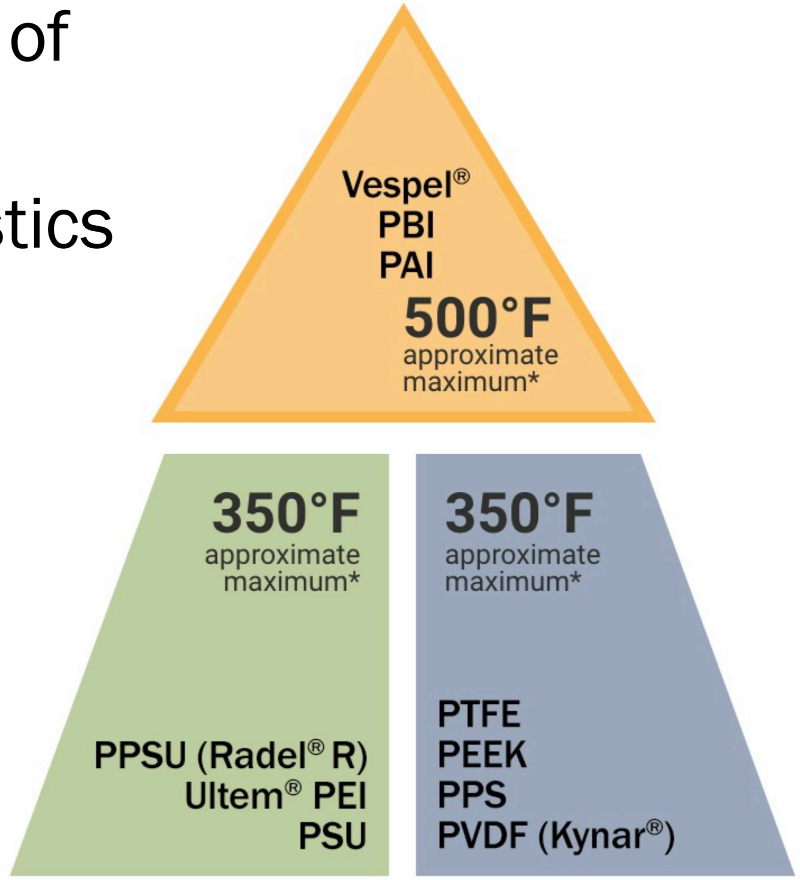
Understanding High Performance Thermoplastics: 10+ Materials for Demanding Applications

Webinar Presented by Curbell Plastics

CURBELL PLASTICS

Agenda

- Briefly discuss the advantages and limitations of the datasheet
- Introduce select high performance thermoplastics and applications
  - Fluoropolymers (PTFE, PVDF, PCTFE, etc.)
  - PSU
  - PPSU
  - Ultem® PEI
  - PPS
  - PEEK (and other PAEK)
  - Torlon® PAI
  - PBI
  - DuPont™ Vespel® PI
- Open the floor to questions



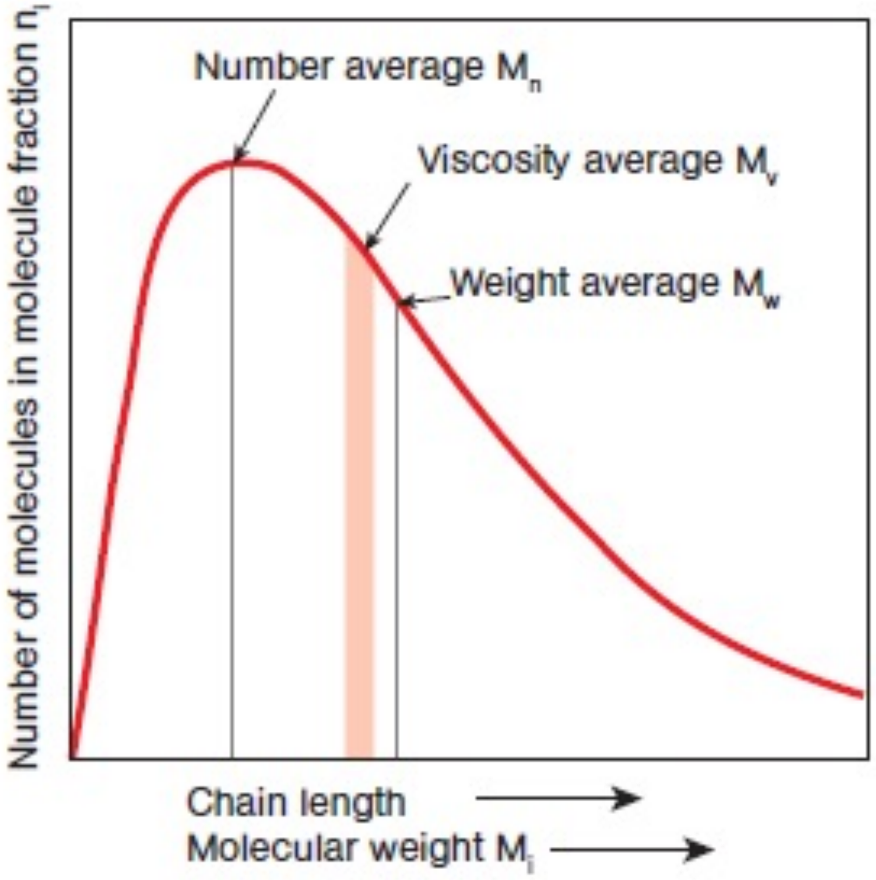
Materials should be considered for applications up to approximate maximum temperature. Selecting a plastic material for use in a high temperature environment requires careful review of material properties data. This chart is for comparison purposes only.

CURBELL PLASTICS

Advantages and Limitations of the Datasheet

Molecular Weight: Polymers are “Polydisperse”

Typical Thermoplastic Molecular Weight Distribution



Source: Osswald

The Datasheet

- Enables quick comparisons between materials
- Not for specification purposes
- Most values do not take into account changes with temperature, strain rate, and/or time
- Often generated from injection molded specimens

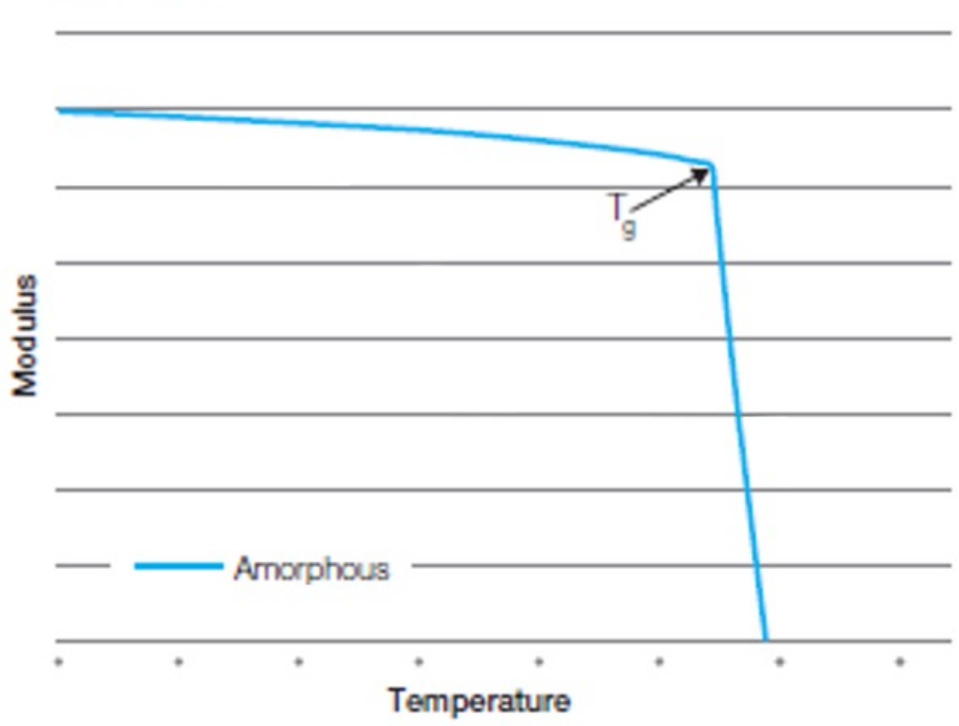
	ASTM Test method	Unit	Value
Physical Properties			
Specific Gravity	D792	g/cm³	1.32
Water Absorption 24 hours	D570	%	0.1
Water Absorption Saturation	D570	%	0.5
Dissipation Factor	D150	1 MHz	0.003
Mechanical Properties			
Hardness	D785	Shore D	D85
Rockwell Hardness	D785	M	M105
Rockwell Hardness	D785	R	R126
Tensile Strength at yield 73 °F	D638	psi	16,000
Tensile Modulus	D638	psi	500,000
Elongation at Break	D638	%	20
Flexural Strength	D790	psi	25,000
Flexural Modulus	D790	psi	600,000
Compressive Strength	D695	psi	18,000
Shear Strength	D732	psi	7,700
Izod Impact, Notched	D256	ft-lb/in	1.2
Coefficient of Friction, Dynamic	-	-	0.4
Thermal properties			
CTE, linear	D696	in/in/°F	2.6×10^{-5}
Melting Point	D3418	°F	630
Continuous Use	-	°F	480
Thermal Conductivity	-	in/hr/ft2/F°	1.73
Deflection Temperature at 1.8Mpa (66psi)	D648	°F	360
Deflection Temperature at 1.8Mpa (264psi)	D648	°F	320
Flammability, UL94	-	⅛ inch	V-0
Electrical properties			
Dielectric constant	D150	-	3.3
Surface resistivity	D257	Ohm/cm	10^{15}
Dielectric strength	D149	V/mil	480
Compliance Properties			
FDA	-	-	Yes

