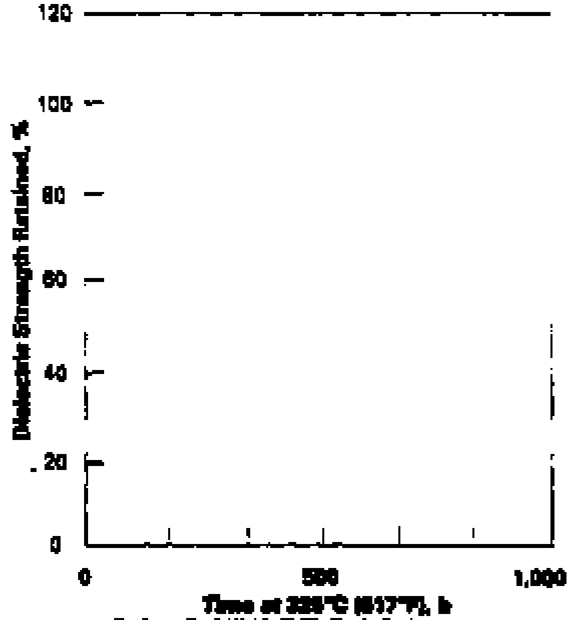
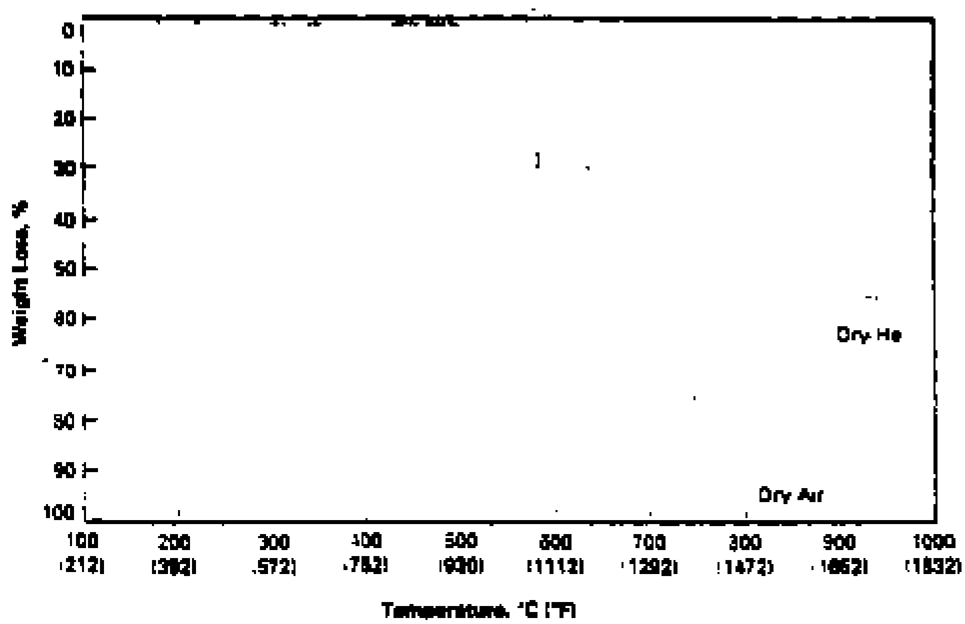
Figure 8. Retained Dielectric Strength at 325°C (617°F) for 25 μm (1 mil) Film. Test Method UL-746B



The life of Kapton® polyimide film at high temperature is significantly extended in a low-oxygen environment. Kapton® is subject to oxidative degradation. Hence, when it was tested in a helium environment, its useful life was at least an order of magnitude greater than in air. Using a DuPont 1090 thermal analyzer system, the weight loss characteristics of Kapton® in air and helium at elevated temperatures are shown in Figures 9 and 10.

Figure 9. Weight Loss, Type HN Film, 25 μm (1 mil)*



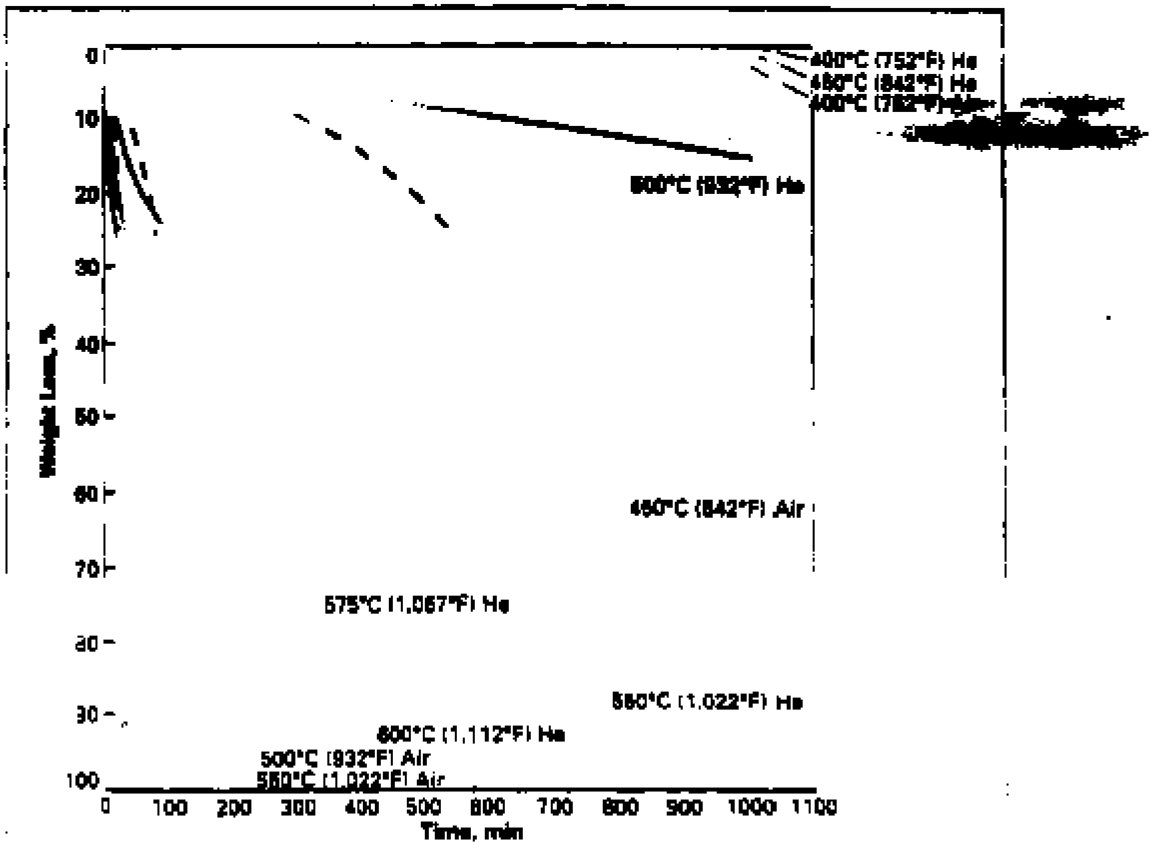
*Rate of temperature rise in °C (°F) was 3°C/min (5.4°F/min).

TI-NHTSA 017832

Table 6
Time Required for Reduction in Ultimate Elongation from 70% to 1%
Type HN Film, 25 µm (1 mil)

Temperature	Air Environment
450°C (840°F)	2 hours
425°C (800°F)	5 hours
400°C (750°F)	12 hours
375°C (710°F)	2 days
350°C (660°F)	6 days
325°C (620°F)	1 month
300°C (570°F)	3 months
275°C (530°F)	1 year
250°C (480°F)	8 years

Figure 10. Isothermal Weight Loss, Type HN Film, 25 µm (1 mil)



The most common electrical properties of Kapton® polyimide film of various gauges are shown in Tables 6 and 7. These values were measured at 23°C (73°F) and 50% relative humidity. The effect of such factors as humidity, temperature, and frequency on these basic values can be found in Table 9 and Figures 11–13.

Table 7
Typical Electrical Properties of Kapton® Types HN and VN Films

Property Film Gauge	Typical Value		Test Condition	Test Method
Dielectric Strength	V/µm (kV/mm)	V/mil	60 Hz	ASTM D-149-81[a]
25 µm (1 mil)	303	(7,700)	1/4" electrodes	
50 µm (2 mil)	240	(6,100)	500 V/sec rise	
75 µm (3 mil)	205	(5,200)		
125 µm (5 mil)	154	(3,900)		
Dielectric Constant			1 kHz	ASTM D-150-81
25 µm (1 mil)	3.4			
50 µm (2 mil)	3.4			
75 µm (3 mil)	3.5			
125 µm (5 mil)	3.5			
Dissipation Factor			1 kHz	ASTM D-150-81
25 µm (1 mil)	0.0018			
50 µm (2 mil)	0.0020			
75 µm (3 mil)	0.0020			
125 µm (5 mil)	0.0026			
Volume Resistivity	Ω·cm			ASTM D-257-61
25 µm (1 mil)	1.5×10^{17}			
50 µm (2 mil)	1.5×10^{17}			
75 µm (3 mil)	1.4×10^{17}			
125 µm (5 mil)	1.0×10^{17}			

Table 8
Typical Electrical Properties of Kapton® Type FN Film

Property	120FN616	150FN019	250FN029
Dielectric Strength, V/µm (V/mil)	272 (6,900)	197 (5,000)	157 (4,000)
Dielectric Constant	3.1	2.7	3.0
Dissipation Factor	0.0015	0.0013	0.0013
Volume Resistivity, Ω·cm			
at 23°C (73°F)	1.4×10^{17}	2.3×10^{17}	1.9×10^{17}
at 200°C (392°F)	4.4×10^{14}	3.6×10^{15}	3.7×10^{14}

TI-NHTSA 017834

Because the water content of Kapton polyimide film can affect its electrical properties, electrical measurements were made on 25 um (1 mil) film after exposure to environments of varying relative humidities at 23°C (73°F). The results of these measurements are shown in Table 9 and Figures 11–13.

Table 9
Relative Humidity vs. Electrical Properties of Kapton *
Type HN Film, 25 um (1 mil)

Relative Humidity, %	Dielectric Strength (AC) V/um (kV/mm)	Dielectric Strength (AC) V/mil	Dielectric Constant	Dissipation Factor
0	339	8600	3.0	0.0015
30	315	8000	3.3	0.0017
50	303	7700	3.5	0.0020
80	280	7100	3.7	0.0027
100	[illegible]	[illegible]	3.8	[illegible]

*For calculations involving absolute water content, 50% RH in our study is equal to 1.8% water in the film, and 100% RH is equal to 2.8% water, the maximum adsorption possible regardless of the driving force.

Figure 11. AC Dielectric Strength vs. Relative Humidity, Type HN Film, 25 um (1 mil)

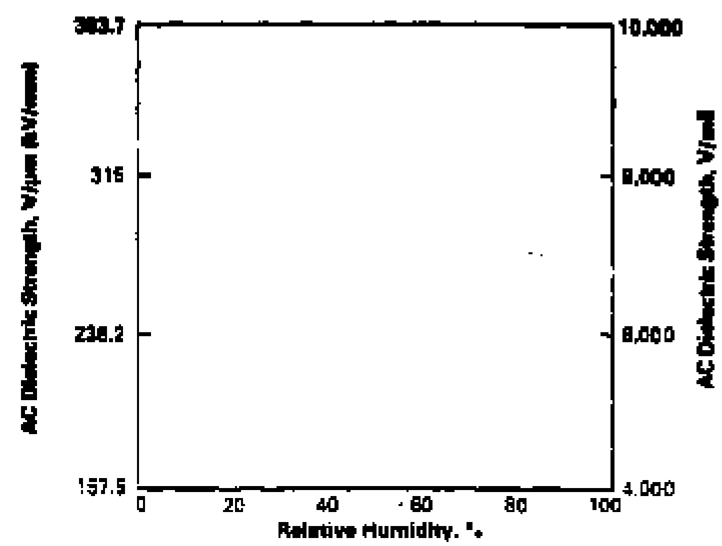


Figure 12. Dissipation Factor vs. Relative Humidity, Type HN Film, 25 μm (1 mil)

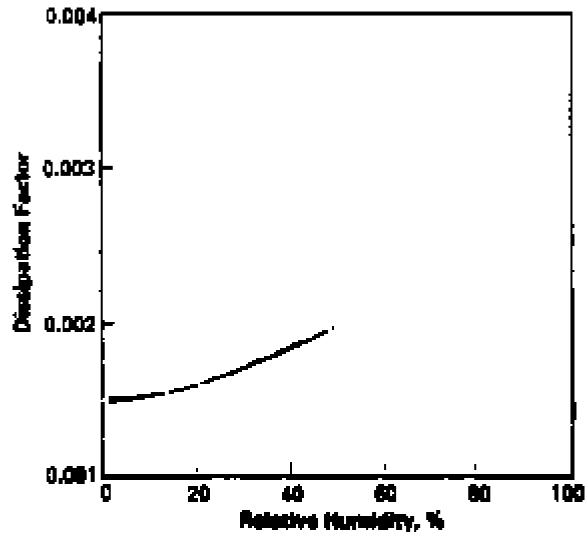
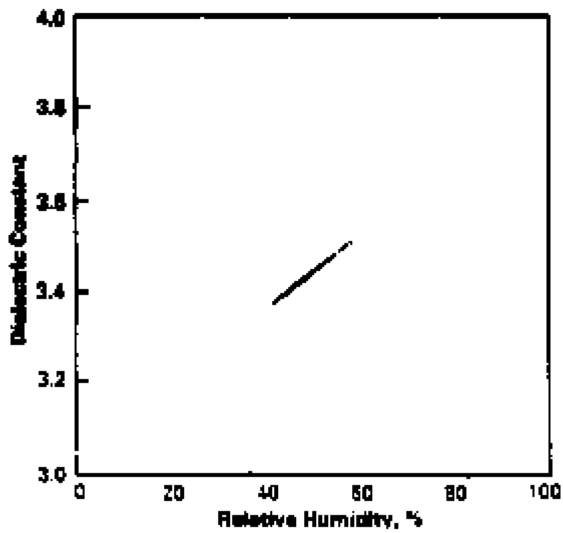


Figure 13. Dielectric Constant vs. Relative Humidity, Type HN Film, 25 μm (1 mil)



TI-NHTSA 017836

As Figures 14–17 indicate, extreme changes in temperature have relatively little effect on the excellent room temperature electrical properties of Kapton polyimide film.

Figure 14. AC Dielectric Strength vs. Temperature, Type HN Film, 25 µm (1 mil)

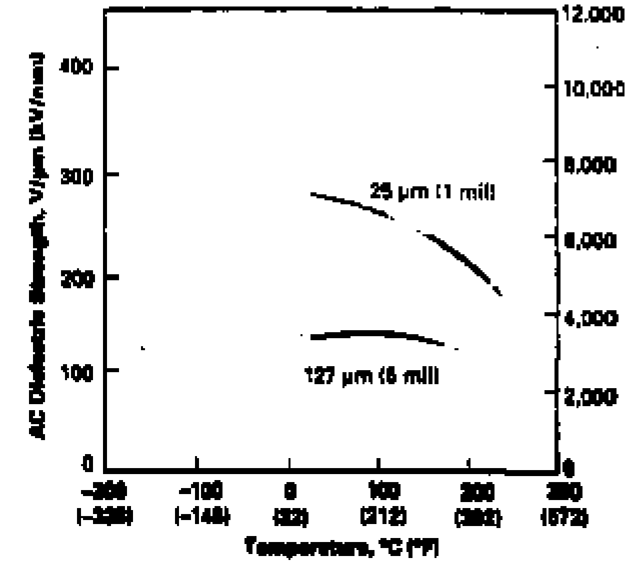
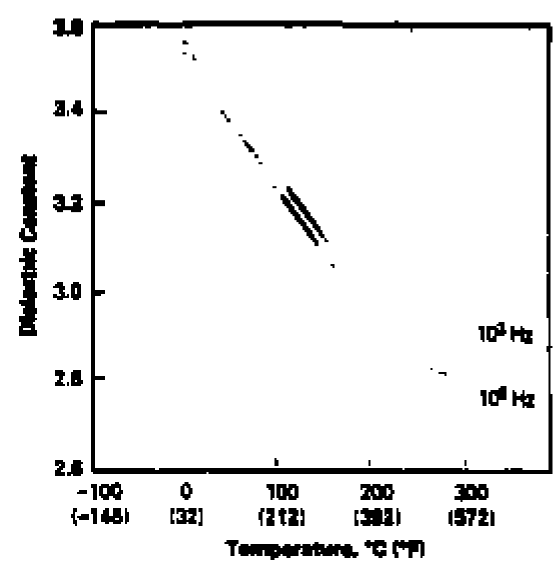


Figure 15. Dielectric Constant vs. Temperature, Type HN Film, 25 µm (1 mil)



TI-NHTSA 017837

Figure 16. Dissipation Factor vs. Temperature, Type HN Film, 25 µm (1 mil)

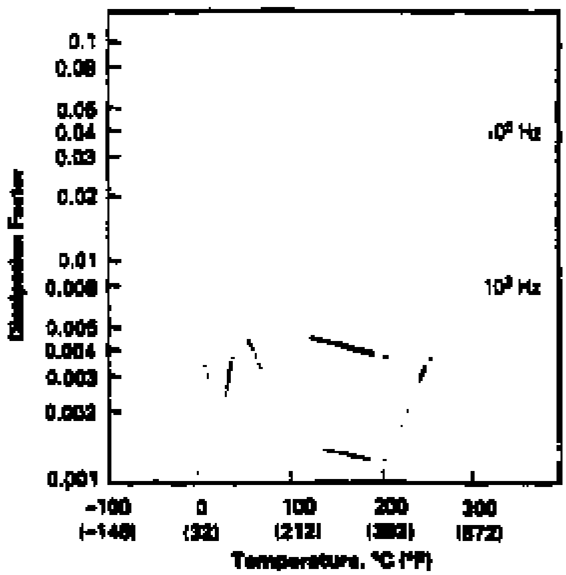
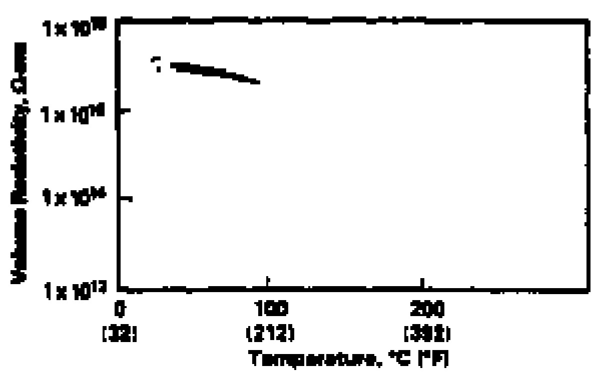


Figure 17. Volume Resistivity vs. Temperature, Type HN Film, 25 µm (1 mil)



TI-NHTSA 017838

The effect of frequency on the values of the dielectric constant and dissipation factor at various isotherms are shown in Figures 18 and 19 for Type HN film, 25 µm (1 mil); and in Figures 20 and 21 for HN, 125 µm (5 mil).

Figure 18. Dielectric Constant vs. Frequency, Type HN Film, 25 µm (1 mil)

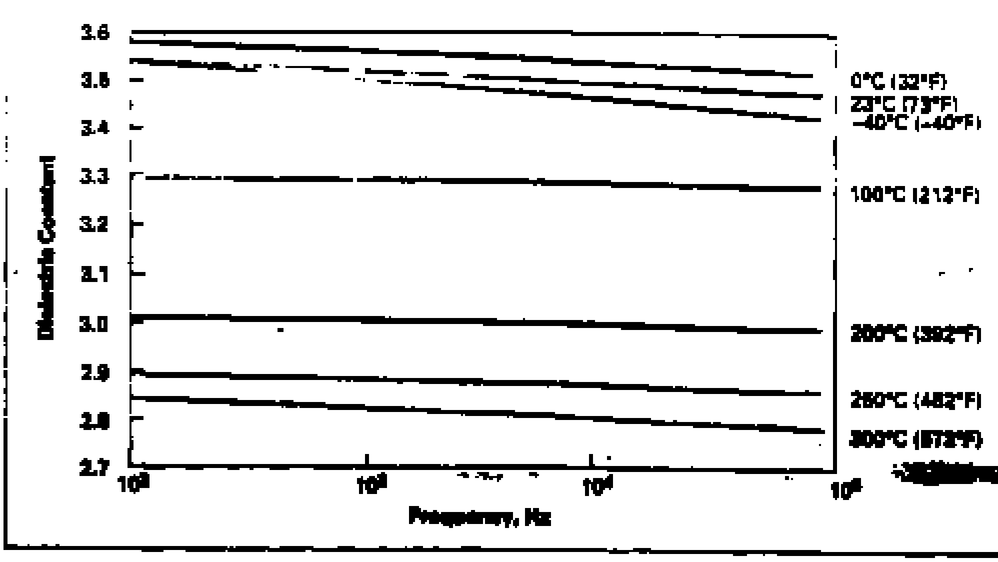
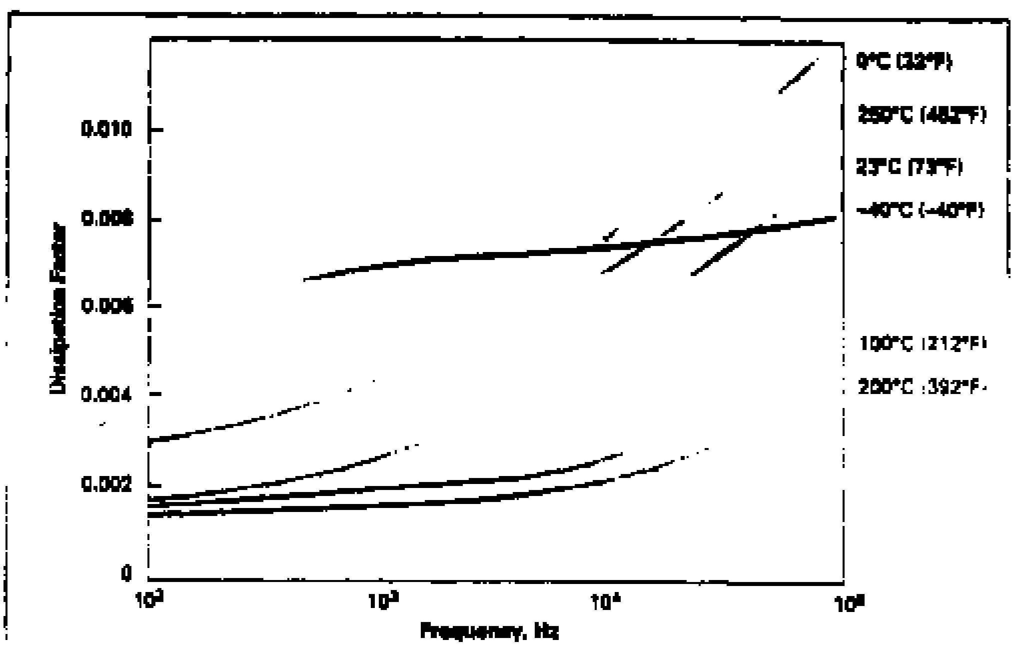


Figure 19. Dissipation Factor vs. Frequency, Type HN Film, 25 µm (1 mil)



TI-NHTSA 017839

Figure 20. Dielectric Constant vs. Frequency, Type HN Film, 125 μm (5 mil)*

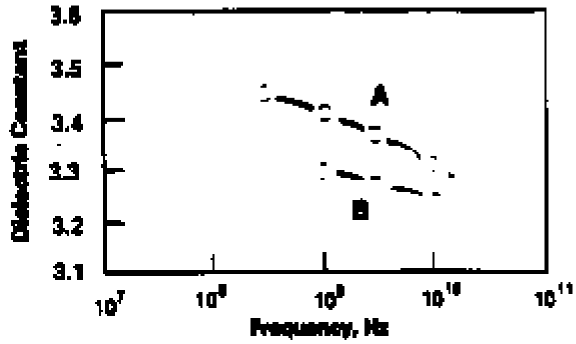
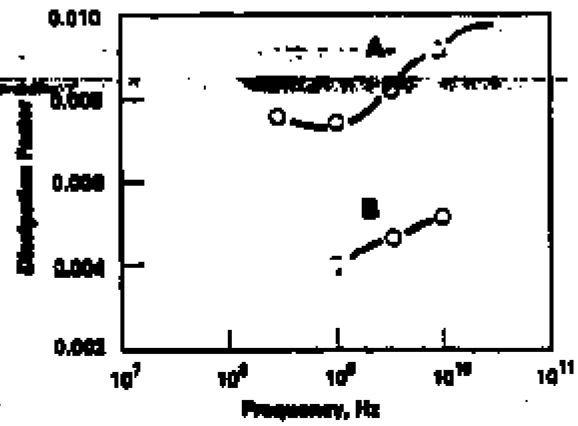


Figure 21. Dissipation Factor vs. Frequency, Type HN Film, 125 μm (5 mil)*



*Technical Report AFML-TR-72-39—Curve A is 500H Kapton® as received and measured at 25°C (77°F) and 45% RH with the electric field in the plane of the sheet. Curve B is the same measurement after conditioning the film at 100°C (212°F) for 48 hours. Performance of 500HN is believed to be equivalent to 500H.

TI-NHTSA 017840

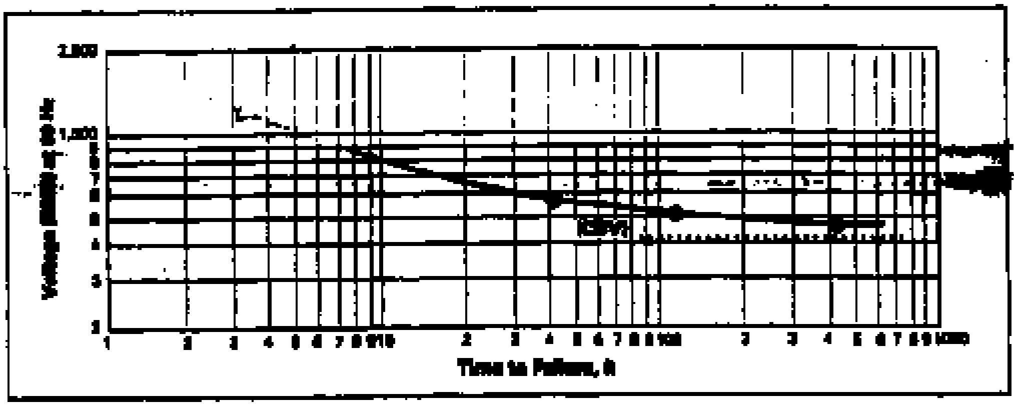
Corona

Like all organic materials, Kapton* is attacked by a corona discharge, and when exposed continuously to it will ultimately fail dielectrically. At moderate levels of corona exposure, devices insulated with Kapton* have survived up to 3,000 h, giving reasonable assurance that brief exposure to a corona will not significantly affect the life of a properly designed insulation system based on Kapton*.

Corona threshold voltage and intensity are functions of many parameters, including insulation thickness, air gap thickness, and device shape. Consult with a DuPont technical representative on the suitability of Kapton* for specific applications where a corona may be present.

Figure 22 shows the life for 25 µm (1 mil) Kapton* HN polyimide film as a function of voltage (RMS) at 60 Hz. As the corona starting level is approached, the Kapton* life curve flattens, indicating a long life. It should be emphasized that the superior thermal and moisture-proof capabilities of Kapton* insulated magnet wire, wrappers, and slot insulation can be utilized without fear of corona in properly designed systems. Kapton* can be used alone or in combination with other insulation materials.

Figure 22. Voltage Endurance of 100HN Kapton* Polyimide Film*



*Corona Starting Voltage (CSV) = 425 V

Chemical Properties

Typical chemical properties of Kapton® Types HN and FN films are given in Tables 10 and 11. The chemical properties of Type VN film are similar to those of Type HN.

