DuPont Teijin Films™

Innovation | Partnerships | Sustainability

Kaladex® PEN Films

Kaladex® is the trademark of DuPont Teijin Films for a range of biaxially oriented polyester films manufactured from polyethylene naphthalate (PEN) polymer, first introduced on a fully commercial basis in 1992

Kaladex® PEN Films

Kaladex® PEN films can be handled and processed in a similar way to more familiar films based on polyethylene terephthalate (PET), but the distinct polymer chemistry of PEN provides several superior properties including greater resistance to heat and hydrolysis, better dimensional stability and higher modulus.

This property set has allowed the development of a range of films that provide cost-effective solutions with an enhanced performance level between that of PET films such as Mylar® and Melinex®, and high-performance but higher cost engineered films such as polyimides, for example Kapton® from DuPont.

Kaladex® PEN films are manufactured using the same stenter processes as Mylar® and Melinex® PET films. They are also biaxially oriented and heat-set to give an optimum balance of crystalline and amorphous regions, providing mechanical and thermal resilience combined with toughness and flexibility. These familiar properties are coupled with enhanced performance in terms of:

- Higher glass transition temperature (Tg) of 121°C (as resin) vs 78°C for PET
- Superior long term ageing performance at elevated temperatures, with a Relative Temperature Index (RTI) to UL746B of 160°C (mechanical) and 180°C (electrical), exceeding that required for Class F electrical insulation applications
- Better dimensional stability at elevated temperatures, in terms of lower shrinkage and better retention of mechanical properties
- Stiffness (Young's modulus) 25% higher than PET
- Improved resistance to hydrolysis and alkalis compared to standard PET
- Very low levels of extractable oligomers for hermetic motor applications
- Inherent screening of UV light below 380nm.

The resulting balance between performance and cost makes Kaladex® PEN films well suited to a wide range of applications including electrical insulation, flexible printed circuits, capacitors, and a range of high-performance industrial applications including belts, casting substrates, speciality packaging and several emerging technologies such as EVs, batteries and fuel cells.

The leading expertise of DuPont Teijin Films in polymer science and film manufacturing technology combined with 30 years of experience with PEN films provide the basis for a highly attractive product range. Kaladex® PEN films offer:

- **New and expanded market opportunities** in applications with technical requirements beyond the limits of PET performance and where it is uneconomical to use higher cost materials.
- **Reduced manufacturing costs** with reduced wastage, increased production yields and better throughput in critical applications.
- **Reduced material costs** by avoiding the use of over-specified materials.

Kaladex® PEN films are currently qualified in several applications with further opportunities under development. Samples of the current Kaladex® grade range are available for testing and evaluation, and further grades will follow as the market demands.

