Kaladex® PEN Films

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Kaladex® PEN films were first introduced on a fully commercial basis in 1992. The distinct polymer chemistry of PEN provides several superior properties including greater resistance to heat and hydrolysis, better dimensional stability and higher modulus.

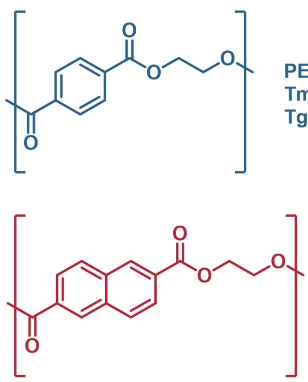
This property set has allowed the development of a range of films that provide cost-effective solutions with an enhanced performance level between that of PET films such as Mylar® and Melinex®, and high-performance but higher cost engineered films such as polyimides, for example Kapton® from DuPont.

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 380 nm

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.

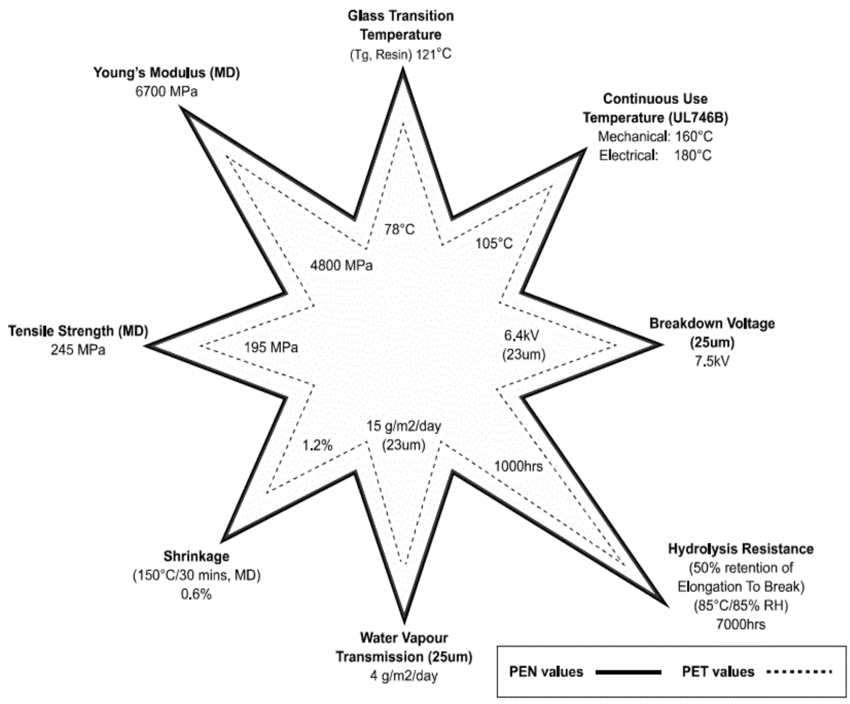
Chemical structure of PEN compared with PET



PET
Tm = 255-260 °C
Tg = 78 °C

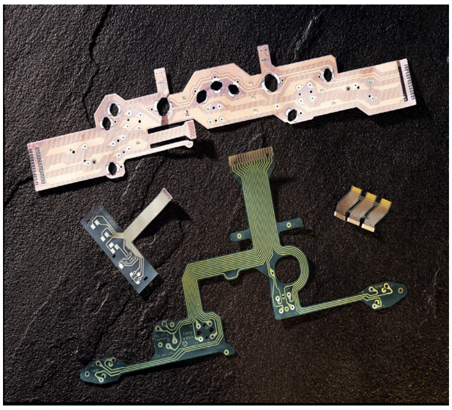
PEN
Tm = 265 °C
Tg = 121 °C

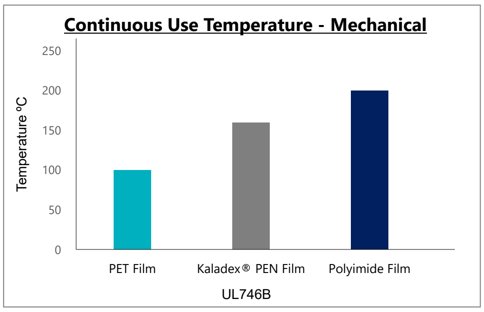
Comparison of key properties between Kaladex® PEN and typical PET films

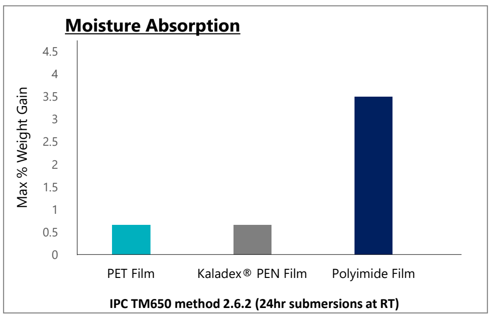


Kaladex® PEN Film for Flexible Printed Circuits

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 forFPC 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.