Table 10
Chemical Properties of Kapton® Type HN Film, 25 μm (1 mil)

Property	Typical Value: Tensile Retained, %	Typical Value: Elongation Retained, %	Test Condition	Test Method
Chemical Resistance				
Isopropyl Alcohol	99	94	10 min at 23°C	IPC TM-650 Method 2.3.2
Toluene	99	91		
Methyl Ethyl Ketone	99	90		
Methylene Chloride/ Trichloroethylene (1:1)	98	86		
2 N Hydrochloric Acid	98	80		
2 N Sodium Hydroxide	83	54		[illegible]
Fungus Resistance	Nonnutrient			IPC TM-650 Method 2.6.9
Moisture Absorption	1.8% Types HN and VN		50% RH at 23°C	ASTM D-570-81 (1988)
	2.8% Types HN and VN		Immersion for 24 h at 23°C (73°F)	
Hygroscopic Coefficient of Expansion	22 ppm/% RH		23°C (73°F), 20–80% RH	[illegible]
Permeability				
Gas	mL/m²·24 h·MPa	cc/(100 in²·24 h·atm)	23°C (73°F), 50% RH	ASTM D-1434-82 (1988)
Carbon Dioxide	6,840	45		
Oxygen	3,800	25		
Hydrogen	38,000	250		
Nitrogen	910	6		
Helium	63,080	415		
Vapor	g/(m²·24 h)	g/(100 in²·24 h)		ASTM E-96-92
Water	54	3.6		

Table 11
Chemical Properties of Kapton® Type FN Films

Property	120FN616	150FN019	400FN022
Moisture Absorption, %			
at 23°C (73°F), 50% RH	1.3	0.8	0.4
98% RH	2.5	1.7	1.2
Water Vapor Permeability,			
g/(m²·24 h)	17.5	9.6	2.4
g/(100 in²·24 h)	1.13	0.62	0.16

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Radiation Resistance

Because of its excellent radiation resistance, Kapton® is frequently used in high radiation environments where a flexible insulating material is required. In outer space, Kapton® is used both alone and in combination with other materials for applications that require radiation resistance at minimum weight. U.S. Government laboratory test data on gamma and neutron radiation exposure of Kapton® are summarized in Tables 12 and 13.

Testing the suitability of Kapton® for nuclear reactors and linear accelerators involves exposure to an adverse chemical environment in addition to radiation. For example, loss of coolant accident (LOCA) tests for qualification in containment areas in nuclear power plants expose the system to steam and sodium hydroxide, both of which tend to degrade Kapton®.

Accordingly, when Kapton® is used in nuclear power systems that require certification to IEEE-323 and -383, engineered designs that protect Kapton® from direct exposure to LOCA sprays are required.

The excellent ultraviolet resistance of Kapton® in the high vacuum of outer space is demonstrated by the data in Table 14. In the earth's atmosphere, however, there is a synergistic effect upon Kapton® if it is directly exposed to some combinations of ultraviolet radiation, oxygen, and water. Figure 23 shows this effect as a loss of elongation when Kapton® was exposed in Florida test panels. Figure 24 shows the loss of elongation as a function of exposure time in an Atlas Weatherometer. Design considerations should recognize this phenomenon.

Table 12
Effect of Gamma Radiation Exposure on Kapton® Polyimide Film (Cobalt 60 Source, Oak Ridge)

Property	Control 1 mil Film	10^4 Gy 1 h	10^5 Gy 10 h	10^6 Gy 4 d	10^7 Gy 42 d
Tensile Strength, MPa (psi × 10^3)	207 (30)	207 (30)	214 (31)	214 (31)	152 (22)
Elongation, %	80	78	78	79	42
Tensile Modulus, MPa (psi × 10^3)	3172 (460)	3275 (475)	3378 (490)	3275 (475)	2903 (421)
Volume Resistivity Ω-cm × 10^{15} at 200°C (392°F)	4.8	6.6	5.2	1.7	1.6
Dielectric Constant 1 kHz at 23°C (73°F)	3.46	3.54	3.63	3.71	3.50
Dissipation Factor 1 kHz at 23°C (73°F)	0.0020	0.0023	0.0024	0.0037	0.0029
Dielectric Strength V/μm (kV/mm)	256	223	218	221	254

Table 13
Effect of Electron Exposure on Kapton® Polyimide Film Mixed Neutron and Gamma

	5 × 10^7 Gy	10^8 Gy
5 × 10^{12} neutrons/cm²/s Flux at 175°C (347°F)	Film Darkened	Film Darkened and Tough

Table 14
Effect of Ultraviolet Exposure on Kapton® Polyimide Film*

	1000 h Exposure
Tensile Strength, % of Initial Value Retained	100
Elongation, % of Initial Value Retained	74

*Vacuum environment, 2 x 10[illegible] mm Hg at 50°C (122°F). UV intensity equal to space sunlight to 2500Å.

Figure 23. Effect of Florida Aging on Kapton® Polyimide Film

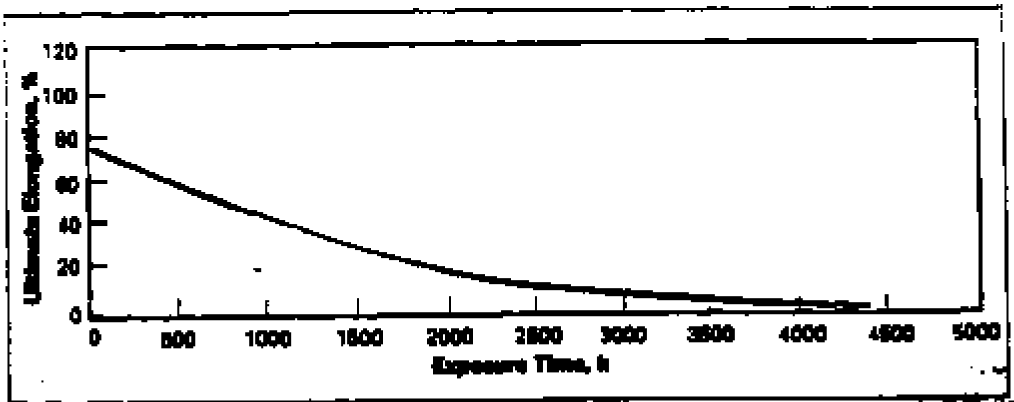
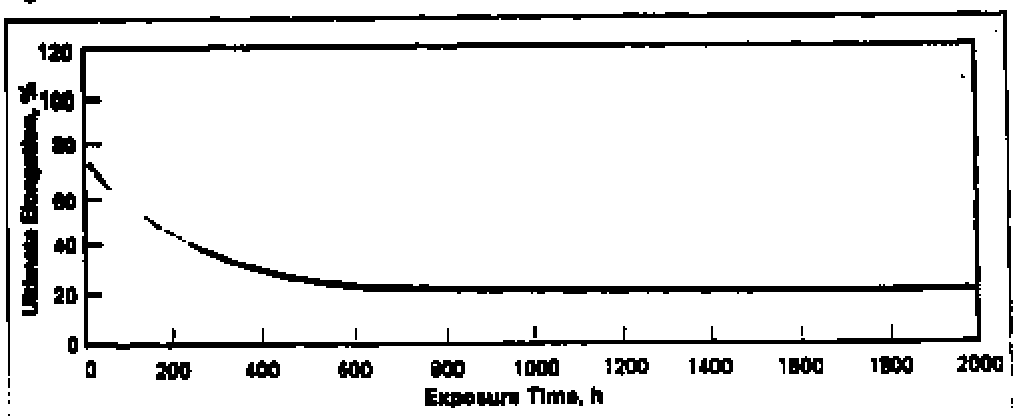


Figure 24. Effect of Weathering on Kapton® Polyimide Film (Atlas Weatherometer)



TI-NHTSA 017844

Kapton Film Type Information

Table 15
Type and Thickness

Type	Nominal Thickness µm	Nominal Thickness mil	Area Factor m²/kg	Area Factor ft²/lb
30HN	7.6	0.3	93	455
50HN	12.7	0.5	56	272
75HN	19.1	0.75	37	181
100HN	25.4	1.0	28	136
200HN	50.8	2.0	14	68
300HN	76.2	3.0	9.2	45
500HN	127	5.0	5.6	27
50VN	12.7	0.5	56	272
75VN	19.1	0.75	37	181
100VN	25.4	1.0	28	136
200VN	50.8	2.0	14	68
300VN	76.2	3.0	9.2	45
500VN	127	5.0	5.6	27
100FN099	25.4	1.0	23	116
120FN616	30.5	1.2	21	104
150FN999	38.1	1.5	14	68
150FN019	38.1	1.5	18	77
200FN011	50.8	2.0	11	54
200FN919	50.8	2.0	11	54
250FN029	63.5	2.5	10	49
300FN021	76.2	3.0	8.8	39
300FN929	76.2	3.0	[illegible]	[illegible]
400FN022	101.6	4.0	5.8	27
400FN031	101.6	4.0	6.1	30
500FN131	127	5.0	4.7	23
600FN051	152.4	6.0	4.3	21

Nominal Construction, Type FN

In the Kapton® Type FN order code of three digits, the middle digit represents the nominal thickness of the base Kapton® in mils. The first and third digits represent the nominal thickness of the coating of Teflon® FEP fluoropolymer resin in mils. The symbol 9 is used to represent 12.7 µm (0.5 mil) and 6 to represent 2.54 µm (0.1 mil). Example: 120FN616 is a 120-gauge structure consisting of a 25.4 µm (1 mil) base film with a 2.54 µm (0.1 mil) coating of Teflon® on each side. Illustrated in Table 16 are several examples of the many film types available.

Table 16
Type FN Film Constructions

Type	Construction: FEP µm	FEP mil	HN µm	HN mil	FEP µm	FEP mil
100FN099			12.7	0.50	12.7	0.50
120FN616	2.54	0.10	25.4	1.00	2.54	0.10
150FN999	12.7	0.50	12.7	0.50	12.7	0.50
150FN019			25.4	1.00	12.7	0.50
200FN011			25.4	1.00	25.4	1.00
200FN919	12.7	0.50	25.4	1.00	12.7	0.50
250FN029			50.8	2.00	12.7	0.50
300FN021			50.8	2.00	25.4	1.00
300FN929	12.7	0.50	50.8	2.00	12.7	0.50
400FN022			50.8	2.00	50.8	2.00
400FN031			76.2	3.00	25.4	1.00
500FN131	25.4	1.00	76.2	3.00	25.4	1.00
600FN051			127	5.00	25.4	1.00

Safety and Handling

Unheated Kapton® polyimide film is insoluble in most common organic solvents after immersion for up to a year. However, Kapton® is dissolved by strong acids, such as fuming nitric and concentrated sulfuric acid, particularly on heating, and is hydrolyzed by alkali and superheated steam.

Kapton® Type FN exhibits better chemical and oxidative resistance than Types HN and VN.

Kapton® film can be used safely at elevated temperatures with proper ventilation. At elevated temperatures, Kapton® can release small amounts of *N,N*-dimethylacetamide residual solvent. Adequate ventilation in accordance with OSHA (29 CFR 1910.1000) will provide safe handling and use.

For additional information, users should refer to the following bulletins: Kapton® Polyimide Film—Safe Handling, E-72084 and Kapton® Polyimide Film—Products of Decomposition, H-16512.

[redacted]

TEXAS INSTRUMENTS — **REPORT OF DISCREPANT NON/PROCESS MATERIAL** — **No: 03[illegible]460**

ATTLEBORO, MASSACHUSETTS 02703

PART NO. & NAME	NEW CONTAINER	REV.	INSPECTOR	DATE	Mfg. Supervision Review:
72B 27235-9 [illegible]	☐		[illegible]	1-16-98	
SOURCE	DEVICE		PROD. CODE	QUANTITY [illegible]	

ITEM	ATTRIBUTE/REQUIREMENT	ACTUAL	#INSP	AC	RE	#DEF
1	KAPTON SHOULD	KAPTON LAMINATE				
	BE BONDED EVENLY	[illegible]				
	THROUGHOUT RAPID AIR	[illegible]				
	AT MC # 2	[illegible]				

MAT'L/PROD. CONTROL

☐ CHECK INVENTORY AT (LOCATION) ______
☐ PART/MATERIAL IN SHORT SUPPLY

PRIORITY ☐1 ☐2 ☐3

COMMENTS:

PLANNER: ______ SIGNATURE ______ DATE ______

MRB ENGINEERING DISPOSITION

☐ RETURN TO SUPPLIER
☐ REWORK AT TI
☐ SORT AT TI
☒ SCRAP
☐ DEVIATE (U A I)

COMMENTS:
SCRAP PARTIAL ROLL
RETURN TO SUPPLIER

NOTE — IF DISP. OTHER THAN RTS - MRB CORRECTIVE ACTION MUST BE COMPLETED

MRB SIGNATURES		DATE
PURCHASING	[illegible]	[illegible]
MFG ENG		[illegible]
QRA ENG	[illegible]	
MFG MGR		
DE MGR		
QRA MGR		

REWORK PROCEDURE: (MFG./ENG.)

ESTIMATED TIME ______

REWORK COMPLETE
ON
BY
ACTUAL STD. HOURS
GOOD FOR REMAINING

INSPECTION AFTER REWORK	#INSP	AC	RE	#DEF	INSPECTOR	DATE	QRA ENG. (Signature required if rej.)

MRB CORRECTIVE ACTION

TI
— CHANGE DRAWING/SPEC (CHANGE) MUST BE ATTACHED ☐
— USE ENCLOSED SAMPLES AS ACCEPTABLE VISUAL STANDARDS ☐
— OTHER (EXPLAIN) ☐

SUPPLIER
— PROVIDE CORRECTIVE ACTION WITH FORMAL RESPONSE ☐
— SUBMIT INSPECTION DATA WITH FUTURE SHIPMENTS ☐
— CONDUCT CAPABILITY STUDY AND SUBMIT TO ENGINEERING ☐
— OTHER (EXPLAIN) ☐

COMMENTS:
ISSUE SUPPLIER ALERT

RECEIVING INSPECTION

R SEQUENCE NO.	DISP. CODE	AREA	LOCATION	ACTION TAKEN TO PREVENT RECURRENCE

REJECT VALIDATION — INITIAL ______ DATE ______
SUPPLIER NOTIFIED — INITIAL ______ DATE ______

PROCUREMENT ASSURANCE — DO NOT WRITE BELOW THIS LINE

☐ FOR INFO ONLY - SUPPLIER ☐
☐ EXTERNAL C.A.R. ☐
☐ FOR INFO ONLY - INTERNAL ☐
☐ INTERNAL C.A.R. ☐
☐ ☐

______ SIGNATURE ______ DATE

FORM [illegible]

TI-NHTSA 017847

ROUTE TO

TEXAS INSTRUMENTS
ATTLEBORO, MASSACHUSETTS 02703

REPORT OF DISCREPANT IN-PROCESS MATERIAL

No. 033785

[redacted]	SPC CERTIFIED	REV.	INSPECTOR 753370	DATE 1/26/98	Mfg. Supervision Review:
SOURCE Dupont	DEVICE 272252		PROD. CODE 60	QUANTITY 4.4	[signature]

ITEM	ATTRIBUTE/REQUIREMENT	ACTUAL	#INSP	AC	RE	#DEF
	No Scratches	Scratches on material	2			2

MAT'L/PROD. CONTROL

☐ CHECK INVENTORY AT (LOCATION)
☐ PARTS/MATERIAL IN SHORT SUPPLY

PRIORITY ☐1 ☐2 ☐3

COMMENTS:

PLANNER: SIGNATURE DATE

MRB ENGINEERING DISPOSITION

☒ RETURN TO SUPPLIER
☐ REWORK AT TI
☐ SORT AT TI
☐ SCRAP
☐ DEVIATE (U A I)

COMMENTS: Rejected see prior report released inspection for spec [illegible] -

MRB SIGNATURES / DATE
PURCHASING [signature] 1/26/98
MFG ENG [signature]
QRA ENG
TAE MGR
DAE MGR
QRA MGR

NOTE — IF DISP. OTHER THAN RTS - MRB CORRECTIVE ACTION MUST BE COMPLETED

REWORK PROCEDURE: (MFG./ENG.)
PO 500830107
Sup 171001
Ayew 5070
PC 060
Def code 2D
MH 035974
ESTIMATED TIME

REWORK COMPLETE
ON
BY
ACTUAL STD. HOURS
GOOD PCS. REMAINING

INSPECTION AFTER REWORK | #INSP | AC | RE | #DEF | INSPECTOR | DATE | QRA ENG. (Signature required if rej.)

MRB CORRECTIVE ACTION

TI
— CHANGE DRAWING/SPEC (DSN/ECN MUST BE ATTACHED) ☐
— USE ENCLOSED SAMPLES AS ACCEPTABLE VISUAL STANDARDS ☐
— OTHER (EXPLAIN) ☐

SUPPLIER
— PROVIDE CORRECTIVE ACTION WITH FORMAL RESPONSE ☐
— SUBMIT INSPECTION DATA WITH FUTURE SHIPMENTS ☐
— CONDUCT CAPABILITY STUDY AND SUBMIT TO ENGINEERING ☐
— OTHER (EXPLAIN) ☐

COMMENTS: Provide corrective action with 8D

RECEIVING INSPECTION

SEQUENCE NO.	DISP. CODE	AREA	LOCATION
9581	RTS	P	B-16

ACTION TAKEN TO PREVENT RECURRENCE:

REJECT VALIDATION INITIAL DG DATE 2-5-98
SUPPLIER NOTIFIED INITIAL DATE

PROCUREMENT ASSURANCE

DO NOT WRITE BELOW THIS LINE

☐ FOR INFO ONLY - SUPPLIER ☐
☐ EXTERNAL C.A.R. ☐
☐ FOR INFO ONLY - INTERNAL ☐
☐ INTERNAL C.A.R. ☐
☐ ☐

SIGNATURE DATE

FORM 20070

TI-NHTSA 017848

ROUTE TO______

TEXAS INSTRUMENTS
ATTLEBORO, MASSACHUSETTS

REPORT OF DISCREPANT IN-PROCESS MATERIAL

No. 033785

DWG NO. & NAME	REV.	INSPECTOR	DATE	Mfg. Supervision Review:
27225-2 Kapton				
SOURCE	DEVICE	PROD. CODE	QUANTITY	
			4.4	

ITEM	ATTRIBUTE/REQUIREMENT	ACTUAL	SMP	AC	RE	DEF

MAT'L/PROD. CONTROL

☐ CHECK INVENTORY AT (LOCATION)
☐ PARTS/MATERIAL IN SHORT SUPPLY

PRIORITY ☐ 1 ☐ 2 ☐ 3

COMMENTS:

PLANNER: SIGNATURE DATE

MRB ENGINEERING DISPOSITION

☒ RETURN TO SUPPLIER
☐ REWORK AT TI
☐ SORT AT TI
☐ SCRAP
☐ DEVIATE (U A I)

COMMENTS:

NOTE — IF DISP. OTHER THAN RTS - MRB CORRECTIVE ACTION MUST BE COMPLETED

MRB SIGNATURES / DATE
PURCHASING
MFG ENG
QRA ENG
MS MGR
DE MGR
QRA MGR

REWORK PROCEDURE: (MFG./ENG.)
PO 500830107
Sup 171001
Buyer 5070
PC 060
Def Code 2D
MH 035974
ESTIMATED TIME

REWORK COMPLETE ON
BY
ACTUAL STD. HOURS
GOOD FOR REMAINING

INSPECTION AFTER REWORK	SMP	AC	RE	DEF	INSPECTOR	DATE	QRA ENG.

MRB CORRECTIVE ACTION

TI
— CHANGE DRAWING/SPEC (REVISION MUST BE ATTACHED) ☐
— USE ENCLOSED SAMPLES AS ACCEPTABLE VISUAL STANDARDS ☐
— OTHER (EXPLAIN) ☐

SUPPLIER
— PROVIDE CORRECTIVE ACTION WITH FORMAL RESPONSE ☐
— SUBMIT INSPECTION DATA WITH FUTURE SHIPMENTS ☐
— CONDUCT CAPABILITY STUDY AND SUBMIT TO ENGINEERING ☐
— OTHER (EXPLAIN) ☐

COMMENTS:

RECEIVING INSPECTION

RI SEQUENCE NO.	DISP. CODE	AREA	LOCATION
9581	RTS	P	B16

ACTION TAKEN TO PREVENT RECURRENCE:

REJECT VALIDATION INITIAL DD DATE 2-5-98

SUPPLIER NOTIFIED INITIAL DATE

PROCUREMENT ASSURANCE

DO NOT WRITE BELOW THIS LINE

☐ FOR INFO ONLY - SUPPLIER ☐
☐ EXTERNAL C.A.R. ☐
☐ FOR INFO ONLY - INTERNAL ☐
☐ INTERNAL C.A.R. ☐
☐ ☐

SIGNATURE DATE

FORM

TI-NHTSA 017849

Form 8-2028 1/91

PURCHASED MATERIAL RELEASE NO. B 34151

P.O. 500830107

R.F.

BUYER Darlene Sauville

PHONE: (508) 699- 3363

TEXAS INSTRUMENTS
INCORPORATED
MATERIALS & CONTROLS GROUP
ATTLEBORO, MA. 02703

DUNS NO.

Vendor: The material originally ordered on our Purchase Order is being returned for the reason(s) indicated below, reference your return authorization No.: 81013

TI REJECTION NO. 33785

VENDOR NUMBER	VENDOR TERMS	PAY DATE
171 011		

SHIPPING MEMO

- ☐ SHIPPING ORDER ONLY NOT A PURCHASE ORDER!
- ☐ REPAIR/PROCESS - CONTACT BUYER WITH PRICE AND AVAILABILITY FOR PO.

DEBIT MEMO

- ☐ CREDIT ONLY. NO REPLACEMENT NECESSARY.
- ☐ CREDIT OUT ACCOUNT, SHIP AND REBILL FOR SATISFACTORY MATERIAL.

☐ RETURN SHIPMENT TO:

SHIP TO:
K-T RE[redacted]D MATERIALS
EI DUPONT
US ROUTE 235
CIRCLEVILLE, OH 43113

CHARGE TO:

DELIVERY REQUIRED:

ITEM	QUANTITY	UNIT	PART NUMBER-SERIAL NUMBER	DESCRIPTION	ACCOUNT NUMBER	PRICE	UNIT	EXTENSION
	4.4	lb	27225-2	KAPTON	050-[illegible]-0040	$90.28/lb		$397.23

TI-NHTSA 017850

TI SHIPPING

APPROVED BY TRAFFIC	SHIPPED BY — DATE SHIPPED	SHIP
WAYBILL NO./BL NO.	CARRIER	

VENDOR TRANSPORTATION INSTRUCTIONS

- ☐ This shipment is released freight collect F.O.B. origin. Any reshipments made as a result of this PMR will be F.O.B. destination freight prepaid.
- ☐ This shipment is released freight prepaid F.O.B. destination. Return shipment freight collect F.O.B. origin per routing on P.O.

CLERICAL SERVICES RELEASE

BY Darlene Sauville 1/29/98

Darlene Sauville 2/2/98

REQUESTED BY/LOCATION OF MATERIAL

ACCOUNTS P... ABLE 2

Texas Instruments Incorporated

TEXAS INSTRUMENTS

34 Forest Street
P.O. Box 118
Attleboro, MA 02703-0003
(508) 236-3800

March 12, 1998

Kurt M. Landgraf
Executive Vice President
E. I. du Pont de Nemours and Company
1007 Market Street
Wilmington, DE 19898

Dear Mr. Landgraf:

TI's Automotive Sensor's & Controls Business and DuPont have enjoyed a mutually beneficial relationship for a number of years. We purchase over 10,000 pounds of Kapton per year, and are on track to spend close to $900K with DuPont's High Performance Films business this year. The purpose of this letter is to highlight a concern I have over the direction our relationship with your High Performance Films business is proceeding.

During a recent meeting with Tom Clyde, the Marketing and Development Manager for the High Performance Films business, we discussed the current state of the automotive marketplace. Our business is being driven to reduce costs every year by our customer base. As we presented to Mr. Clyde, our customers are requiring annual cost reductions ranging from 3 - 5% per year. During this same period we have seen substantial increases in our business with DuPont. Pressure Switch orders for Kapton have increased by 200% over the last six years and Pressure Switch Manifold orders have increased from 0 in 1991 to over 2000 pounds in 1998. Unfortunately, the same time period has seen price increases from DuPont of over 10% on our high volume Kapton products.

During the meeting, we also discussed our investigations into Kapton alternatives for use within our Pressure Switch designs. These investigations have been ongoing over the past several years and have resulted in the identification of a viable, lower cost material which we are qualifying for our products. Our message for Mr. Clyde was that if DuPont insists on raising prices, it would drive us to the alternative material. Mr. Clyde reiterated DuPont's position, that it required additional price increases to fund future expansion and that he would be unable to agree to any pricing negotiations to retain this business.

I believe the result of our meeting with Mr. Clyde was unsatisfactory for both sides. DuPont High Performance Films is moving toward losing a long term generally satisfied customer, and Texas Instruments is making preparations to move its entire film type business elsewhere. In addition, we are looking more closely at TI's other business with DuPont. TI currently purchases or consumes over 500,000 pounds of Zytel (6/6 nylon) moding compound. This material comes to us via raw compound from DuPont, its distributors, and as molded parts from TI suppliers such as ITW, Capsonic, Tomco and others. We control the material specifications and therefore select the material supplier. In addition, we are a large consumer of Mylar and other products which add value to the overall relationship.

I understand that Mr. Clyde's limited area of control may be forcing him to remain inflexible on pricing adjustments to TI. He made it clear that his ability to acquire additional funding for required expansion programs in his plant, was tied to meeting corporate goals for growth and earnings. From an overall perspective, however, it may be in DuPont's best interest to maintain a healthy relationship with us given that our growth, particularly within the automotive arena, continues to be very strong. The prognosis for the future is excellent, and we are looking for companies who wish to share in that growth. It has always been our assumption that DuPont would be one of those companies. While it is true that life within the automotive business can be very challenging, the rewards for those companies which can successfully compete are excellent.

I firmly believe there are opportunities for TI and DuPont to work together. We have enjoyed a long and positive association, but we must find a way to both win in this relationship, or it will not remain intact. Before heading irrevocably down the path of disengagement, I want to make sure that DuPont's top management understands the entire situation. If you feel there is someone in DuPont's organization who would be better suited to address the larger picture I would be very interested in meeting with them. I would also welcome the opportunity to discuss the situation with you, and look forward to hearing from you in this regard.

Very truly yours,

Edward J. O'Neill

Edward J. O'Neill, CPM
Supply Process Manager
Automotive Sensors & Controls

cc: John Haynes
Tom Clyde, DuPont

FORM [illegible]

PURCHASED MATERIAL RELEASE NO. B 34168

P.O. 500030107

R.F.

BUYER Darlene Sauville

PHONE: (508) 699- 3363

TEXAS INSTRUMENTS
INCORPORATED
MATERIALS & CONTROLS GROUP
ATTLEBORO, MA. 02703

DUNS NO. [illegible]

Vendor: The material originally ordered on our Purchase Order is being returned for the reason(s) indicated below, reference your return authorization No.: 81046

TI REJECTION NO. 033793

VENDOR NUMBER	VENDOR TERMS	PAY DATE
171 011		

SHIPPING MEMO	DEBIT MEMO
☐ SHIPPING ORDER ONLY NOT A PURCHASE ORDER	☐ CREDIT ONLY, NO REPLACEMENT NECESSARY.
☐ REPAIR/PROCESS - CONTACT BUYER WITH PRICE AND AVAILABILITY FOR P.O.	☐ CREDIT OUR ACCOUNT. SHIP AND REBILL FOR SATISFACTORY MATERIAL.