Table 1: Properties of Kaladex® 2000 PEN film

	Property	Units		Kaladex® 2000	Test Method
Structure	Density	g/cm^3		1.36	DTF Method
	Surface Roughness	nm	Sa	22	DTF Method
			Sq	33	DTF Method
Mechanical Properties	Young's Modulus	MPa	MD	6700	ASTM D882
			TD	6900	
	F5	MPa	MD	150	ASTM D882
			TD	155	
	Tensile Strength	MPa	MD	245	ASTM D882
			TD	275	
	Elongation to Break	%	MD	90%	ASTM D882
			TD	70%	
	Tear Initiation	N	25um in MD	5.5	ASTM D1004 (50mm/minute)
			25um in TD	5.9	
	Tear Propagation	N	25um in MD	1.5	ASTM D1938 (1000mm/minute)
			25um in TD	1.6	
	Coefficient of Friction	-	Static	0.43	
			Dynamic	0.37	
Physical and Thermal Properties	Melting Temperature	°C		265	DTF Method by DSC
	Glass Transition Temperature (Resin)	°C		121	DTF Method by DSC
	Glass Transition Temperature (Film)	°C		155	DTF Method by DMA
	Shrinkage (150°C for 30 mins)	%	MD	0.6	DTF Method
			TD	0.6	
	Shrinkage (190°C for 5 mins)	%	MD	1.2	DTF Method
			TD	1.4	
	Coefficient of Thermal Expansion	10^{-6}/°C	MD	13	DTF Method
	Coefficient of Hygroscopic Expansion	10^{-6}/%RH	MD	11	DTF Method
	Continuous Use Temperature (RTI)	°C	Mechanical	160	UL746B (UL File E93687)
			Electrical	180	
Chemical Properties	Moisture Adsorption	%		0.20%	DTF Method (20°C & 50% RH)
	Moisture Permeability	g/m^2.24hr	25um	4.3	ASTM E398
	Oxygen Permeability	cm^3/m^2.24hr.atm	25um	15.2	ASTM D3985
Electrical Properties	Electric Strength	kV/mm	16um	390	ASTM D149
			25um	331	
			38um	261	
			50um	248	
			75um	198	
			100um	187	
			125um	163	
	Permittivity	-	23°C, 50Hz	3.24	ASTM D150
			23°C, 1kHz	3.22	
			23°C, 10kHz	3.20	
			50°C, 50Hz	3.27	
			100°C, 50Hz	3.29	
			150°C, 50Hz	3.40	
	Dissipation Factor	-	23°C, 50Hz	0.0034	ASTM D150
			23°C, 1kHz	0.0042	
			23°C, 10kHz	0.0048	
			50°C, 50Hz	0.0048	
			100°C, 50Hz	0.0055	
			150°C, 50Hz	0.0125	
	Surface Resistivity	Log Ω/Sq		15	ASTM D257 (500V d.c., 20°C & 54% RH)
	Volume Resistivity	Log Ω.m		16	ASTM D257 (100V d.c., 25°C & 1000s)
Optical Properties	Refractive Index	-	nMD	1.75	DTF Method
			nTD	1.76	
			nz	1.50	
	Total Light Transmission	%	16um	87	ASTM D1003
			25um	86	
			38um	85	
			50um	84	
			75um	83	
			100um	83	
			125um	82	
	Wide Angle Haze	%	16um	5	ASTM D1003
			25um	6	
			38um	8	
			50um	13	
			75um	18	
			100um	25	
			125um	30	

Table 2: Comparison of Kaladex® 2000 PEN film with a typical PET film

Property	Units		Kaladex® 2000 PEN film	Typical PET film	Test Method	Key Benefit
Density	g/cm³		1.36	1.40	DTF Method	PEN offers 3% better area yield than an equivalent PET film
Young's Modulus	MPa	MD	6700	4800	ASTM D882	PEN is >25% stiffer than an equivalent PET film and exhibits excellent mechanical properties.
		TD	6900	5000		
F5	MPa	MD	150	100	ASTM D882	
		TD	155	100		
Tensile Strength	MPa	MD	245	195	ASTM D882	
		TD	275	235		
Elongation to Break	%	MD	90%	115%	ASTM D882	
		TD	70%	90%		
Melting Temperature	°C		265	254	DTF Method by DSC	PEN has excellent heat stability, with a significantly higher Tg and a continuous use temperature that exceeds the requirements for Class F (155°C) applications.
Glass Transition Temperature (Resin)	°C		121	78	DTF Method by DSC	
Glass Transition Temperature (Film)	°C		155	110	DTF Method by DMA	
Continuous Use Temperature (RTI)	°C	Mechanical	160	105	UL746B (UL File E93687)	
		Electrical	180	105		
Shrinkage (150°C for 30 mins)	%	MD	0.6	1.2	DTF Method	PEN offers better dimensional stability than PET and can also be further heat-stabilised (pre-shrunk) if required.
		TD	0.6	1.0		
Shrinkage (190°C for 5 mins)	%	MD	1.2	2.5	DTF Method	
		TD	1.4	1.5		
Moisture Permeability	g/m².24hr	25um	4	15	ASTM E398	PEN has better inherent barrier properties than PET.
Oxygen Permeability	cm³/ m².24hr. atm	25um	15	52	ASTM D3985	
Breakdown Voltage	kV	25um	7.5	6.4*	* 23um for PET IEC 243-1	PEN has a higher breakdown voltage than an equivalent PET film providing excellent electrical insulation properties.
		50um	12.4	10.0		
		75um	14.8	12.0		
		125um	20.3	16.0		