Source: Röchling

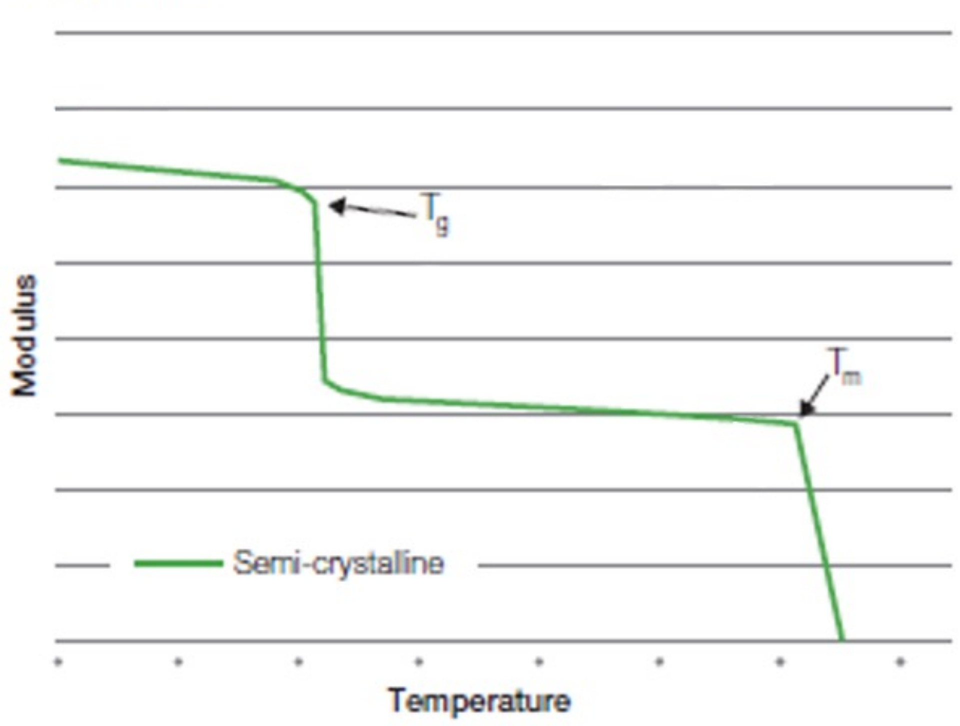
CURBELL PLASTICS

DMA Curves

Typical Behavior of an Amorphous Thermoplastic with Respect to Heat



Typical Behavior of a Semi-Crystalline Thermoplastic with Respect to Heat

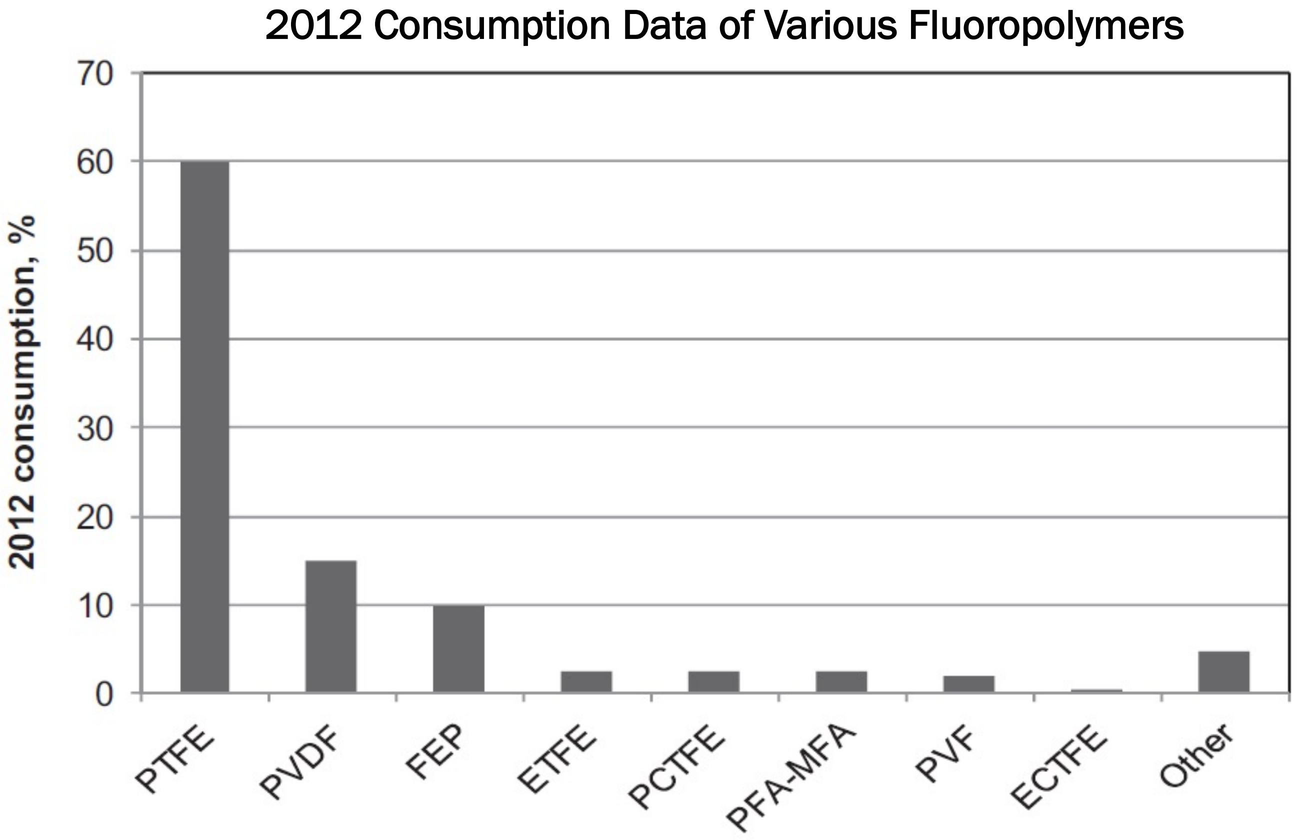


CURBELL PLASTICS

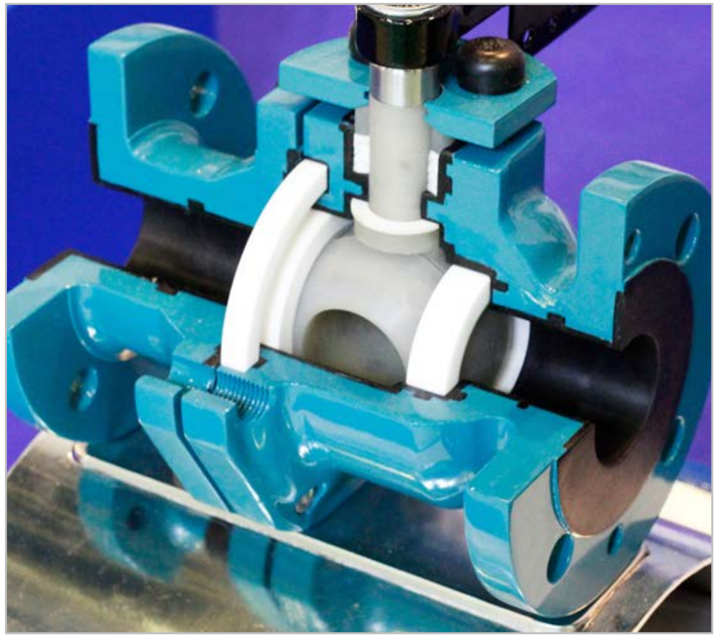
High Performance Thermoplastics

Fluoropolymers

- Known for chemical resistance (especially PTFE)



Source: Fluoroplastics, Vol. 1

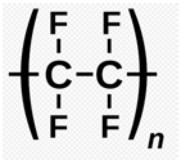


PTFE, FEP, and PFA

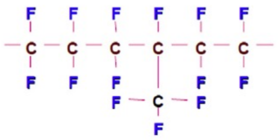
- FEP and PFA are melt processible

	PTFE
Specific Gravity	2.16
Tensile Strength	3,000 psi
Elongation at Break	300%
Flex Modulus	70,000 psi
IZOD Impact (Notched)	3.5 ft-lb/in
Coefficient of Thermal Expansion	7.5×10^{-5} in/in/°F
Coefficient of Friction	0.05
Limiting Oxygen Index	95%

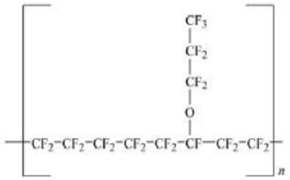
PTFE



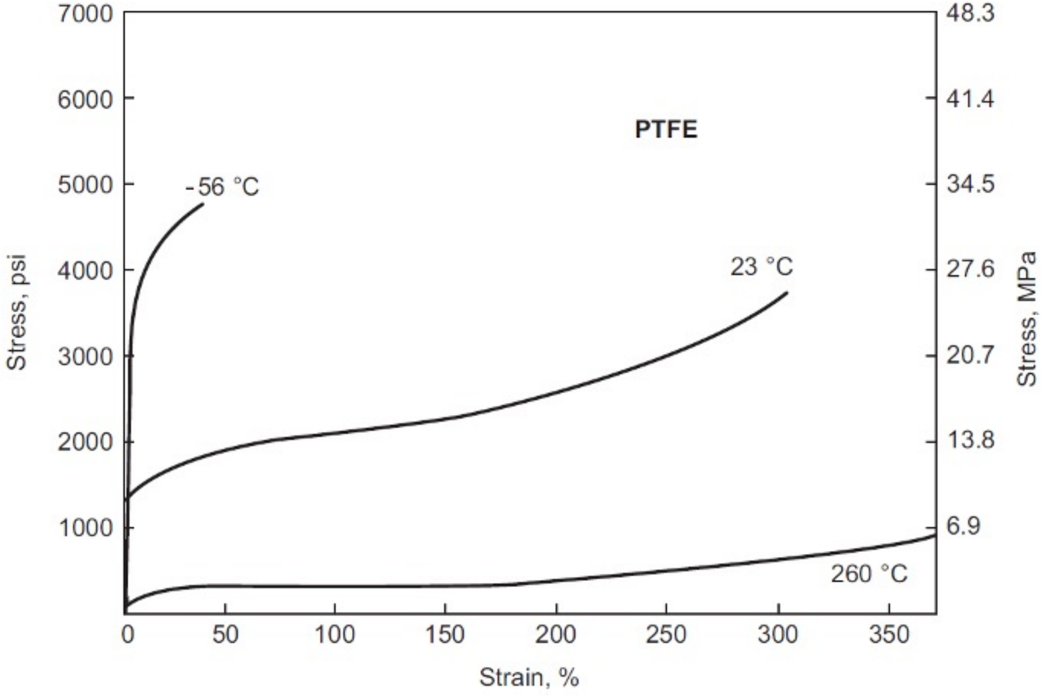
FEP



PFA



Tensile Stress/Strain of PTFE at Various Temperatures

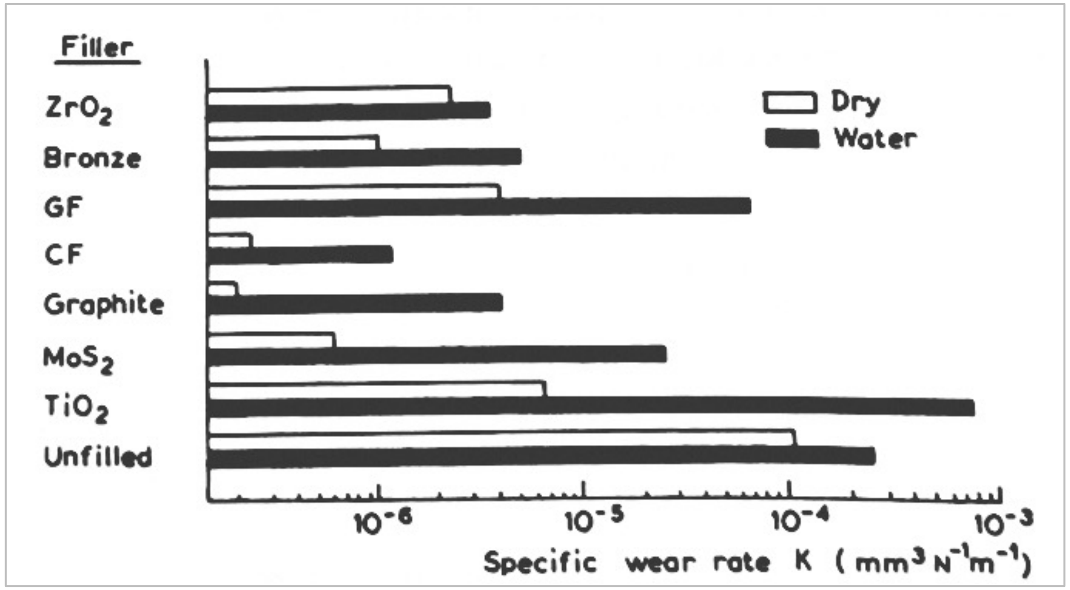


Source: Fluoroplastics, Vol. 1

CURBELL PLASTICS

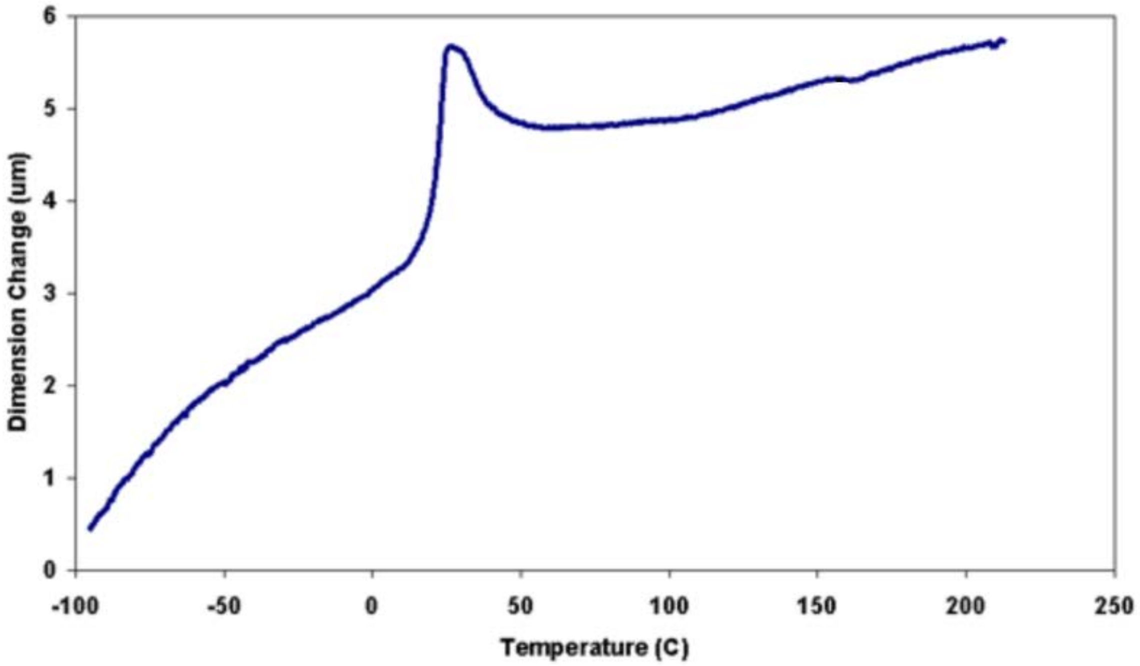
Wear and Thermal Expansion of PTFE

Dry and Wet Wear Rates of Various Grades of PTFE



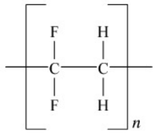
Source: Tanaka

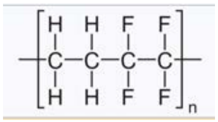
Thermomechanical Analysis (TMA) of PTFE

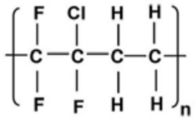


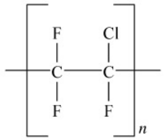
Source: Anderson Materials

PVDF, ETFE, ECTFE, and PCTFE



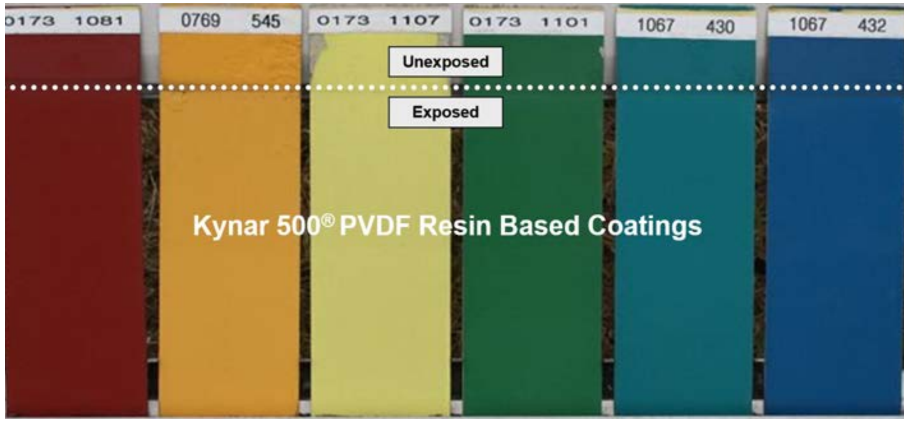


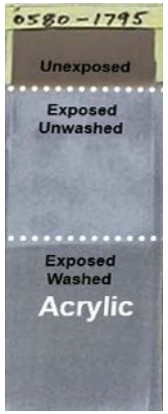




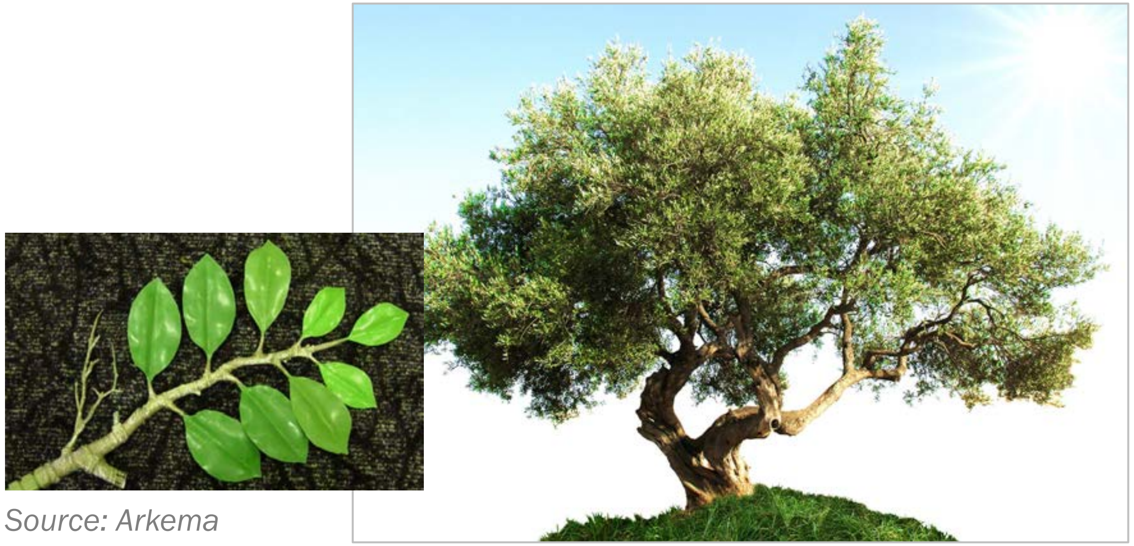
	PVDF	PVDF (Copolymer)	ETFE	ECTFE	PCTFE
Specific Gravity	1.78	1.78	1.70	1.68	2.13
Tensile Strength	7,000 psi	5,000 psi	6,000 psi	7,000 psi	5,000 psi
Elongation at Break	50%	300%	300%	250%	150%
Flex Modulus	300,000 psi	170,000 psi	170,000 psi	240,000 psi	200,000 psi
IZOD Impact (Notched)	3.0 ft-lb/in	6.0 ft-lb/in	No Break	No Break	5.0 ft-lb/in
Coefficient of Thermal Expansion	7.0 x 10^{-5} in/in/°F	8.5 x 10^{-5} in/in/°F	7.4 x 10^{-5} in/in/°F	5.6 x 10^{-5} in/in/°F	7.0 x 10^{-5} in/in/°F
Limiting Oxygen Index	44%	43%	30%	52%	95%