☐ RETURN SHIPMENT TO:

DELIVERY REQUIRED:

SHIP TO:
E-T Returned Materials
EI Dupont
US RT.23S
Circleville,OH 43113

CHARGE TO:

	QUANTITY		PART NUMBER-SERIAL NUMBER	DESCRIPTION	ACCOUNT NUMBER	PRICE		EXTENSION
	3.6 lbs		27225-2	Kapton	030-1301-0000	$90.28/lb.		$325.00

TI-NHTSA 047863

TI SHIPPING		SHIP	VENDOR TRANSPORTATION INSTRUCTIONS	CLERICAL SERVICES RELEASE	
APPROVED BY TRAFFIC	SHIPPED BY-- DATE SHIPPED	☐ [illegible]	☐ This shipment is returned freight collect F.O.B. origin. Any reshipments made as a result of this PMR will be F.O.B. destination freight prepaid.	BY Darlene Sauville	DATE 9/16/98
WAYBILL NO./B/L NO.	CARRIER	☐ [illegible]	☐ This shipment is returned freight prepaid F.O.B. destination. Return shipment freight collect F.O.B. origin per routing on P.O.	REQUESTED EVALUATION OF MATERIAL	

ROUTE TO______

TEXAS INSTRUMENTS
ATTLEBORO, MASSACHUSETTS 02703

REPORT OF DISCREPANT IN-PROCESS MATERIAL

No. 033818

DWG NO. & NAME	SRC CERTIFIED	REV.	INSPECTOR	DATE	Mfg. Supervision Review:
21225-2	☐		13345	4.1.98	
SOURCE: 291	DEVICE		PROD. CODE: 60	QUANTITY: 1 - coil	

ITEM	ATTRIBUTE/REQUIREMENT	ACTUAL	SMP	AC	RE	REJ
	Workmanship	cut to ...	1	0	1	1

MAT'L/PROD. CONTROL

☐ CHECK INVENTORY AT (LOCATION) ______
☐ PARTS/MATERIAL IN SHORT SUPPLY

PRIORITY ☐ 1 ☐ 2 ☐ 3

COMMENTS:

PLANNER | SIGNATURE | DATE

MRB ENGINEERING DISPOSITION

☒ RETURN TO SUPPLIER
☐ REWORK AT TI
☐ SORT AT TI
☐ SCRAP
☐ DEVIATE (U A I)

COMMENTS:

NOTE — IF DISP. OTHER THAN RTS - MRB CORRECTIVE ACTION MUST BE COMPLETED

MRB SIGNATURES		DATE
PURCHASING		
MFG ENG.		
QRA ENG		
MfE MGR		
DE MGR		
QRA MGR		

REWORK PROCEDURE: (MFG./ENG.)

PO 500 830 107 PC 060
Sup 121011 Defcode 2E
Buyer 5070 MH 120098

ESTIMATED TIME ______

INSPECTION AFTER REWORK	SMP	AC	RE	REJ	INSPECTOR	DATE	QRA ENG. (Signature required if rej.)

REWORK COMPLETE ON
BY
ACTUAL STD. HOURS
GOOD FOR REMAINING

MRB CORRECTIVE ACTION

TI
— CHANGE DRAWING/SPEC (REVISION MUST BE ATTACHED) ☐
— USE (ENCLOSED) SAMPLES AS ACCEPTABLE VISUAL STANDARDS ☐
— OTHER (EXPLAIN) ☐

SUPPLIER
— PROVIDE CORRECTIVE ACTION WITH FORMAL RESPONSE ☒
— SUBMIT INSPECTION DATA WITH FUTURE SHIPMENTS ☐
— CONDUCT CAPABILITY STUDY AND SUBMIT TO ENGINEERING ☐
— OTHER (EXPLAIN) ☐

COMMENTS:

RECEIVING INSPECTION

RI SEQUENCE NO.	DISP. CODE	AREA	LOCATION
9569	RTS	P	B-16

REJECT VALIDATION: INITIAL DO DATE 4-16-98
SUPPLIER NOTIFIED: INITIAL DATE
ACTION TAKEN TO PREVENT RECURRENCE:

PROCUREMENT ASSURANCE

DO NOT WRITE BELOW THIS LINE

☒ FOR INFO ONLY - SUPPLIER
☐ EXTERNAL C.A.R.
☐ FOR INFO ONLY - INTERNAL
☐ INTERNAL C.A.R.
☐

SIGNATURE | DATE

FORM

TI-NHTSA 017854

ROUTE TO______

TEXAS INSTRUMENTS
ATTLEBORO, MASSACHUSETTS 02703

REPORT OF DISCREPANT IN-PROCESS MATERIAL

No. 033818

DWG NO. & NAME		REV.	INSPECTOR	DATE	Mfg. Supervision Review:
SOURCE	DEVICE		PROD. CODE	QUANTITY	
			64		

ITEM	ATTRIBUTE/REQUIREMENT	ACTUAL	#INSP	AC	RE	#DEF
				0		

MAT'L/PROD. CONTROL

☐ CHECK INVENTORY AT (LOCATION) ______
☐ PARTS/MATERIAL IN SHORT SUPPLY

PRIORITY ☐ 1 ☐ 2 ☐ 3

COMMENTS:

PLANNER: SIGNATURE DATE

MRB ENGINEERING DISPOSITION	COMMENTS:	MRB SIGNATURES	DATE
☐ RETURN TO SUPPLIER		PURCHASING	
☐ REWORK AT TI		MFG ENG	
☐ SORT AT TI		QRA ENG	
☐ SCRAP		MFG MGR	
☐ DEVIATE (U A I)		DE MGR	
NOTE — IF DISP. OTHER THAN RTS - MRB CORRECTIVE ACTION MUST BE COMPLETED		QRA MGR	

REJECT

REWORK PROCEDURE: (MFG./ENG.)

PO 5[illegible] 107 PC 060
Sup 17011 Defcode 2F
Buyer 5020 MH 170098

ESTIMATED TIME ______

REWORK COMPLETE ON
BY
ACTUAL STD. HOURS
GOOD PCS. REMAINING

INSPECTION AFTER REWORK	#INSP	AC	RE	#DEF	INSPECTOR	DATE	QRA ENG. (Signature)

MRB CORRECTIVE ACTION

TI
— CHANGE DRAWING/SPEC (CHANGE MUST BE ATTACHED) ☐
— USE ENCLOSED SAMPLES AS ACCEPTABLE VISUAL STANDARDS ☐
— OTHER (EXPLAIN) ☐

SUPPLIER
— PROVIDE CORRECTIVE ACTION WITH FORMAL RESPONSE ☐
— SUBMIT INSPECTION DATA WITH FUTURE SHIPMENTS ☐
— CONDUCT CAPABILITY STUDY AND SUBMIT TO ENGINEERING ☐
— OTHER (EXPLAIN) ☐

COMMENTS:

RECEIVING INSPECTION

RI SEQUENCE NO.	DISP. CODE	AREA	LOCATION	ACTION TAKEN TO PREVENT RECURRENCE:
9569	RTS	P	B 16	
REJECT VALIDATION #16878 INITIAL DJ DATE		SUPPLIER NOTIFIED INITIAL DATE		

PROCUREMENT ASSURANCE — DO NOT WRITE BELOW THIS LINE

☒ FOR INFO ONLY - SUPPLIER ☐
☐ EXTERNAL C.A.R. ☐
☐ FOR INFO ONLY - INTERNAL ☐
☐ INTERNAL C.A.R. ☐
☐ ☐

SIGNATURE DATE

FORM

TI-NHTSA 017855

DuPont High Performance Films
U.S. Route 23 & DuPont Road
P.O. Box 89
Circleville, OH 43113
Tel. (740) 474-0724
Fax (740) 474-0880

DuPont High Performance Films

May 1, 1998

Mr. Bryan Dague
Texas Instruments
34 Forest Street
MS 23-04
Attleboro, MA 02703-3261

Dear Mr. Dague:

We are pleased to enclose our latest brochure for Kapton®, Oasis®, and Cirlex® products. This brochure describes new capabilities and a wide variety of new applications. We hope you find it helpful.

New Kapton® applications are also described in detail on our new website: http://www.kapton-dupont.com.

Please contact your DuPont representative, Khadijah Fladger, for further information on any of these new applications.

We appreciate the opportunity to be of service to you.

Sincerely,

Thomas Clyde

Thomas E. Clyde
Market Development Manager

Enclosure

TI-NHTSA 017856

Kapton® FN is *Kapton*® HN film coated or laminated on one or both sides with DuPont *Teflon*® FEP to impart heat sealability and to provide a moisture barrier and enhanced chemical resistance. It is available in a variety of constructions.

Kapton® BCL-Y eliminates the need for thick opaque coatings. It offers the thermal and electrical durability, as well as the chemical resistance of *Kapton*® HN, along with excellent surface reflectivity and bar code label contrast.

Kapton® KJ is a heat-sealable polyimide film used for high-temperature and high-performance material constructions. It maintains excellent adhesion well above its glass transition temperature.

Cirlex® adhesiveless manufactured all-polyimide laminate construction material complements DuPont *Kapton*® polyimide films. Available in sheets from 9 mil (225 μm) to 60 mil (1,500 μm), *Cirlex*® provides an expanded range of thickness options, while offering the excellent chemical, physical, thermal and electrical properties of *Kapton*®. It is readily modified by laser cutting, drilling, machining and chemical etching.

Oasis® composite film is heat sealable and is made using DuPont polyimide film and DuPont *Teflon*® fluoropolymer.

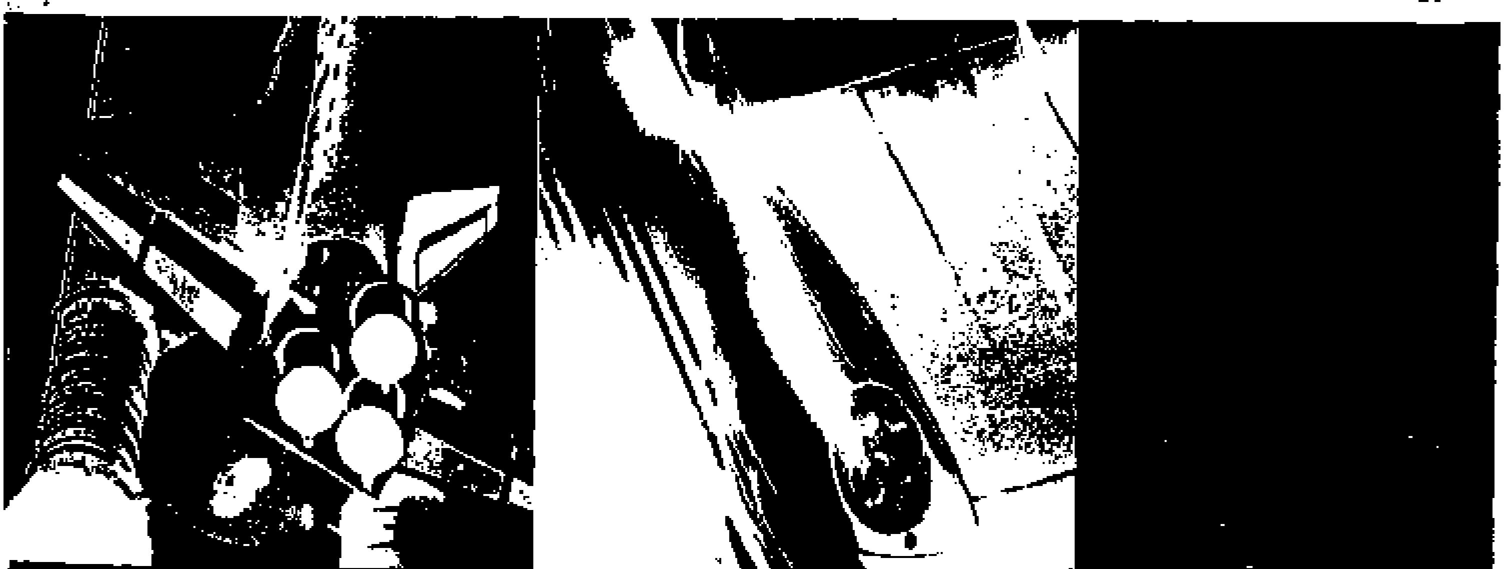
Oasis® composite film has excellent electrical, thermal, mechanical and chemical resistance properties.

DuPont *Kapton*® polyimide film can be laminated, coated a otherwise converted to meet a broad range of high-perform operating requirements. This outstanding versatility allow *Kapton*® to be custom-tailored to fit an almost endless vari of applications.

These high-quality performance films are supported by 30 years' experience, and we are committed to remaining the v leader in the manufacture and diversification of polyimide product offerings. Our significant investments in research, development and equipment in response to your needs con to help us design products that can insulate or conduct ele tricity, as well as pigmented and heat conductive films, an new adhesive systems.

DuPont also offers custom-tailored products and programs t meet your special design requirements, where appropriate. I more information, please call 1-800-237-4357.

TI-NHTSA 017857



High-performance DuPont *Kapton*® stands

Heat Sink Pads. When used in heat sink pads, *Kapton*® MT film provides improved heat transfer compared to *Kapton*® HN, while maintaining dielectric strength for interface and cut-through protection.

Speaker Coils. *Kapton*® HPP-FST and HPP-ST films provide outstanding electrical and thermal insulation for speaker coils. *Kapton*® resists distortion at high operating temperatures, offers superior dimensional stability and maintains excellent adhesion with other materials used in speaker manufacture.

TI-NHTSA 017858

to both low and high temperature extremes.

For speaker coils, *Kapton*® Type MTB, a black polyimide film, [illegible] high levels of heat and provides outstanding electrical and thermal insulation. It has [illegible] times the thermal conductivity of [illegible] *Kapton*® and resists distortion at high operating temperatures.

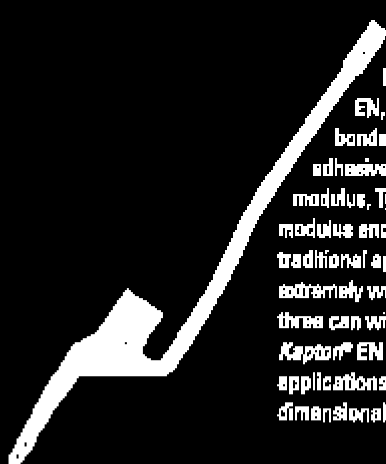
Lightweight and resistant to [illegible] *Kapton*® HN film is the ideal insulation material [illegible] use in space applications. In spacecraft blankets, *Kapton*® 3 provides outstanding [illegible] extremely high and low temperatures while maintaining superior dielectric strength, durability and flexibility.

Bar Code Labels. *Kapton*® BCL-ST film provides ideal surface characteristics for opaque coatings. *Kapton*® BCL-Y film offers excellent surface reflectivity and contrast. Both films have outstanding temperature and chemical resistance for bar code labels for flexible printed circuit boards and other high-temperature, harsh environment applications.

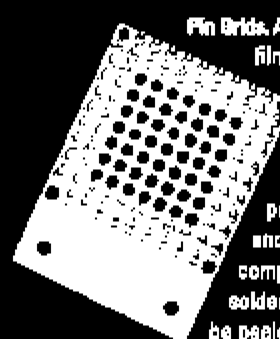
Fiber Optics Cable. Using *Kapton*® HN film, fiber optics cable can be made smaller and lighter, allowing a much higher count conductor. The thermal resistance and low flame propagation of *Kapton*® HN help cables stand up to the UL® 1666 burn test. *Kapton*® HN is also non-porous, making it ideal for indoor/outdoor cable applications.

TI-NHTSA 017859

DuPont *Kapton*® polyimide film opens up your desig

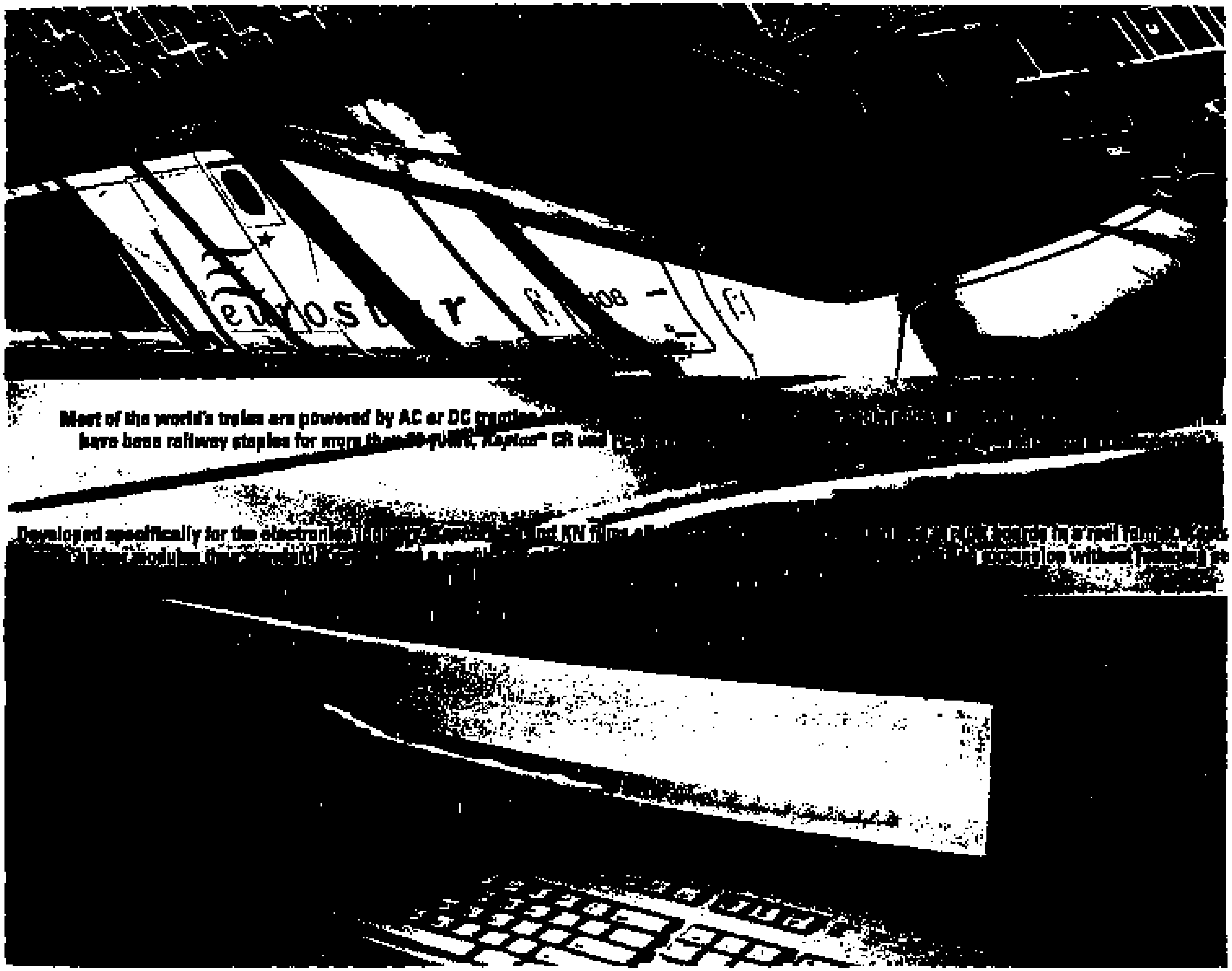


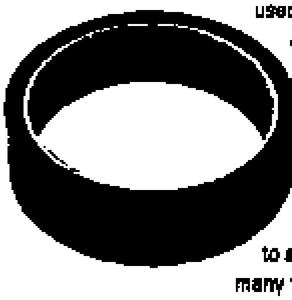
Flexible Circuits. *Kapton*® FPC, EN, and KN films offer excellent bondability to copper with various adhesives. Type EN has the highest modulus, Type KN has a mid-range modulus and Type FPC is well-suited for traditional applications. Adhesives work extremely well with these films and all three can withstand solder temperatures. *Kapton*® EN is well-suited for use in applications requiring exceptional dimensional stability.



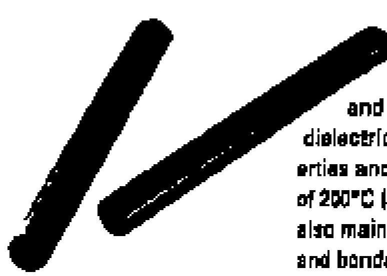
Pin Grids. As a pin grid array, *Kapton*® HN film allows insertion of all pins into a circuit board in a single, high-speed operation. *Kapton*® HN withstands the high temperatures of wave soldering and allows visual inspection of completed connections. After soldering, *Kapton*® HN can either be peeled away or left in place as additional support for pins during further processing and handling.

possibilities with its outstanding electrical properties





Pressure-Sensitive Tape. Whether it's used as protection for printed circuits during the manufacturing process, or as a repair/utility tape for high-performance electrical insulation applications, *Kapton*® PST film provides high-temperature capability, dimensional stability, resistance to solvents and compatibility with many types of adhesives.



Insulation Tubing. In tubing used for electrical insulation protection, *Kapton*® HN, MT and HPP-ST films have excellent dielectric and thermal insulation properties and can withstand temperatures of 200°C (392°F) or higher. These films also maintain good physical properties and bondability for manufacture of this spiral wound, high-temperature tubing.

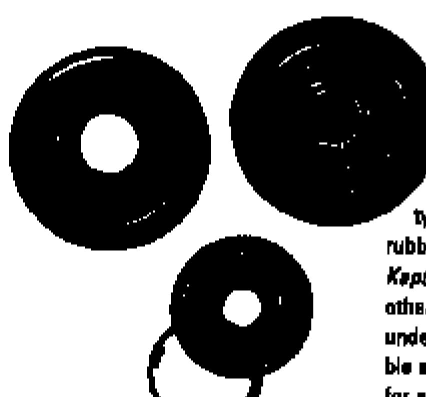
DuPont *Kapton*® polyimide film resists m

Kapton® polyimide film—only by DuPont—is an ideal material for use in demanding environments where hostile elements such as chemicals, gases and radiation are present. Whether it's used as motor windings insulation in [illegible] pump operating in [illegible] and brine 20,000 feet (6,096 m) below the surface of the earth, a protective layer for a liquid level sensor submerged in [illegible], or in demanding automotive applications, *Kapton*® can take the punishment and still deliver reliable performance.

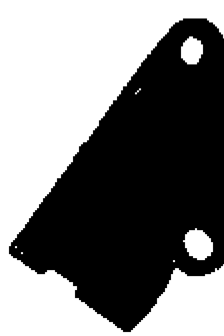
In flexible circuitry, conductors bonded between layers of *Kapton*® polyimide film are protected against [illegible], moisture, [illegible] and foreign materials [illegible] demanding environments. In military and aerospace applications, *Kapton*® remains tough and flexible. Although it is unaffected by most organic chemicals, solvents, fuels and lubricants, *Kapton*® can be dissolved by certain strong bases — a fact that printed circuit manufacturers use to their advantage in the chemical milling of features in printed circuits.

Kapton® FN is a heat-sealable film that offers the unique balance of properties of *Kapton*® HN with a wide [illegible]. This is achieved by combining *Kapton*® HN with DuPont *Teflon*® FEP fluoropolymer [illegible].

Kapton® [illegible] polyimide film was developed specifically to [illegible] insulation [illegible] hydrolytic stability [illegible] available as [illegible] laminated with DuPont *Teflon*® FEP (*Kapton*® FWR) for use as a heat-sealable magnet wire insulation.



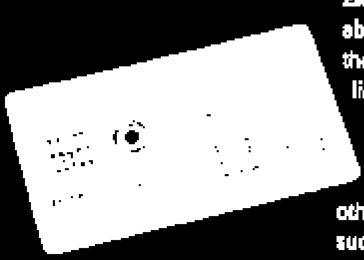
Automotive Diaphragms. Although thin and lightweight, *Kapton*® HN and FN films can withstand flexing without developing cracks or tears, which are typical problems encountered with rubber and other common materials. *Kapton*® enables diaphragms and other parts to work "in movement" under high pressure and remain flexible and functional, while performing for a half-million plus cycles.



Automotive Sensors. *Kapton*® HN and FN films are used in automotive sensor devices because they are flexible, highly processable and able to withstand the extreme temperature changes that occur under the hood. These films also have excellent durability and proven resistance to automotive solvents, oils and fuels.

TI-NHTSA 017862

emicals, solvents, lubricants and fuels.



Etched Applications. *Kapton®* is etchable and can be well controlled within the etching process, resulting in a fine line capability and high quality of etching. Although *Kapton®* HN or HPP-FST films are most frequently used for chemical etching, several other types of *Kapton®* have also been successfully etched.

Etching Controllability. *Kapton®* HKJ film is made from layers of *Kapton®* HA and KJ film, which have been bonded together. In this application, the *Kapton®* HA film has been etched through, while leaving the *Kapton®* KJ polyimide adhesive intact.

DuPont *Kapton*® polyimide films and *Oasis*® compo

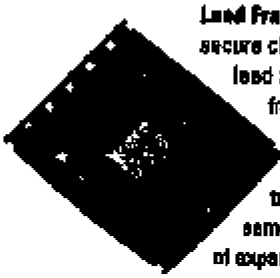
Kapton® polyimide films and *Oasis*® composite films, only by DuPont, provide a host of performance options not available from conventional materials such as fibers, resins, metals, glass, ceramics, mica and others. The films' tensile strength and initial tear resistance provide the mechanical durability necessary for many critical manufacturing operations, such as printed circuit processing and installation. Exceptional toughness and resistance to cut-through and abrasion make *Kapton*® and *Oasis*® especially useful as insulation for appliance and communication wire and cable, where it can be pulled through even the tightest routing.

Since the outside diameter of a wire or cable insulated with *Kapton*® polyimide film or *Oasis*® composite film is smaller than conventional wiring using extruded insulations, more cable can be run through a given size conduit or plenum. Stripping and termination are also easier.

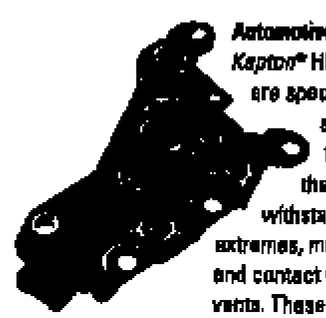
The strength, toughness, flexibility and wear resistance of *Kapton*® polyimide film have proven reliable for a number of non-electrical applications as well, such as drive belts, pressure switch diaphragms, wear strips, washers and seals. Three-dimensional shapes of *Kapton*® are also available.

Kapton® JP polyimide film provides optimum forming characteristics. It offers high elongation at elevated temperatures, while maintaining the combination of excellent physical, electrical and mechanical properties inherent in *Kapton*® HN and HA. The forming properties of *Kapton*® JP enable drawing at lower temperatures in shorter cycle times. After forming, parts exhibit excellent shape retention and minimum shrinkage.

TI-NHTSA 017864



Lead Frame Tape. Used to secure chips to circuit boards, lead frame tape made from *Kapton*® EN and KN films remains stable at high temperatures and provides the same thermal coefficient of expansion as copper.



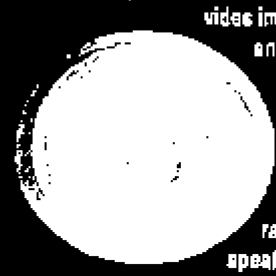
Automotive Manifolds. *Kapton*® HN and FN films are specified for use in automotive manifolds because they are able to withstand temperature extremes, mechanical stress and contact with organic solvents. These films are unmatched for their resistance to fuels, fluids and other harsh chemicals.

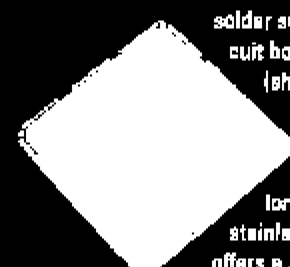
Shims of *Cirlex*® *Cirlex*® is an adhesiveless all-polyimide laminate construction material that possesses the same thermal and physical properties as *Kapton*® polyimide films. A thicker alternative to *Kapton*®, *Cirlex* helps eliminate weak points in adhesive construction and can be used as shims.

ilms are proven strong, tough and abrasion resistan

Aircraft Shims. *Kapton®* HN is lighter than metal, and more compatible with the advanced composite materials now used in aircraft assemblies. The multilayer shims can be easily peeled to fill the gap.

Speaker Cones. *Kapton®* JP film provides improved acoustics and longer life for precision-formed loudspeaker cones. *Kapton®* JP film maintains a higher stiffness-to-weight ratio than conventional speaker part materials, displays superior electrical properties and withstands high wattages.





Solder Mask Frames. Used solder stencils for printed c cuit boards, *Kapton®* HPP- (shown) and *Cirlex*[1] maintain through-hole definition, dent resistance an longevity better than stainless steel. *Cirlex®* al: offers a smoother surface f more efficient disbursemer of solder paste.

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Oasis® is a registered trademark of DuPont for its composite film.
Cirlex® is a registered trademark of DuPont for its adhesiveless manufactured all-polyimide laminate construction material.
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Only DuPont makes *Kapton*®, *Oasis*®, *Cirlex*® and *Teflon*®.

Caution: Do not use in medical applications involving permanent implantation in the human body. For other medical applications, see "DuPont Medical Caution Statement," H-50102.

