Selecting Plastic Materials for Radomes: Balancing RF Performance, Environmental Factors, Manufacturability, and Cost

Webinar Presented by Curbell Plastics

CURBELL PLASTICS

Today's Presenter:

Keith Hechtel, DBA, Vice President of Business Development & Marketing

With 35+ years in plastics, Keith helps companies identify plastic materials that can be used to replace metal components to achieve cost savings, quality improvements, and design innovation.

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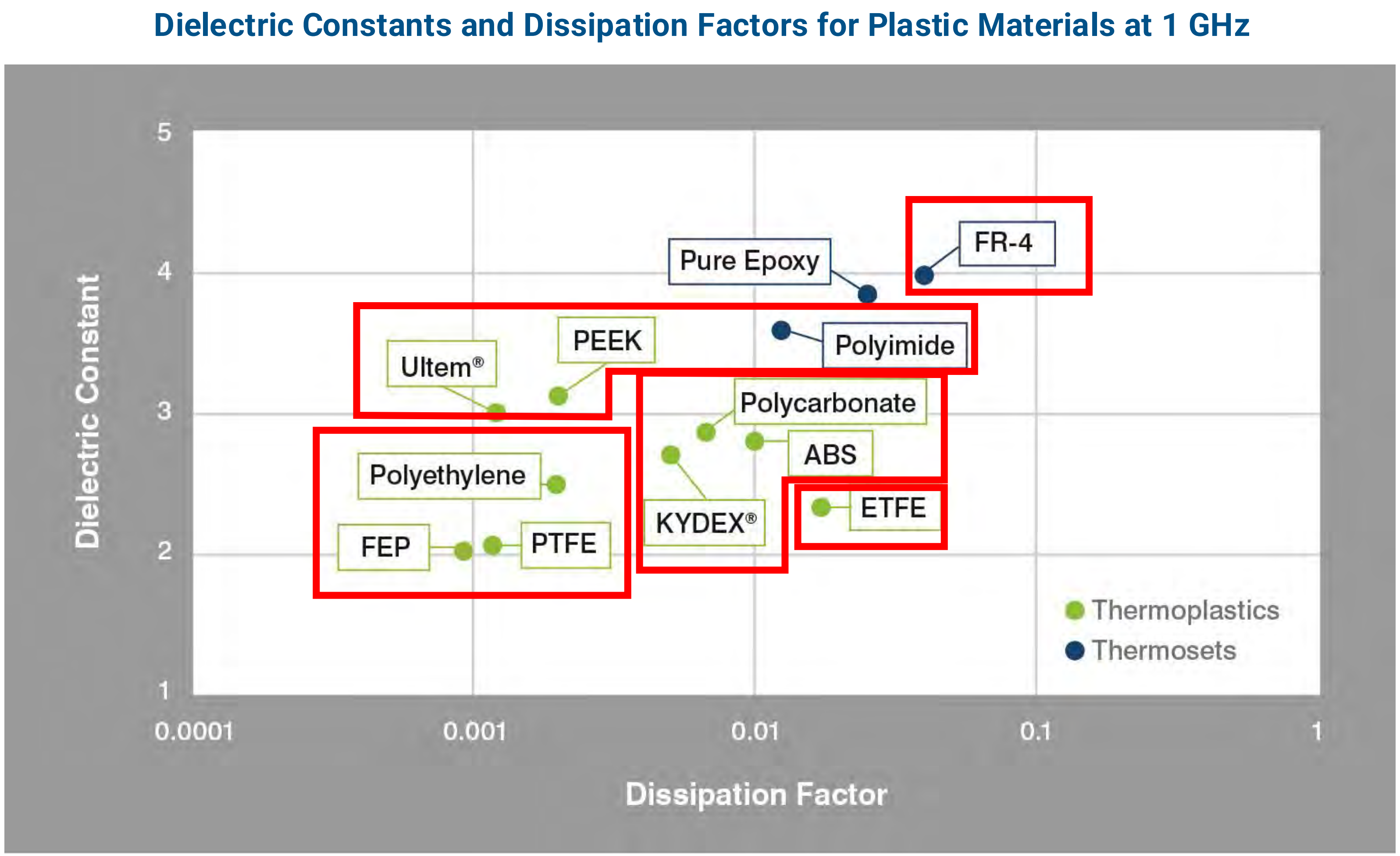
Critical-to-Quality

- Electrical properties
- Mechanical properties
- Operating temperature range
- Outdoor weatherability
- Part geometry, quantity, manufacturing
- Erosion resistance
- Conformance to specifications, test reports, traceability
- Chemical resistance
- Environmental considerations (radiation, vacuum, etc.)
- Color / appearance
- Cost