PVDF Weatherability

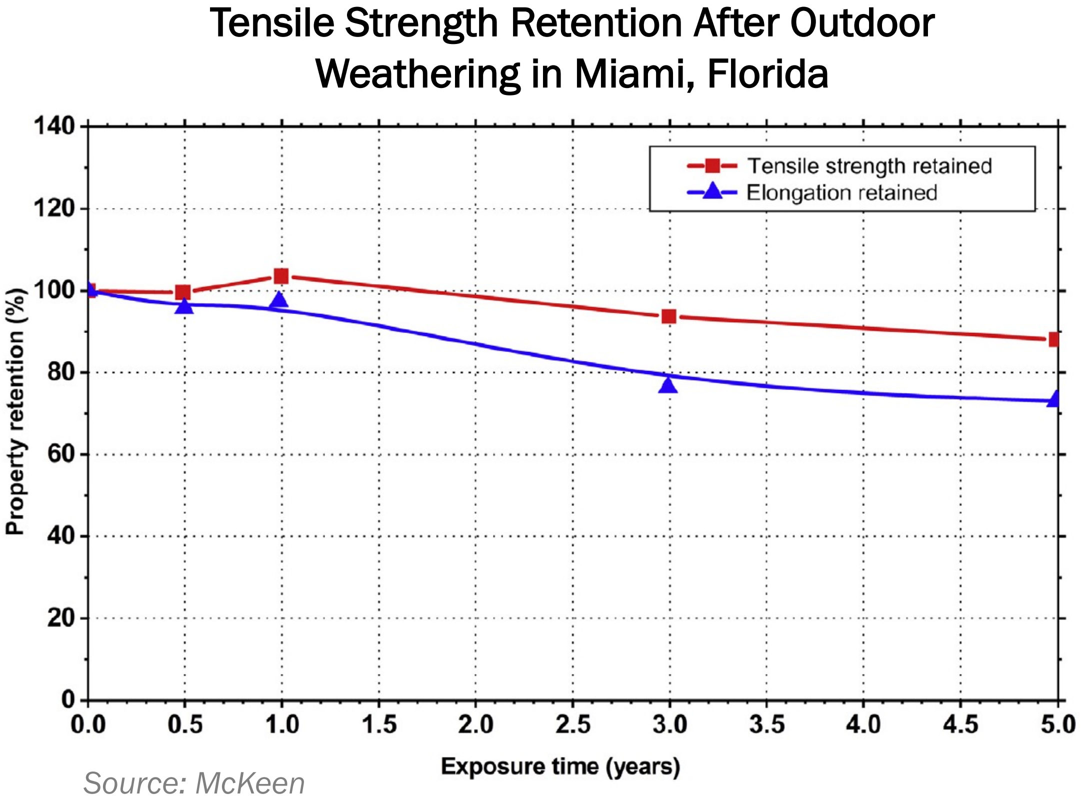




Source: Arkema



Source: Arkema

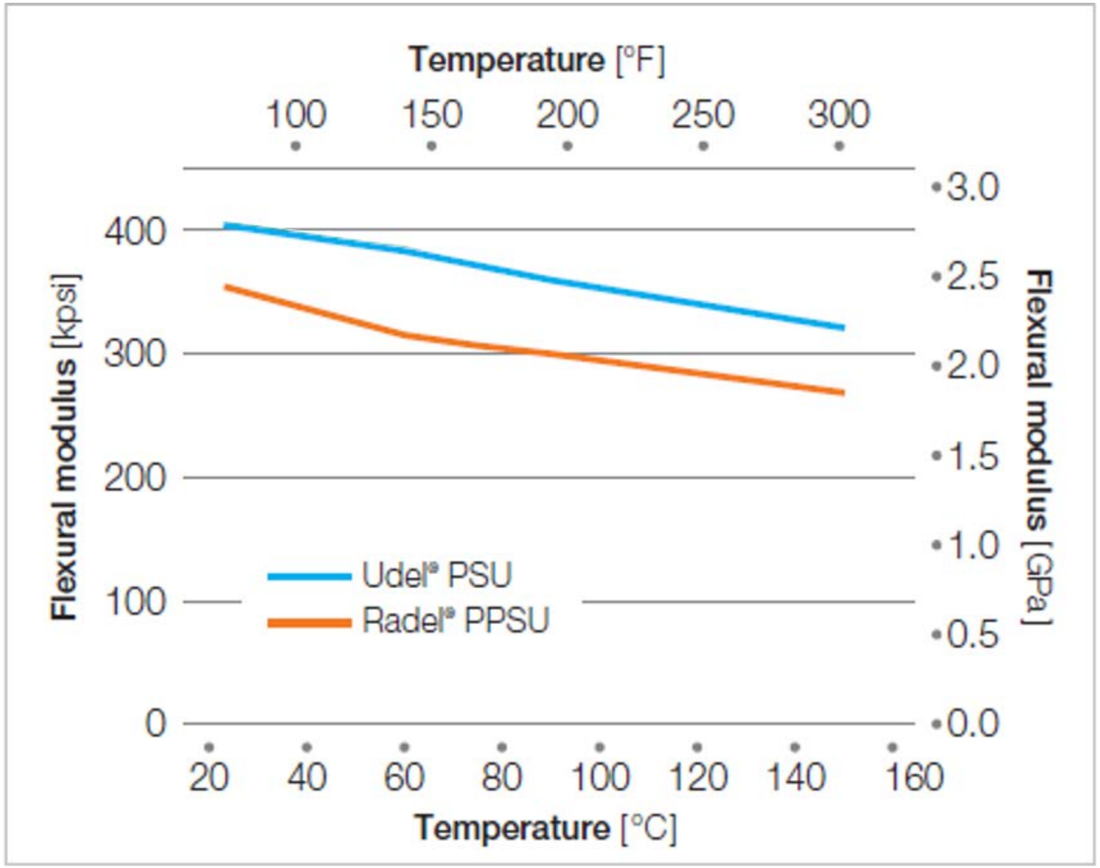


Source: McKeen

PSU and PPSU (Radel® R)

	PSU	PPSU
Specific Gravity	1.24	1.29
Tensile Strength	10,000 psi	11,000 psi
Elongation at Break	50%	60%
Flex Modulus	400,000 psi	350,000 psi
IZOD Impact (Notched)	1.3 ft-lb/in	13.0 ft-lb/in
Coefficient of Thermal Expansion	3.1 x 10^{-5} in/in/°F	3.1 x 10^{-5} in/in/°F
Glass Transition Temperature	365°F	428°F

Flexural Modulus vs. Temperature of Neat Resins

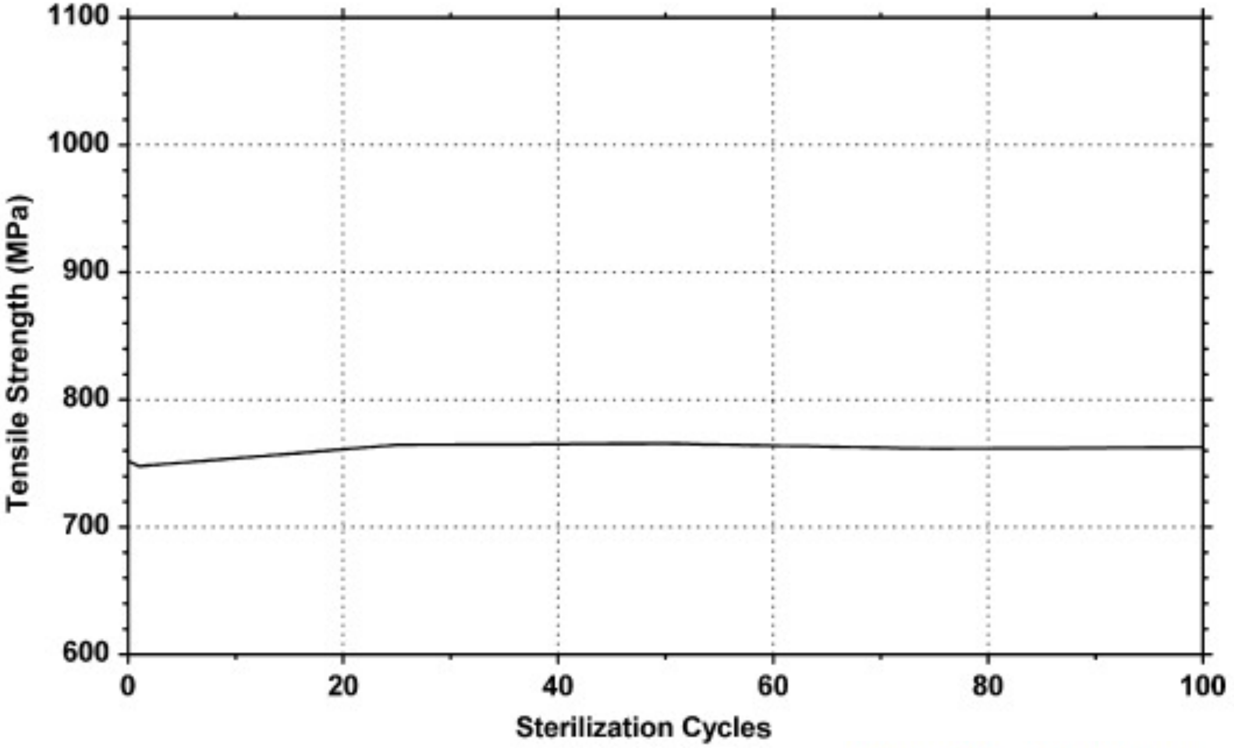


Source: Solvay

CURBELL PLASTICS

PPSU (Radel® R) Sterilizability

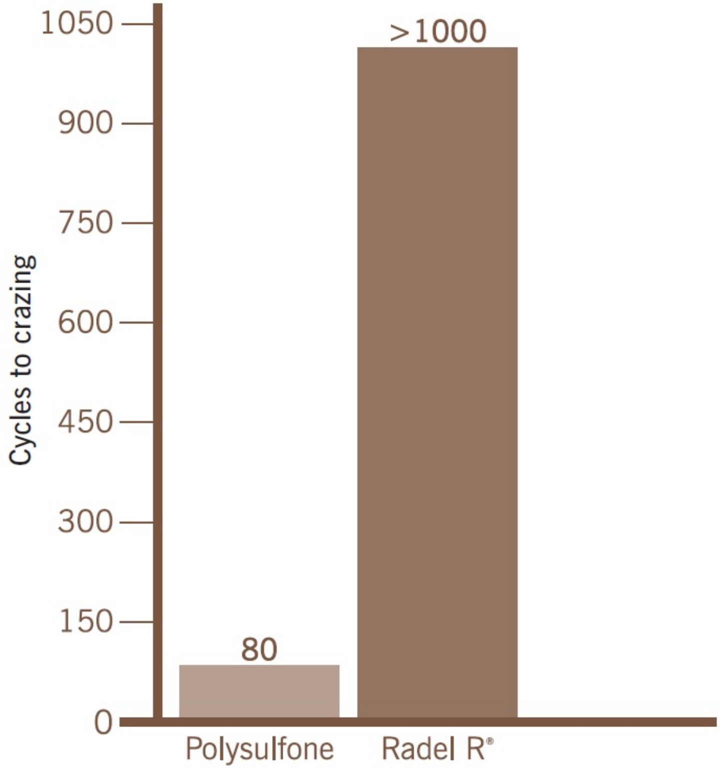
EtO Sterilization Resistance of Radel® R



Source: McKeen

Figure 11.35 Tensile strength after EtO sterilization of Solvay Solexis Radel® R PPSU.[2] Note: Cycle = 55 °C, 60 min, 70% RH, aeration 60 min.