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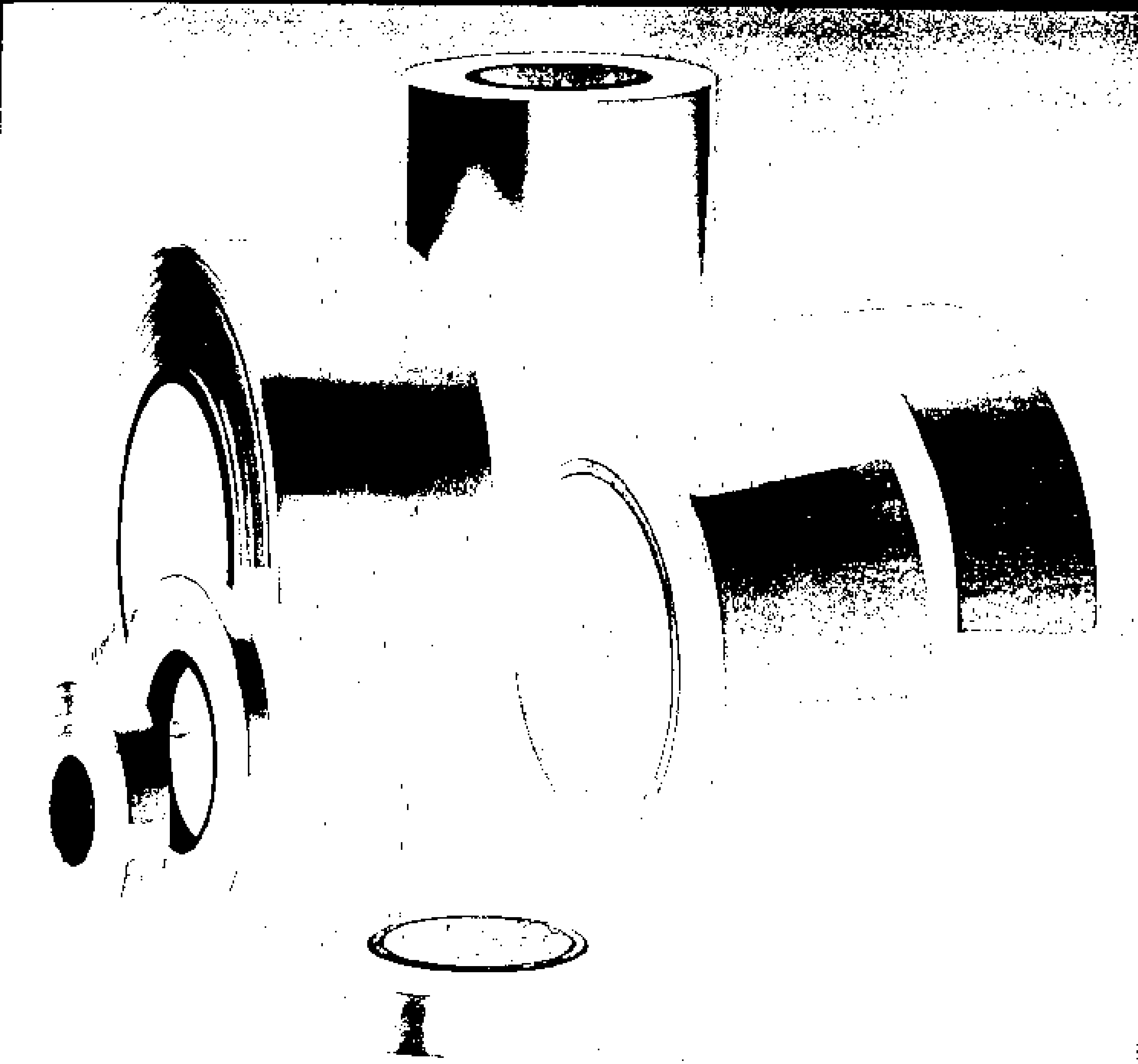
DuPont High Performance Films

TI-NHTSA 017866

Kapton

POLYIMIDE FILM

SUMMARY OF PROPERTIES



DUPONT

CONTENTS

Kapton®

POLYIMIDE FILM

GENERAL INFORMATION

KAPTON* polyimide film possesses a unique combination of properties previously unavailable among polymeric film materials. The ability of KAPTON to maintain its excellent physical, electrical and mechanical properties over a wide temperature range has opened new design and application areas to plastic films. KAPTON has proved to be especially useful in applications involving high operating temperatures.

KAPTON is synthesized by a polycondensation reaction between an aromatic dianhydride and an aromatic diamine. There is no known organic solvent for the film and it is infusible and flame resistant. The outstanding properties of KAPTON permit it to be used at both high and low temperature extremes where other organic materials would not be functional.

Adhesives are available for bonding KAPTON to itself, to metals, to papers of various types and to other films.

Applications for KAPTON polyimide film include a variety of electrical and electronic insulation applications: wire and cable tapes, formed coil insulation, substrates for flexible printed circuits, motor slot liners, magnet wire insulation, transformers and capacitor insulation, magnetic and pressure sensitive tapes and tubing. Many of these applications are based on the excellent electrical properties of KAPTON, such as dielectric strength and dissipation factor, which remain nearly constant over a wide range of temperature and frequency. Other applications make use of the film's radiation resistance or chemical resistance at elevated temperatures. It is this combination of useful properties at extremes in temperatures that makes KAPTON a unique industrial material.

Du Pont makes three types of KAPTON:

- KAPTON Type H, an all-purpose, all-polyimide film that has been used successfully in applications at temperatures as low as 4K (−269°C) and as high as 673K (400°C). Type H film can be laminated, metalized, punched, formed or adhesive coated. It is available as 0.3, 0.5, 1, 2, 3 and 5 mil film.
- KAPTON TYPE V, an all-purpose, all-polyimide film with all of the properties of Type H, plus superior dimensional stability. Type V is available in 2, 3 and 5 mils.
- KAPTON Type F, a Type H film coated on one or both sides with TEFLON* FEP fluorocarbon resin to impart heat sealability, to provide a moisture barrier and to enhance chemical resistance. It is available in a variety of constructions.

Note: This bulletin provides a summary of typical properties for all three KAPTON polyimide films Type H, Type V and Type F. Additional data should be obtained from your Du Pont Industrial Films Division representative for specification purposes.

*Reg. U.S. Pat. Off.

PHYSICAL & THERMAL PROPERTIES

KAPTON® Type H Film

25 μm (1 mil)

PHYSICAL PROPERTIES

PHYSICAL PROPERTIES	TYPICAL VALUES 78K (−195°C)	296K (23°C)	473K (200°C)	TEST METHOD
Ultimate Tensile (MD) Strength, MPa (psi)	241 (35,000)	172 (25,000)	117 (17,000)	ASTM D-882-81
Yield Point (MD) at 3%, MPa (psi)		69 (10,000)	41 (6,000)	ASTM D-882-81
Stress to Produce (MD) 5% Elongation, MPa (psi)		90 (13,000)	59 (8,500)	ASTM D-882-81 ASTM D-882-81
Ultimate Elongation (MD)%	2	75	90	ASTM D-882-81
Tensile Modulus, GPa (MD) (psi)	3.5 (510,000)	3.0 (430,000)	1.86 (250,000)	ASTM D-882-81
Impact Strength, J/mm (kg-cm)		23 (6)		Du Pont Pneumatic Impact Test
Folding Endurance MIT		10,000 cycles		ASTM D-2176-69
Tear Strength—Propagating (Elmendorf), g		8		ASTM D-1922-67
Tear Strength—Initial (Graves), g (g/mil)		510 (510)		ASTM D-1004-66
Density, g/cm³		1.42		ASTM D-1505-68
Coefficient of Friction Kinetic (Film-to-Film)		.42		ASTM D-1894-78
Refractive Index (Becke Line)		1.78		Encyclopaedic Dictionary of Physics, Vol. 1
Poisson's Ratio		.34		Ave. 3 Samples Elongated at 5%, 7%, 10%

MD—Machine Direction

THERMAL PROPERTIES

THERMAL PROPERTIES	TYPICAL VALUES	TEST CONDITION	TEST METHOD
Melting Point	NONE		ASTM E-794-8
Zero Strength Temperature	1088K (815°C)	.14 MPa (20 psi) load for 5 seconds	Du Pont Hot Bar Test
Coefficient of Linear Expansion	2.0×10^{-5} m/m/K (2.0×10^{-5} in/in/°C)	259 to 311K (−14°C to 38°C)	ASTM D-696-44
Coefficient of Thermal Conductivity, W/m·K $\left(\frac{(cal)(cm)}{(cm^2)(sec)(°C)}\right)$	0.155 (3.72×10^{-4}) 0.163 (3.89×10^{-4}) 0.178 (4.26×10^{-4}) 0.189 (4.51×10^{-4})	296K (23°C) 348K (75°C) 473K (200°C) 573K (300°C)	Model TC-1000 Twin Heatmaster Comparative Tester
Specific Heat	1.09 (.261)	J/g·K (cal/g/°C)	Differential Calorimetry
Flammability	94 VTM-0		UL-94 (1-24-80)
Shrinkage	(See chart on Page 7)		IPC Method 2-2-2-A
Heat Sealability	Not Heat Sealable		
Limiting Oxygen Index	100H-38		ASTM D-2863-77
Smoke Generation	100H − DM = less than 1	NBS Smoke Chamber	NFPA-258 procedures
Glass Transition Temperature (Tg)	A second order transition occurs in KAPTON between 633K (360°C) and 683K (410°C). This is assumed to be the glass transition temperature. Different measurement techniques produce different results within the above temperature range.		

KAPTON® Type V Film

PROPERTY	TYPICAL VALUES Film Gauge 25 μm (1 mil)	50 μm (2 mil)	75 μm (3 mil)	125 μm (5 mil)	TEST METHOD
Tensile Strength MPa (psi) @ 296K (23°C). Machine Direction (MD) and Transverse Direction (TD).	172 (25,000)	172 (25,000)	172 (25,000)	172 (25,000)	ASTM D-882, Method A using an Instron Tensile Tester (specimen size: 25 × 127 mm (1" × 5", jaw separation: 50 mm (2"), jaw speed: 50 mm (2"/min.) Average of 5 specimens based on original measured thickness.
Elongation, % MD and TD	75	70	70	70	Same method as above
Shrinkage, % MD and TD Typical after 60 min. @ 473K (200°C).	0.10	.02	.02	.02	Average of 3 measurements in each direction before and after exposure to 473K (200°C) for 60 min. Film must be allowed to come to equilibrium with equivalent room conditions before and after exposure.

KAPTON® Type F Film

PROPERTY	TYPICAL VALUES Film Type* 120F616	150F019	250F029
Ultimate Tensile Strength (MD), MPa (psi)			
296K (23°C)	165 (24,000)	117 (17,000)	172 (25,000)
473K (200°C)	110 (16,000)	76 (11,000)	110 (16,000)
Yield Point at 3% (MD), MPa (psi)			
296K (23°C)	62 (9,000)	50 (7,300)	69 (10,000)
473K (200°C)	38 (5,500)	28 (4,000)	55 (8,000)
Stress at 5% Elongation (MD), MPa (psi)			
296K (23°C)	86 (12,500)	62 (9,000)	
473K (200°C)	52 (7,500)	38 (5,500)	
Ultimate Elongation (MD)			
296K (23°C)%	65	75	80
473K (200°C)%	95	85	
Tensile Modulus, MD GPa (psi)			
296K (23°C)	2.86 (415,000)	2.21 (320,000)	
473K (200°C)	1.48 (215,000)	1.19 (173,000)	
Impact Strength at 296K (23°C)			
g-m (Kg-cm/μm)	70 (7)	70 (7)	
g-m/μ (Kg-cm/mil)	2.3 (6.0)	1.8 (4.6)	
Tear Strength—Propagating (Elmendorf)			
g		20	
g/μm (g/mil)	0.39 (10)	0.53 (13.5)	0.47 (12)
Tear Strength—Initial (Graves)			
g		650	
g/μm (g/mil)	19 (750)	17 (435)	
Weight % Polyimide	80	57	73
Weight % FEP	20	43	27
Density $Kg/m^3 \times 10^{-3}$	1.53	1.67	1.57

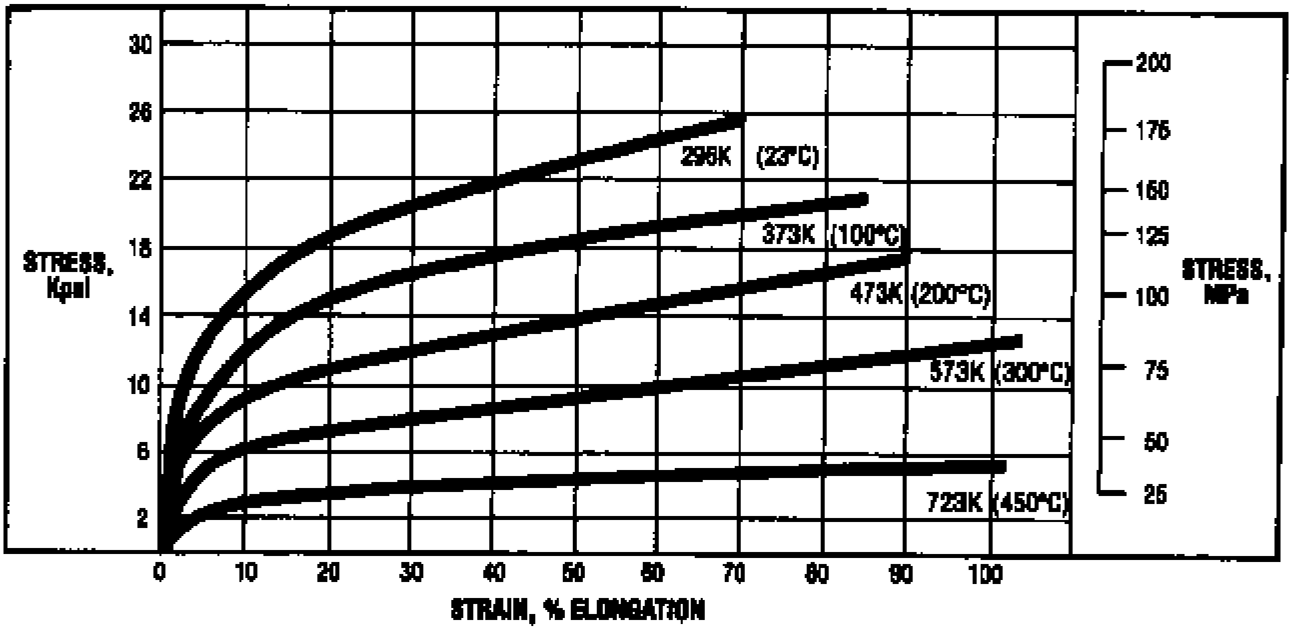
*Since a number of combinations of polyimide film and fluorocarbon coating add up to the same total gauge, it is necessary to distinguish among them. A three digit system is used in which the middle digit represents the nominal thickness of the base KAPTON film in mils. The first and third digits represent the nominal thickness of the coating of TEFLON FEP fluorocarbon resin in mils. The symbol 9 is used to represent 13 μm (½mil), and 6 to represent 2.5 μm (1/10 mil). Example: 120F616 is a 120-gauge structure consisting of a 25 μm (1-mil) base film with a 2.5 μm (1-10 mil) coating of TEFLON on each side. See page 22 for construction explanation.

MECHANICAL PROPERTIES

The usual values of tensile strength, tensile modulus, and ultimate elongation at various temperatures can be obtained from the typical stress-strain curves shown below. Such properties as tensile strength and modulus have an inverse relation with temperature, while elongation peaks to a maximum value at about 573K (300°C). Other factors such as humidity, film thickness, and Instron elongation rate were found to have only a negligible effect on the shape of the 296K (23°C) curve.

TENSILE STRESS STRAIN CURVES

(Type H Film 25 μm (1 mil))

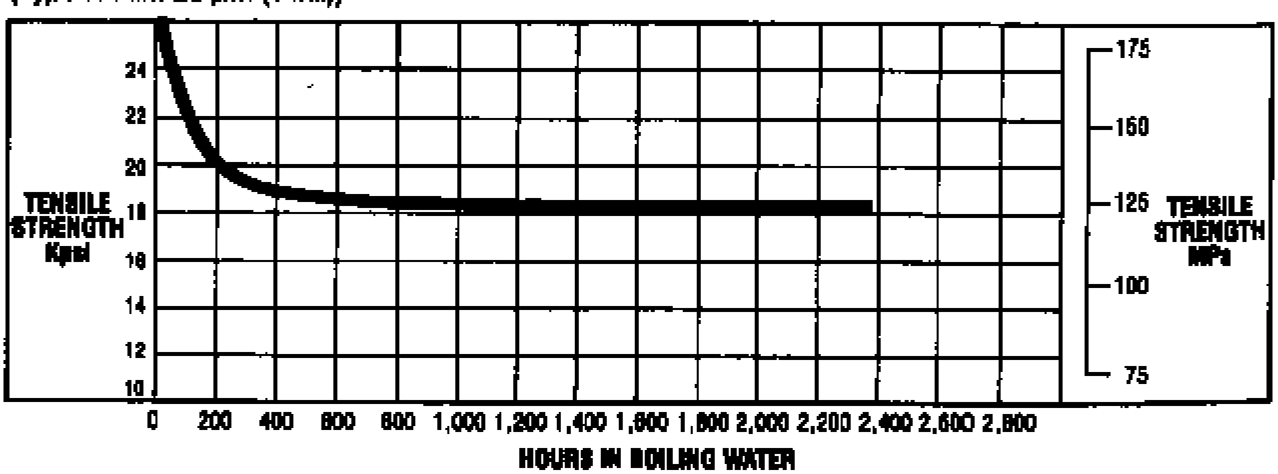


HYDROLYTIC STABILITY

KAPTON® polyimide film is made by a condensation reaction; therefore, its properties are affected by water. Although long-term exposure to boiling water, as shown in the curves below, will reduce the level of film properties, sufficient tensile and elongation remain to insure good mechanical performance. A decrease in the temperature and the water concentration will reduce the rate of KAPTON property reduction while higher temperatures and pressures will increase it.

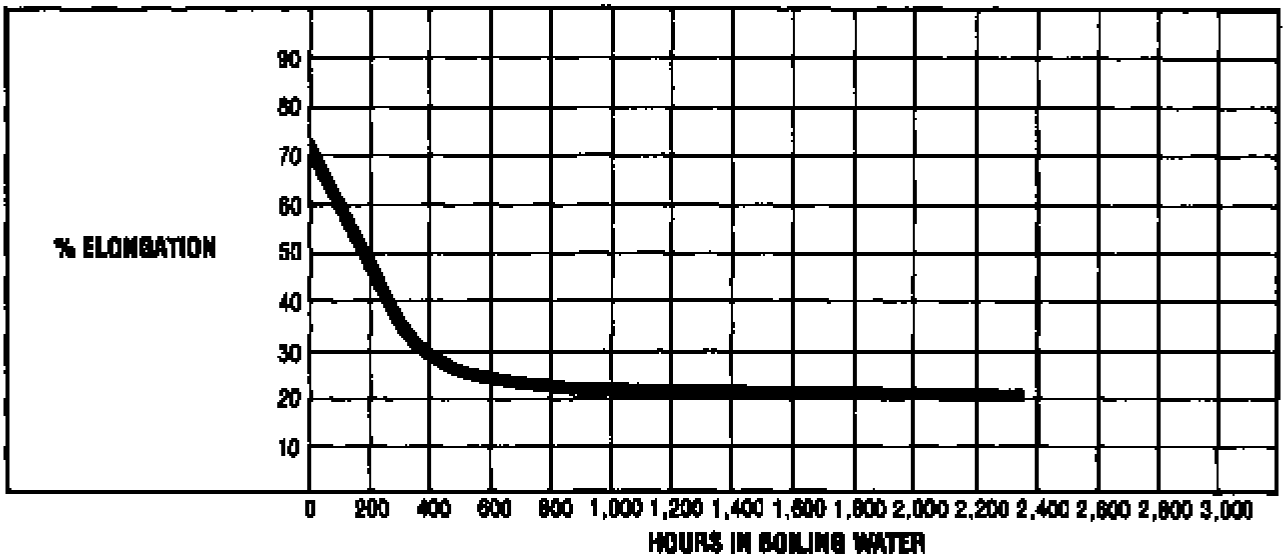
TENSILE STRENGTH AFTER EXPOSURE TO 373K (100°C) WATER

(Type H Film 25 μm (1 mil))



ULTIMATE ELONGATION AFTER EXPOSURE IN 373K (100°C) WATER

(Type H Film 25 μm (1 mil))

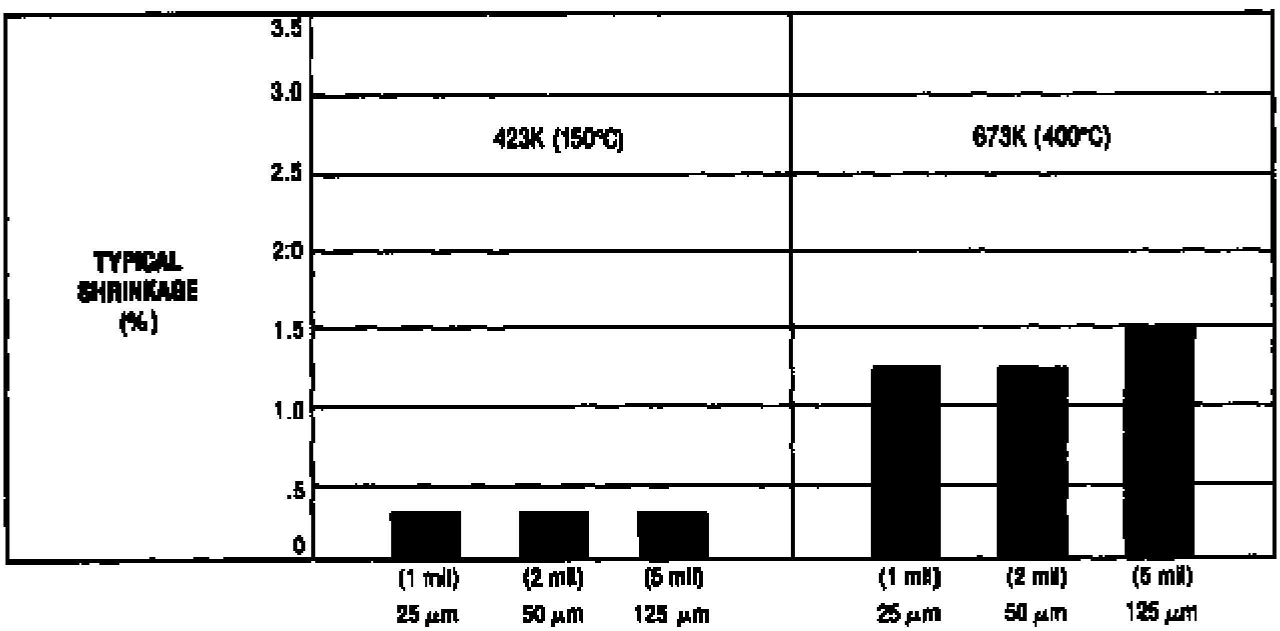


DIMENSIONAL STABILITY

The dimensional stability of KAPTON® polyimide film depends on two factors—the normal coefficient of thermal expansion and the residual stresses placed in the film during manufacture. The latter causes KAPTON to shrink on its first exposure to elevated temperatures as indicated in the bar graphs below. Once the film has been exposed, the normal values for thermal expansion listed on Page 6 can be expected.

RESIDUAL SHRINKAGE VS. EXPOSURE TEMPERATURE AND GAUGE

(Type H Film)



TI-NHTSA 017873

THERMAL COEFFICIENT OF EXPANSION

(Type H Film 25 μm (1 mil)) Thermally Exposed

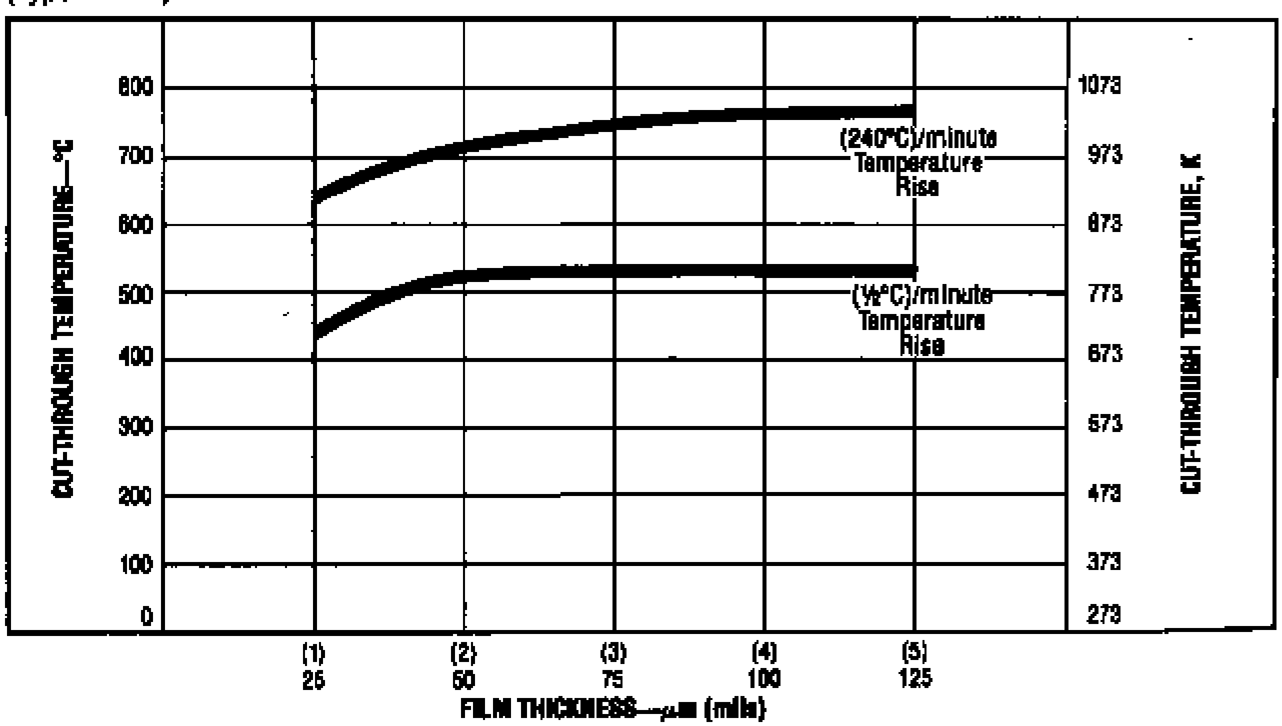
Temperature Range	"K" m/m•K x 10^{-5}
296-373K (23-100°C)	1.80
373-473K (100-200°C)	3.10
473-573K (200-300°C)	4.65
573-673K (300-400°C)	7.75
296-673K (23-400°C)	4.55

CUT-THROUGH AND COLD FLOW

Most organic films exhibit a tendency to flow or thin out under high compressive stresses, especially at elevated temperatures. KAPTON® polyimide film possesses an extremely high resistance to such stresses. Test procedures described in ASTM D-876-61 have been adapted to flat films to provide the data below. Stresses range from an infinitely high point load to 83 MPa (12,000 psi) at cut-through for a 25 μm (1 mil) film.