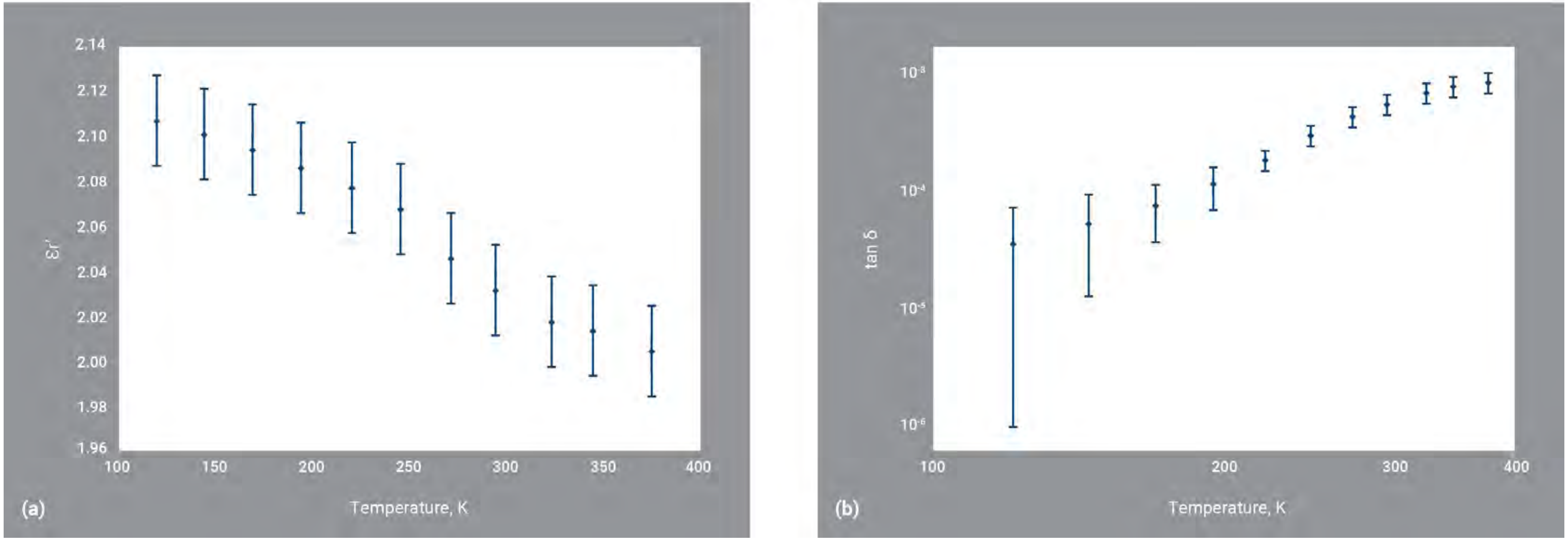
Electrical Properties

RF Performance for Thermoplastics and Thermosets



RF Performance as a Function of Temperature

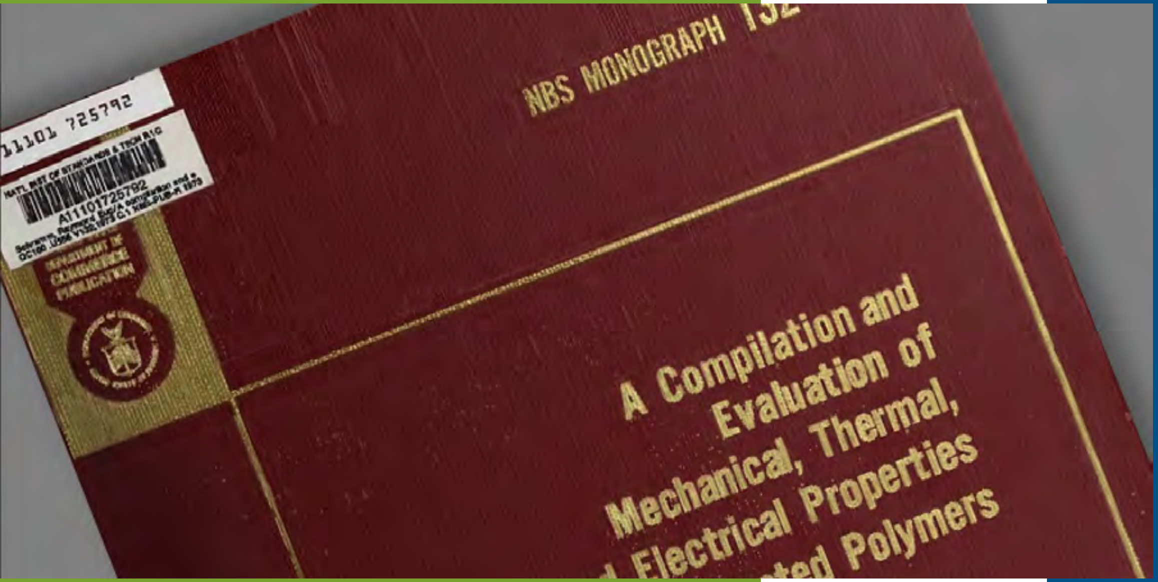
Complex Permittivity Measurements of PTFE at Various Temperatures



Polytetrafluoroethylene, $f \approx 11.5$ GHz. (a) Relative permittivity vs. temperature. (b) Loss tangent vs. temperature.

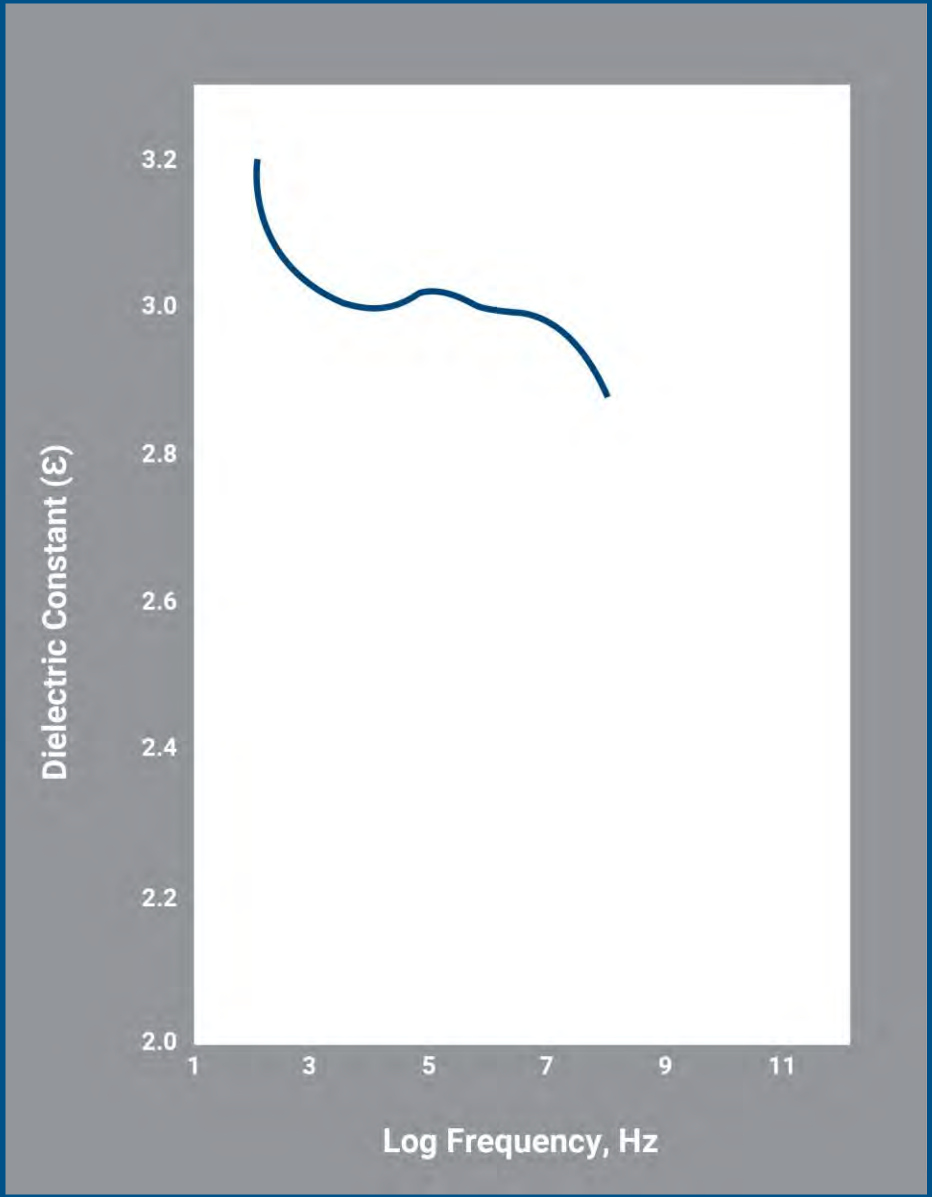
Source: Riddle, W. & Baker-Jarvis, J. (2003). Complex permittivity measurements of common plastics over variable temperatures.
IEEE Transactions on Microwave Theory and Techniques, VOL., 51, NO. 3.