Steam Autoclave Resistance of Radel® R Compared with Polysulfone



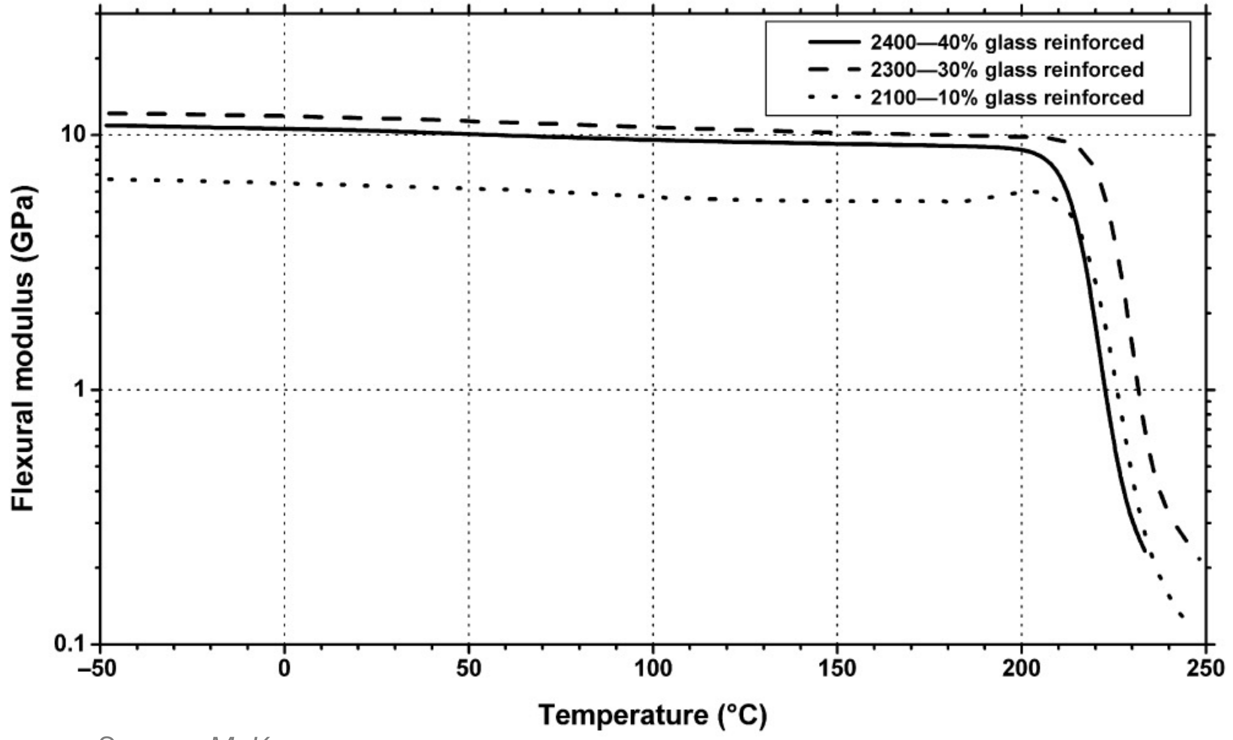
Autoclave: 27 psig steam, 270°F steam contains 50ppm Morpholine
Test conditions: Bar - 5 x 0.5 x 0.125 in, Flexural stress - 1000psi

Ultem® PEI

- Amorphous thermoplastic with a Tg ~422°F/217°C

	Ultem® 1000 (Unfilled)	Ultem® 2300 (30% Glass Filled)
Specific Gravity	1.28	1.51
Tensile Stress (Yield)	16,000 psi	24,000 psi
Elongation (Break)	60%	3%
Flex Modulus	500,000 psi	1,300,000 psi
IZOD Impact (Notched)	1 ft-lb/in	1.6 ft-lb/in
CTE (Flow)	3.1×10^{-5} in/in/°F	1.1×10^{-5} in/in/°F
CTE (Xflow)	3.0×10^{-5} in/in/°F	2.7×10^{-5} in/in/°F
Dielectric Strength	830 V/mil	630 V/mil
UL94 5VA	≥ 0.118"	≥ 0.047"

DMA of Glass-Filled Grades of Ultem®



Source: McKeen

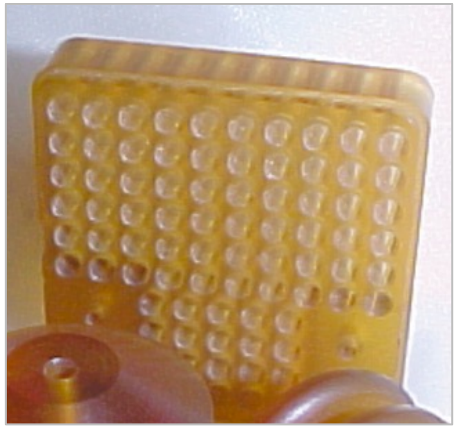
CURBELL PLASTICS

Sulfone and Ultem® PEI Application Examples


PSU Food Warming Trays


Medical Trays

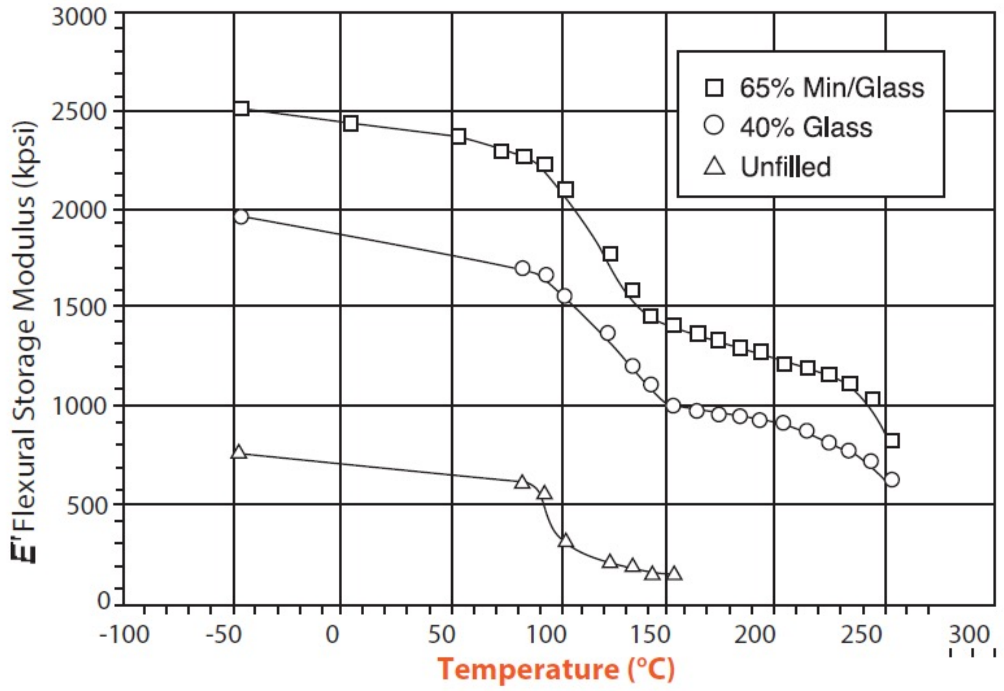

PPSU (Radel® R) Medical Instrument Handle


Ultem® Test Socket

PPS

- Semi-crystalline thermoplastic with Tg ~194°F/90°C and Tm ~ 540°F/282°C

DMA of Unfilled and Filled Grades of PPS



Source: Celanese

Anisotropic Effects on Mechanical Properties at 23°C

Material	Dt/Df (%) Flexural Strength	Flexural Modulus	Tensile Strength	Tensile Elongation
40% Glass-Reinforced Fortron® PPS	50	60	55	65

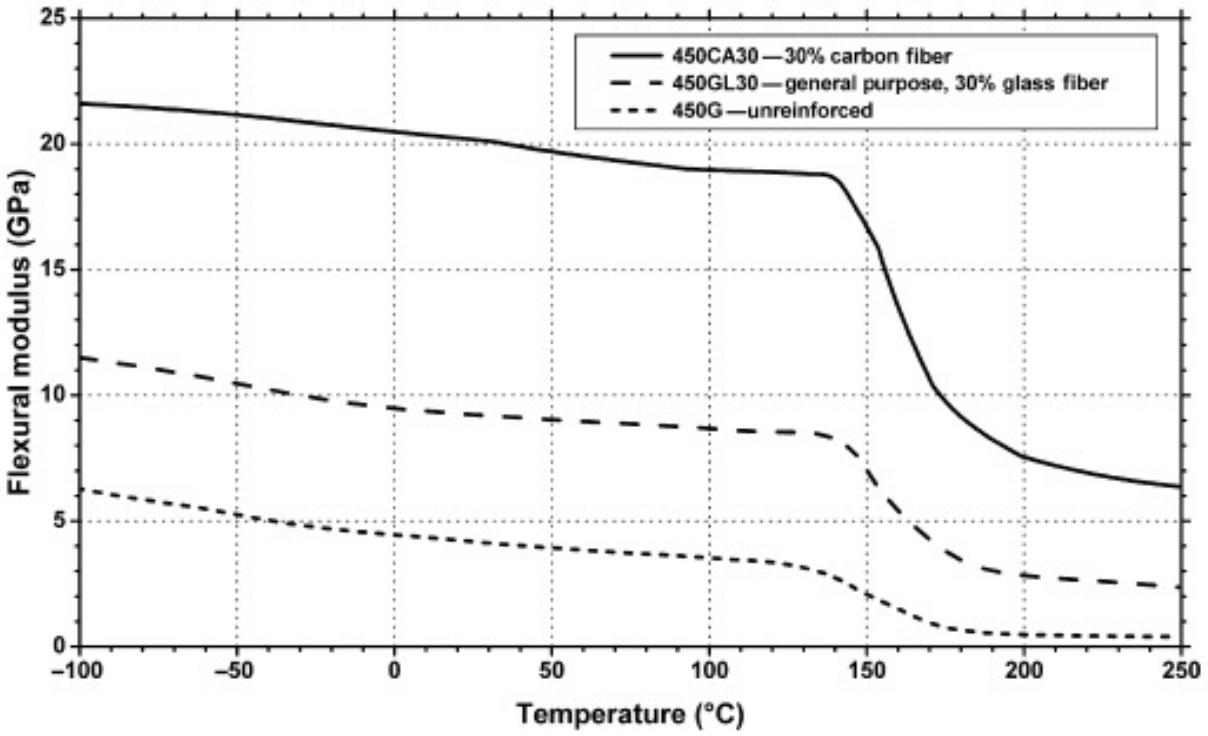
Source: Celanese

CURBELL PLASTICS

PEEK

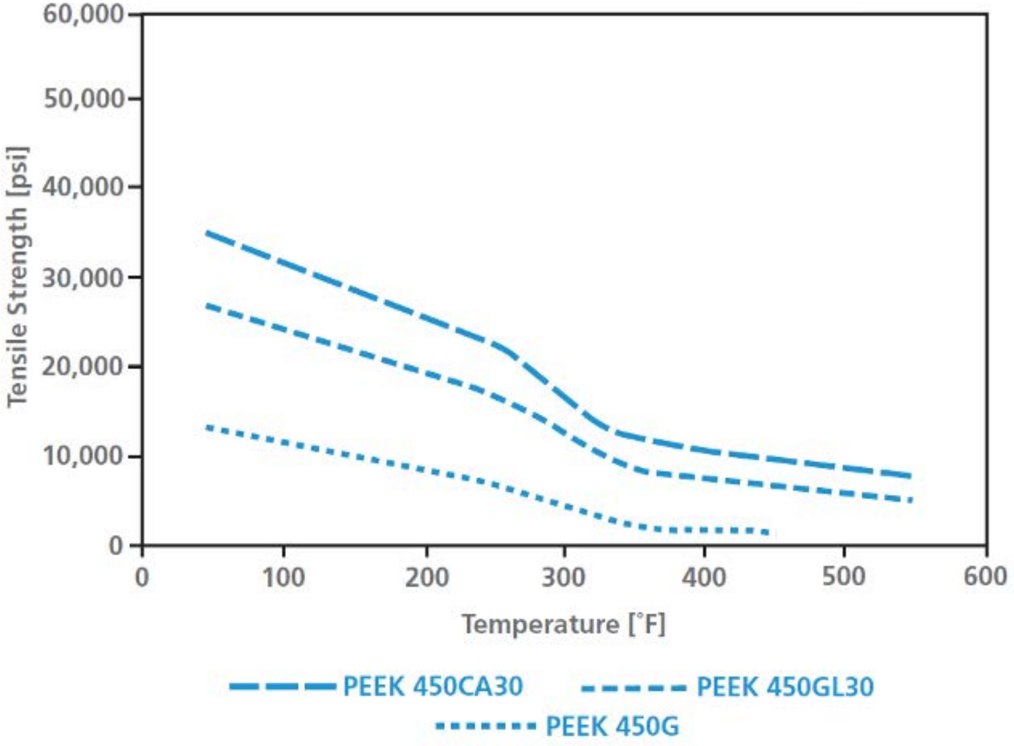
- Semi-crystalline thermoplastic with Tg ~ 289°F/143°C and Tm ~ 650°F/343°C

DMA Curves for Standard PEEK Grades



Source: McKeen

Tensile Strength vs. Temperature of Various PEEK Materials



Source: Victrex

CURBELL PLASTICS

PEEK Steam and Radiation Resistance

Table 2: A Comparison of the Mechanical Properties of VICTREX PEEK Materials After Conditioning in Steam at 200°C (392°F) and 1.4 MPa (200 psi)							
Property	Standard	Control	Time/hours				
			75	350	1000	2000	2500
Tensile Strength/MPa (psi) VICTREX 450G	ISO 527	103 (14,900	111 (16,100)	109 (15,800)	109 (15,800)	109 (15,800)	109 (15,800)
Flexural Strength/MPa (psi) VICTREX 450G	ISO 178	165 (23,900)	188 (27,300)	192 (27,800)	185 (26,800)	196 (28,400)	181 (26,300)
Flexural Modulus/GPa (psi) VICTREX 450G	ISO 178	4.1 (590,000)	4.4 (640,000)	4.4 (640,000)	4.2 (610,000)	4.4 (640,000)	4.0 (580,000)