CUT-THROUGH TEMPERATURE VS. RATE OF TEMPERATURE RISE AND GAUGE

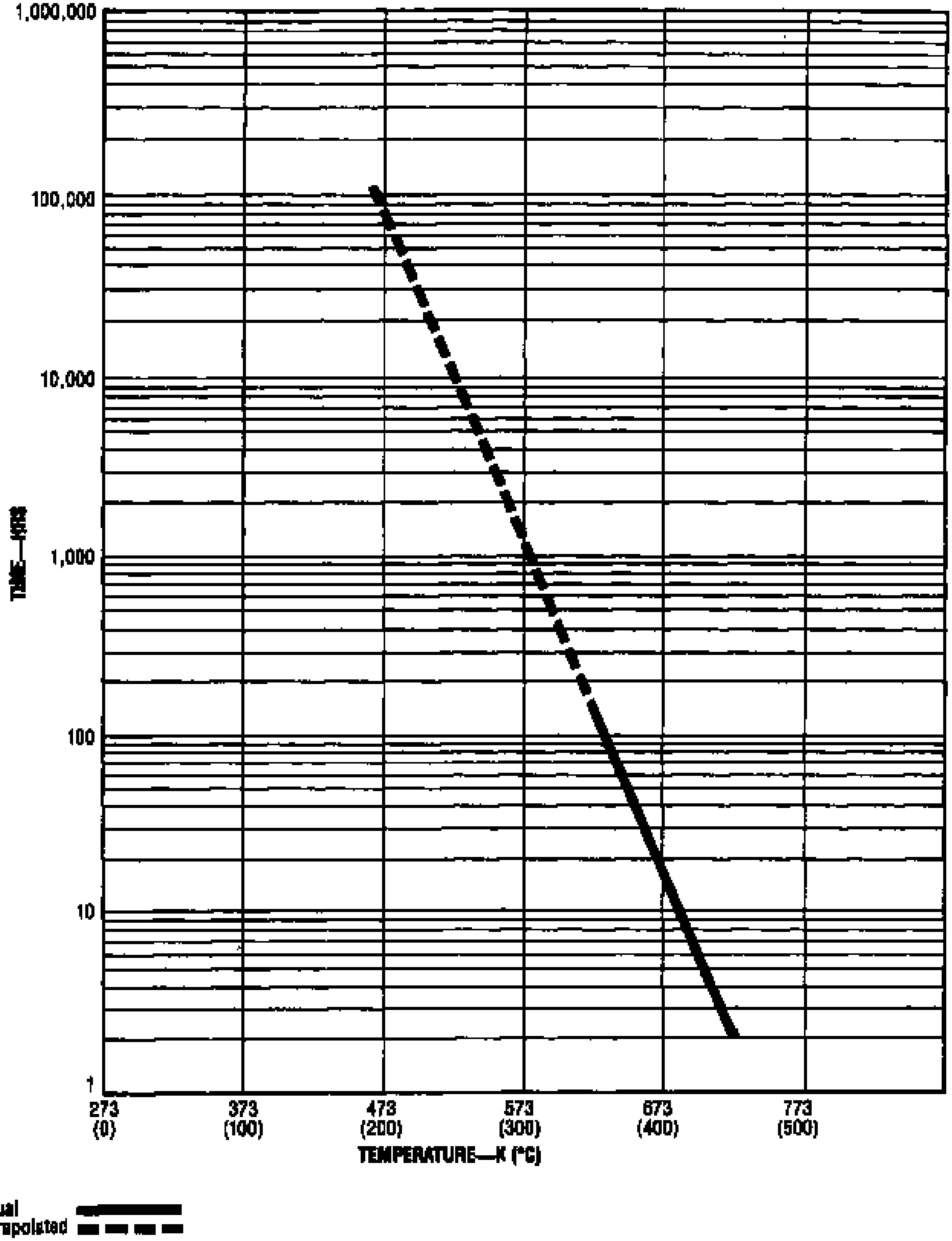
(Type H Film)



TI-NHTSA 017874

RE. .TANCE TO CUT-THROUGH VS. TEMPERATURE

(Type H Film—25 μm (1 mil))



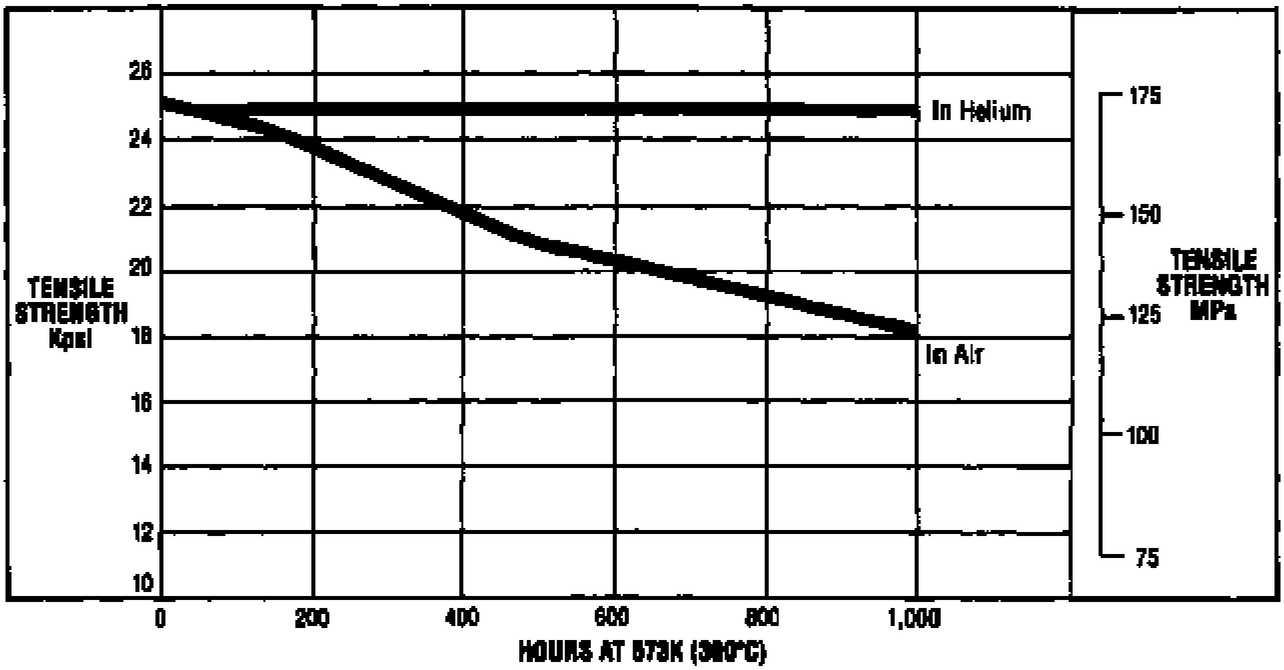
TI-NHTSA 017875

THERMAL AGING

KAPTON® polyimide film is subject to oxidative degradation. Therefore its useful life is a function of both temperature and oxygen concentration in the test environment. The effect of these factors is shown below.

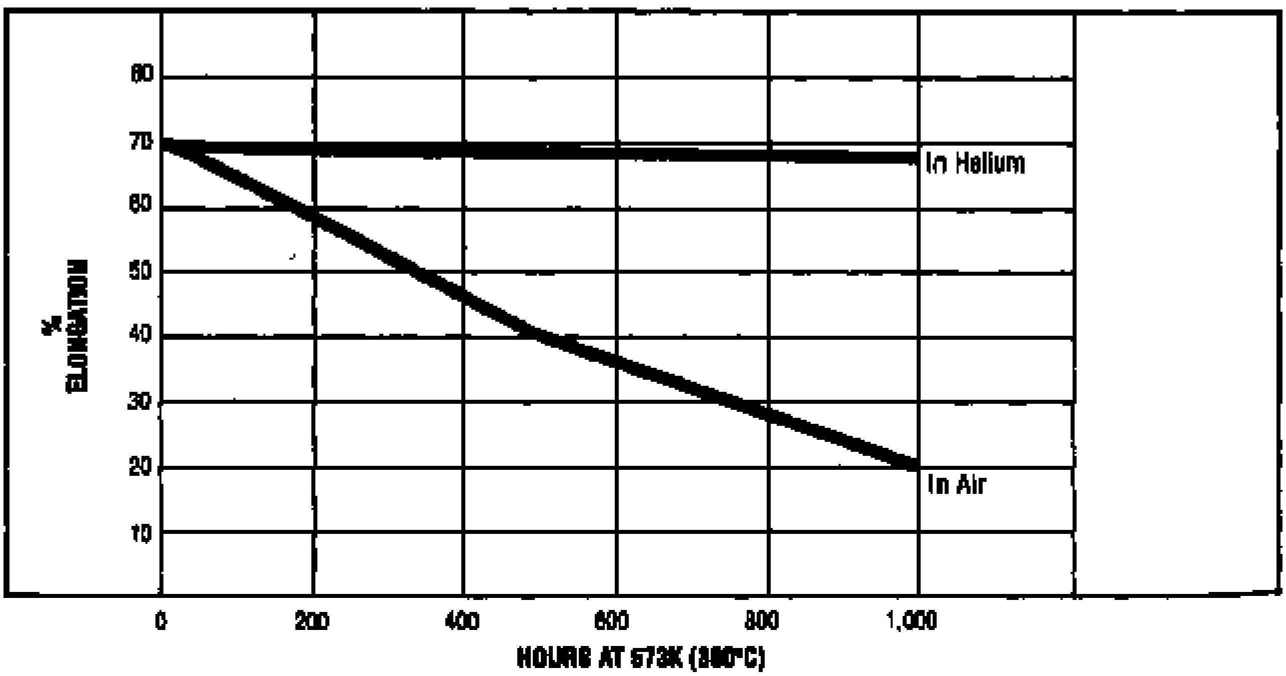
TENSILE STRENGTH VS. AGING AT 573K (300°C)

(Type H Film 25 μm (1 mil))



ULTIMATE ELONGATION VS. AGING AT 573K (300°C)

(Type H Film 25 μm (1 mil))



TI-NHTSA 017676

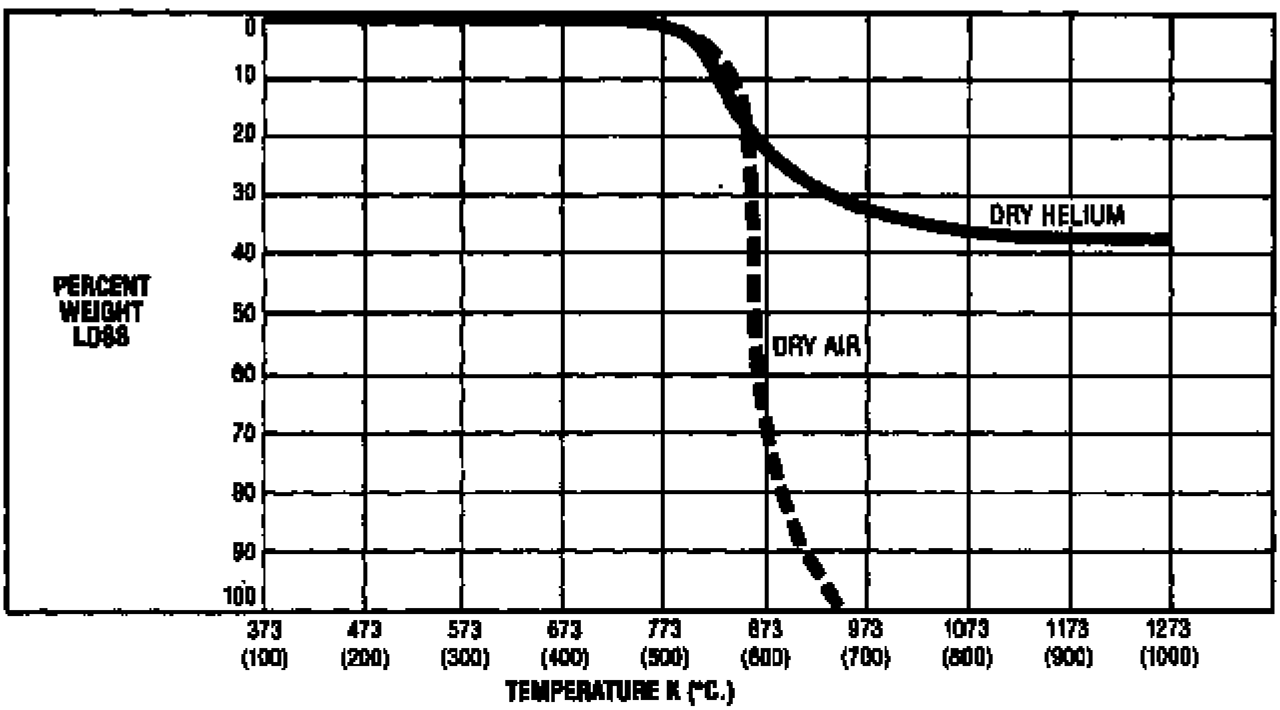
TIME REQUIRED FOR REDUCTION IN ULTIMATE ELONGATION FROM 70% to 1%

(Type H Film 25 μm (1 mil))

Temperature		Environment: Air	Environment: Helium
723K	(450°C)	2 hours	22 hours
698K	(425°C)	5 hours	3½ days
673K	(400°C)	12 hours	2 weeks
648K	(375°C)	2 days	2 months
623K	(350°C)	6 days	1 year
573K	(300°C)	3 months	—
548K	(275°C)	1 year	—
523K	(250°C)	8 years	—

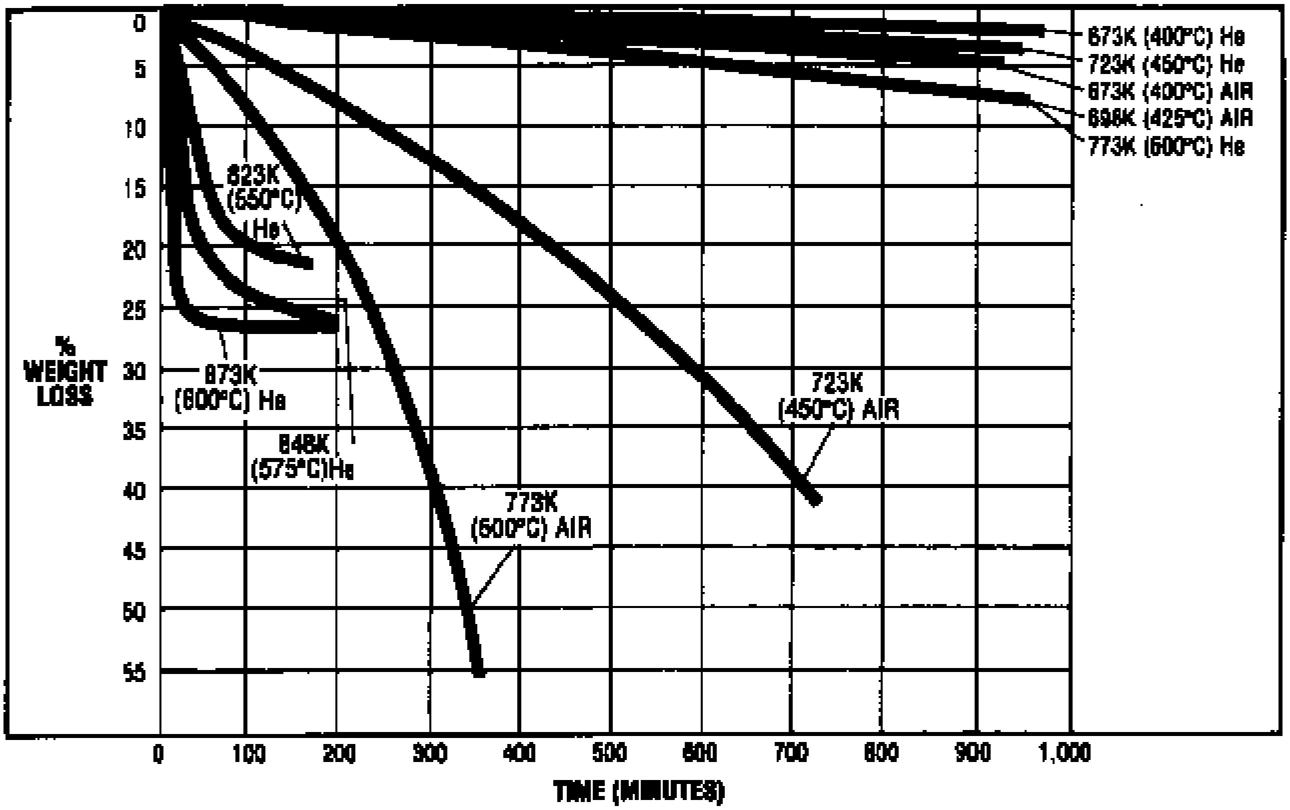
WEIGHT LOSS AT (3°C)/MINUTE TEMPERATURE RISE

(Type H Film 25 μm (1 mil))



TI-NHTSA 017677

ISOTHERMAL WEIGHT LOSS
(Type H Film 25 μm (1 mil))



TI-NHTSA 017878

ELECTRICAL PROPERTIES

KAPTON® Type H Film

TYPICAL ELECTRICAL PROPERTIES

PROPERTY	TYPICAL VALUE	TEST CONDITION	TEST METHOD
Dielectric Strength			
25 μm (1 mil)	276 v/μm (7,000 v/mil)	60 hertz ¼" electrodes	ASTM D-149-81
50 μm (2 mil)	213 v/μm (5,400 v/mil)		
75 μm (3 mil)	181 v/μm (4,600 v/mil)		
125 μm (5 mil)	142 v/μm (3,600 v/mil)		
Dielectric Constant			
25 μm (1 mil)	3.5	1 kilohertz	ASTM D-150-81
50 μm (2 mil)	3.6		
75 μm (3 mil)	3.7		
125 μm (5 mil)	3.7		
Dissipation Factor			
25 μm (1 mil)	.0025	1 kilohertz	ASTM D-150-81
50 μm (2 mil)	.0025		
75 μm (3 mil)	.0025		
125μm (5 mil)	.0027		
Volume Resistivity			
25 μm (1 mil)	1×10^{16} ohm-m	125 volts	ASTM D-257-78
50 μm (2 mil)	8×10^{15} ohm-m		
75 μm (3 mil)	5×10^{16} ohm-m		
125μm (5 mil)	1×10^{16} ohm-m		

KAPTON® Type V Film

TYPICAL ELECTRICAL PROPERTIES

PROPERTY	TYPICAL VALUE	TEST CONDITION	TEST METHOD
Dielectric Strength			
50 μm (2 mil)	213 v/μm (5,400 v/mil)	60 hertz ¼" electrodes	ASTM D-149-81
75 μm (3 mil)	181 v/μm (4,600 v/mil)		
125 μm (5 mil)	142 v/μm (3,600 v/mil)		
Dielectric Constant			
50 μm (2 mil)	3.6	1 kilohertz	ASTM D-150-81
75 μm (3 mil)	3.7		
125 μm (5 mil)	3.7		
Dissipation Factor			
50 μm (2 mil)	.0025	1 kilohertz	ASTM D-150-81
76 μm (3 mil)	.0025		
125μm (5 mil)	.0027		
Volume Resistivity			
50 μm (2 mil)	6×10^{16} ohm-m	125 volts	ASTM D-257-78
75 μm (3 mil)	5×10^{16} ohm-m		
125 μm (5 mil)	1×10^{16} ohm-m		

KAPTON® Type F Film

TYPICAL ELECTRICAL PROPERTIES

PROPERTY	120F616	150F019	250F029
Dielectric Strength Total volts volts/μm (volts/mil)	 7,500 267 (6,800)	 6,300 165 (4,200)	 157 (4,000)
Dielectric Constant	2.8	3.0	
Dissipation Factor	.0022	.0014	
Volume Resistivity ohm-m @ 296K (23°C) (ohm-cm.) ohm-m @ 473K (200°C) (ohm-cm.)	 1.5×10^{14} (1.5×10^{16}) 5×10^{12} (5×10^{14})	 10^{16} (10^{18}) 10^{14} (10^{16})	 7×10^{15} (7×10^{17})

EFFECT OF HUMIDITY

(Type H Film 25 μm (1 mil))

Because the water content of KAPTON® polyimide film can affect its electrical properties, electrical measurements were made on 1 mil film after exposure to environments of varying relative humidities at 296K (23°C).

The results of these measurements are given below.

RELATIVE HUMIDITY VS. ELECTRICAL PROPERTIES OF KAPTON

% RELATIVE HUMIDITY	AC DIELECTRIC STRENGTH V/μm	(V/mil)	DIELECTRIC CONSTANT	DISSIPATION FACTOR
0	307	(7,800)	3.0	.0016
30	287	(7,300)	3.3	.0021
50	276	(7,000)	3.5	.0025
80	256	(6,500)	3.7	.0037
100	244	(6,200)	3.8	.0047

For calculations involving absolute water content, 50% RH in our study is equal to 1.3% water in the film and 100% RH is equal to 2.9% water, the maximum adsorption possible regardless of the driving force.

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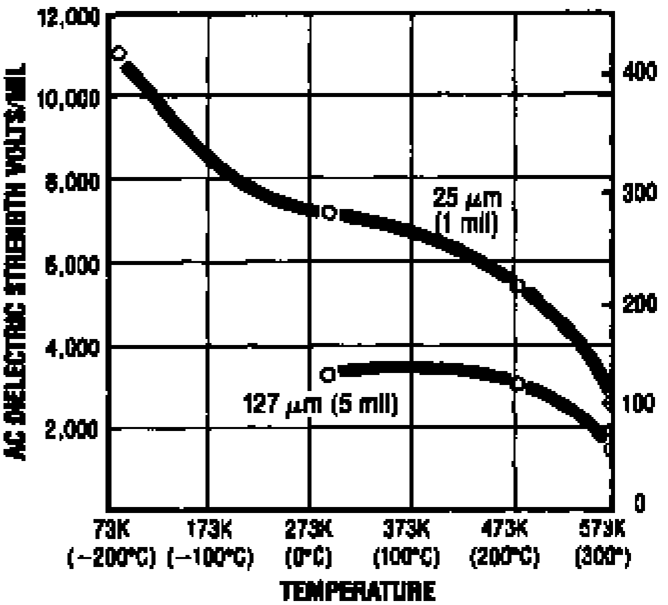
EFFECT OF TEMPERATURE

As the graphs below indicate, extreme changes in temperature have relatively little affect on the excellent room temperature electrical properties of KAPTON.

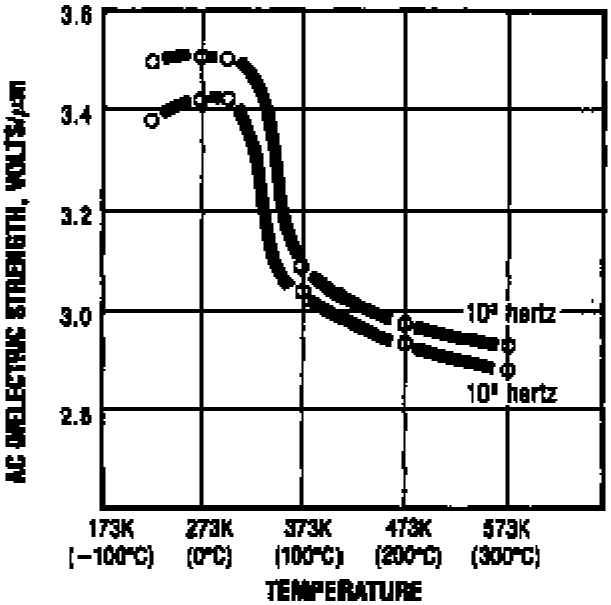
AC DIELECTRIC STRENGTH VS. TEMPERATURE

(Type H Film)



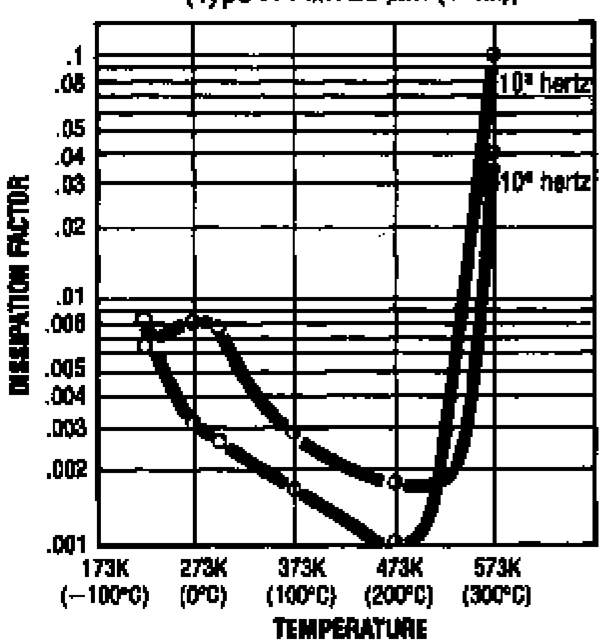
DIELECTRIC CONSTANT VS. TEMPERATURE

(Type H Film—25 μm (1 mil))



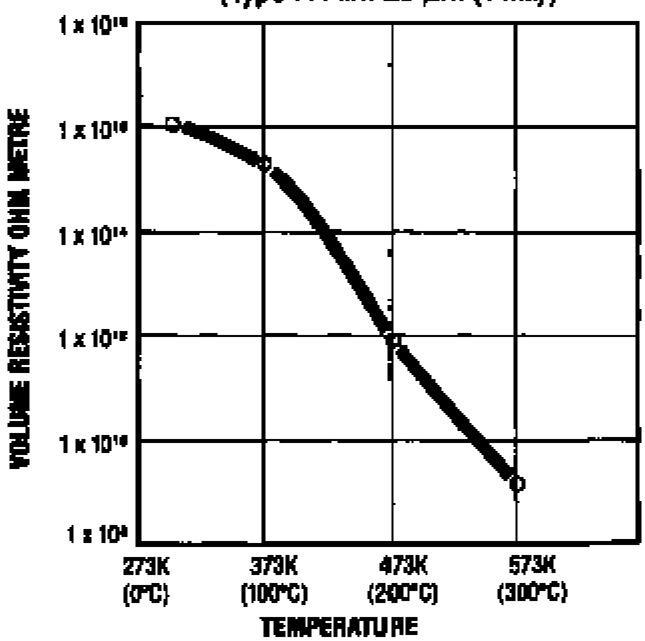
DISSIPATION FACTOR VS. TEMPERATURE

(Type H Film 25 μm (1 mil))



VOLUME RESISTIVITY VS. TEMPERATURE

(Type H Film 25 μm (1 mil))



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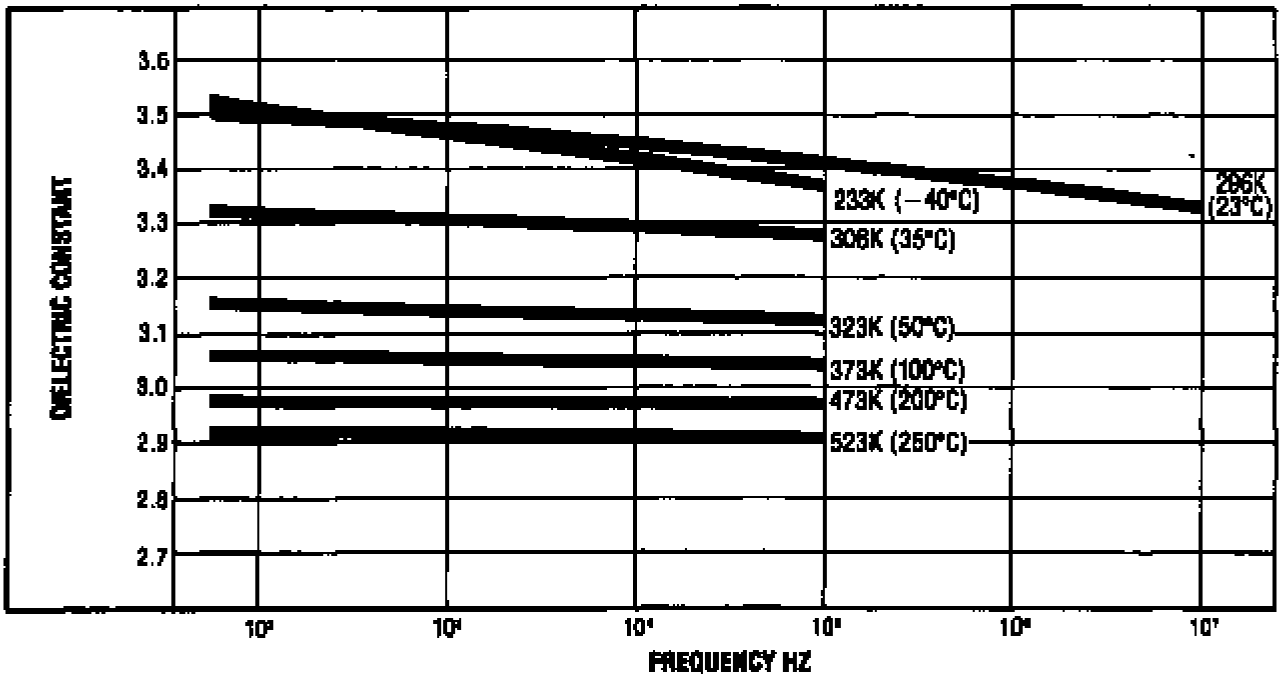
EFFECT OF FREQUENCY

The effects of frequency on the value of the dielectric constant and dissipation factor at various isotherms are shown below.