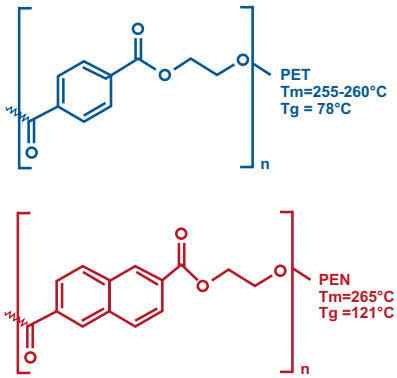


Figure 1:
Chemical structure of PEN compared with PET

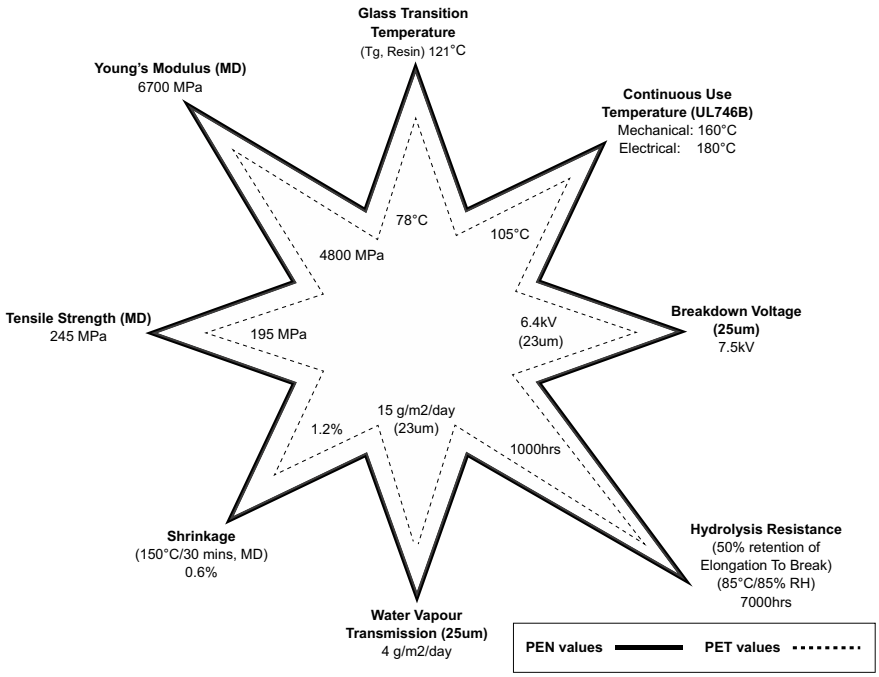


Figure 2:
Comparison of key properties between Kaladex® PEN and typical PET films

Kaladex®
for Electrical Insulation

As the inventor of polyester film DuPont Teijin Films has close to 70 years of experience in the design, development and manufacture of products for a wide range of industries and applications.

One of the earliest to benefit from the property set of polyester films was electrical insulation, with Mylar® becoming the industry standard for high quality PET films offering reliability, consistency and best-in-class properties. Kaladex® PEN films build on this heritage by adding a number of superior properties to the well-known performance of PET films such as Mylar®.

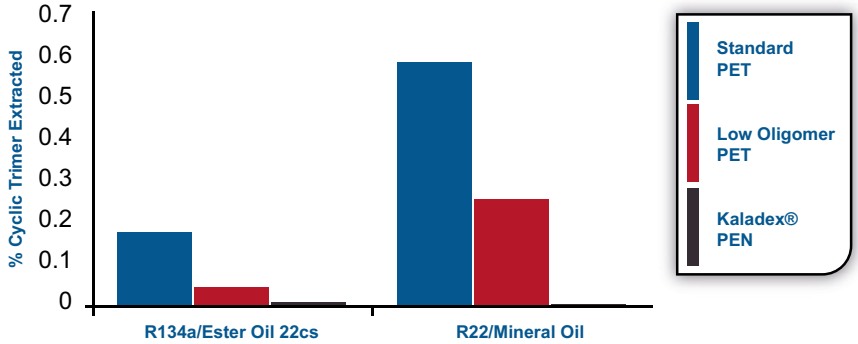
The main grade used in electrical insulation applications is Kaladex® 2000 which exhibits the following key features:

- Elevated RTIs of 160°C mechanical and 180°C electrical under UL746B (File E93687)
- Good mechanical strength with stiffness 25% higher than PET
- Excellent dielectric strength (typically 8 x aramid paper)
- Good thermal conductivity (2 x aramid paper at same thickness)
- Greater hydrolysis resistance compared to standard PET
- Low moisture absorption
- Excellent solvent resistance
- Very low oligomer extraction in hermetic motor applications.