Source: Victrex

Radiation Resistance of Various Plastics

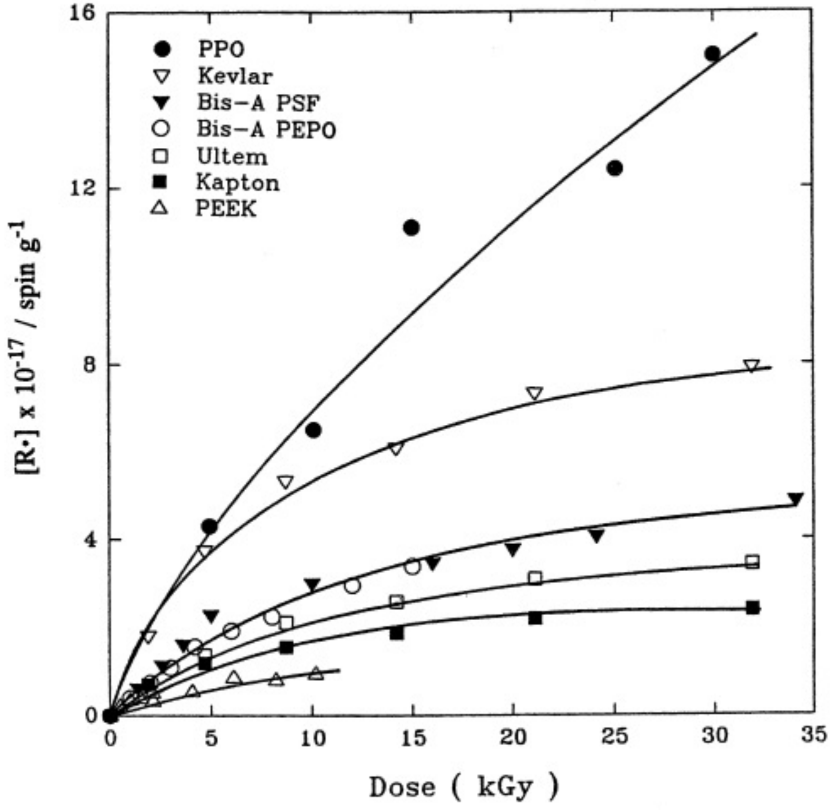


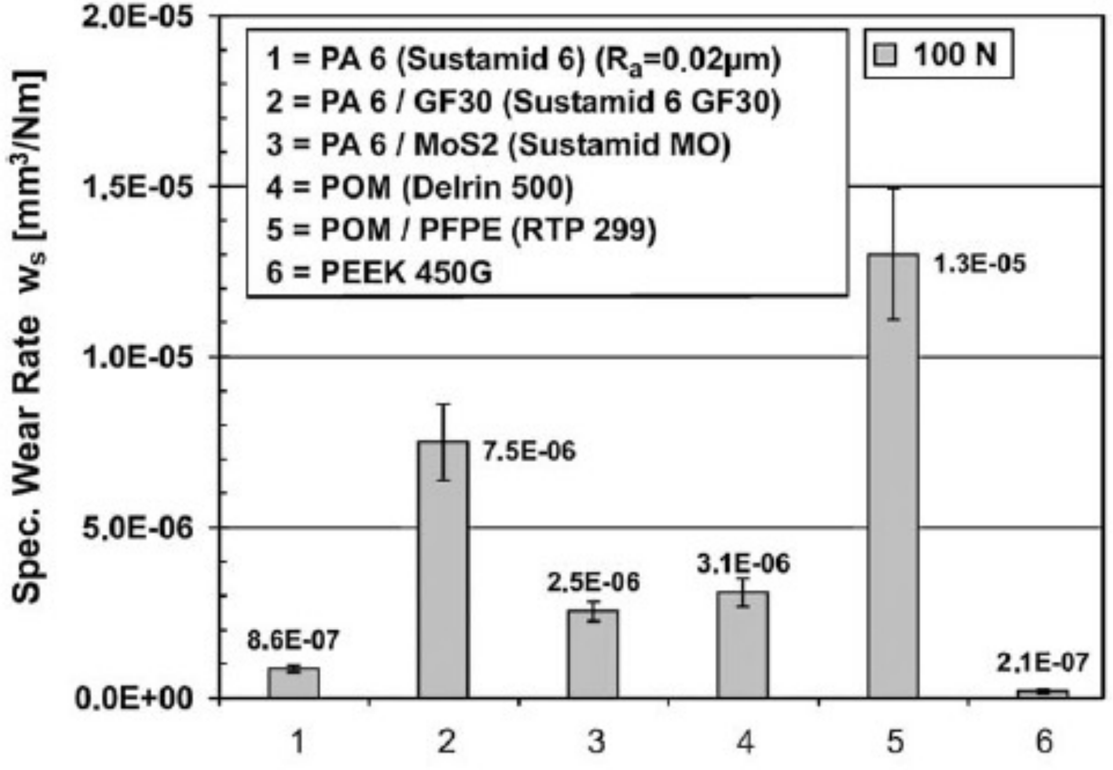
Figure 2. Plots of the radical yield versus dose for γ-radiolysis of polymers at a dose rate of 1–5 kGy/h at 77 K.

Source: Heiland

CURBELL PLASTICS

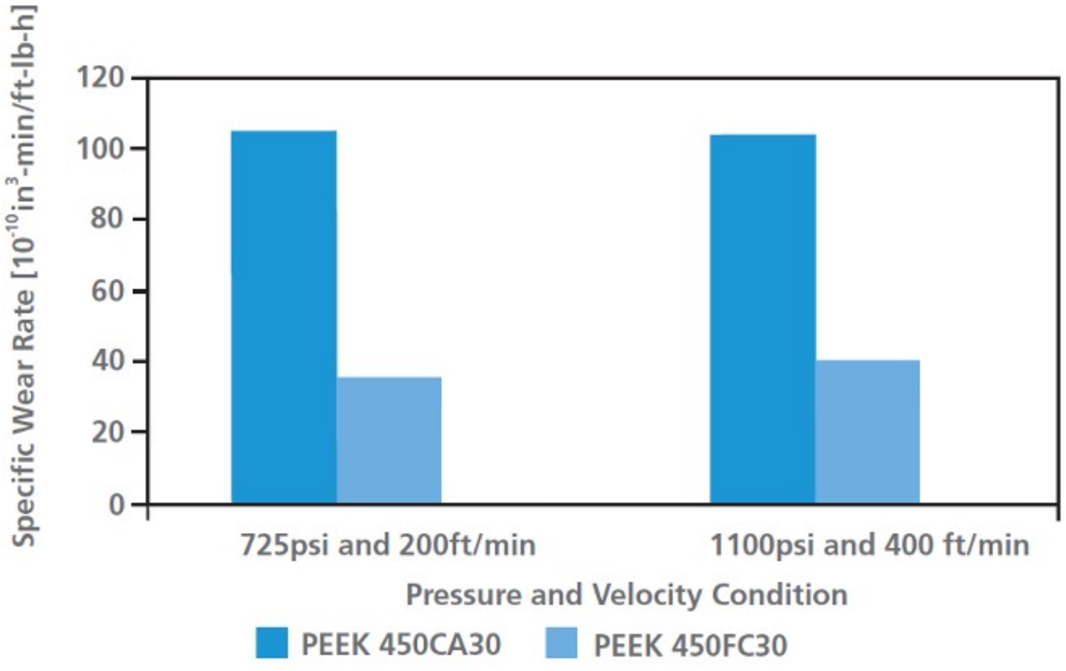
PEEK Wear Resistance

Rolling Contact Wear of Nylon, POM, and PEEK



Source: Harrass

Specific Wear Rate of Various Victrex Materials Tested Using the Block-On-Ring Method



Source: Victrex

CURBELL PLASTICS

PEEK and PPS Application Examples

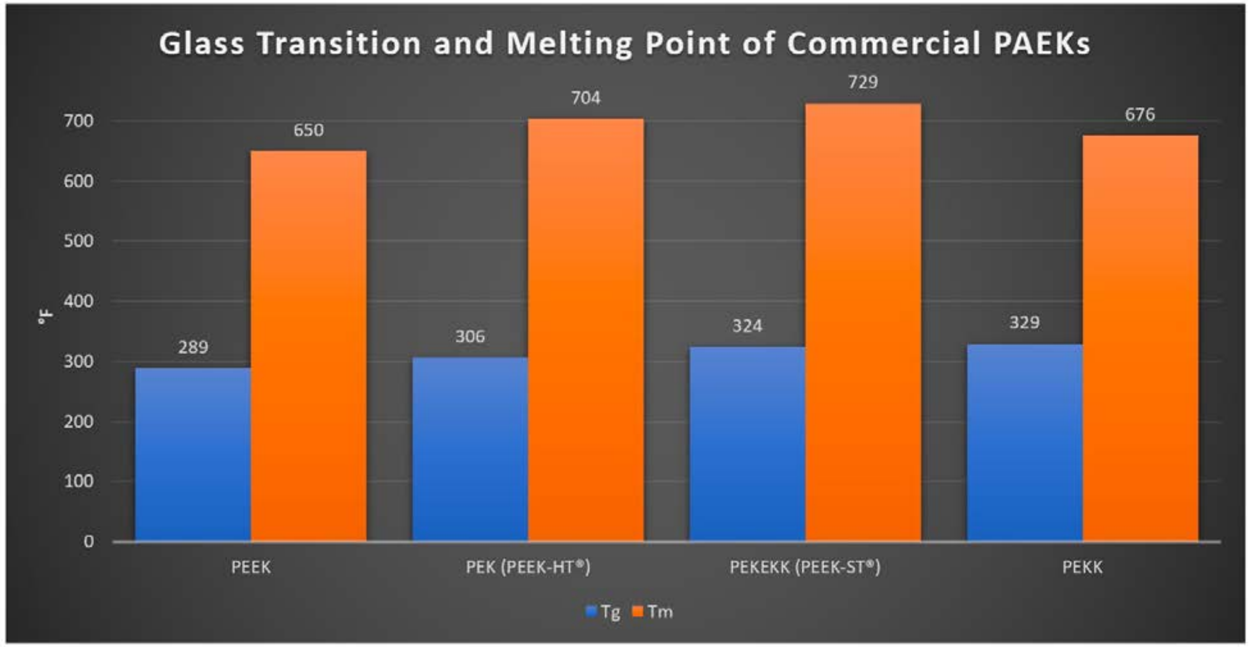
PEEK Split Ring

PPS CMP Retaining Ring

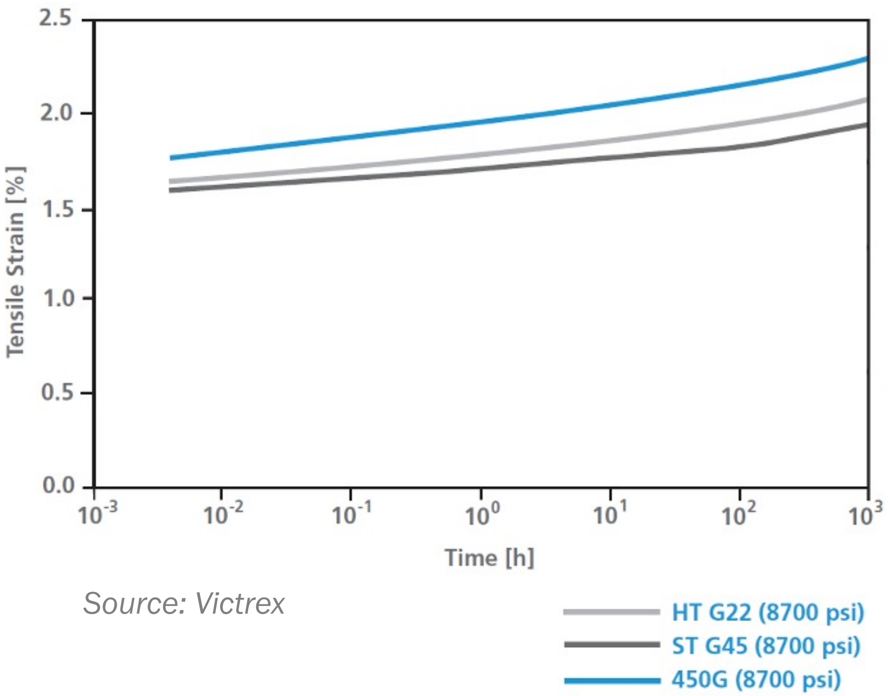
PEEK Insulating Connector Component

CURBELL PLASTICS

Other PAEK



Tensile Creep of PEEK 450G, HT and ST at 73°F

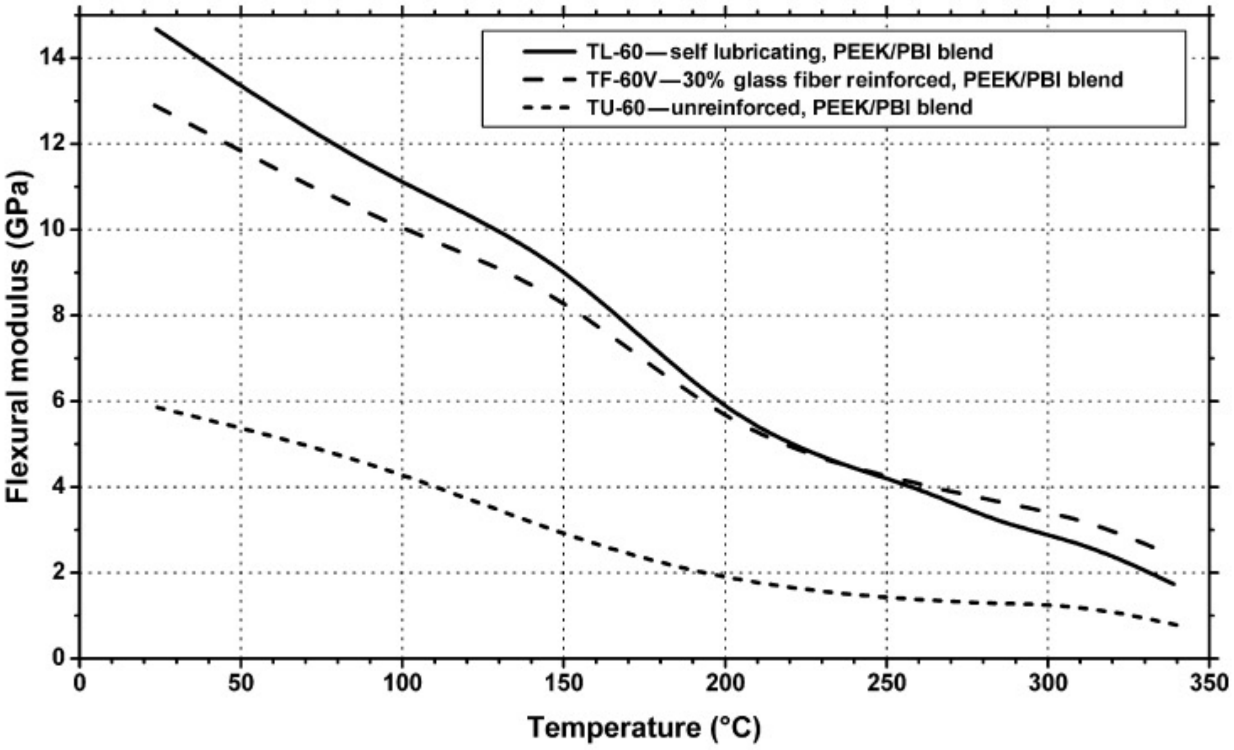


Source: Victrex

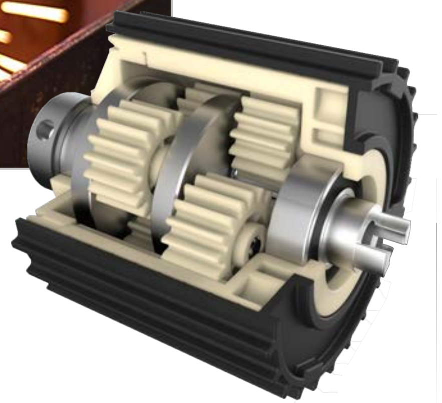
CURBELL PLASTICS

PEEK/PBI Blends (Celazole® T-Series)