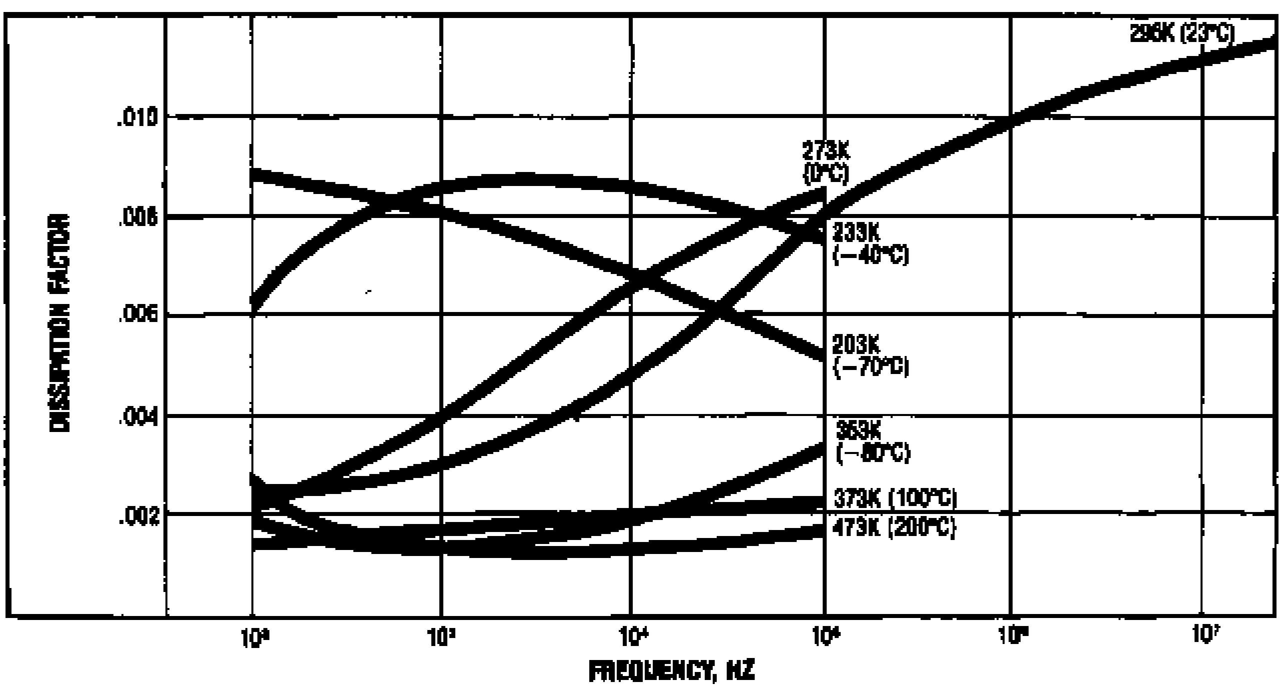
DIELECTRIC CONSTANT VS. FREQUENCY

(Type H Film 25 μm (1 mil))



DISSIPATION FACTOR VS. FREQUENCY

(Type H Film 25 μm (1 mil))



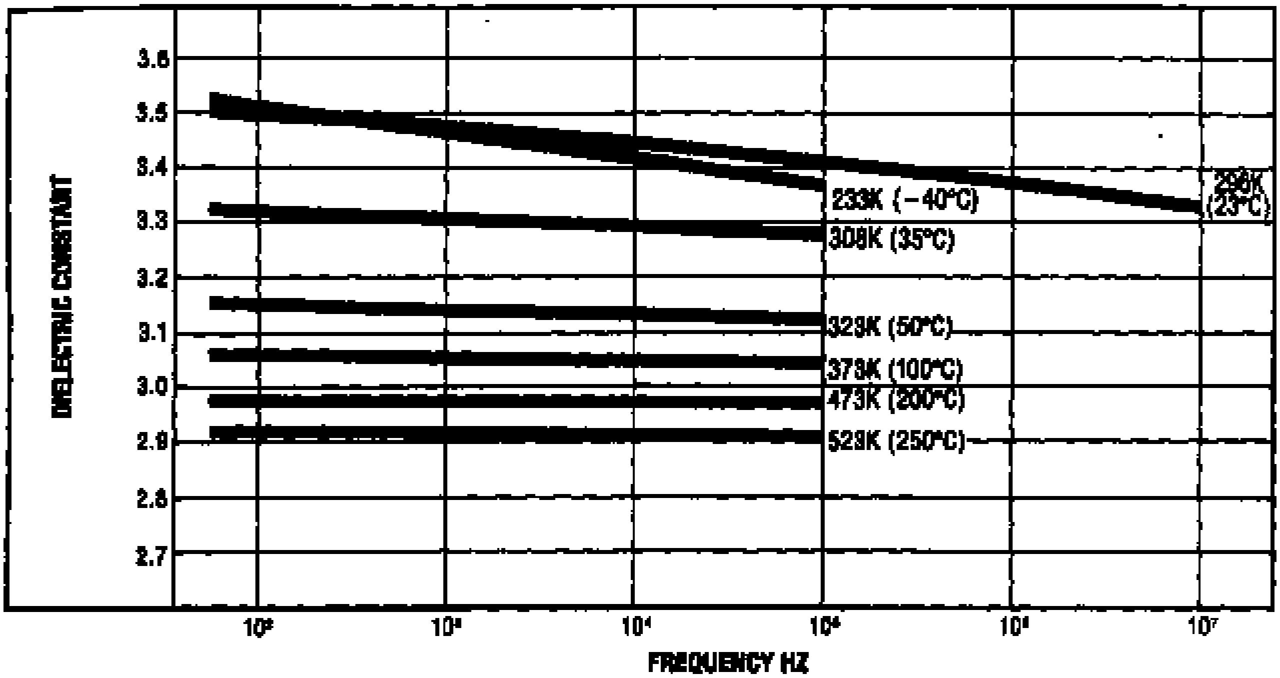
TI-NHTSA 017883

EFFECT OF FREQUENCY

The effects of frequency on the value of the dielectric constant and dissipation factor at various isotherms are shown below.

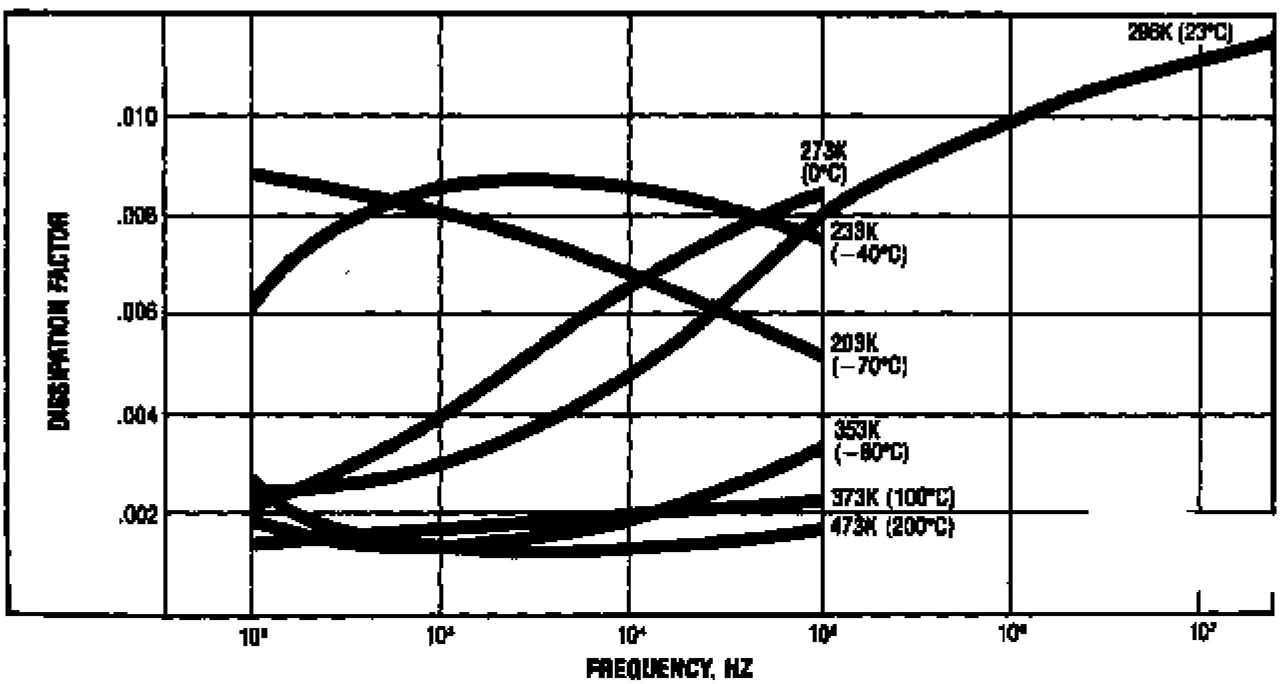
DIELECTRIC CONSTANT VS. FREQUENCY

(Type H Film 25 μm (1 mil))



DISSIPATION FACTOR VS. FREQUENCY

(Type H Film 25 μm (1 mil))



TI-NHTSA 017884

EFFECT OF FREQUENCY

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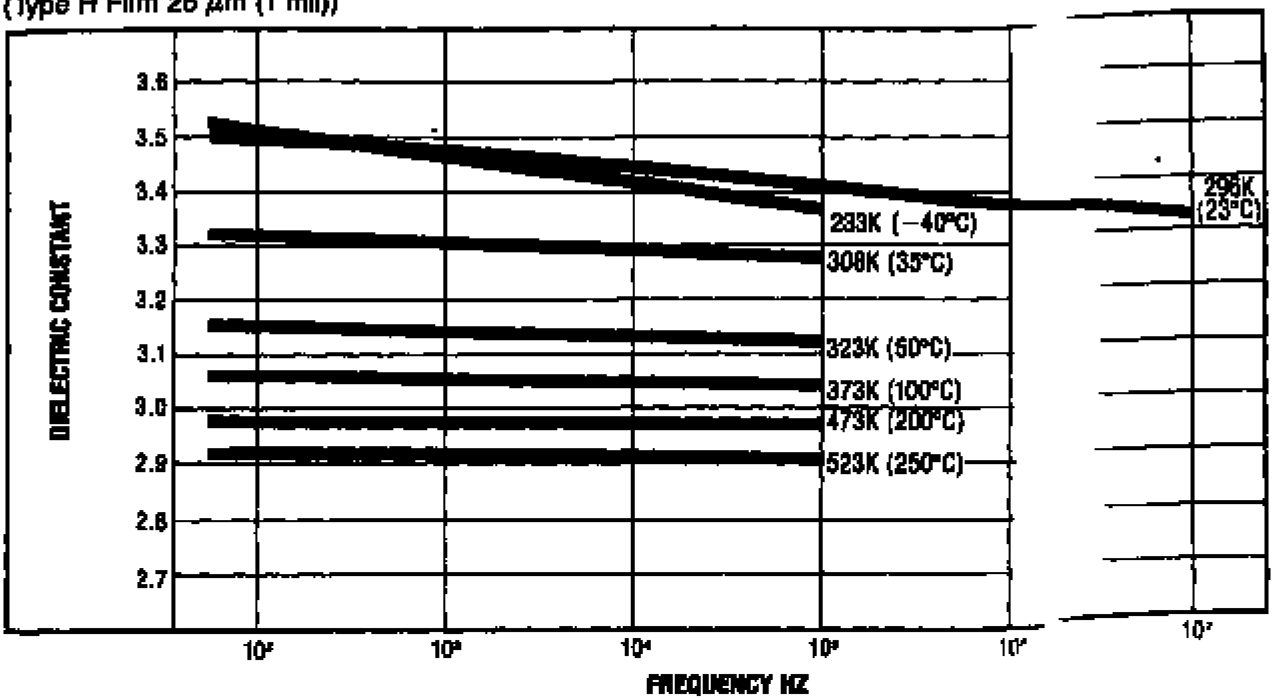
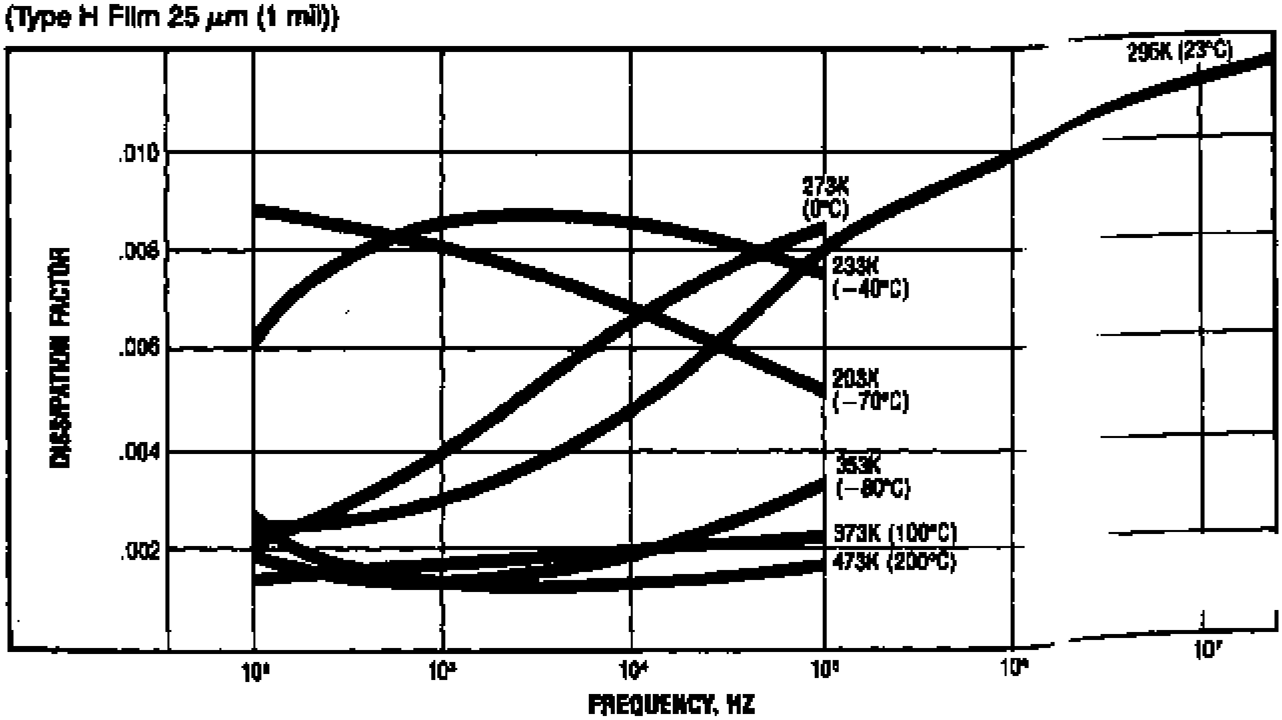
DIELECTRIC CONSTANT VS. FREQUENCY

(Type H Film 25 μm (1 mil))



DISSIPATION FACTOR VS. FREQUENCY

(Type H Film 25 μm (1 mil))



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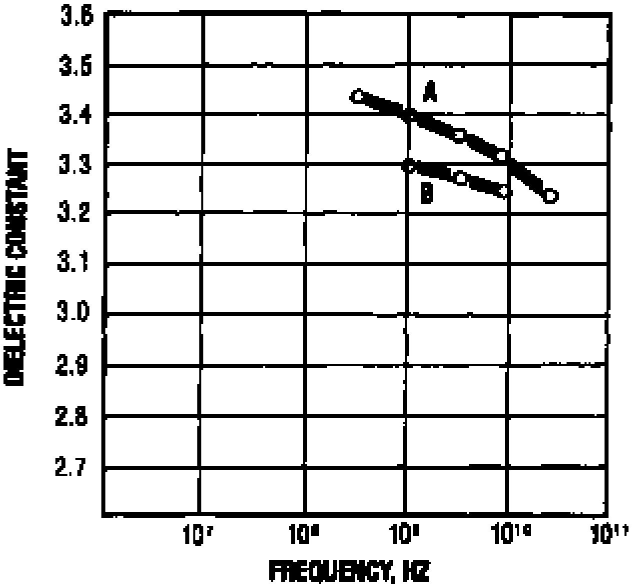
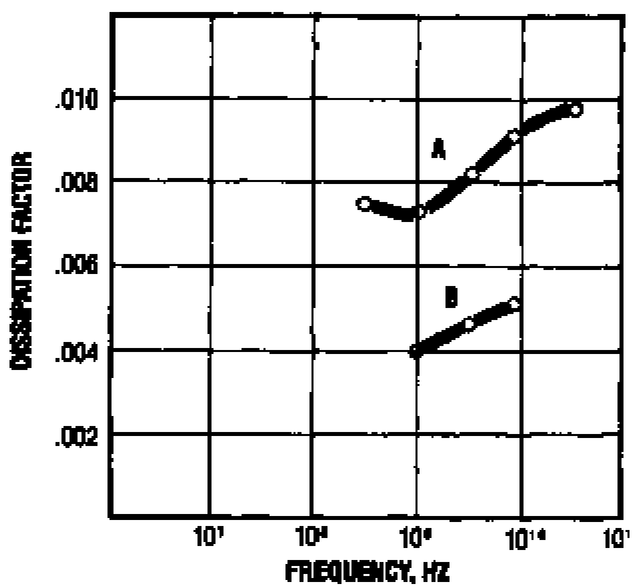
DIELECTRIC PROPERTIES IN GIGAHERTZ FREQUENCY RANGE

(Type H Film, 125µm (5 mil))*



(Type H Film, 125µm (5 mil))*



*Technical Report AFML-TR-72-39—Curve A is 500H KAPTON as received and measured at 25°C and 45% RH with the electric field in the plane of the sheet. Curve B is the same measurement after conditioning the film at 100°C for 48 hours.

TRACKING RESISTANCE

A 125 µm (5 mil) KAPTON® polyimide film, Type H, has a tracking resistance of 163 seconds as measured by ASTM D-495-61. The failure was due to true tracking rather than erosion, etc.

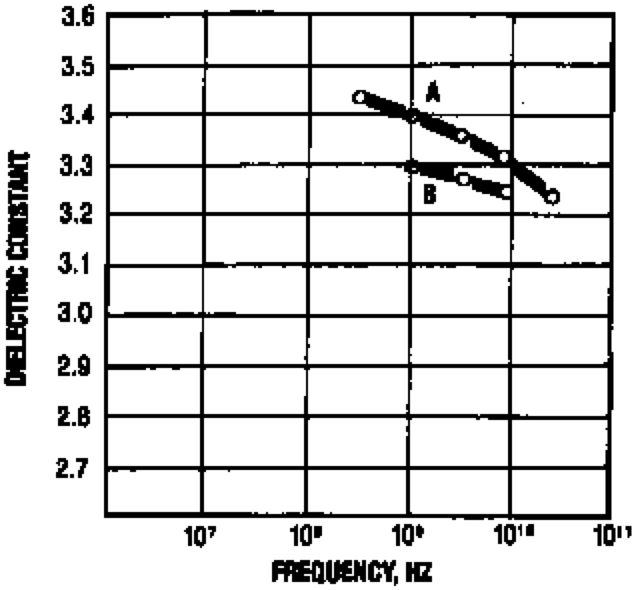
CORONA LIFE

Like all organic materials, KAPTON is attacked by corona and will ultimately fail dielectrically when exposed continuously to corona. At moderate levels of corona exposure, devices insulated with KAPTON have survived up to 3,000 hours, giving reasonable assurance that brief exposures to corona will not significantly affect the life of a properly designed insulation system based on KAPTON.

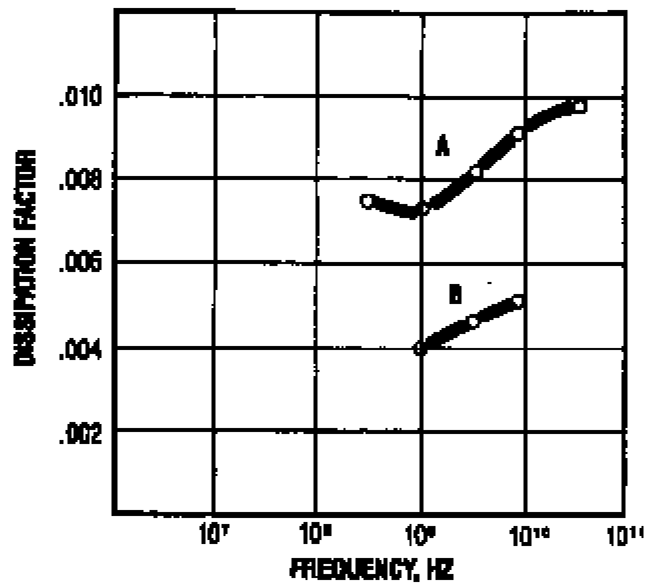
Corona inception voltage and corona intensity are functions of many parameters, including insulation thickness, air gap thickness, and device shape. Consult with a Du Pont technical representative on the suitability of KAPTON for specific applications where corona may be present.

DIELECTRIC PROPERTIES IN GIGAHERTZ FREQUENCY RANGE

(Type H Film, 125μm (5 mil))*



(Type H Film, 125μm (5 mil))*



*Technical Report AFML-TR-72-39—Curve A is 500H KAPTON as received and measured at 25°C and 45% RH with the electric field in the plane of the sheet. Curve B is the same measurement after conditioning the film at 100°C for 48 hours.

TRACKING RESISTANCE

A 125 μm (5 mil) KAPTON® polyimide film, Type H, has a tracking resistance of 183 seconds as measured by ASTM D-495-61. The failure was due to true tracking rather than erosion, etc.

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TI-NHTSA 017887

To Place an Order or Check on Status

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- Telex: 6717326
- Teletype: TWX 510 886-2954/2217
- Fax: 202-733-6137 or
  1-800-477-6790

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Mississauga, Ontario
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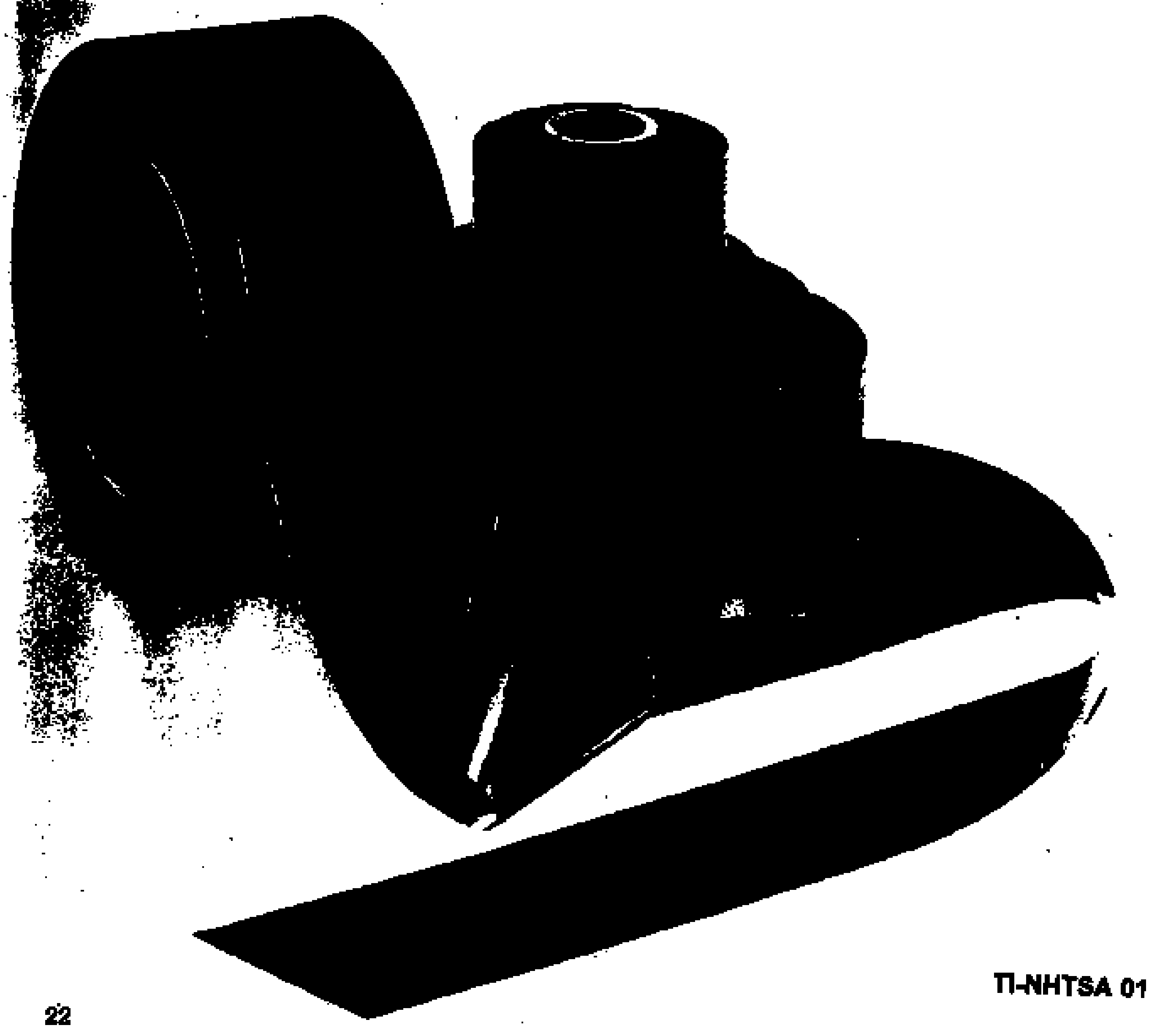
INQUIRIES

NOMINAL CONSTRUCTION, Type F Film

In the KAPTON® Type F order code of 3 digits, the middle digit represents the nominal thickness of the base KAPTON in mils. The first and third digits represent the nominal thickness of the coating of TEFLON® FEP fluorocarbon resin in mils. The symbol 9 is used to represent 13 μm (½ mil) and 6 to represent 2.5 μm ($^1/_{10}$ mil). Example: 120F616 is a 120 gauge structure consisting of a 25 μm (1-mil) base film with a 2.5 μm ($^1/_{10}$ mil) coating of TEFLON on each side. Illustrated are 3 examples of the many types available.

ORDER CODE	NOMINAL THICKNESS		"TEFLON" FEP		"KAPTON" TYPE H		"TEFLON" FEP	
	μm	mils	μm	mils	μm	mils	μm	mils
120F616	30	1.2	2.5	0.1	25	1	2.5	0.1
150F019	38	1.5	0	0	25	1	13	½
250F029	64	2.5	0	0	51	2	13	½

ORDER CODE	STANDARD WIDTHS		AREA FACTOR	
	mm	inches	m^2/Kg	$FT^2/LB.$
120F616	3.18-914	1/8-36	21.3	104
150F019	3.18-914	1/8-36	15.8	77
250F029	3.18-914	1/8-36	11.1	49



TI-NHTSA 017891

KAPTON® Type V Film

CHEMICAL PROPERTIES

Typical chemical properties for Type V film are similar to Type H.