These features of Kaladex® PEN film provide a number of benefits in electrical insulation applications:

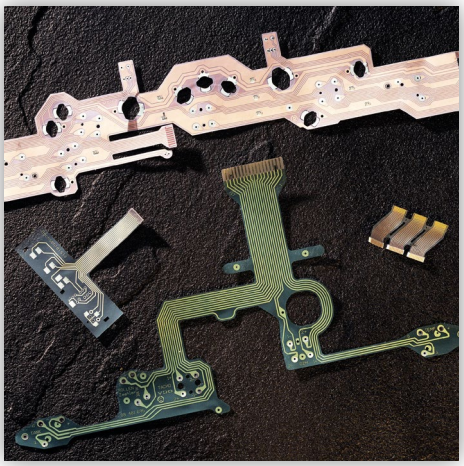
- RTIs suitable for use in Class F (155°C) applications, with the possibility of use as a system component at higher classes
- Thinner insulation for a given temperature rating, offering:
  - Reduced cost of insulation
  - Space-saving/size reduction of finished device
  - Better heat transfer
  - Reduced cost of other materials
  - New design possibilities for more compact units
  - Easy to handle and laminate in a very similar way to PET films
  - Can be laminated to a range of materials to generate cost-effective higher temperature systems.

Oligomer Extraction



Kaladex®
for Flexible Printed Circuits

The evolution of Flexible Printed Circuit (FPC) technology along with Flat Flexible Cables (FFC) has greatly benefitted from the development of suitable dielectric film substrates.



Since its inception, FPC/FFC usage has grown steadily based on several inherent characteristics providing advantages in use:

- Minimal space requirement
- Lower weight than printed circuit boards or round wire
- Placement permitted in restricted areas
- Simplified assembly procedures.

These advantages have driven the adoption of FPC/FFC in numerous applications from military and consumer electronics to automotive dashboards and cabling.

Historically two types of film have been the dominant substrates of choice for FPC applications, polyethylene terephthalate (PET) and polyimide (PI).

PET films tend to be lower cost and have proven adequate for many applications where the circuit is exposed to moderate environmental conditions.

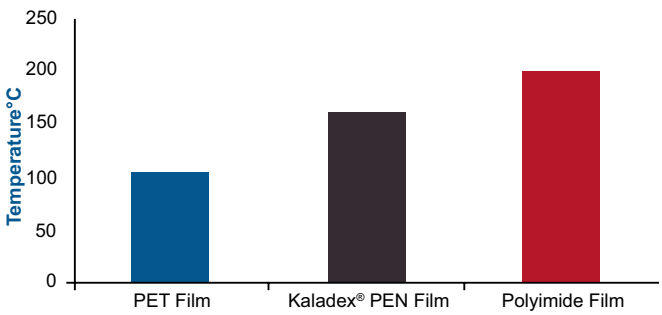
PI films are significantly more costly but provide better heat resistance and dimensional stability. The resulting gap in performance and economics between PET and PI films is considerable.

However, Kaladex® PEN films can provide a very cost-effective solution to bridge this gap, offering a higher level of performance than PET coupled with ease of processing at an attractive price point. Characteristics of Kaladex® PEN films that are highly beneficial to FPC/FFC applications include:

- Glass transition temperature (Tg) of 121°C (as resin), 43°C higher than that of PET films.
- Continuous use temperature mid-way between PET and PI films
- Excellent dimensional stability with lower shrinkage grades available
- Excellent chemical resistance including better resistance to hydrolysis than standard PET films
- Low levels of moisture absorption.