RF Performance as a Function of Frequency



Source: Adapted from Hechelhammer, W., & Peilstocker, G. (1959). Makrolon: A thermoplastic material from the polycarbonate group. Part I: Production and Properties, Kunststoffe (49) 3. Figure referenced in Schram, R., Clark, A., & Reed, R., (1973). A compilation and evaluation of mechanical, thermal, and electrical properties of selected polymers. NBS monograph 132. Washington, DC: U.S. Government Printing Office.

Dielectric Constant of Polycarbonate at Various Frequencies



Thermal and Mechanical Properties

Operating Temperature Range

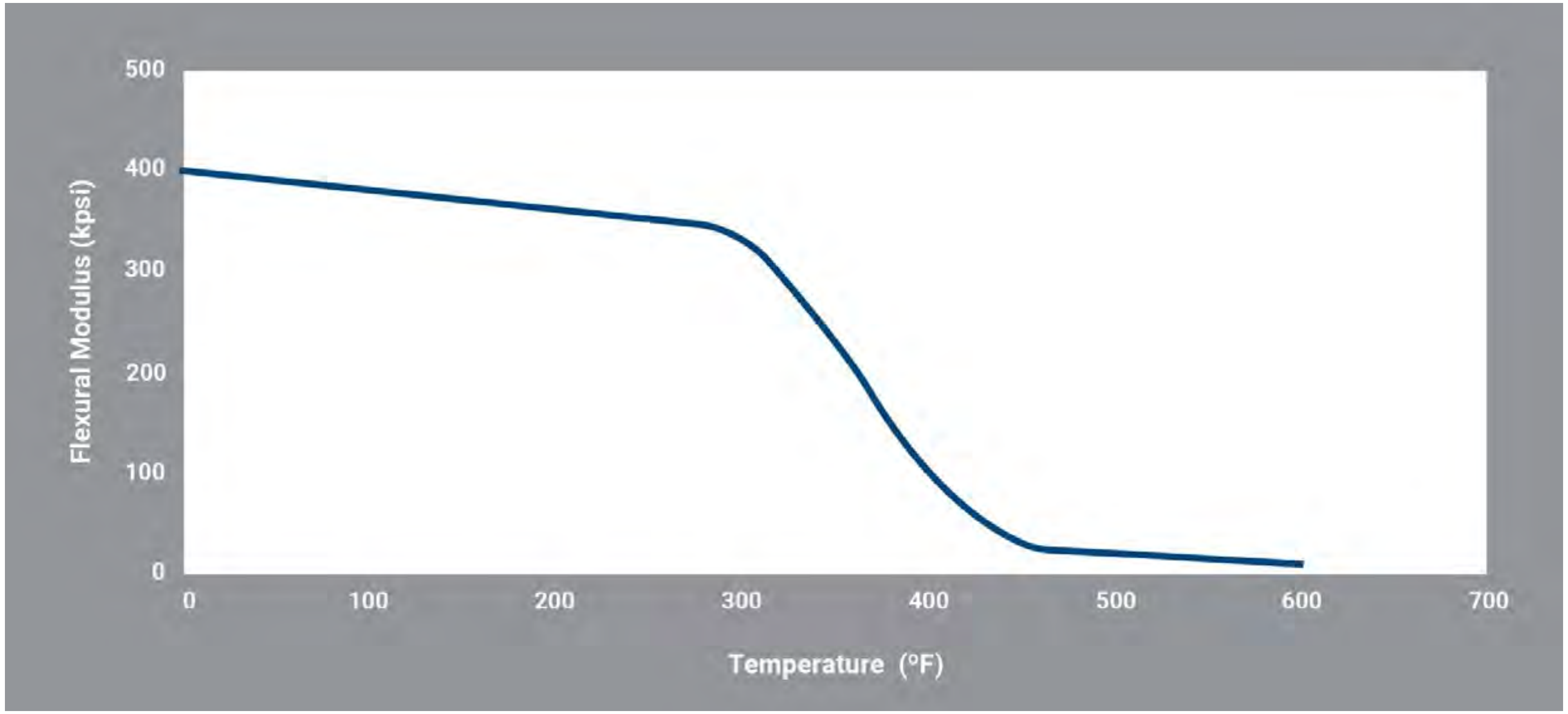
Materials	Max Continuous Service Temperature In Air
PEEK	480
PPSU	392
FEP	392
PCTFE	380
Ultem®	338
PPS	338

Maximum service temperature values provide limited information.

Operating temperature range is actually a complex design issue.

Modulus as a Function of Temperature

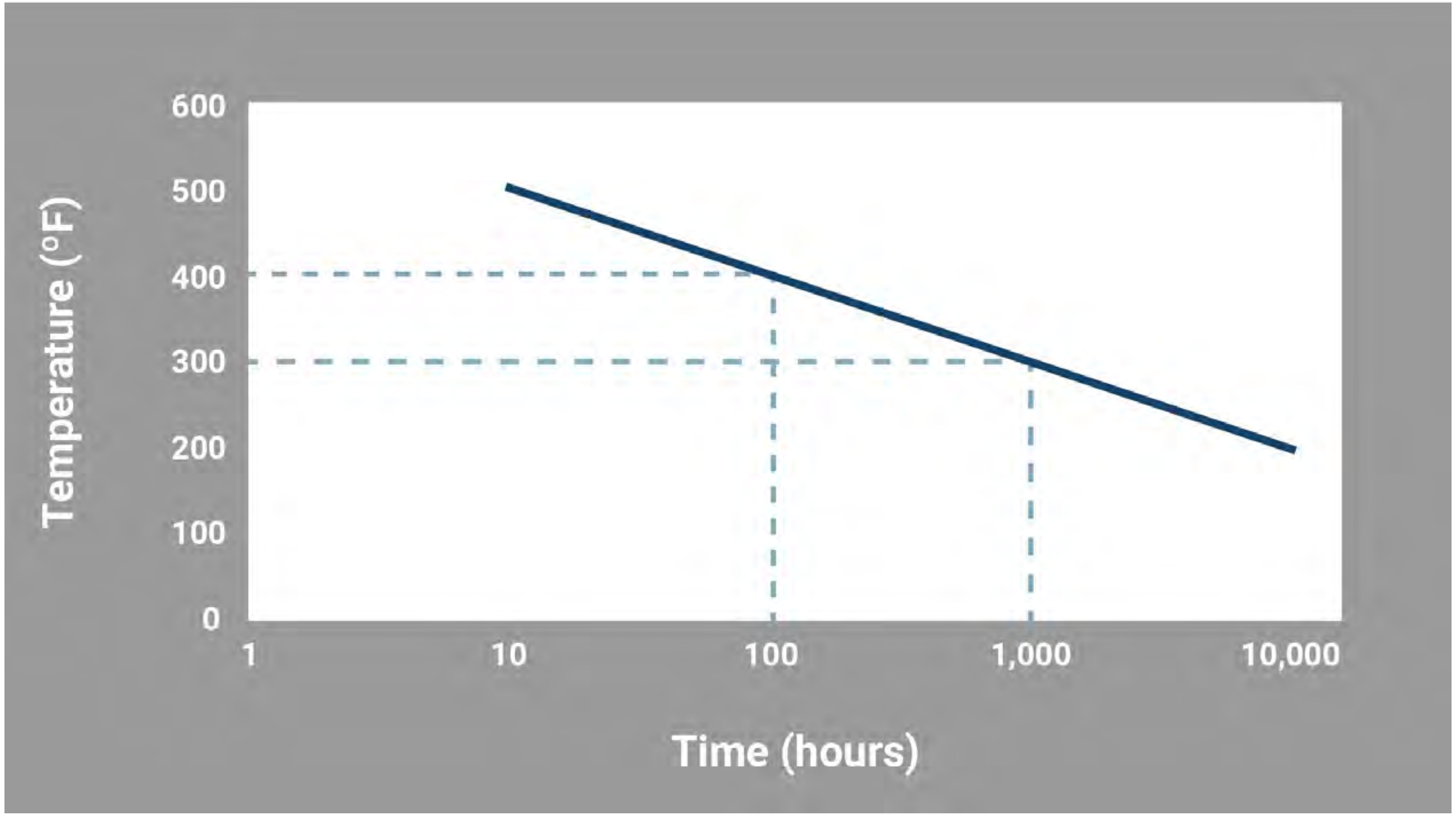
Relationship Between Modulus and Temperature for a Thermoplastic