KAPTON® Type F Film

CHEMICAL PROPERTIES

PROPERTY	120F616	150F019	400F022
Moisture Absorption @ 296K (25°C), 50% R.H. 98% R.H.	 1.3% 2.5%	 .8% 1.7%	 .4% 1.2%
Water Vapor Permeability $g/m^2 \cdot d$ (gm./(100 in^2) (24 hrs.) $g/m^2 \cdot d \cdot \mu m$ (g./(100 in^2)(24 hrs./mil)	 13.7 (0.89) 0.44 (1.07)	 8.8 (0.57) 0.35 (0.85)	 3.6 (0.23) 0.14 (0.92)

TI-NHTSA 017892

KAPTON® Type H Film

25 μm (1 mil)

CHEMICAL PROPERTIES

PROPERTY	TYPICAL VALUES (-25 μm (1 mil)) % Tensile Retained	% Elongation Retained	% Modulus Retained	TEST CONDITION/METHOD
RESISTANCE TO:				Days Immersed at Room Temperature
Benzene	100	82	100	365
Toluene	99	91	97	365
Methanol	100	73	140	365
Acetone	67	62	160	365
10% Sodium Hydroxide		Degrades		5
Glacial Acetic Acid	85	62	102	36 days @ 383K (110°C)
p-Cresol	100	77	102	22 days @ 473K (200°C)
Transformer Oil	100	100	100	180 days @ 423K (150°C)
Water pH = 1	65	30	100	14 days @ 373K (100°C)
pH = 4.2	65	30	100	14 days @ 373K (100°C)
pH = 7.0	65	20	100	166 days @ 373K (100°C)
pH = 8.9	65	20	100	14 days @ 373K (100°C)
pH = 10.0	60	10	100	4 days @ 373K (100°C)

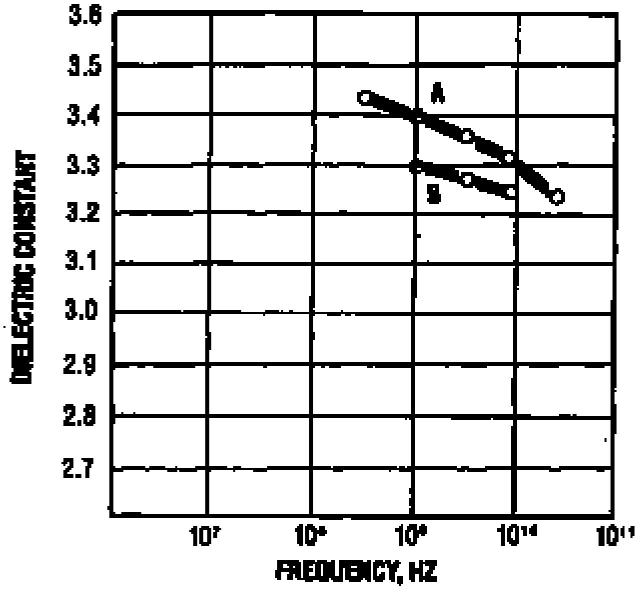
PROPERTY	TYPICAL VALUES	TEST CONDITION/METHOD
RADIATION RESISTANCE		
Gamma (Savannah River)	Still Flexible (180° Bend)	Exposure: 4.16×10^7 Gy
Electron (Van de Graaff)	Retains 50% of Original Elongation	Exposure: 6×10^7 Gy
Neutron plus Gamma (Brookhaven)	Darkened but tough	Exposure: 10^8 Gy
FUNGUS RESISTANCE	Inert	Soil Burial
MOISTURE ABSORPTION	1.3% Type H	50% Relative Humidity at 296K (23°C)
	2.9% Type H & V	Immersion for 24 hours at 296K (23°C)
HYGROSCOPIC COEFFICIENT OF EXPANSION	2.2×10^{-5} m/m/% Relative Humidity	295K (72°F) 20%-80% Relative Humidity
PERMEABILITY		
Gas	$ml/m^2 \cdot MPa \cdot day$ ($cc/(100\ in^2)$ (24 hrs.) (atm/mil))	
Carbon Dioxide	6.9 (45)	ASTM D-1434-63 @ 296K (23°C)
Hydrogen	38 (250)	
Nitrogen	0.9 (6)	
Oxygen	3.8 (25)	
Helium	63 (415)	
Water Vapor	$g/m^2 \cdot day$ 84 $g/(100\ in^2)$ (24 hrs.)/mil 5.4	ASTM E-96-63T

TI-NHTSA 017893

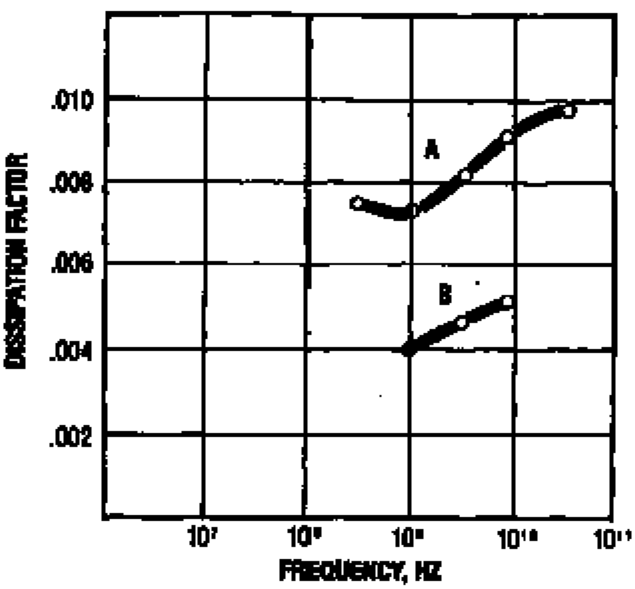
CHEMICAL PROPERTIES

DIELECTRIC PROPERTIES IN GIGAHERTZ FREQUENCY RANGE

(Type H Film, 125μm (5 mil))*



(Type H Film, 125μm (5 mil))*



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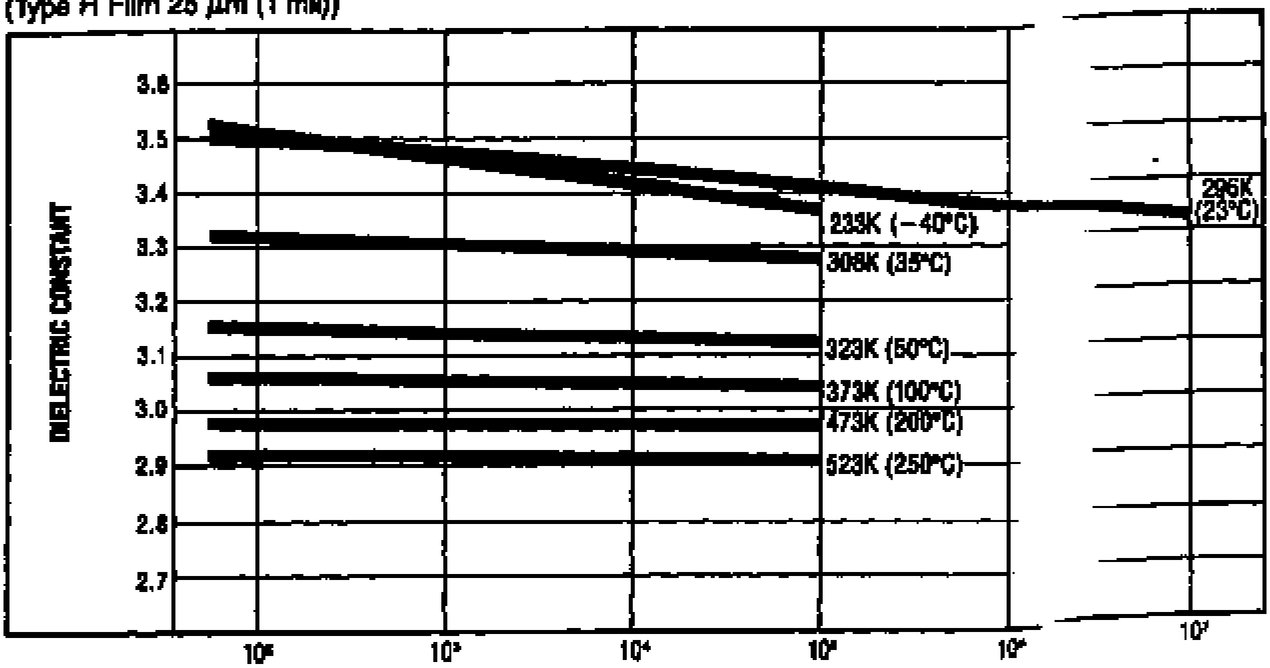
Corona inception voltage and corona intensity are functions of many parameters, including insulation thickness, air gap thickness, and device shape. Consult with a Du Pont technical representative on the suitability of KAPTON for specific applications where corona may be present.

EFFECT OF FREQUENCY

The effects of frequency on the value of the dielectric constant and dissipation factor at various isotherms are shown below.

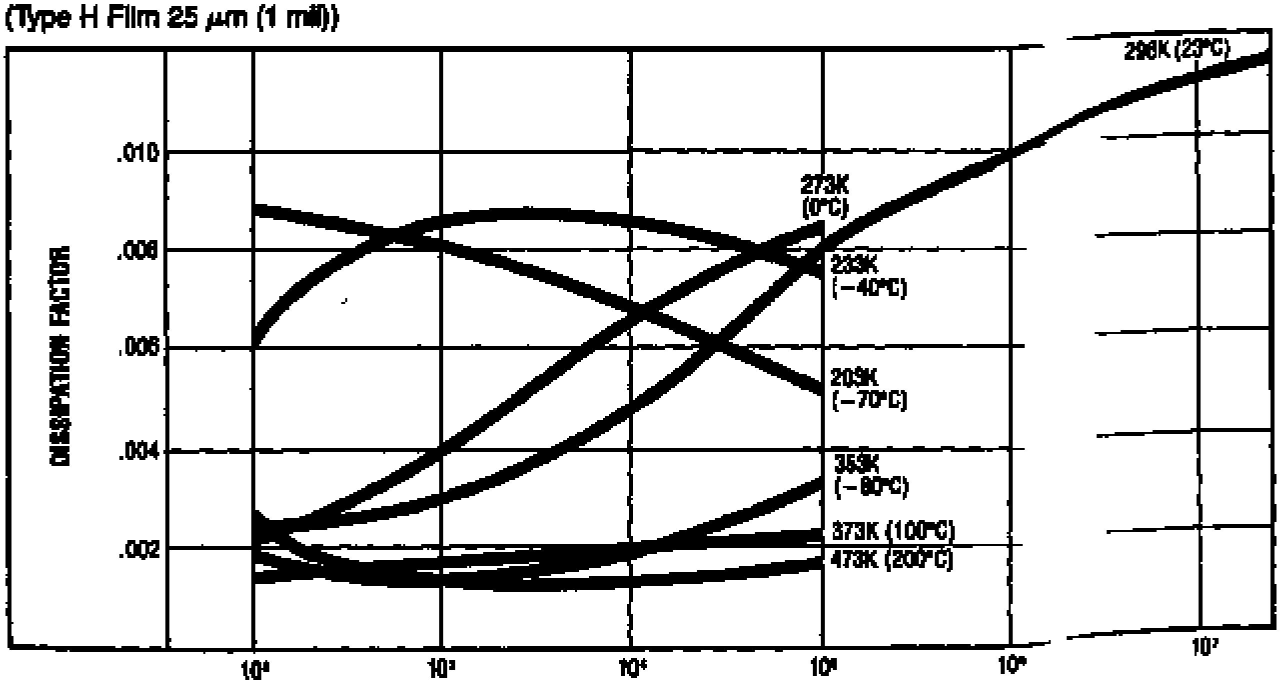
DIELECTRIC CONSTANT VS. FREQUENCY

(Type H Film 25 μm (1 mil))



DISSIPATION FACTOR VS. FREQUENCY

(Type H Film 25 μm (1 mil))



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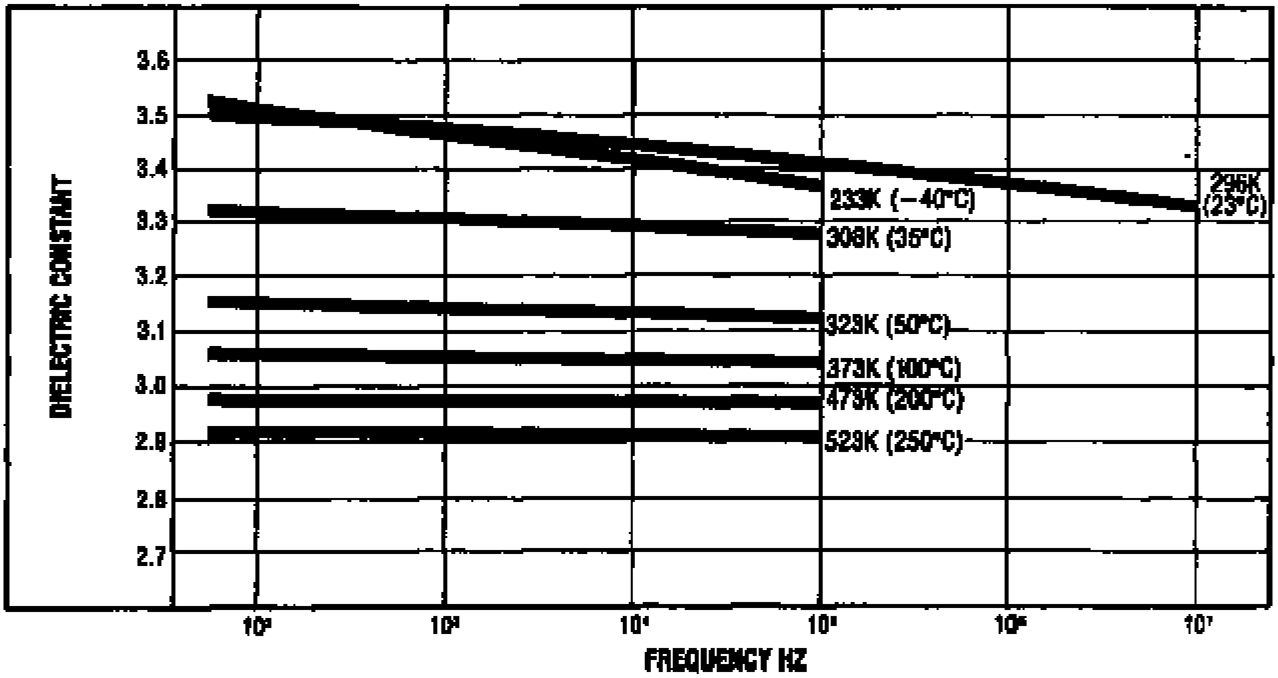
DIELECTRIC CONSTANT VS. FREQUENCY

(Type H Film 25 μm (1 mil))



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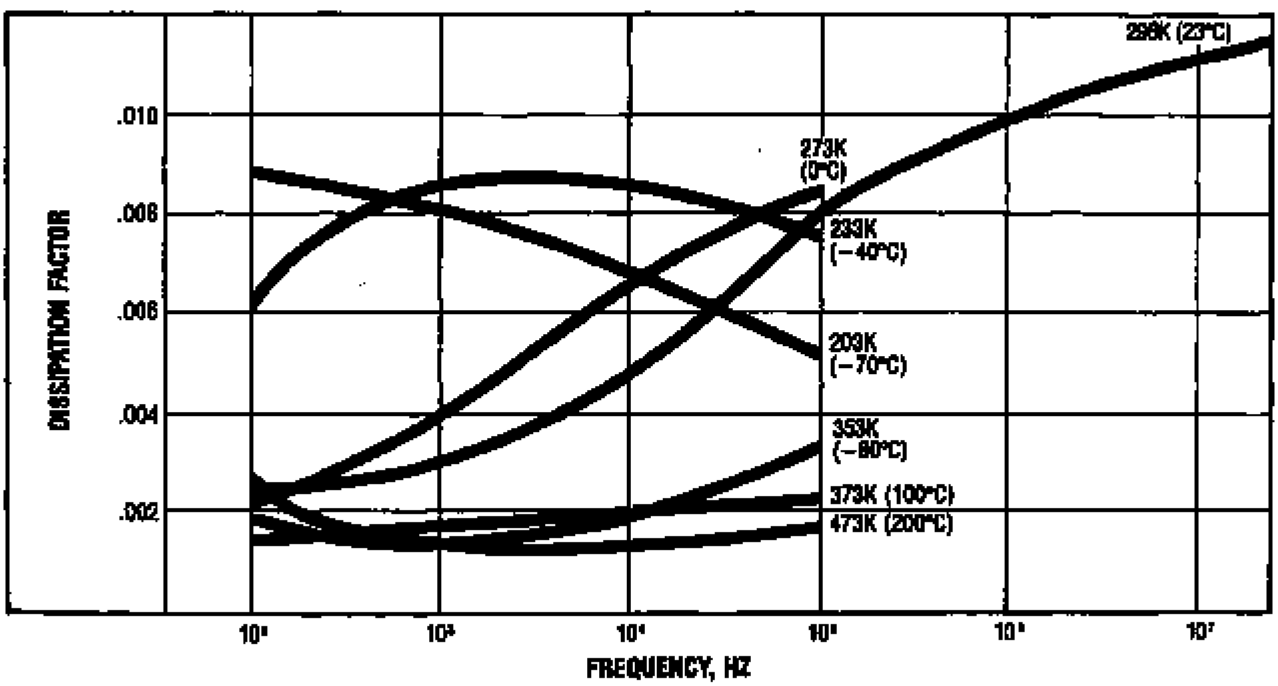

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CHEMICAL PROPERTIES

Kapton®
POLYIMIDE FILM

ADHESION TO KAPTON®

KAPTON® polyimide film, made only by Du Pont, is available in three basic film types. Type H KAPTON is 100% polyimide film. Type F is coated on one or both sides with a TEFLON® FEP fluorocarbon adhesive and Type V is a plain polyimide film having superior dimensional stability properties. Typical property information for KAPTON is found in Bulletin E-72087, "Summary of Properties." Specifications are found in Bulletin E-67824, "Industry Specifications Bulletin FC-85-2." For flexible printed circuit applications the trade specification IPC-FC-231/Sheet 1, applies to KAPTON.

ADHESIVE SELECTION

For some applications KAPTON must be bonded to other materials, such as copper foil, which requires the use of an adhesive. Optimum adhesion results are usually obtained from commercially coated KAPTON which is available from a variety of suppliers such as those listed in Bulletin E-72091, "Suppliers of Adhesive Coatings on KAPTON." This listing represents most of those companies offering coated KAPTON but should not be regarded as a complete listing. Detailed information on the use of these adhesive coated products can be obtained from the supplier's bulletins. Specific requirements for copper laminates produced as substrates for flexible printed circuits are outlined in trade specifications:

- USA: IPC-FC-241
- British: BS-4584
- German: DIN-40802

When commercially coated film is not suitable for an application, most vendors offer a dry film form of their adhesives for use as a bonding film in laminations. However, better adhesion is normally obtained from commercial solution coatings than from the dry bonding film. The dry film adhesive does have the advantage that it can be cut to shapes which cover only that portion of the polyimide film where adhesion is desired.

If neither commercially coated polyimide film nor adhesive bonding film is suitable for the application, the remaining option is for the user to apply a solution adhesive. Some generic classes of adhesives which bond KAPTON include acrylics, epoxies, butyral-phenolics, polyesters, silicones, urethanes, fluorocarbons and blends of these materials.

Selection of an adhesive is usually dependent on the properties required of the adhesive and the demands of the application. Property considerations are the thermal rating, chemical resistance, fill and flow characteristics, flexibility, peel strength, flammability, moisture resistance and insulation resistance. Also to be considered is the ease of processing, lamination temperature and whether the lamination is to be made in continuous roll equipment or in a platen press.

ADHESIVE PROPERTIES

Adhesives used with KAPTON Type H are usually a modified version of the generic adhesive family (e.g., modified-epoxy). These formulations are proprietary to the suppliers of coated KAPTON and require specific processing conditions to achieve the maximum bond strength. Always use the supplier's recommended lamination conditions for the specific adhesive you select.

Listed in Table I are several adhesive types along with information on typical lamination temperatures and maximum operating temperatures (short term exposure). When using an epoxy adhesive, anhydride curing agents are preferred. If an amine curing agent must be used, avoid an excess of curing agent as the free alkaline materials can degrade the polyimide.

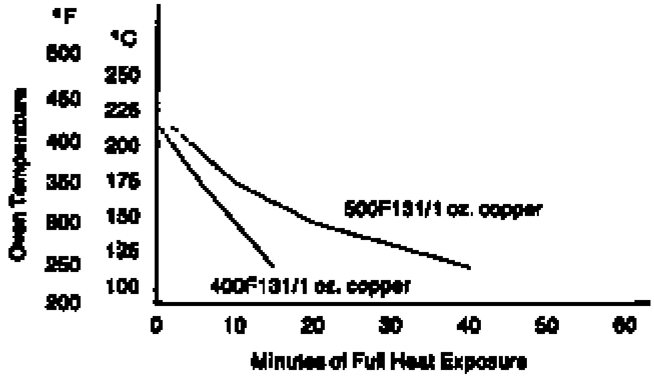
TABLE 1

Adhesive Types	Lamination Temperatures °F (°C)	Maximum Operating Temperature °F (°C)
Fluorocarbons	550-600 (290-315)	to 500 (260)
Polyimides	500-700 (260-370)	to 650 (345)
Epoxies	73-450 (23-230)	to 600 (315)
Pressure Sensitive Silicones	73-300 (23-150)	to 500 (260)
Rubber-Phenolics	300-400 (150-205)	to 500 (260)
Acrylics	350-375 (175-190)	to 550 (290)
Polyesters	275-300 (135-150)	to 220 (105)

Solution forms of most of the adhesives above are available from suppliers of adhesives to the electronics industry. Listings of suppliers can be found in buyer's guides for electronic products. Bulletin E-74149, "Suppliers of Adhesives to the Electronics Industry," provides a representative listing of adhesive suppliers who can be consulted with for specific adhesive needs.

Given in Figure 3 are minimum times to dry laminates of Type F to copper prior to dip soldering. The times are different than in Figure 2 due to the presence of the copper foil.

FIGURE 3
DRYING CONDITIONS FOR KAPTON TYPE F LAMINATES PRIOR TO DIP SOLDERING



SOLDERING AND PRESS CONDITIONS FOR TYPE H LAMINATES

The recommended predrying conditions prior to dip soldering and platen pressing laminates based on type H film will vary according to type of thermoset adhesive used in addition to factors mentioned for Type F laminates. The moisture retention and permeability of the film and adhesive must be considered along with the impermeability of the copper foil layers. Consult your laminate supplier for recommended predrying conditions specific to the combination of materials supplied.

EFFECTS OF HUMIDITY ON PEEL STRENGTH

Humidity can have a large effect on peel strength with certain adhesive systems, and RH ought to be controlled in peel strength measurements. A summary of our investigation into this phenomenon is given in Table III. Results show that those adhesives having functional groups capable of absorbing water vapor will promote high peel strengths at high RH and low peel strengths at low RH. Between an RH of 10% and an RH of 70%, the effect can be as large as 6 lbs. per lineal inch (10.5 N/cm). Those adhesives which do not have hygroscopic functional groups are not affected by RH changes in terms of peel values.

TABLE III
EFFECTS OF RELATIVE HUMIDITY ON PEEL STRENGTH

Adhesive Type	Peel Strength, lb./in. (N/cm) 10% RH	70% RH
Acrylic	5.8 (10.2)	11.5 (20.1)
Epoxy-Amide	5.4 (9.5)	10.0 (17.5)
Epoxy-Novolac	2.0 (3.5)	2.1 (3.7)
Phenolic-Butyral	3.8 (6.7)	5.2 (9.1)
Phenolic-Nitrile	4.7 (8.2)	4.3 (7.5)

EFFECT OF SURFACE ON PEEL STRENGTH

The top surface of KAPTON is referred to as the "bright" or "shiny" side. The bottom side is "dull" and purposely roughened in the manufacture of the film to improve film handling characteristics. Most adhesives bond better to the dull side of the film. The effect is generally 1-2 lbs. per lineal inch (1.8-3.5 N/cm) but can be as high as 4 lbs. per inch (7.0 N/cm) or negligible depending on the adhesive system used.

Experience has also shown that peel strength normally increases with the thickness of the film. Within a laminate based on a given film thickness, a range of peel strengths can also be expected, which is inherent in the film surface, the adhesive system and the test method applied. For example, a typical peel strength range for an acrylic adhesive is 6 lbs./in. (10.5 N/cm). For 100H this range can result in values as low as 2 lbs./in. (3.5 N/cm).

Unless specifically recommended by the adhesive supplier, the surface of KAPTON should be used as received. If the film has been contaminated with grease or oils, it should be cleaned with solvent (such as methylethyl ketone or toluene). Metal surfaces should be thoroughly cleaned. For best adhesion, they should be roughened mechanically or by chemical treatment.

When higher adhesion levels are required for a given adhesive system, the range of the peel strength values for the laminate may usually be reduced if the surface of the film is mechanically or chemically abraded, light pumice scrubbing or caustic etching. Caution must be exercised with any such treatment to avoid damaging the film.

EFFECT OF THERMAL TREATMENT ON PEEL STRENGTH

High thermal treatment of KAPTON will often improve bondability. Temperatures of about 400°C for as long as 5-10 minutes are required, and structural changes probably occur.

Studies of adherability of typical printed circuit adhesives to heat treated KAPTON and standard KAPTON have shown that heat treatment provides an advantage with most adhesives. The greatest advantage was gained with acrylic, epoxy, phenolic butyrals and phenolic nitriles. Improvement over standard film averaged from 40% to 97% for these adhesive types.

KAPTON® Type H Film

25 μm (1 mil)

CHEMICAL PROPERTIES

PROPERTY	TYPICAL VALUES (~25 μm (1 mil)) % Tensile Retained	% Elongation Retained	% Modulus Retained	TEST CONDITION/METHOD
RESISTANCE TO:				Days Immersed at Room Temperature
Benzene	100	82	100	365
Toluene	99	91	97	365
Methanol	100	73	140	365
Acetone	67	62	160	365
10% Sodium Hydroxide		Degrades		5
Glacial Acetic Acid	85	62	102	36 days @ 383K (110°C)
p-Cresol	100	77	102	22 days @ 473K (200°C)
Transformer Oil	100	100	100	180 days @ 423K (150°C)
Water pH = 1	65	30	100	14 days @ 373K (100°C)
pH = 4.2	65	30	100	14 days @ 373K (100°C)
pH = 7.0	65	20	100	166 days @ 373K (100°C)
pH = 8.9	65	20	100	14 days @ 373K (100°C)
pH = 10.0	60	10	100	4 days @ 373K (100°C)
RADIATION RESISTANCE				
Gamma (Savannah River)		Still Flexible (180° Bend)		Exposure: 4.16×10^7 Gy
Electron (Van de Graaff)		Retains 50% of Original Elongation		Exposure: 6×10^7 Gy
Neutron plus Gamma (Brookhaven)		Darkened but tough		Exposure: 10^8 Gy
FUNGUS RESISTANCE		Inert		Soil Burial
MOISTURE ABSORPTION		1.3% Type H		50% Relative Humidity at 296K (23°C)
		2.9% Type H & V		Immersion for 24 hours at 296K (23°C)
HYGROSCOPIC COEFFICIENT OF EXPANSION		2.2×10^{-5} m/m/% Relative Humidity		295K (72°F) 20%-80% Relative Humidity
PERMEABILITY				
Gas		ml/m²·MPa·day (cc/(100 in²) (24 hrs.) (atm/mil))		
Carbon Dioxide		6.9 (45)		ASTM D-1434-63 @ 296K (23°C)
Hydrogen		38 (250)		
Nitrogen		0.9 (6)		
Oxygen		3.8 (25)		
Helium		63 (415)		
Water Vapor		g/m²·day 84 g/(100 in²) (24 hrs.)/mil 5.4		ASTM E-96-63T

TI-NHTSA 017902

In U.S.A.
Du Pont Company
Polymer Products Department
Industrial Films Division
Wilmington, DE 19898
800-527-2601

In Canada
Du Pont Canada Inc.
Packaging Division
P.O. Box 2200 Streetsville Postal Station
Mississauga, Ontario
L5M 2H3
(416) 821-3300

In Europe
Du Pont de Nemours International
Polymer Products Department
78-82 Route des Acacias
CH-1211 Geneva 24, Switzerland
(022) 37 81 11

In The Far East
Du Pont Japan Limited
Kowa Building No. 2
11-39 Akasaka 1-chome
Minato-Ku
Tokyo 107, Japan
011-81-3-585-5511

In Brazil
Du Pont do Brasil S/A
Divisao de Plasticos or Elastomers
Caixa Postal, 26 – Alphaville
06400 Barueri/Sao Paulo, Brazil

Worldwide (Except Europe)
Du Pont Company
International Customer Services
Concord Plaza-Read Bldg.
Wilmington, DE 19898
(302) 772-6120

KAPTON® Type V Film

CHEMICAL PROPERTIES

Typical chemical properties for Type V film are similar to Type H.