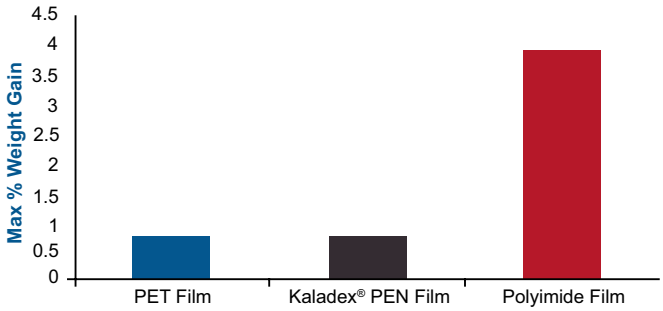
These characteristics position Kaladex® PEN films as an ideal alternative to both PET and PI films. It surpasses PET films in demanding high-end applications and replaces PI films where the combination of performance and cost offered by Kaladex® PEN film can result in considerable savings to the FPC manufacturer. This latter factor is of particular interest in automotive applications where circuits can often have a relatively large area.

Continuous Use Temperature - Mechanical



UL746B

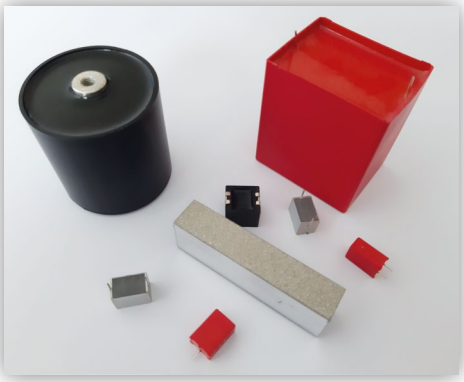
Moisture Absorption



IPC TM 650, method 2.6.2 (24hr submersions at RT)

Kaladex® for Capacitors

DuPont Teijin Films is the leading supplier of thin PET and PEN films for capacitor dielectrics. Our specialised biaxial stretching process creates a unique balance of mechanical properties and thermal shrinkages that makes them the films of choice for both wound and stacked capacitors.



This process also minimises surface defects and leads to fewer voltage breakdown events in the finished capacitor.

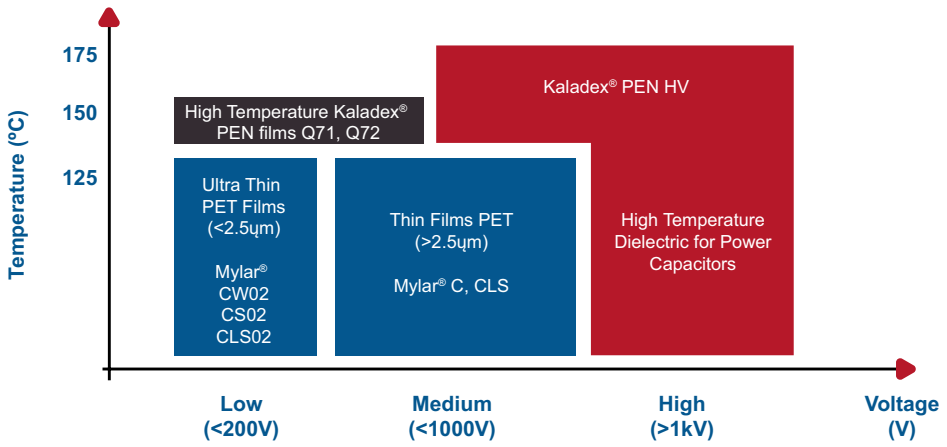
Thin and ultra-thin Kaladex® PEN films extend the performance envelope offered by Mylar® PET films and are particularly suited for applications where a higher service temperature is required, such as surface mount capacitors using lead free solder and automotive lighting.

Kaladex® PEN HV is a thin dielectric for power capacitors under development to provide a high service temperature together with an outstanding breakdown voltage strength, comparable to state of the art dielectric biaxially oriented polypropylene (BOPP).

These unique properties, achieved by sophisticated polymer material science, combine to create a capacitor dielectric offering the highest energy density currently available across a wide range of operating temperatures from -55°C to +175°C.

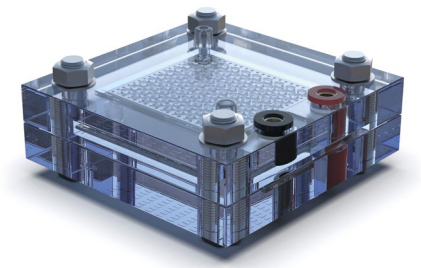
In addition, when metallised it has excellent self-healing properties. Kaladex® PEN HV is intended for high temperature power applications such as DC link in EV/HEV automotive and avionics, industrial energy conversion and renewable energy. It's high energy density per unit volume and weight allows the most compact capacitor design in power applications combined with high operating temperatures.