Thermal Degradation

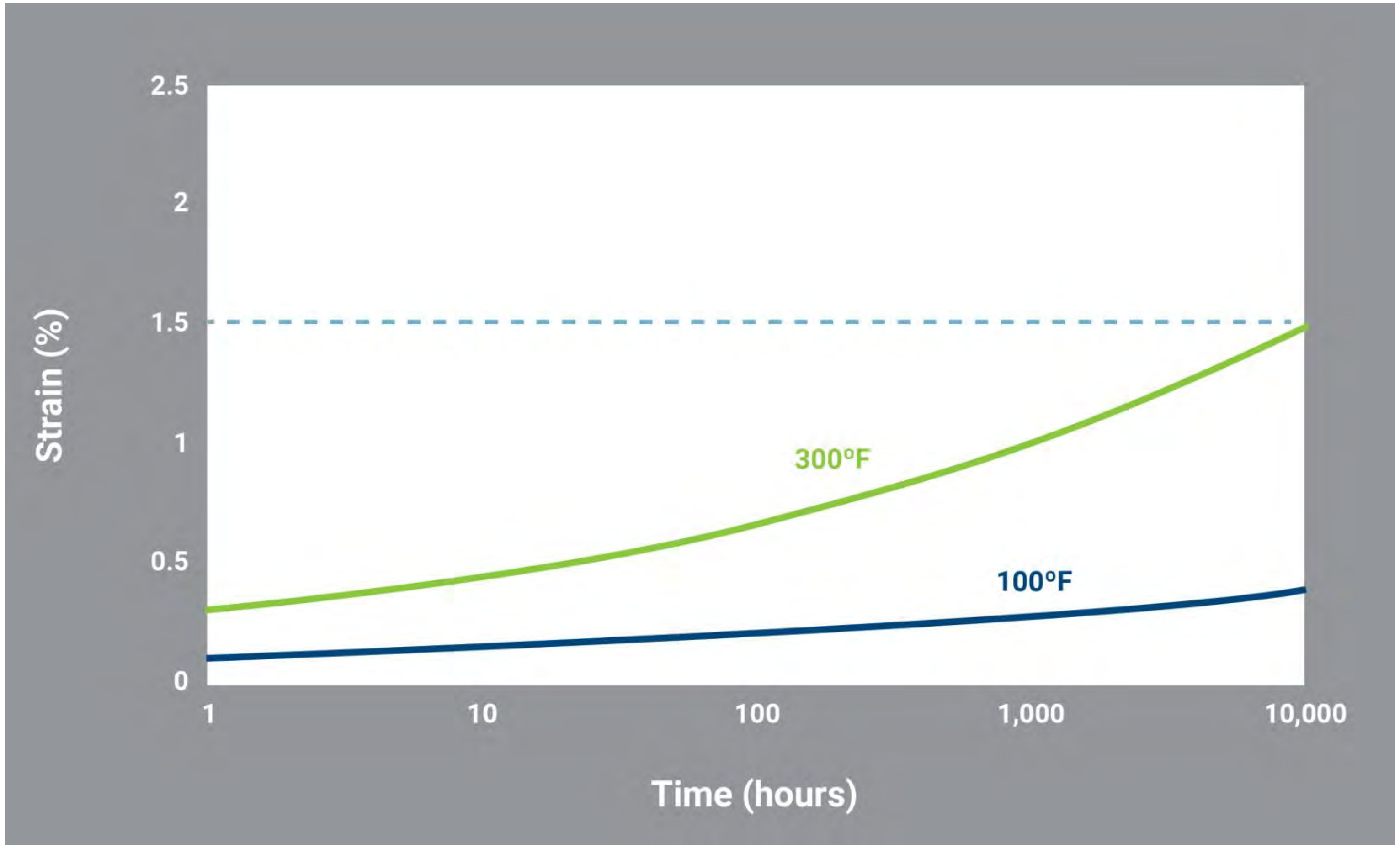
Thermal Degradation

Time to 50% Loss of Tensile Strength for a Thermoplastic at Various Temperatures



Creep

Thermoplastic Creep Behavior
1000 psi Load at Various Operating Temperatures



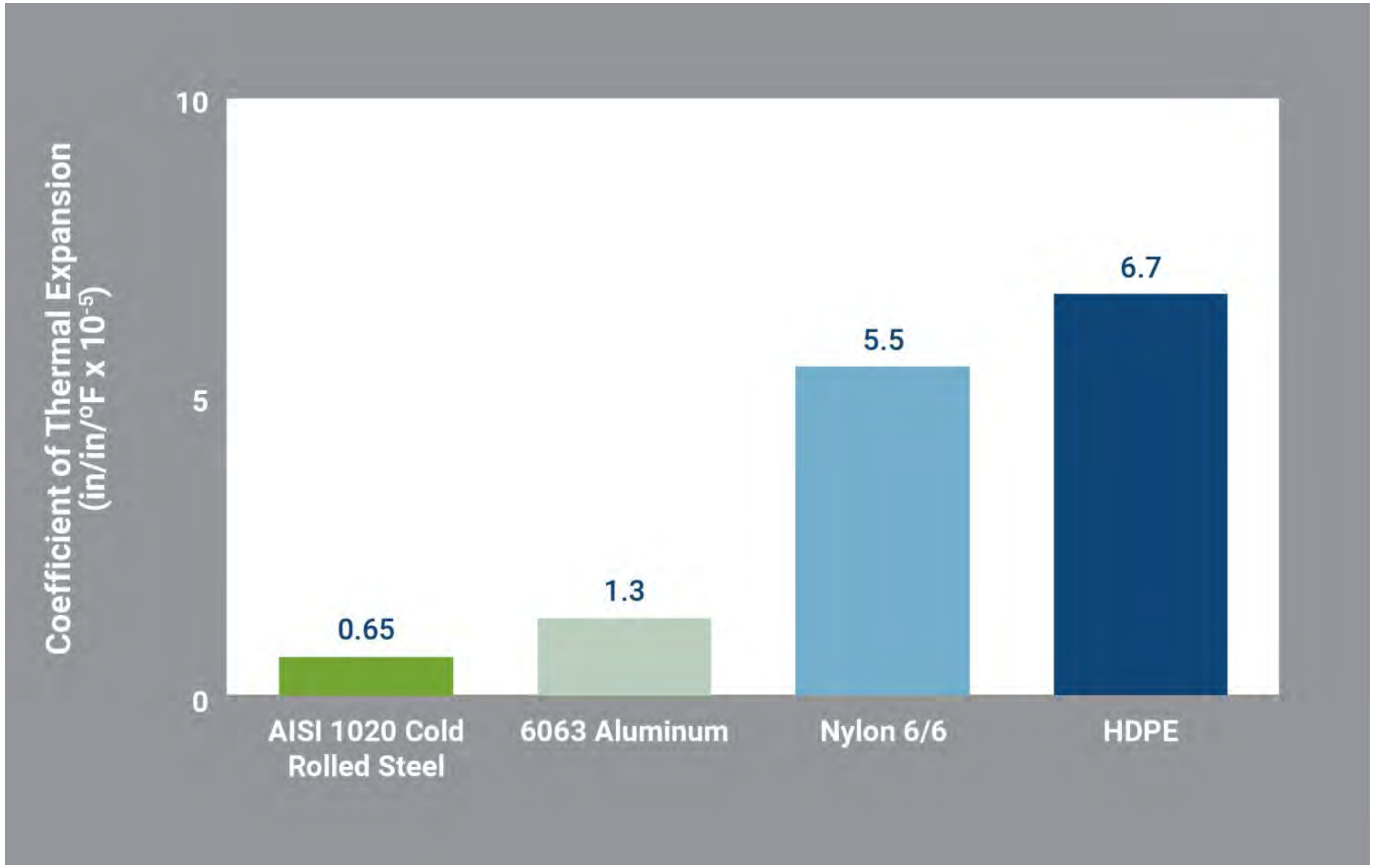
Cold Temperature Behavior

- Hardness, strength and modulus increase
  - Conformability is important for seals
- CTE mismatch between polymer and mating metal part
- Loss of elongation/toughness