KAPTON® Type F Film

CHEMICAL PROPERTIES

PROPERTY	120F616	150F019	400F022
Moisture Absorption @ 298K (25°C), 50% R.H. 98% R.H.	 1.3% 2.5%	 .8% 1.7%	 .4% 1.2%
Water Vapor Permeability $g/m^2 \cdot d$ (gm./(100 in²) (24 hrs.) $g/m^2 \cdot d \cdot \mu m$ (g./(100 in²)(24 hrs./mil)	 13.7 (0.89) 0.44 (1.07)	 8.8 (0.57) 0.35 (0.86)	 3.6 (0.23) 0.14 (0.92)

TI-NHTSA 017904

Kapton®
Polymide Film

DuPont
Electronics

High Performance Films

TI-NHTSA 017905

TI-NHTSA 017906

If you need additional information, please contact our Customer Services Center

Du Pont Electronics
HPF Customer Services
Wilmington, Delaware 19880
Product Information: 1-800-237-4357
Ordering Information: 1-800-237-2374

United States
Headquarters
Du Pont Electronics
Barley Mill Plaza
P.O. Box 80019
Wilmington, DE 19880-0019
Product Information: 1-800-237-4357
Ordering Information: 1-800-237-2374

Electronics Technology Center
Du Pont Electronics
14 T.W. Alexander Drive
Research Triangle Park, NC 27709
(919) 248-5000
Fax: 919-248-5650

Canada
Du Pont Canada Inc.
Du Pont Electronics
7070 Mississauga Road
Box 2200, Streetsville
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L5M 2H3 Canada
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Fax: 416-821-5000

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Du Pont Argentina S.A.
Av. Eduardo Madero 1020
(1106) Buenos Aires
54-1-312-9011
Fax: 54-111-1329

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Av. Presidente Kennedy, 611
09900 - Diadema
Sao Paulo - Brasil
55-11-445-3711
Fax: 55-11-445-3692

Mexico
Du Pont, S.A. de C.V.
Homero 206-10
Col. Chapultepec Morales
Mexico, D.F. 11570
525-250-6033
Fax: 525-250-3845

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Du Pont de Venezuela C.A.
Apartado Del Este 61562
Caracas 1060-A, Venezuela
58-2-92-6022
Fax: 58-2-92-9442

Europe
Du Pont de Nemours International S.A.
P.O. Box 50
2, chemin du Pavillon
CH-1218 Le Grand-Saconnex
Geneva, Switzerland
41 (22) 717-5111
Fax: 41 (22) 717-5109

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Japan
Du Pont Japan Ltd.
Du Pont Tower, Shin-Nikko Building
10-1, Toranomon 2-chome
Minato-ku, Tokyo
105 Japan
81-3-3585-5511
Fax: 81-3-3224-8983

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Du Pont Singapore PTE Ltd.
1 Maritime Square
07-01, World Trade Centre
Singapore 0409
65-273-2244
Fax: 65-272-6066

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Northside Gardens
168 Walker Street
North Sydney, NSW 2060
Australia
61-2-923-6111
Fax: 61-2-929-7217

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1122 New World Office Bldg
East Wing
Salisbury Road, Kowloon
Hong Kong
852-734-5345
Fax: 852-724-4458

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Du Pont Korea Ltd.
9th Floor, Kyobo Bldg.
1, Chongro 1-Ka, Chongro-Ku
Seoul 110-714, Korea
82-2-721-5114
Fax: 82-2-732-6930

Taiwan
Du Pont Taiwan Ltd.
13th Floor, Hung Kuo Building
167 Tun Hwa North Road
Taipei, Taiwan 10590, R.O.C.
886-2-719-1999
Fax: 886-2-712-0444

Du Pont Electronics

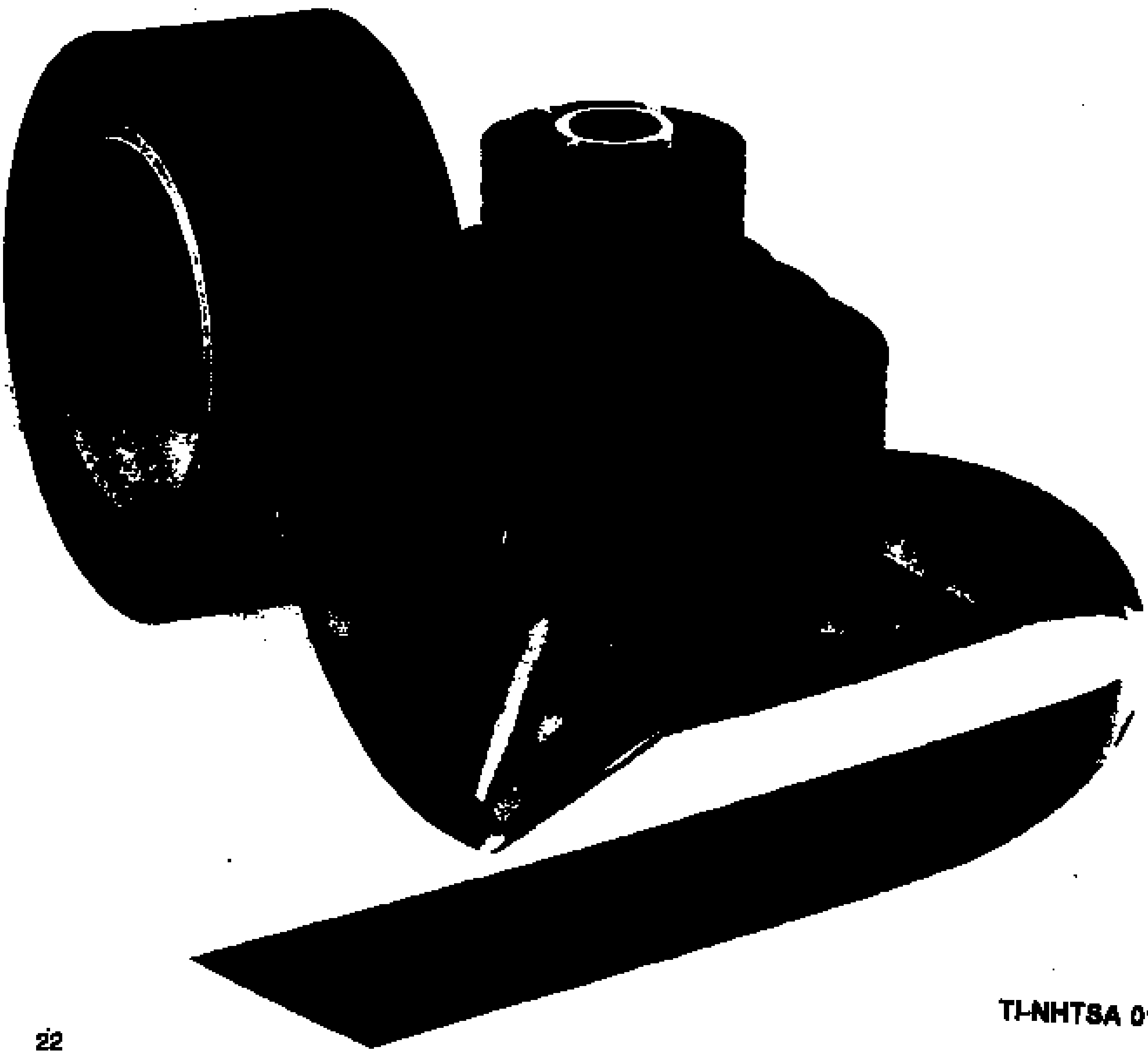
TI-NHTSA 017907

NOMINAL CONSTRUCTION, Type F Film

In the KAPTON® Type F order code of 3 digits, the middle digit represents the nominal thickness of the base KAPTON in mils. The first and third digits represent the nominal thickness of the coating of TEFLON® FEP fluorocarbon resin in mils. The symbol 9 is used to represent 13 μm (½ mil) and 6 to represent 2.5 μm ($^1/_{10}$ mil). Example: 120F616 is a 120 gauge structure consisting of a 25 μm (1-mil) base film with a 2.5 μm ($^1/_{10}$ mil) coating of TEFLON on each side. Illustrated are 3 examples of the many types available.

ORDER CODE	NOMINAL THICKNESS μm	NOMINAL THICKNESS mils	"TEFLON" FEP μm	"TEFLON" FEP mils	"KAPTON" TYPE H μm	"KAPTON" TYPE H mils	"TEFLON" FEP μm	"TEFLON" FEP mils
120F616	30	1.2	2.5	0.1	25	1	2.5	0.1
150F019	38	1.5	0	0	25	1	13	½
250F029	64	2.5	0	0	51	2	13	½

ORDER CODE	STANDARD WIDTHS mm	STANDARD WIDTHS inches	AREA FACTOR m^2/Kg	AREA FACTOR $FT^2/LB.$
120F616	3.18-914	1/8-36	21.3	104
150F019	3.18-914	1/8-36	15.8	77
250F029	3.18-914	1/8-36	11.1	49



TI-NHTSA 017908

KAPTON® Polyimide Film
Technical Bulletin

DuPont
Electronics

Suppliers of Adhesives to the Electronics Industry

High Performance Substrates and Materials

September 1989

3M/ Adhesives-Coatings-Sealers, St. Paul, MN .... (612) 733-1106
Aremco Products Inc., Ossining, NY .... (914) 762-0685
Assembly Systems Inc., Providence, RI .... (401) 331-9154
Bacon Industries Inc., Watertown, MA .... (617) 926-2550
Bostik Div. (Emhart Corp.) Middleton, MA .... (617) 777-0100
Conap Inc., Olean, NY .... (716) 372-9650
Crest Products Co., Santa Ana, CA .... (714) 540-9067
Dolph, John C. Co., Monmouth Junction, NJ .... (201) 329-2333
Dow Corning Corp., Midland, MI .... (517) 496-4000
Epoxy Technology Inc., Billerica, MA .... (508) 667-3805
Fenwal Inc., Ashland, MA .... (508) 881-2000
Formulated Resins Inc., Greenville, RI .... (401) 949-2060
GE/ Silicon Products Div., Waterford, NY .... (518) 237-3330
B. F. Goodrich Adhesives Div., Akron, OH .... (216) 374-2000
Hardman Inc., Belleville, NJ .... (201) 751-3000
Hysol Division, City of Industry, CA .... (818) 968-6511
Isochem Products Co., Lincoln, RI .... (401) 723-2100
Loctite Corp., Newington, CT .... (203) 246-1223
Henry Mann Inc., Huntingdon Valley, PA .... (215) 355-7200
Miller-Stephenson Co., Danbury, CT .... (203) 743-4447
Oneida Electronic Mfg. Inc., Meadville, PA .... (814) 336-2125
PTM&W, Santa Fe Springs, CA .... (213) 946-4511
Shell, Houston, TX .... (713) 493-7275
Symplastics Inc., Montrose, CA .... (818) 249-7810
Tech Spray Inc., Amarillo, TX .... (806) 372-8523
Techni-Tool Inc., Plymouth Meeting, PA .... (215) 825-4990
Technit, Cranford, NJ .... (201) 272-5500
Thermalloy Inc., Dallas, TX .... (214) 243-4321
Thermoset Plastics Inc., Indianapolis, IN .... (317) 259-4161
Tra-Con Inc., Medford, MA .... (617) 391-5550
Vigor Co., New York, NY .... (212) 807-3845
Whittaker (Dayton Chemicals Div.) West Alexandria, OH .... (513) 839-4612

This list is believed to be complete as of the date of publication. There may be others not known to us, who manufacture similar products based on KAPTON polyimide film.

DUPONT

TI-NHTSA 017909

INQUIRIES

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In Canada
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Electronics Department
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(022) 37 81 11

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5-6, Nihonbashi-Honcho 1-chome
Chuo-ku, Tokyo 103 Japan
03 245 5061

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In South East Asia
Du Pont Asia Pacific (Ltd.)
1122 New World Office Building (East Wing)
Salisbury Road, Kowloon
Hong Kong, BCC
03 734 5377

Worldwide (Except Europe)
Du Pont Company
International Customer Services
Concord Plaza-Read Bldg.
Wilmington, DE 19898
(302) 772-6120

TI-NHTSA 017911

To Place an Order or Check on Status:

- Call: 800-222-8377
- Telex: 8717326
- Teletype: TWX 810 666-2964/2317
- Fax: 302-733-8137 or
  1-800-477-6790

KAPTON® offers inherent heat and flame resistance and excellent thermal performance.

For all of its outstanding properties, KAPTON is probably best known for its ability to "take the heat." With a UL-94 rating of V-O for flammability — the best possible — KAPTON polyimide film will not sustain or propagate flame. Nor will it melt, drip or produce any significant smoke when exposed to flame.

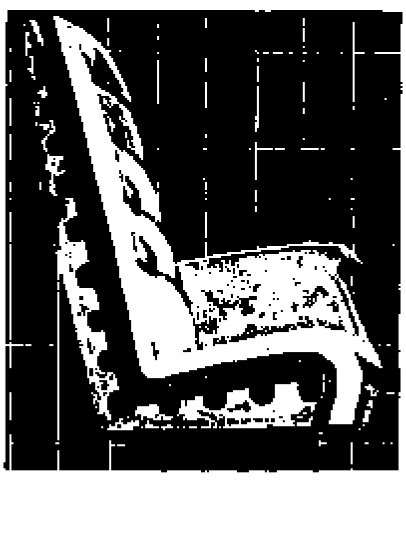
Rated at 240°C for continuous service, KAPTON can still function after exposure to temperatures up to 400°C for brief periods. Best of all — it retains its high dielectric strength even at elevated temperatures — 2,500 volts/mil at 300°C.

These outstanding thermal properties provide significant advantages to the designer. Insulation thickness on the windings of large coils for motors can be significantly reduced in size; flexible circuits can be wave-soldered without distortion; and, when used in combination with inorganic insulating tapes, high-performance cables will continue to operate in direct exposure to flame.

KAPTON polyimide film is compatible with a number of high-temperature impregnating varnishes used in modern electrical equipment manufacture — including polyimides, esterimides, epoxides, silicones, amides-imides, and organo-silicones. Magnet wire made with certain combinations of polyimide film and varnishes has a IEEE #57 thermal stability rating of 260°C.

But flame and heat resistance aren't the only thermal advantages of KAPTON. It also performs very well at the other end of the temperature scale. KAPTON film retains its flexibility at −269°C without embrittlement or significant loss of other properties.

Keeping people and equipment warm is a natural for KAPTON. As a strong, lightweight, flexible laminated sheet, it can be used to insulate and protect embedded heater wires for such diverse applications as car seat or ski-lift chair heaters, aircraft wing deicers, engine warmers, hot trays and electric blankets.



7. A strip of KAPTON Type H film is positioned over the pins in this IC socket to prevent wicking during wave soldering. The strip also provides a dielectric barrier between the leads and printed circuit.

8. A steel mill now gets 3,000 extra horsepower from the same size motor thanks to KAPTON as the coil insulation. The motor manufacturer reports that insulated windings of KAPTON last as much as 50 times longer at the 200°C rated operating temperature versus those with previously used insulations.

9. Used as insulation in rotor and stator windings, KAPTON reduced the weight of traction motors in the world's fastest train by 5%. It also helped reduce motor production costs and increased horsepower.

10. The low smoke properties of insulation of KAPTON permit its use as a cable jacket for plenum cable, eliminating the need for expensive metal conduit.

11. As a pin grid array, KAPTON allows insertion of all pins into a circuit board in a single, high-speed operation. Registration is perfect, and the need for expensive loading machinery is eliminated. KAPTON withstands the high temperatures of wave soldering and allows visual inspection of completed connections. After soldering, KAPTON can either be peeled away or left in place as additional support for pins during further processing and handling.

12. PC boards are identified for quality control and inventory purposes by bar code labels using an overlay of KAPTON. Since KAPTON can withstand the temperatures of wave soldering without significant shrinkage or distortion, it can be used for labelling on the *underside* of printed circuit boards where space is not at a premium.

KAPTON® has superior strength, toughness, abrasion resistance and workability.

KAPTON polyimide film can solve a host of parts' performance problems that fibers, resins, metals, composites, glass, ceramics, mica or asbestos and conventional films cannot. The high tensile strength and initial tear resistance of KAPTON provide the mechanical durability necessary for many critical manufacturing operations, such as printed circuit processing and installation. Its exceptional toughness and resistance to cut-through and abrasion make it especially useful as insulation for aerospace communications wire and cable where it can be pulled through even the tightest routing.

Since the outside diameter of a wire or cable insulated with KAPTON is smaller than conventional wiring using extruded insulations, more cables can be run through a given size conduit or plenum. Stripping and termination are easier, too.

The strength, toughness, flexibility and wear resistance of KAPTON film are leading to greater numbers of non-electrical applications as well. Applications such as drive belts, pressure switch diaphragms, wear strips, washers, and seals.

As a material for use in space, KAPTON has virtually no limitations. Designers already envision huge inflatable structures that could be used for a variety of purposes, including space station repairs, energy collection and transmission, and temporary protection of unassembled equipment components.

13. Flexible circuits of KAPTON can be bent, coiled, folded or twisted — and remain that way for the life of the product — without impairing circuit integrity while offering additional design freedom.

14. KAPTON protects plenum cables from damage by abrasion, kinking and snagging during installation when it is "fished" over sharp places in plenums and through ducting and conduit.

15. Automotive pressure sensing switches use KAPTON for the diaphragm because it is flexible, easily fabricated and withstands the dramatic temperature changes under the hood. KAPTON also resists most organic solvents, oils and greases.

16. KAPTON is an ideal material for tractor belts on high-speed computer printers. Because of its excellent toughness, dimensional stability and thermal properties, KAPTON stands up to the shock of abrupt start and stop operation and the heat of high-speed operation. The tractor belt teeth are injection molded directly into KAPTON film.

KAPTON® has outstanding electrical properties.

Next to its thermal properties, KAPTON polyimide film is selected by designers most frequently because of its excellent dielectric strength, dielectric constant, and dissipation factor. The dielectric strength of 1 mil KAPTON — 7,000 volts at room temperature (23°C) — is typically 2,500 volts even at an elevated temperature of 300°C. In fact, short-term exposure to temperatures as high as 400°C will not significantly affect the electrical properties of KAPTON.

The combination of high dielectric strength, thermal stability, uniform thickness and excellent mechanical properties allows designers of electrical equipment to specify thinner insulation on coils for transformer, generator or motor windings. This is very important because more conductors can be physically located within a given space, yielding greater power per unit. Or, if the power requirement is constant, the weight and dimensions of a given coil, stator or rotor can be substantially reduced.

In flexible circuits, the high dielectric constant of KAPTON and low dissipation factor combine to reduce signal loss to a minimum at relatively low operating voltages.

KAPTON film will play a major role in the world's largest linear particle accelerator. Proposed as the insulation for the research instrument's superconductive magnet wire, KAPTON is the only material — repeat, the *only* material — that can provide the extremely close tolerances, excellent dielectric strength and resistance to the liquid helium temperatures that are required for this unique application.

17. This electric locomotive, equipped with 3,000 volt DC traction motors, uses KAPTON Type F as an insulation on its motor windings. The KAPTON permitted an 8% increase in power over the conventional insulation material it replaced.

18. A thin, circular band of KAPTON provides outstanding electrical and thermal insulation for this high-frequency "super-tweeter" voice coil. KAPTON resists distortion at high operating temperatures, and is fully compatible with the epoxies, resins and paints used in speaker manufacture.

19. The elongation of KAPTON polyimide film is such that magnet wire insulated with KAPTON Type F sealable film can be easily bent to the desired shape without creating air gaps in the insulation, which could lead to dielectric failure or "hot spots".

20. By utilizing KAPTON on the coil winding of this electric utility line trap, the size and weight of the device can be reduced 30% — a significant advantage for substations in locations where real estate is at a premium.

KAPTON® has outstanding resistance to most chemicals, solvents, lubricants and fuels.

KAPTON is an ideal material for use in demanding environments in which a combination of hostile elements such as chemicals, gasses, radiation and high temperature is present. No matter whether you're talking about the motor windings insulation in an oil well pump operating in a pit of gas and brine 20,000 feet below the surface of the earth, a protective layer for a liquid level sensor submerged in an organic solvent, or in a pressure switch in the cooling system of an automobile — KAPTON can take the punishment and still deliver reliable performance.

In flexible circuitry, conductors bonded between layers of KAPTON polyimide film are protected against chemicals, moisture, gasses and foreign materials so they can operate reliably in demanding environments. In military and industrial applications, KAPTON film remains tough and flexible even after exposure to 10^9 RADS of gamma radiation. And, although it is unaffected by most organic chemicals, solvents, fuels and lubricants, KAPTON can be dissolved by certain strong bases — a fact that printed circuit manufacturers use to advantage in the chemical milling of holes in printed circuits.

As mobile research vehicles brave the hostile environments of distant planets and traverse their rugged surfaces gathering samples and data, they will undoubtedly have the protection of KAPTON film. In applications ranging from wire and cable insulation to surface protection — from tractor belts to solar panels — KAPTON will make these robot explorers lighter, stronger, more resistant to chemicals, radiation and abrasion, and ultimately — more reliable.

21. This 2,300 VAC submersible oil well pump uses KAPTON polyimide film in the magnet wire and slot liner insulation system. Motors of this type often operate at depths of 20,000 feet or more in hostile, high-temperature environments which contain brine, petrochemicals and hydrogen sulfide. Manufacturers report a 50% improvement in service life using motors insulated with KAPTON.

22. Specialty conductors metallized between sheets of KAPTON comprise a highly reliable and accurate automotive electrothermal fuel level sensor developed in Germany by VDO. In addition to its outstanding thermal and dielectric properties, KAPTON can be directly immersed in a wide variety of fuels, including blended ethanol and methanol.

23. KAPTON is an ideal substrate for this CTS throttle position transducer. Not only is it resistant to automotive chemicals and lubricants; it can also withstand both high underhood temperatures, and cold winter mornings while still performing reliably.

24. Critical fuel lines of satellites in space are kept from freezing at ultra-low temperatures by heater cables insulated with KAPTON. Nickel-chromium heating elements are encapsulated in a sandwich of KAPTON which provides both superior dielectric properties and full protection against the thermal shock of extremely high and extremely low temperatures.

TEXAS INSTRUMENTS INCORPORATED,
AUTOMOTIVE SENSORS & CONTROLS

TITLE: PROCESSING AND FLOW OF INPROCESS MATERIAL REJECTIONS	DOC. NO. QAS 231

SUPPLIER ALERT
Please respond within 10 days
Not a Corrective Action Request

Address Response To:
Ron Souza Mail Stop: 11-09 Texas Instruments, Inc. P.O. Box 2964 34 Forest Street Attleboro, MA 02703-0964 Tel: 508-236-3988 Fax:: 508-236-3827 E-mail:

DATE PREPARED: 2/27/98 SUPPLIER: EI Dupont

PART NAME: Select one PART NUMBER: 27225-4

LOT No. N/A DRAWING REV: AA

RDIM No. 032450 attached QUANTITY: 1 REEL
attached QUANTITY:

This notice is being issued by the PSM Material Review Board to inform you that parts inspected on the date shown above were found to contain unacceptable dimensions and/or conditions outlined below. Even though no formal rejection has been issued, it is expected that you will review your processes or system(s) in order to identify areas that will improve the acceptability of your product.

SPECIFICATION: No deformities per note 1.

OBSERVED CONDITION: There appears to be a curvature of the roll along one edge which apparently causes some jamming in our automated assembly machinery. Data included for your information

---

SUPPLIER RESPONSE: Please reply to the following inquiries and reply to above addresses.

1) Do you recognize this as a discrepancy you may have seen before? ☐ Yes, ☒ No

2) Do you currently have a process control mechanism in place to prevent this discrepancy from occurring?
☐ Yes, ☒ No

3) If you answered Yes to question (2), why do you think it occurred again? If you answered No to question 2, what actions, if any, would you anticipate on taking to prevent recurrence?

ADD A CUSTOMIZATION FOR (TBD) FILM CURL.
I WILL SPEAK WITH FINISHING AREA TO DETERMINE ACTION.

Authorized Signature: [signature] Date: 5/19/98

Please respond within 10 days.

Materials & Controls
Supplier Corrective Action Request

NOTE: YOUR CORRECTIVE ACTIVE RESPONSE IS DUE 15 WORKDAYS AFTER RECEIPT OF THIS REQUEST AT YOUR FACILITY.

RETURN TO:
Lorraine Horton MS: 12-11
Texas Instruments Incorporated
34 Forest St. P.O. Box 2964
Attleboro, Ma.
02703-0964

PREPARATION DATE [redacted] 4/20/99

SUPPLIER: E. I. DUPONT [redacted] 27225-2

ATTENTION: MARK McALEES [redacted] 037977

PLEASE ADDRESS APPROPRIATE CATEGORIES BELOW ◆ INDICATES SUPPLIER TO ADDRESS

1. A.) TEXAS INSTRUMENTS INCORPORATED MSS MEMBERS & APPROPRIATE MANAGERS

BUYER: DARLENE SANVILLE MS: 23-4 ◆ ____ MS:
◆ ____ MS: ◆ ____ MS:
◆ ____ MS: ◆ ____ MS:

◆ 1. b.) SUPPLIER IDENTIFIED SUB-TIER SUPPLIERS: (WRITE NONE, IF NONE)

NAME: ____ ADDRESS (IF APPLICABLE): ____

◆2. DESCRIPTION OF NONCONFORMANCE:

MANUFACTURING DATE: ____ LOT NUMBER (IF APPLICABLE): ____

ATTRIBUTE SPECIFICATION ____ +/- ____ ACTUAL: ____

OTHER: SCRATCHES ON FILM
VISUAL DEFECT

◆3. CONTAINMENT: SHORT TERM FIX PROBLEM, ISOLATE PRODUCT & DATE
CONTACT LAMINATING & FINISHING.
MAKE AREA MANAGEMENT AWARE OF ISSUE.

◆4. DEFINE AND VERIFY ROOT CAUSE: ANALYZE AND PROPOSE SOLUTION
HANDLING OF FILM IN LAMINATOR
AND FINISHING AREA EQUIPMENT

*5. PERMANENT CORRECTIVE ACTION: SOLUTION THAT ADDRESSES CORRECTIVE ACTION, DATE TO BE IMPLEMENTED, AND DATE CORRECTED PART TO BE SHIPPED OR PROCESS TO BE FOLLOWED.

REINFORCE QUALITY WITH OPERATORS
AND QUALITY CONTROL INSPECTOR

*6. VERIFICATION: DEFINE TEST / ANALYSIS OF ROOT CAUSE TO ENSURE CORRECTIVE ACTION

TRAIN / COMMUNICATE NEED FOR QUALITY
AND DEFECT FREE MATERIAL.

*7. CONTROL: ENSURE CORRECTIVE ACTION REMAINS IN EFFECT (MONITOR PROCESS)

MONITOR CAR. SYSTEM AND CONTINUE TRAINING
ON A REGULAR BASIS WITH OPERATORS

*8. PREVENTION: EXPLAIN ACTIONS TAKEN TO PREVENT REOCCURANCE

COMMUNICATE INFORMATION TO AREA
SUPERINTENDENT, MANAGEMENT WILL
CONTINUE TO REVIEW STATUS

SUPPLIER'S AGENT: MARK MCALEES TITLE: SR. TECH. SERVICE REP.

AGENT'S SIGNATURE: [signature] DATE COMPLETED: 4/20/99

TEXAS INSTRUMENTS INCORPORATED PQA & MRB REVIEW:

☐ *THIS SUPPLIER CORRECTIVE ACTION RESPONSE HAS BEEN APPROVED BY PROCUREMENT QUALITY ASSURANCE, AND HAS BEEN DISTRIBUTED TO ALL IDENTIFIED IN SECTION 1a*

Congratulations to all participants for the accomplishment!

PQA INITIALS & DATE: ____________

☐ THIS SUPPLIER CORRECTIVE ACTION RESPONSE HAS NOT BEEN APPROVED BY PROCUREMENT QUALITY ASSURANCE, BECAUSE:

☐ A SECOND RESPONSE HAS BEEN REQUESTED ON: ____________

☐ THE MRB DOES NOT ACCEPT THIS CORRECTIVE ACTION AND HEREBY REQUEST THAT PROCUREMENT QUALITY ASSURANCE ISSUE AN ADDITIONAL REQUEST FOR CORRECTIVE ACTION.

REQUESTED BY: ____________

☐ THE MRB IS HEREBY ALERTED TO A LESS THAN 100% EFFECTIVE CORRECTIVE ACTION, AND MAY REQUEST AN ADDITIONAL SUPPLIER RESPONSE THROUGH THE APPROPRIATE BUYER.

DUPONT 18008794481 04/22/99 08:45 :05/07 NO:065

TEXAS INSTRUMENTS

REPORT OF DISCREPANT IN-PROCESS MATERIAL

No. 037477

					Mfg. Supervision Review:
77225-7			783357	8-5-99	Tom Orango
BUTTON STRIP		PSM	27	1 ROLL	

Item	Attribute/Requirement	Actual				
	MATERIAL SHOULD BE FREE OF DAMAGE	SCRATCHES ON METAL TAPE ??		0	1	

MATL/PROD. CONTROL

COMMENTS:

MRB DISPOSITION

COMMENTS: ... to be sent to ... for ...

MRB SIGNATURES

REWORK PROCEDURE: (MFG./ENG.)

ESTIMATED TIME

MRB CORRECTIVE ACTION

COMMENTS: Provide Formal Response to Notification.

RECEIVING INSPECTION

PROCUREMENT ASSURANCE

DO NOT WRITE BELOW THIS LINE

SIGNATURE DATE

TI-NHTSA 017920