Material	Dielectric Constant (25°C, 1kHz)	Dissipation Factor (%) (25°C, 1kHz)	Breakdown Strength (V/mm)	Max. Temp (°C)
Mylar®/Melinex® PET	3.25	0.5	290-350	125
Kaladex® PEN	3.05	0.5	280-350	150
Kaladex® PEN HV	2.95	0.3	450-525	175



Kaladex®
for other applications

The advanced property set of Kaladex® PEN films has also proved to be highly beneficial for a wide range of additional applications, both established and emerging:



Casting belts and substrates
- Better high temperature performance and improved modulus supports a wider range of applications in more extreme environments.

Image transfer belts for copiers and printers
- High modulus gives a lower tendency to stretch allowing better image definition and increased heat resistance.

High performance loudspeaker diaphragms
- Highly attractive modulus-to-density ratio for better fidelity combined with higher glass transition temperature for use in applications subject to heat.

Dermal patch release liners
- Inherent barrier properties prevent unwanted migration of active ingredients to give a longer shelf life.

High performance sailcloth laminates
- High modulus for better stiffness results in race-winning performance.

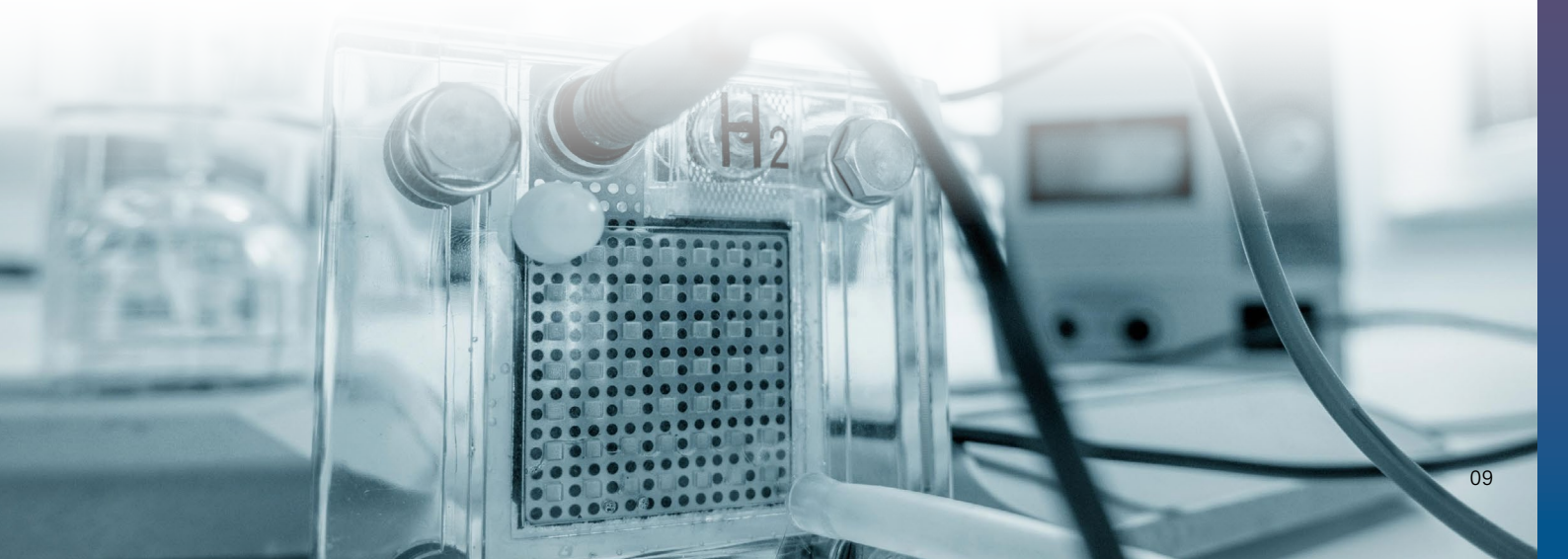
Deposition substrate for flexible photovoltaic cells
- High temperature performance allows efficient use of PECVD processes for active layers.