Thermal Expansion

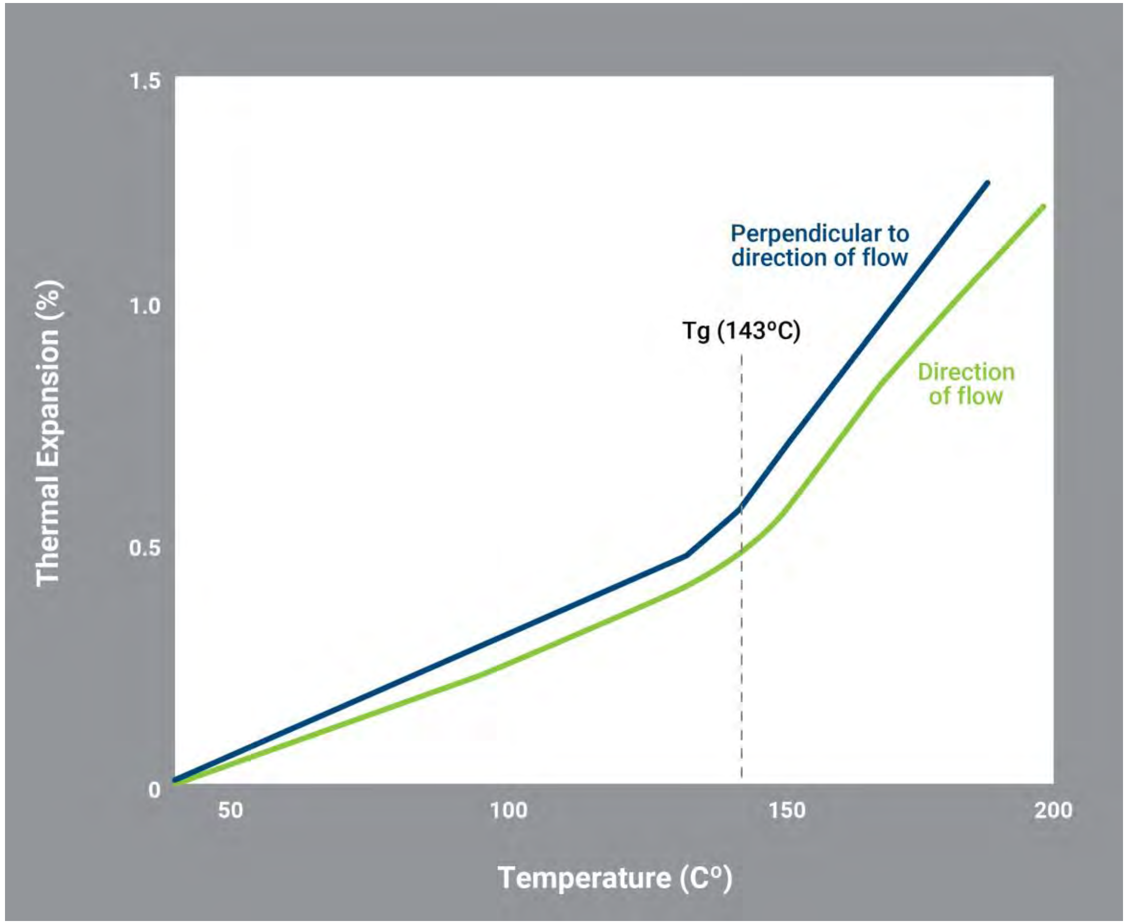
Thermal Expansion

Thermal Expansion Rates of Plastics and Metals



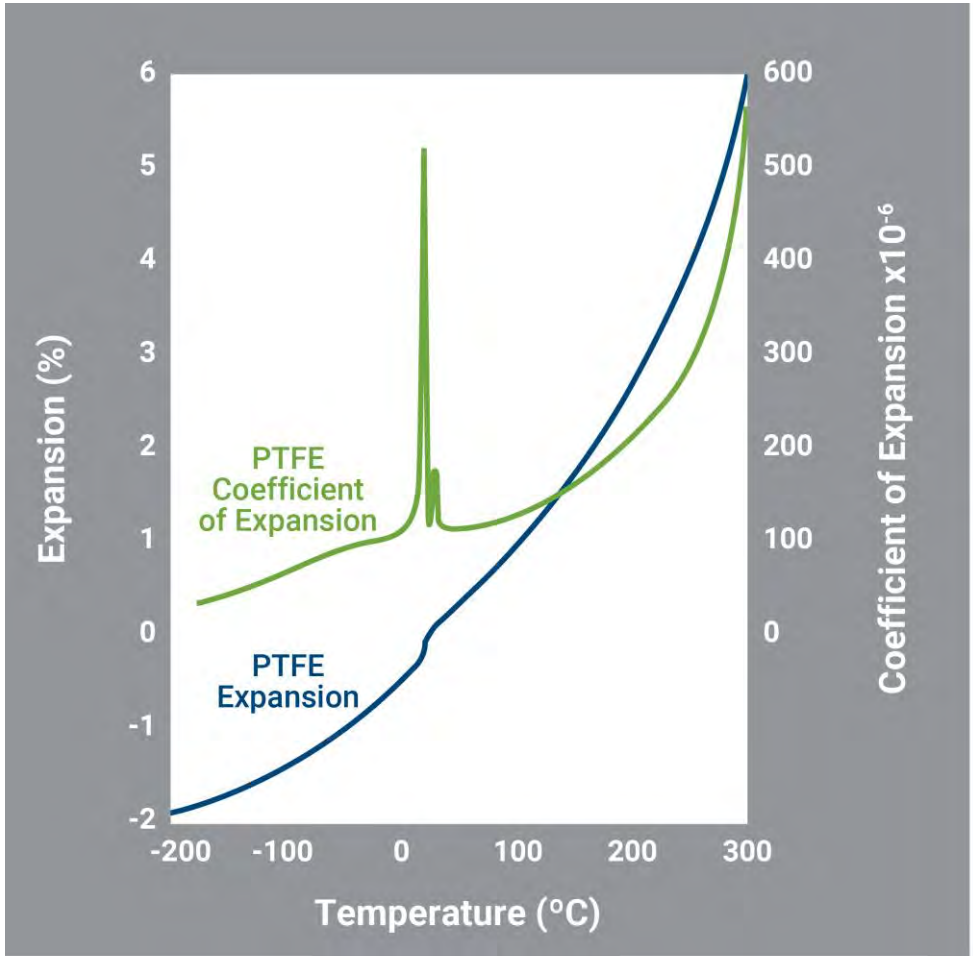
Thermal Expansion

Thermal Expansion Curves for PEEK in the Direction of Flow and Perpendicular to the Direction of Flow, Both Above and Below the Material's Glass Transition Temperature



Thermal Expansion

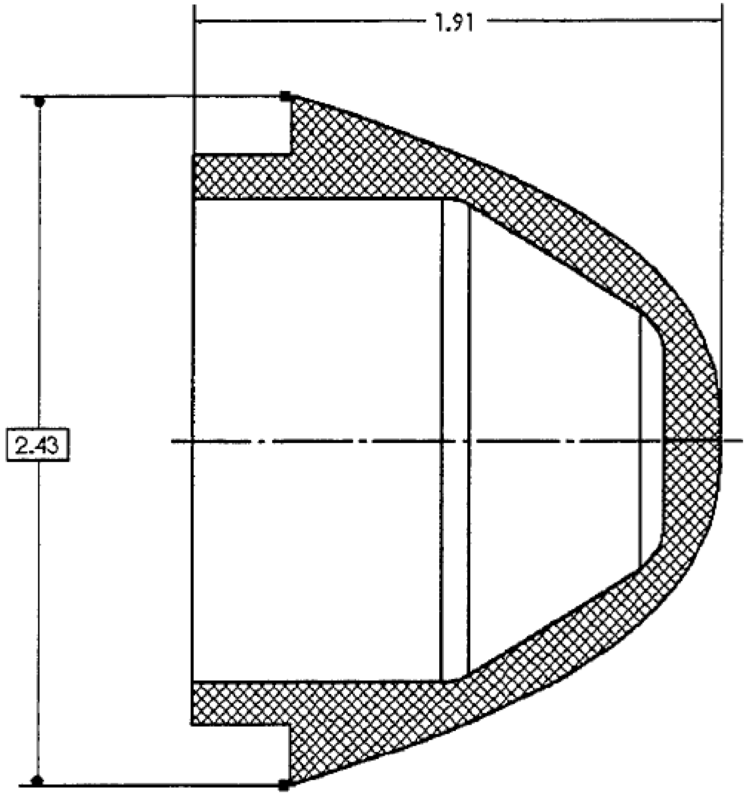
Linear Thermal Expansion and Coefficient of Linear Thermal Expansion of Annealed Teflon®