DMA Curves of Various T-Series PEEK/PBI Blends



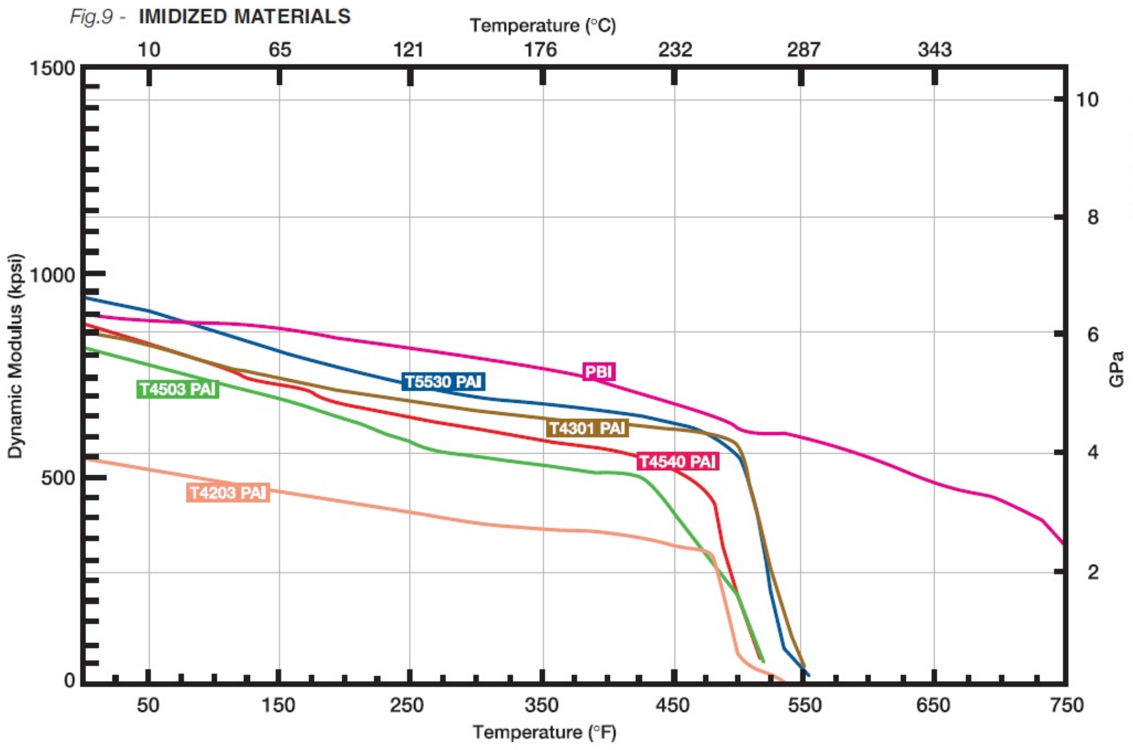
Source: McKeen



Torlon® PAI and Celazole® PBI

	Torlon® 4203	Celazole® PBI U-60
Specific Gravity	1.41	1.30
Tensile Strength	20,000 psi	23,000 psi
Elongation at Break	7.6%	3.0%
Flex Modulus	600,000 psi	950,000 psi
Compressive Strength	24,000 psi	50,000 psi
IZOD Impact (Notched)	2.0 ft-lb/in	0.5 ft-lb/in
Coefficient of Thermal Expansion	1.7×10^{-5} in/in/°F	1.4×10^{-5} in/in/°F
Glass Transition Temperature	527°F/275°C	800°F/427°C

DMA Curves for Torlon® PAI and PBI Materials

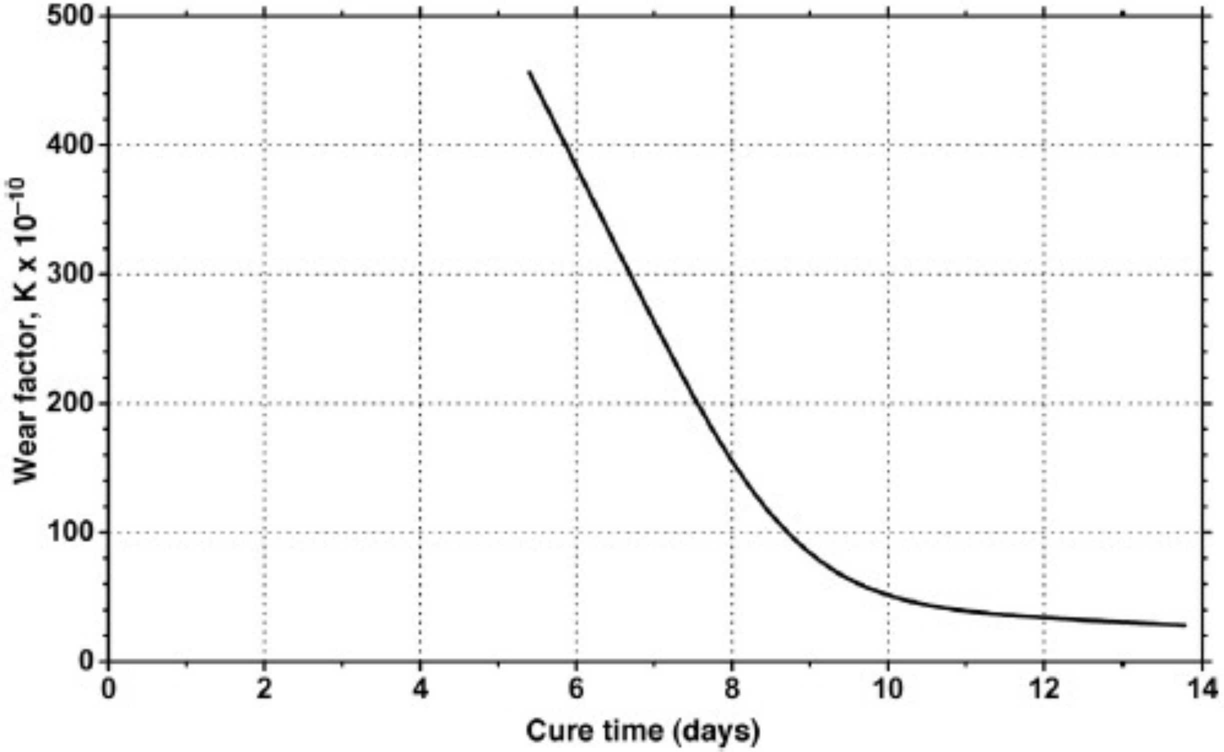


Source: Quadrant

CURBELL PLASTICS

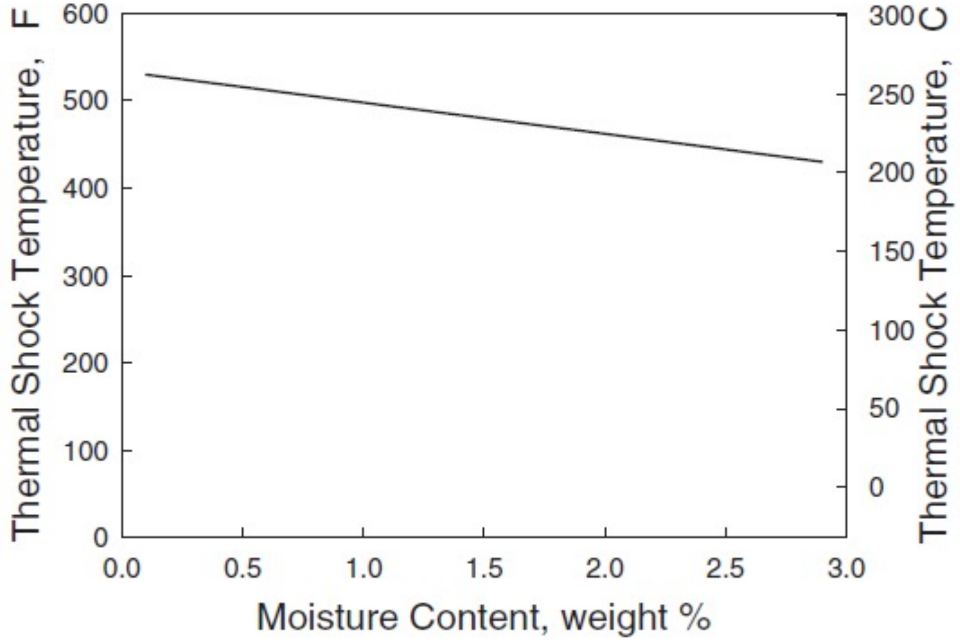
Torlon® PAI Other Considerations

Torlon® PAI Wear Factor with Respect to Cure Time



Source: McKeen

Thermal Shock Temperature vs. Moisture Content of TORLON 4203L

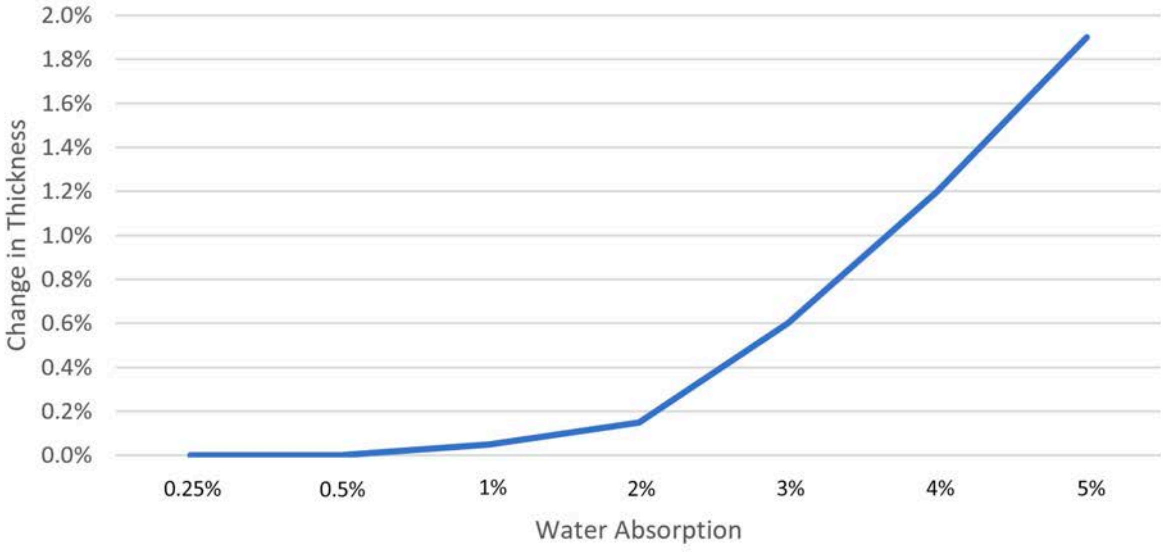


Source: Solvay

CURBELL PLASTICS

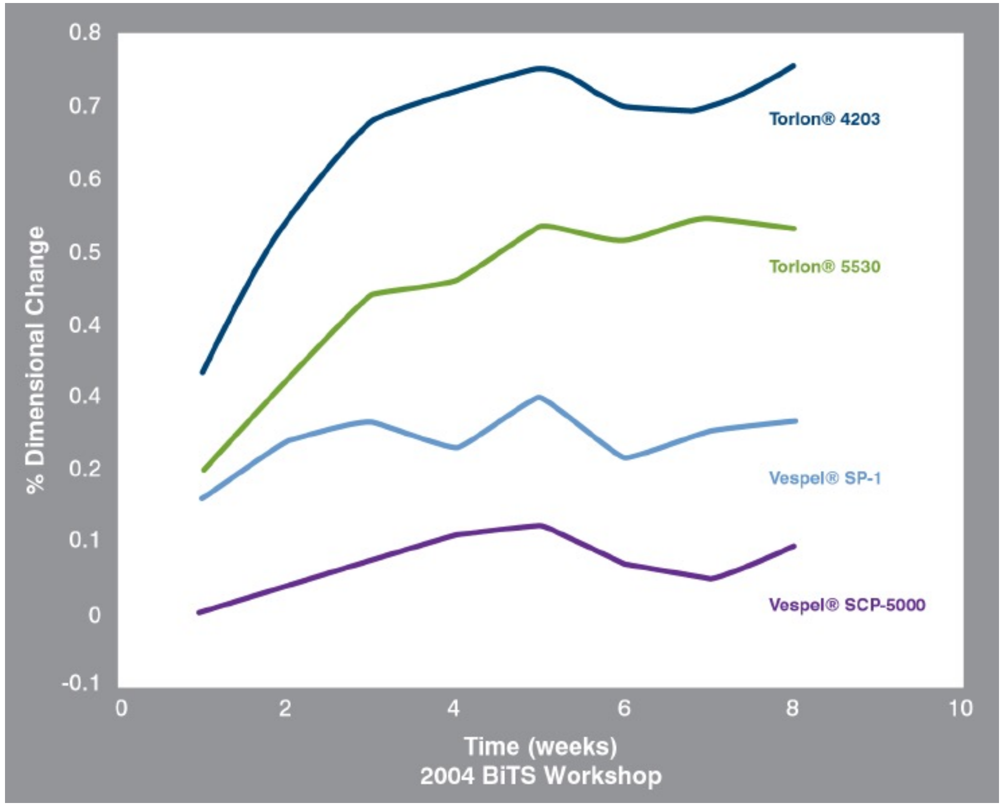
PBI and Torlon® PAI Dimensional Change Due to Moisture

Dimensional Change of PBI U-60 Disk in Water



Source: PBI Performance

Dimensional Change Due to Moisture Uptake of Torlon® PAI and DuPont™ Vespel®



Source: Kane and Bloom

CURBELL PLASTICS

DuPont™ Vespel® SP and SCP Materials

DuPont™ Vespel® Polyimide Shapes

Vespel® SP-1
For physical and electrical properties
SP-1 has high purity and provides physical strength, elongation and toughness, along with electrical and thermal insulation properties. Semiconductor manufacturers often find components fabricated from Vespel® SP-1 shapes useful in production processes.