Automotive seat sensors based on membrane touch switch technology
- High glass transition temperature and high modulus resists deformation thereby providing enhanced durability in hot car interiors.

High temperature labels
- High temperature performance and better resistance to hydrolysis provides increased durability.

Advanced packaging solutions
- High glass transition temperature, inherent UV screening properties and better barrier allows the design of innovative structures.

Gaskets for fuel cells
- This important emerging technology requires components with reliable high temperature performance and resistance to hydrolysis, ideally suited to the properties of PEN films such as Kaladex®.



Kaladex®
Manufacturing Process

Kaladex® PEN films are biaxially oriented and heat set to give a partially crystalline microstructure resulting in excellent mechanical and thermal properties. They are manufactured using the same basic processes as for Mylar® and Melinex® PET films.

Figure 3:
Polyester film manufacturing process – sequential draw (16-125um)

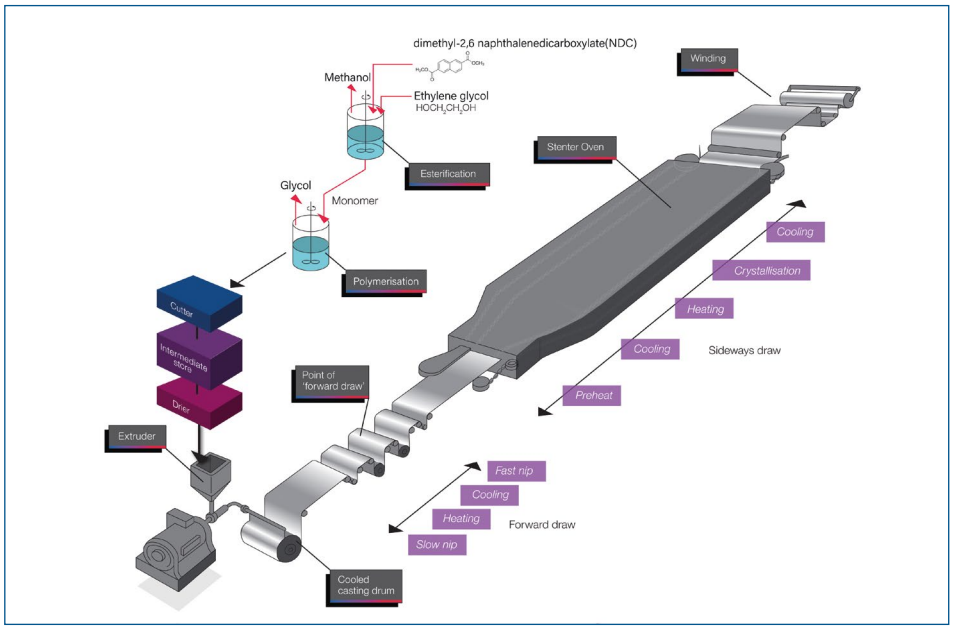


Figure 4:
Polyester film manufacturing process – simultaneous biaxial draw (1.2-12.0um)