Source: Kirby, R. (1956). Thermal expansion of polytetrafluoroethylene from -190 degrees to +300 degrees C. Journal of Research of the National Bureau of Standards, 57(2), 91-94.

Frictional Heat from Air at Hypersonic Velocities

Vespel® may be a candidate for radomes for hypersonic munitions.



Hemispherical Radome Geometry (units in inches).

Source: Army Research Library, Parameterized Design of a Supersonic Radome, Michael Hollis, April 2001.

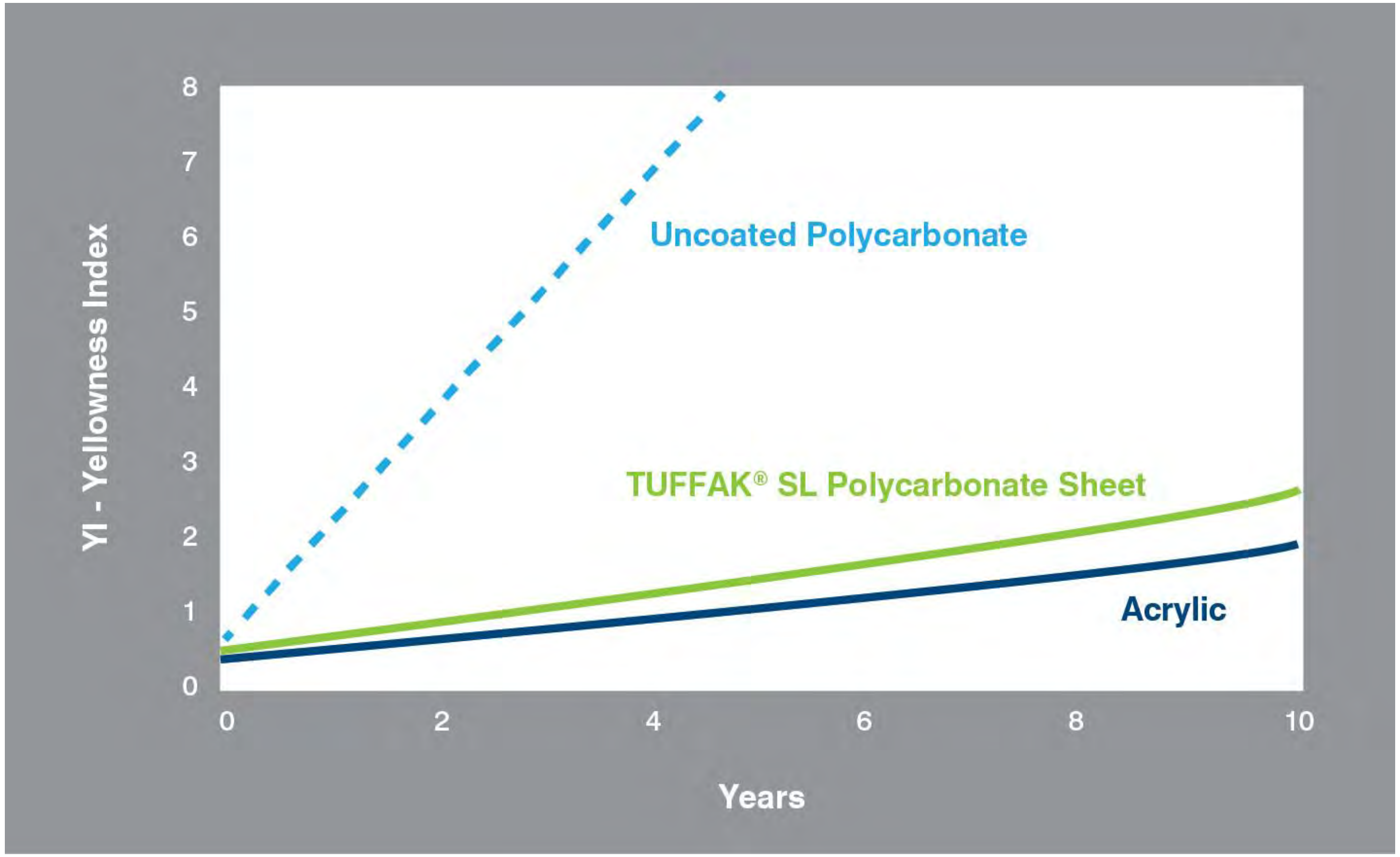
Chemical Resistance and Environmental Considerations