Vespel® SP-21
For balanced low wear and physical properties
SP-21 is ideal for low wear and friction in applications. SP-21 has physical strength, elongation, and toughness.

Vespel® SP-22
For low wear and dimensional stability
SP-22 provides enhanced resistance to wear and friction as well as improved dimensional and oxidative stability.

Vespel® SP-211
For low coefficient of friction and unlubricated wear
SP-211 provides the lowest coefficient of friction over a wide range of operating conditions. It offers excellent wear resistance up to 300°F (149°C).

Vespel® SP-3
For unlubricated sealing and low wear in vacuum or dry environments
SP-3 provides lubrication for seals and bearings in vacuum or dry environments. SP-3 provides maximum wear and friction resistance in vacuum and other moisture-free environments, where graphite becomes abrasive.

Vespel® SCP-5000
For strength, hardness, and chemical resistance over a broad temperature range
SCP-5000 is ideal for demanding applications that require toughness, thermal and dimensional stability, chemical resistance, and stable dielectric performance across a broad temperature range.

Vespel® SCP-5009
For high wear and friction applications under high operating pressure and elevated temperature environments
SCP-5009 shapes have a low coefficient of thermal expansion and provide good sealing as well as outstanding mechanical properties like high compressive strength and low creep, even in extreme conditions.

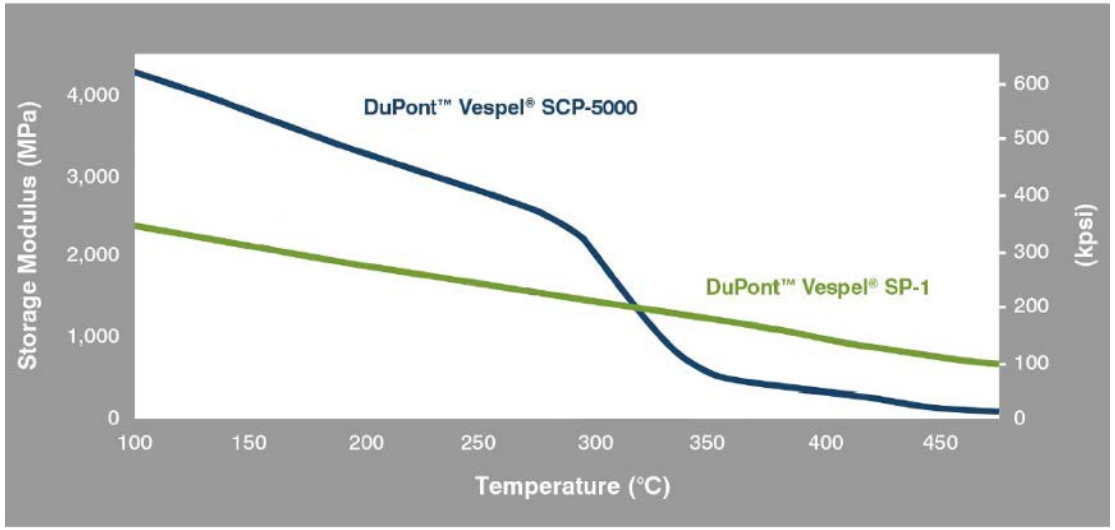
Vespel® SCP-5050
For high temperature, wear resistance, and exceptional coefficient of thermal expansion
SCP-5050 is a new and innovative polyimide composition. SCP-5050 has improved high temperature and wear resistance compared to conventional polyimides allowing replacement of metal and graphite in more applications. Its proprietary composition is designed to offer a coefficient of thermal expansion (CTE) close to the CTE of metals.

Vespel® SCP-50094
For high temperature and wear resistance
SCP-50094 is a proprietary polymer designed for demanding applications that require high strength, high temperature, and wear resistance.

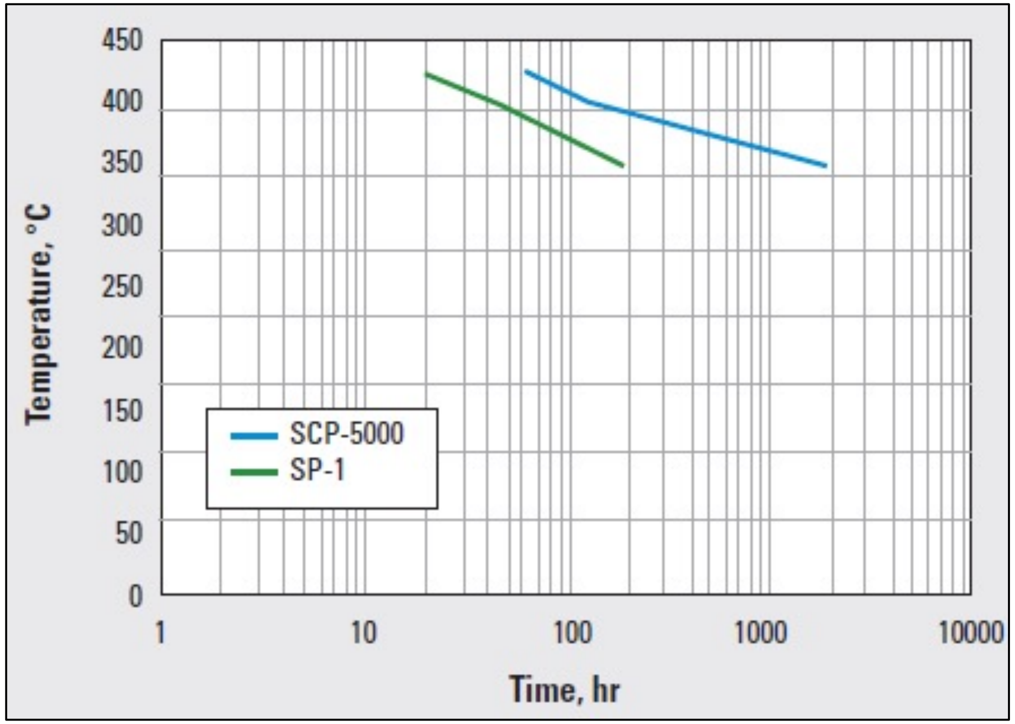
CURBELL PLASTICS

DuPont™ Vespel® SP and SCP Thermal Data

DMA Curves for Unfilled DuPont™ Vespel®



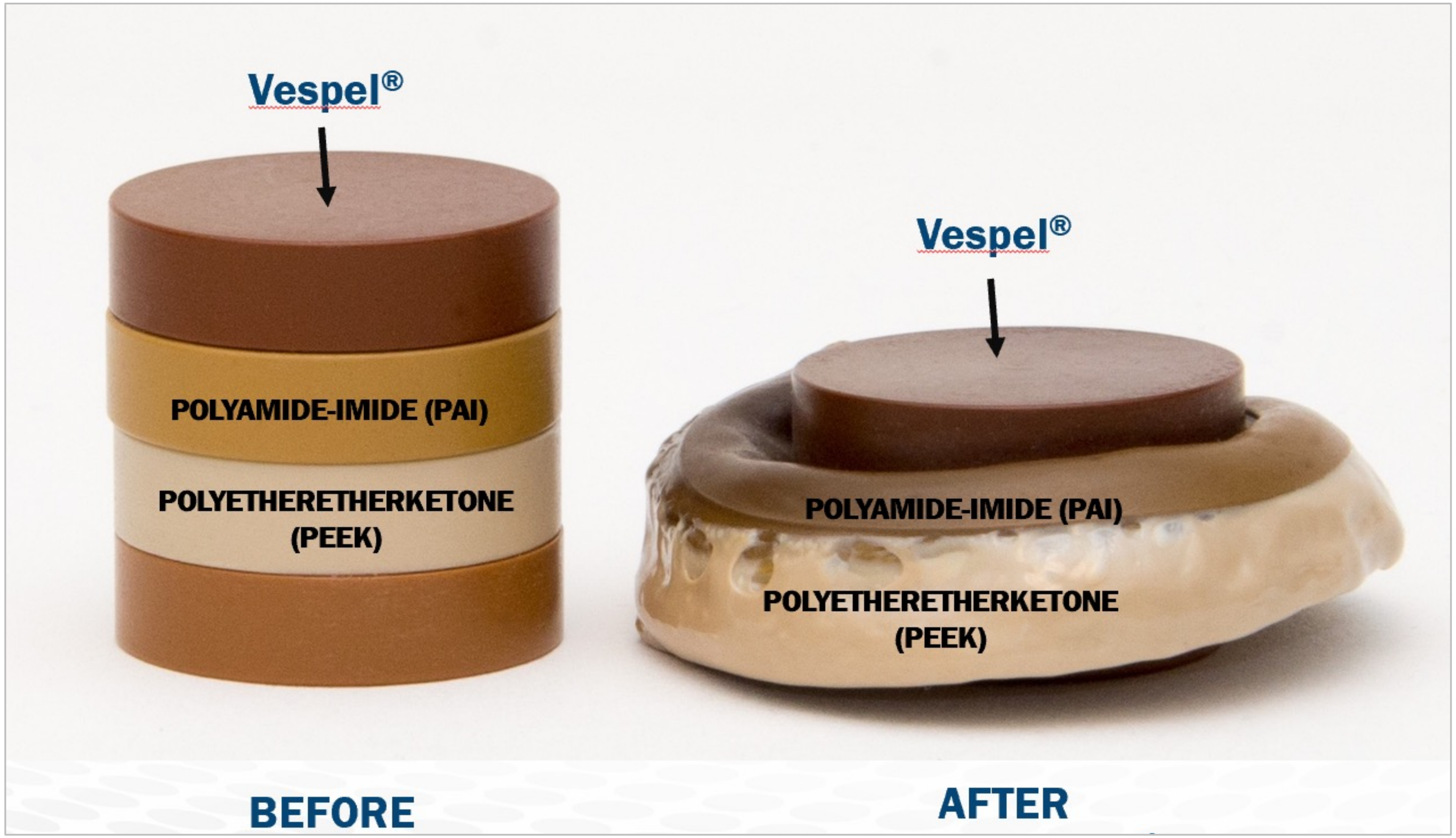
Approximate Time to 50% Reduction in Tensile Strength with Respect to Temperature



Source: DuPont

CURBELL PLASTICS

DuPont™ Vespel® SP and SCP Thermal Data



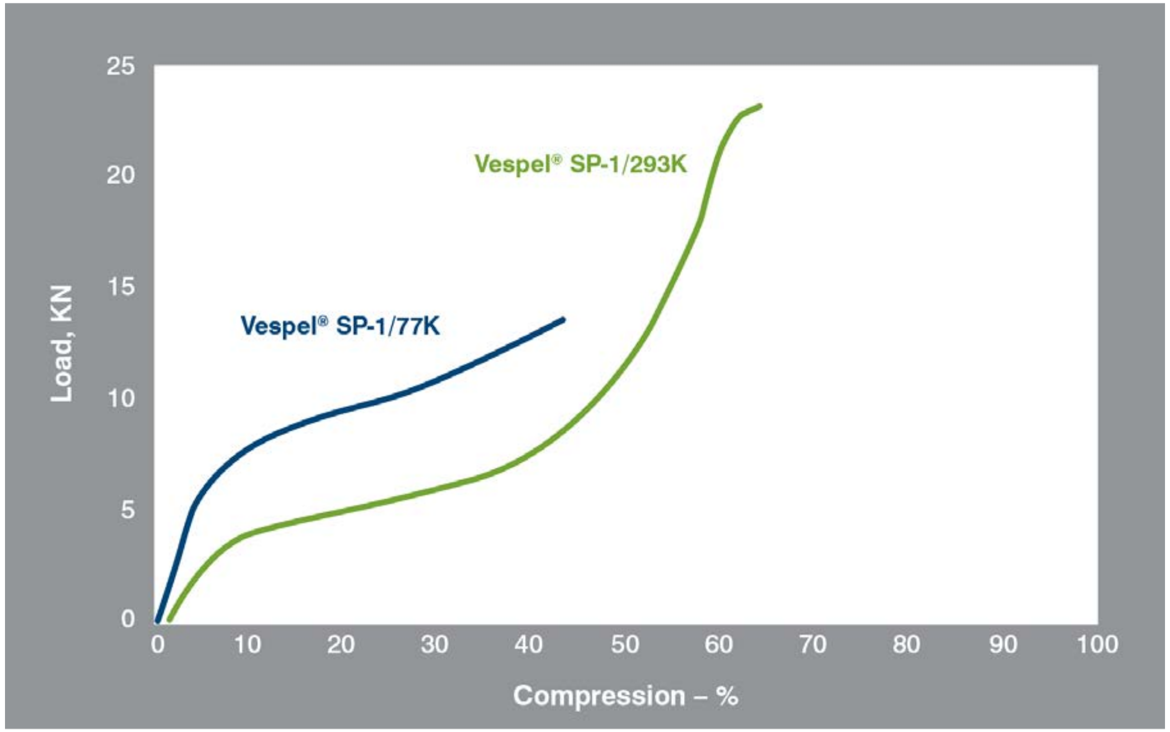
Source: Dupont

At 700°F

CURBELL PLASTICS

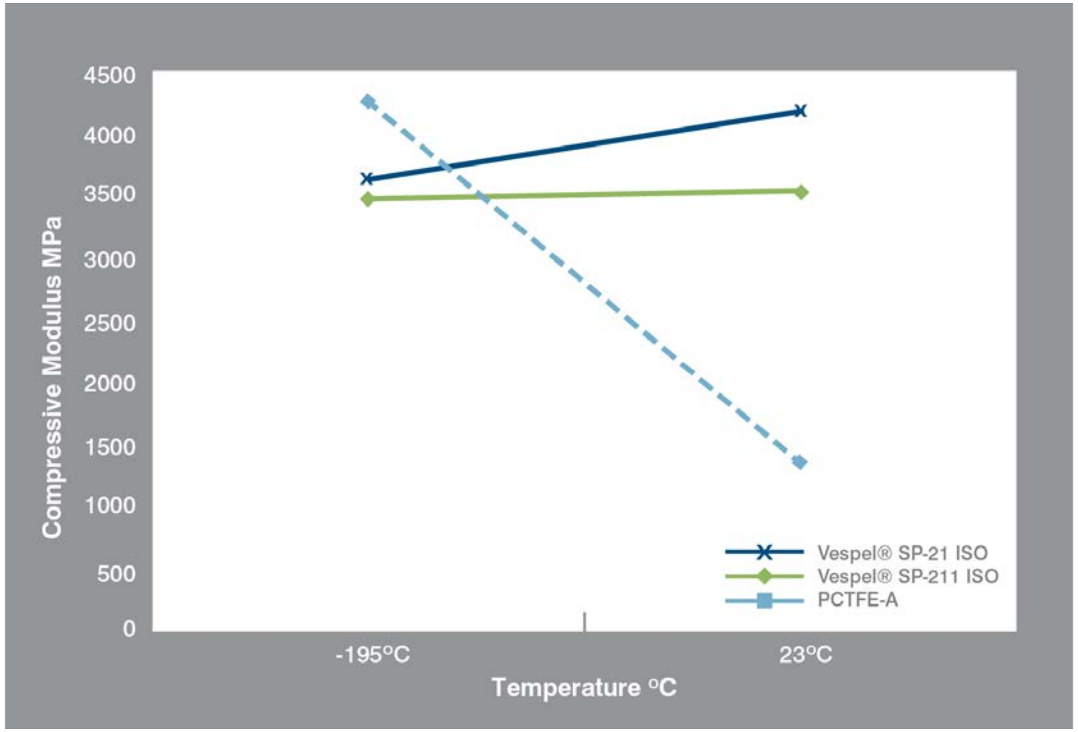
DuPont™ Vespel® Cold Temperature Performance