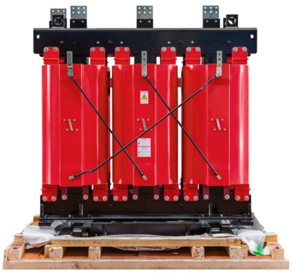
Characteristics of Kaladex® PEN films that are highly beneficial to FPC/FFC applications include:

- 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 oftenhave a relatively large area.

Kaladex® PEN Film for Electrical Insulation

One of the earliest to benefit from the property set of polyester films was electrical insulation, with Mylar® PET 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®

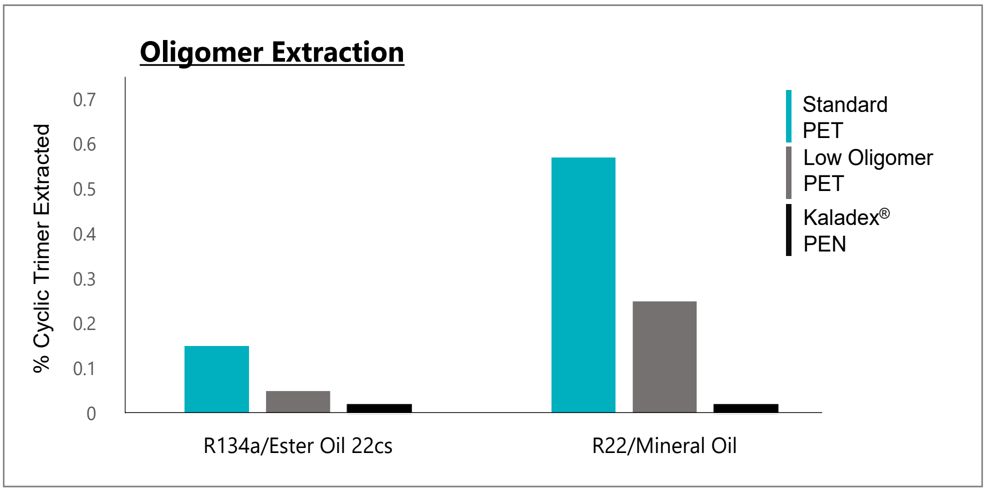


The main grade used in electrical insulation applications is Kaladex® 2000 which exhibits the following key features:

- 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

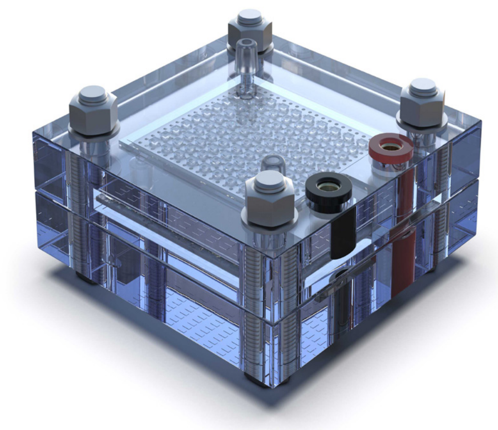
These features of Kaladex® PEN film provide a number of benefits in electrical insulation applications:

- 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



Kaladex® PEN Film 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®

Table 1: Properties of Kaladex® 2000 PEN film

	Property	Units		Kaladex® 2000	Test Method
Structure	Density	g/cm^3		1.36	In-house Method
	Surface Roughness	nm	Sa	22	In-house Method
			Sq	33	
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	65%	
	Tear Initiation	N	25 um in MD	5.5	ASTM D1004 (50 mm/minute)
			25 um in TD	5.9	
	Tear Propagation	N	25 um in MD	1.5	ASTM D1938 (1000 mm/minute)
			25 um in TD	1.6	
	Coefficient of Friction	-	Static	0.43	
			Dynamic	0.37	
Physical and Thermal Properties	Melting Temperature	ºC		269	In-house Method by DSC
	Glass Transition Temperature (Resin)	ºC		121	In-house Method by DSC
	Glass Transition Temperature (Film)	ºC		155	In-house Method by DMA
	Shrinkage (150ºC for 30 mins)	%	MD	0.6	In-house Method
			TD	0.6	
	Shrinkage (190ºC for 5 mins)	%	MD	1.2	In-house Method
			TD	1.4	
	Coefficient of Thermal Expansion	10^{-6}/ºC	MD	13	In-house Method
	Coefficient of Hydroscopic Expansion	10^{-6}/%RH	MD	11	In-house Method
	Continuous Use Temperature (RTI)	ºC	Mechanical	160	UL746B (UL File E93687)
			Electrical	180	
Chemical Properties	Moisture Absorption	%		0.20%	In-house Method (20ºC & 50% RH)
	Moisture Permeability	g/m^2, 24hr	25 um	4.3	ASTM E398
	Oxygen Permeability	cm^3/m^2 24hr.atm	25 um	15.2	ASTM D3985
Electrical Properties	Electric Strength	kV/mm	16 um	390	ASTM D149
			25 um	331	
			38 um	261	
			50 um	248	
			75 um	198	
			100 um	187	
			125 um	163	
	Permitivity	_-	23ºC, 50 Hz	3.24	ASTM D150
			23ºC, 1 kHz	3.22	
			23ºC, 10 kHz	3.20	
			50ºC, 50 Hz	3.27	
			100ºC, 50 Hz	3.29	
			150ºC, 50 Hz	3.40	
	Dissipation Factor	-	23ºC, 50 Hz	0.0034	ASTM D150
			23ºC, 1 kHz	0.0042	
			23ºC, 10 kHz	0.0048	
			50ºC, 50 Hz	0.0048	
			100ºC, 50 Hz	0.0055	
			150ºC, 50 Hz	0.0125	
	Surface Resistivity	Log Ω/Sq		15	ASTM D257 (500V d.c., 20ºC & 54%RH)
	Volume Resistivity	Log Ω.m		16	ASTM D257 (100V d.c., 25ºC & 1000s)
Optical Properties	Refractive Index	-	nMD	1.75	In-house Method
			nTD	1.76	
			nz	1.50	
	Total Light Transmission	%	16	87	ASTM D1003
			25	86	
			38	85	
			50	84	
			75	83	
			100	83	
			125	82	
	Wide Angle Haze	%	16	5	ASTM D1003
			25	6	
			38	8	
			50	13	
			75	18	
			100	25	
			125	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	In-house Method	PEN offers 3% better area yield than an equivalent PET Film
Youngs 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	65%	90%		
Melting Temperature	ºC		269	254	In-house 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 (155ºC) applications.
Glass Transition Temperature (Resin)	ºC		121	78	In-house Method by DSC	
Glass Transition Temperature (Film)	ºC		155	110	In-house Method by DMA	
Continuous Use Temperature (RTI)	ºC	Mechanical	160	105	UL746B (UL File E9368)	
		Electrical	180	105		
Shrinkage (150 ºC for 30 mins)	%	MD	0.6	1.2	In-house 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 ºC for 5 mins)	%	MD	1.2	2.5	In-house Method	
		TD	1.4	1.5		
Moisture Permeability	g/m2.24hr	25 um	4	115	ASTM E398	PEN has better inherent barrier properties than PET.
Oxygen Permeability	cm3/m2 24hr. atm	25 um	15	52	ASTM D3985	
Breakdown Voltage	kV	25 um	7.5	6.4*	*23 um for PET	PEN has a higher breakdown voltage than an equivalent PET film providing excellent electrical insulation properties.
		50 um	12.4	10.0		
		75 um	14.8	12.0	IEC 243-1	
		125 um	20.3	16.0		

Current Range of Kaladex® PEN Films

Kaladex® Grade Range	Description	Thickness Range micron (gauge)
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 Mylar Specialty Films.	16, 25, 38, 50, 75, 100 and 125 micron (64, 100, 152, 200, 300, 400, 500 gauge)
Kaladex® 2000L	A slightly hazy PEN film with excellent handling properties and carefully controlled lower shrinkage. Designed to be used in application requiring better dimansional stability, such as flexible printed circuits.	50 micron (200 gauge) 25 and 125 microns (100 and 500 gauge) 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 promotion 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 dimentionally stable PEN substrates coupled with enhanced adhesion, for example fuel cell gaskets.	Under development at 25 microns (200 gauge) Other gauges also possible subject to discussion and sufficient demand.

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