Outdoor Weatherability

Note: Carbon black UV additives may affect electrical performance.

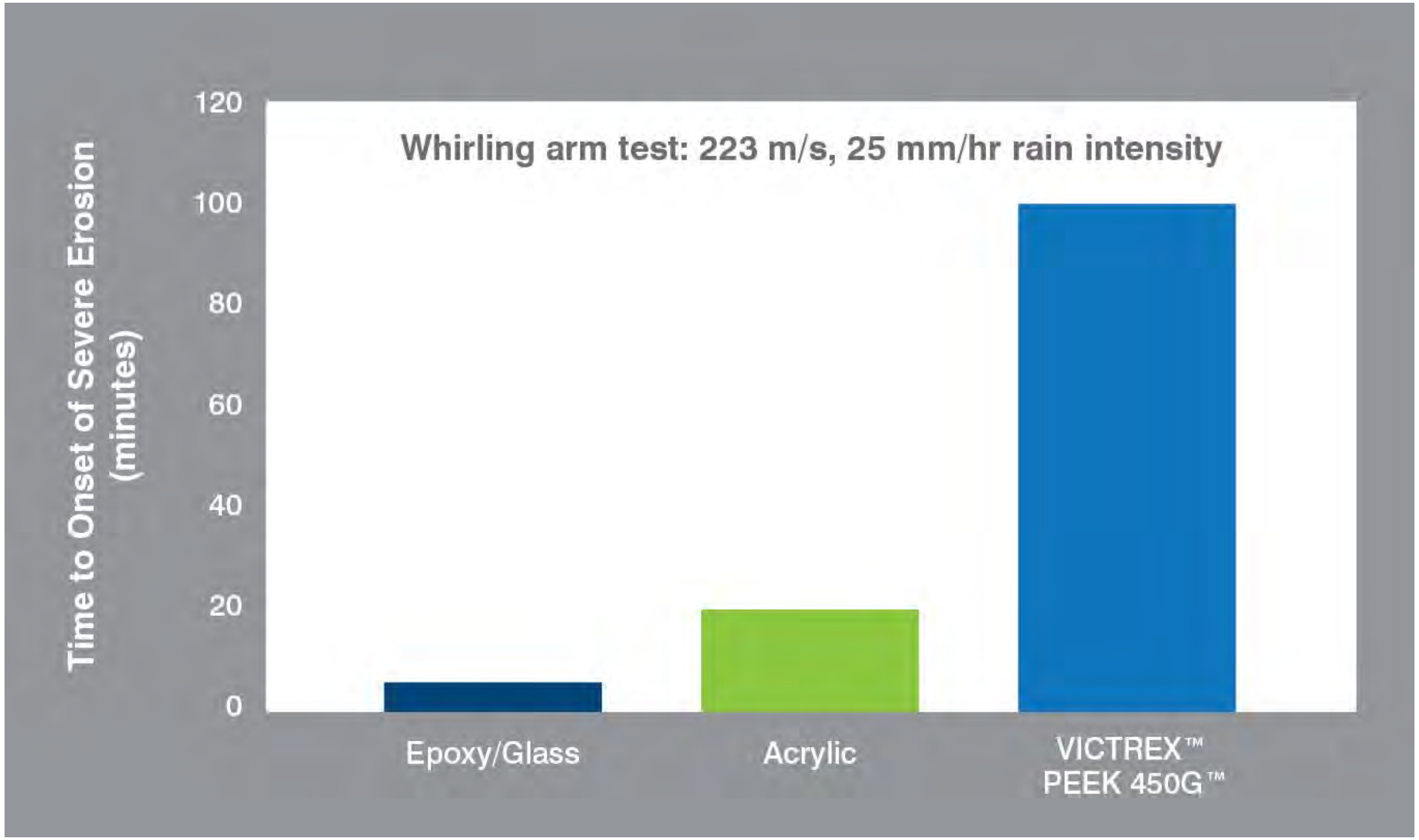
Source: Adapted from Plaskolite TUFFAK® SL Data Sheet 2019.