Low Temperature Compressive Strength of Vespel® SP-1



Source: McDonald and Rao

Low Temperature Compressive Modulus of DuPont™ Vespel® and PCTFE



Source: Lewis

Extreme Wear Performance

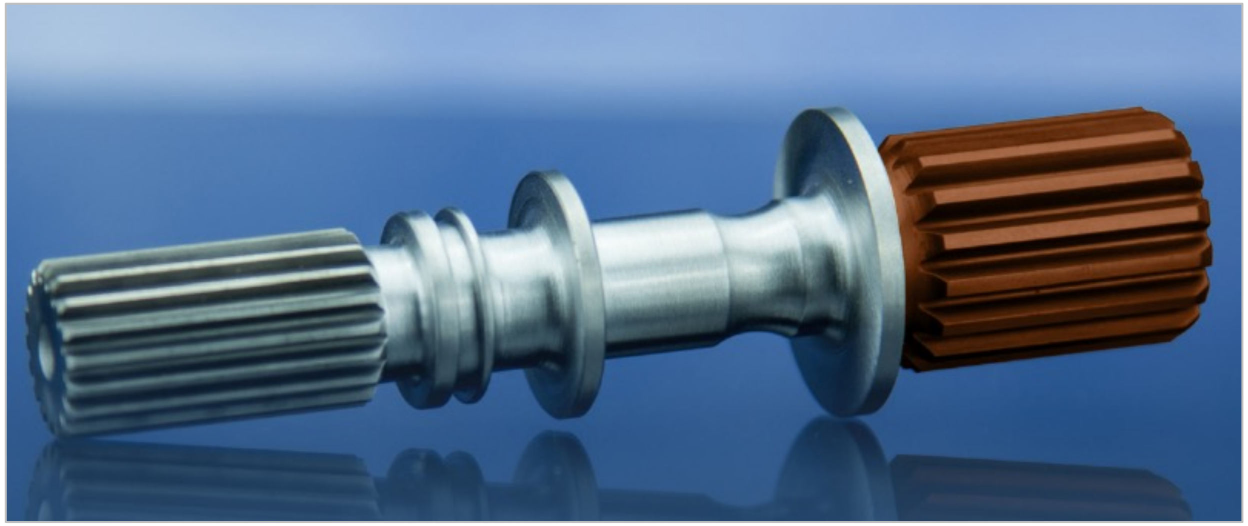
Wear Factor K at 800 fpm (in^3-min/ft-lb-hr x 10^{-10})

PV	Torlon 4435	Torlon 4275	Vespel SP-21	PEEK 450FC30	Celaz TL-60 Mach'd	Celaz TL-60 Inj'n	Torlon 4203L
50000	88	89	31	melted	20	24	
75000	70	76	39		17	23	
100000	46	194*	22		13	20	
125000	melted		43		test end; no failure	15	
150000			38			27	
175000			27			40^	
200000			26				
225000			24				
250000			22				
275000			20				
300000			17				
325000			20				
350000			23				
375000			28				
400000			29				

Source: Gruender

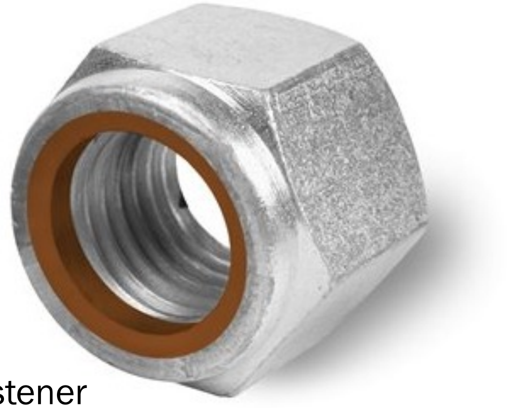
CURBELL PLASTICS

Torlon® PAI, PBI, & DuPont™ Vespel® Application Examples



DuPont™ Vespel® Spline Coupling

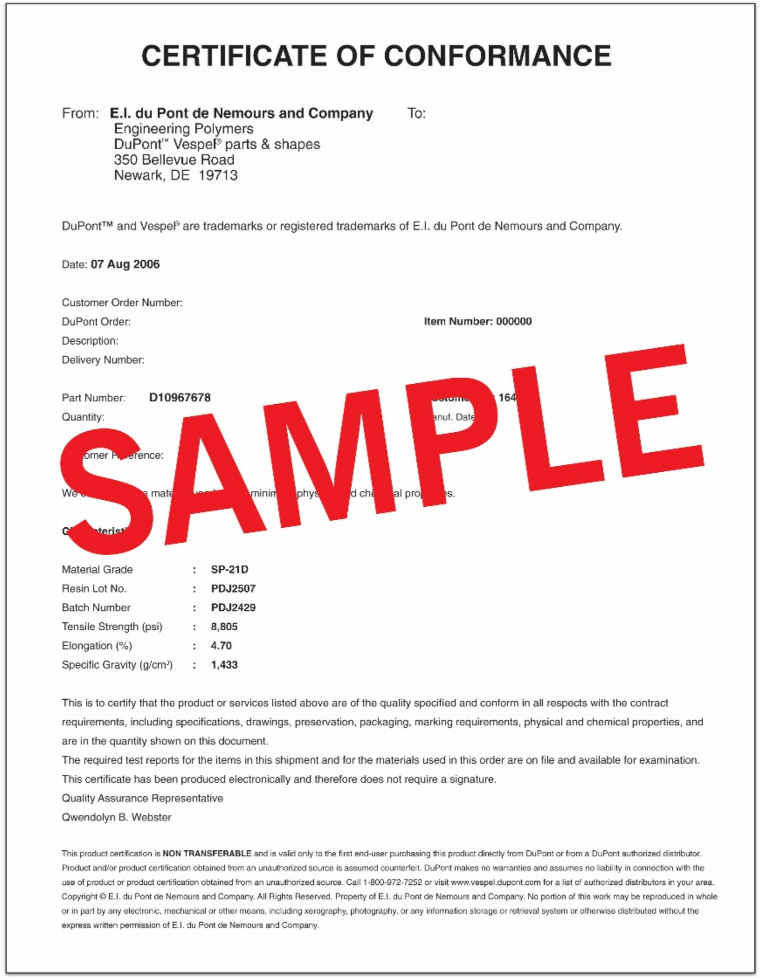
Labyrinth Seal



DuPont™ Vespel® Locking Fastener

CURBELL PLASTICS

Authentic Certifications for DuPont™ Vespel®



CERTIFICATE OF CONFORMANCE

From: **E.I. du Pont de Nemours and Company** To:
Engineering Polymers
DuPont™ Vespel® parts & shapes
350 Bellevue Road
Newark, DE 19713

DuPont™ and Vespel® are trademarks or registered trademarks of E.I. du Pont de Nemours and Company.

Date: **07 Aug 2006**

Customer Order Number:
DuPont Order: **Item Number: 000000**
Description:
Delivery Number:

Part Number: **D10967678** [illegible] **164**[illegible]
Quantity: [illegible]nuf. Date

SAMPLE

[illegible]omer R[illegible]erence:

We [illegible]

C[illegible]teristi[illegible]

Material Grade	:	**SP-21D**
Resin Lot No.	:	**PDJ2507**
Batch Number	:	**PDJ2429**
Tensile Strength (psi)	:	**8,805**
Elongation (%)	:	**4.70**
Specific Gravity (g/cm³)	:	**1,433**

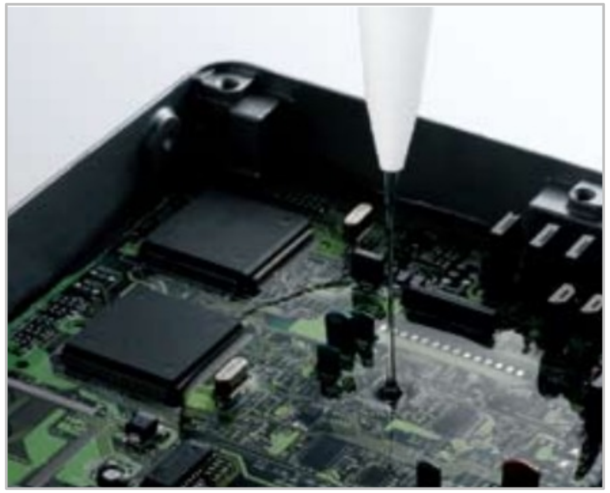
This is to certify that the product or services listed above are of the quality specified and conform in all respects with the contract requirements, including specifications, drawings, preservation, packaging, marking requirements, physical and chemical properties, and are in the quantity shown on this document.
The required test reports for the items in this shipment and for the materials used in this order are on file and available for examination.
This certificate has been produced electronically and therefore does not require a signature.
Quality Assurance Representative
Qwendolyn B. Webster

This product certification is **NON TRANSFERABLE** and is valid only to the first end-user purchasing this product directly from DuPont or from a DuPont authorized distributor. Product and/or product certification obtained from an unauthorized source is assumed counterfeit. DuPont makes no warranties and assumes no liability in connection with the use of product or product certification obtained from an unauthorized source. Call 1-800-972-7252 or visit www.vespel.dupont.com for a list of authorized distributors in your area.

CURBELL PLASTICS

Silicones for Critical-Service Electronics

- High thermal conductivity and electrical insulation
- Continuous use range from -175°F to 500°F
- Low outgassing grades for spacecraft applications
- Outstanding adhesion to a variety of substrates
- Low modulus to accommodate thermal expansion mismatch
- Elastomeric behavior to prevent damage from vibration and fatigue
- Grades available with low dielectric constant and low dielectric loss for antenna applications
- Optically transparent grades available



References

- Osswald, Tim A., et al. *Plastics Handbook*. 5th ed., Carl Hanser Verlag GmbH Co KG, 2019, p. 22.
- Ebnesajjad, Sina. *Fluoroplastics, Volume 1*. 2nd ed., Elsevier, 2014, p. 10, 410.
- Tanaka, Kyuichiro. “Effects of Various Fillers on the Friction and Wear of PTFE-Based Composites.” *Friction and Wear of Polymer Composites*, Elsevier, 1996.
- McKeen, Laurence W. *The Effect of UV Light and Weather on Plastics and Elastomers*.
- *Radel® PPSU, Veradel ® PESU & Acudel ® modified PPSU Design Guide*. Solvay Specialty Polymres, 2014, p. 25.
- “CTE, Thermal Expansion.” *Anderson Materials Evaluation, Inc.*, Anderson Materials Evaluation, Inc., https://www.andersonmaterials.com/cte-thermal-expansion/
- McKeen, Laurence W. *The Effect of Sterilization on Plastics and Elastomers*. 4th ed., William Andrew, 2018, p. 293.
- McKeen, Laurence W. *The Effect of Temperature and Other Factors on Plastics and Elastomers*. 3rd ed., William Andrew Pub, 2014, p. 229, 471, 490.
- *Designing with Fortron ® Polyphenylene Sulfide Design Manual*. Celanese, 2013, pp. 2-2, 3-3, 3-5.
- *Materials Property Guide*. Victrex, p. 2, 3, 13.
- *Victrex ® High Performance PEEK Polymers Materials Property Guide*. Victrex, p. 13.
- Heiland, Kirstin, et al. “Measurement of Radical Yields To Assess Radiation Resistance in Engineering Thermoplastics.” *Polymer Durability*, American Chemical Society, 1996.
- Harrass, M., et al. “Tribological behavior of selected engineering polymers under rolling contact.” *Tribology International*, Elsevier Ltd., Oct. 2009.
- *Quadrant High Performance Products and Applications Guide*. The Quadrant Group, 2017, p. 10.
- McKeen, Laurence W. *Fatigue and Tribological Properties of Plastics and Elastomers*. 2nd ed., William Andrew, 2016, p. 188.
- *Torlon ® polyamide-imide design guide*. 2.1, Solvay Advanced Polymers, LLC, 2003, p. 23.
- *Celazole ® PBI U-60 Moisture Management Guide*. PBI Performance Products, Inc., 2012, p. 3.
- Kane, Paul, and Joy Bloom. *Dimensional Stability and High Frequency Properties of Polymeric Materials for Machined Test Sockets*. BiTs Workshop, 2004, p.7.
- *Dupont™ Vespel ® Parts & Shapes SCP-5000 Technical Bulletin*. Dupont, 2006, p. 3.
- McDonald, P.C., and M.G. Rao. *Thermal and Mechanical Properties of Vespel at Low Temperatures*. Institute of Cryogenics, p. 5.
- Lewis, Geoff, et al. *High performance polyimide parts can help reduce actuation torque and improve sealing in cryogenic ball vales for LNG (Liquid Natural Gas) applications*. Dupont, 2015, p.10.
- Gruender, Michael. *High-PV Wear Study of Six High Performance Wear Grade Engineering Plastics*. PBI Performance Products, Inc., 2012, p.4.

CURBELL PLASTICS

Thank you for your time today! Questions?

Dave Seiler

Senior Plastics Product Specialist – High Performance Polymers
Curbell Plastics, Inc.
Cell Phone: 610-316-9370
dseiler@curbellplastics.com

Ask a Plastics Expert form on curbellplastics.com
for help with your applications

CURBELL PLASTICS