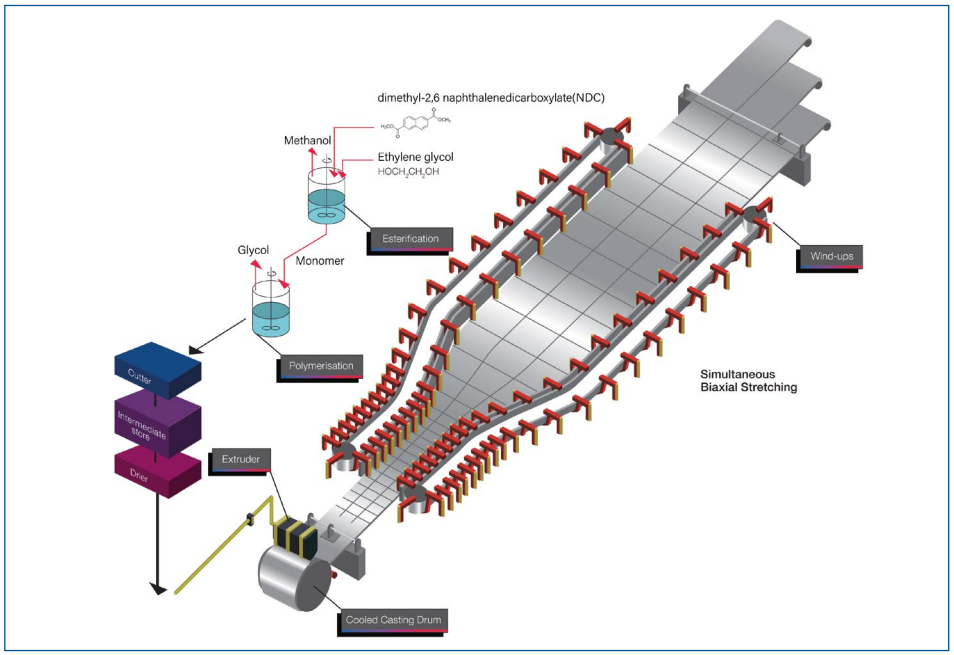


Table 3: Current range of Kaladex® PEN films

Kaladex® Grade Range	Description	Thickness Range
Kaladex® 2000	A slightly hazy PEN film with excellent handling properties. For use in a wide range of applications including electrical insulation and general industrial areas. Kaladex® 2000 is the standard grade of PEN film from DuPont Teijin Films.	16, 25, 38, 50, 75, 100 and 125 microns.
Kaladex® 2000L	A slightly hazy PEN film with excellent handling properties and carefully controlled lower shrinkage. Designed to be used in applications requiring better dimensional stability, such as flexible printed circuits.	50 microns, with 25 and 125 microns under development. Additional gauges are also possible subject to discussion and sufficient demand.
Kaladex® 2021L	A slightly hazy PEN film with excellent handling properties and carefully controlled lower shrinkage, combined with an adhesion promoting pretreatment on one side. The pretreatment offers enhanced adhesion to solvent-based inks, lacquers and adhesives. This film has been designed for use in systems requiring more dimensionally stable PEN substrates coupled with enhanced adhesion, for example fuel cell gaskets.	Under development at 25 microns, with other gauges also possible subject to discussion and sufficient demand.
Kaladex® Q71	Thin PEN film manufactured using a unique biaxial stretching process. Primarily designed as a high performance capacitor dielectric film where higher service temperatures are required, but also suitable for general industrial applications requiring a thinner film.	7-12 microns. With additional gauges also possible subject to discussion and sufficient demand.
Kaladex® Q72	Ultra-thin PEN film manufactured using a unique biaxial stretching process. Designed for use as a high performance capacitor dielectric film where higher service temperatures are required.	1.2-6.0 microns. With additional gauges also possible subject to discussion and sufficient demand.
Kaladex® PEN HV	Ultra-thin PEN film manufactured using a unique biaxial stretching process, designed to provide a market-leading combination of a high service temperature with a significantly higher operating voltage.	Under development at 3-8 microns.

The above listing includes both fully commercial grades and also grades that are at an advanced stage of development. It is our expectation that the development grades listed will be added to the standard grade range in due course, but this cannot be guaranteed. Samples of most Kaladex® grades are available upon application for testing and evaluation.

The market-leading expertise of DuPont Teijin Films in polymer science and film process technology often allows the design of additional products and variants for new applications, and these can be added to the grade range in response to market demand. Please contact us with your requirements.

Kaladex® PEN Films

www.dupontteijinfilms.com
europe.films@dupont.com / usa.films@dupont.com

DuPont Teijin Films™

Innovation | Partnerships | Sustainability

United Kingdom
DuPont Teijin Films U.K. Ltd
The Wilton Centre
Redcar
TS10 4RF
Tel +44 (0) 1642 572000

Continental Europe
DuPont Teijin Films Luxembourg S.A.
BP-1681
L-1016
Luxembourg
Tel +352 2616 4004

United States
DuPont Teijin Films U.S.
Limited Partnership
3600 Discovery Drive
Chester, VA 23860 USA
Tel +1 800 635-4639

DuPont Teijin Films China Limited
Room 702, 7th Floor, China Life Center,
Tower A, One Harbour Gate,
No. 18 Hung Luen Road, Hung Hom,
Kowloon Hong Kong
Tel +852-27345427