UV Weather Resistance – Visible Yellowing



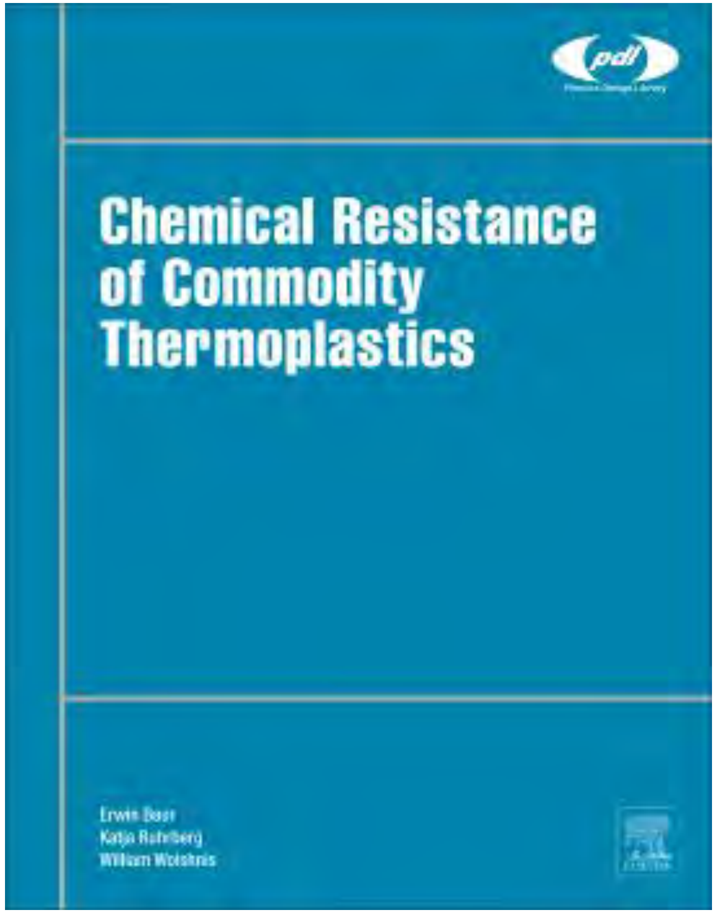
Erosion Resistance

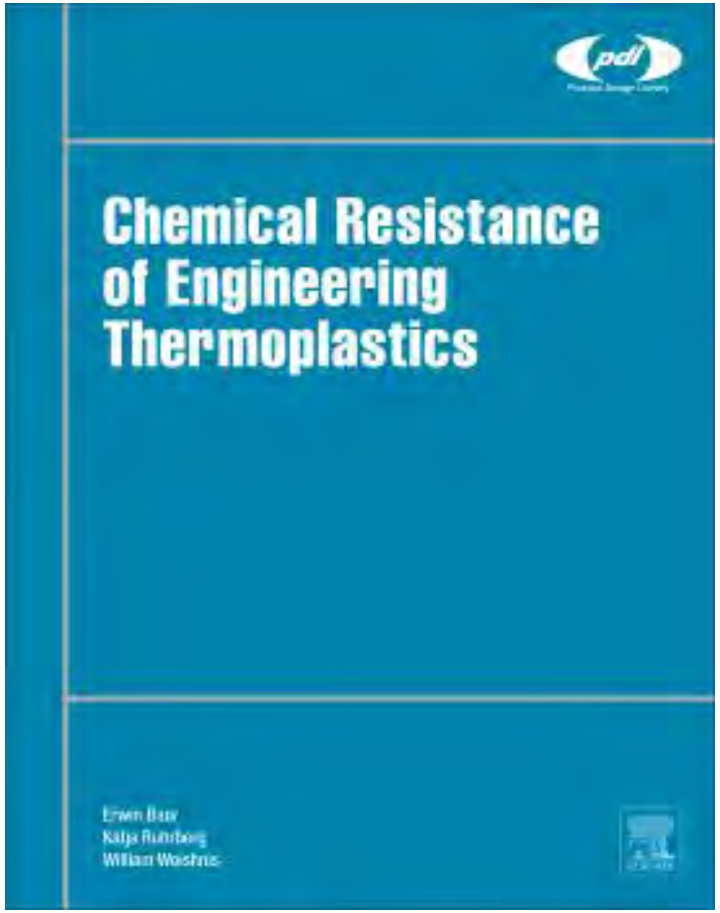
Rain Erosion Resistance of an Epoxy/Glass Composite, Acrylic, and PEEK

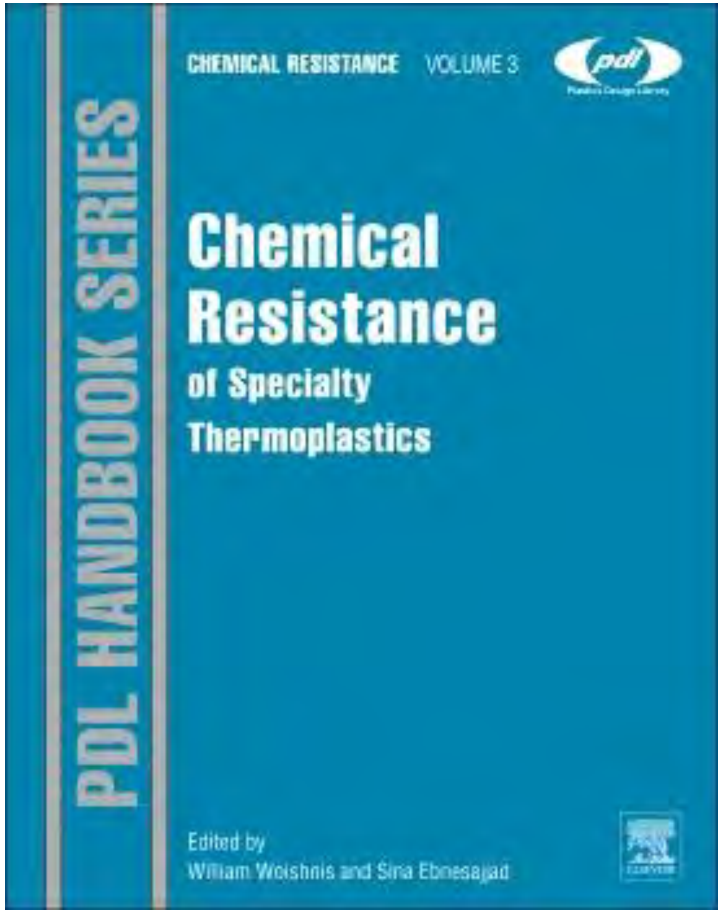


Source: Gentilcore, G. (1992). Ph.D. Dissertation. Impact and water jet impact of high performance thermoplastics. University of Bath.

Chemical Resistance / ESC Resistance



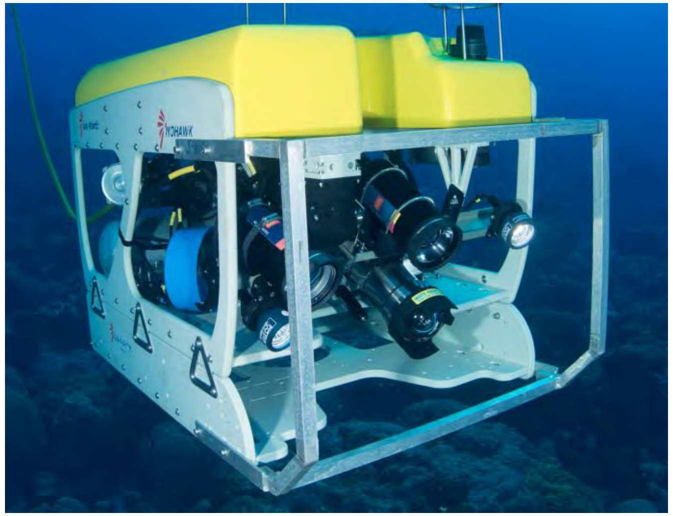




Source: Plastics Design Library

Environmental Considerations

Radiation



Deep Ocean

Space

Specifications

- MIL Specs
- SAE AMS
- ASTM

MIL-P-46183
20 June 1984

MILITARY SPECIFICATION

PLASTIC MOLDING and EXTRUSION MATERIAL,
POLYETHERETHERKETONE (PEEK)

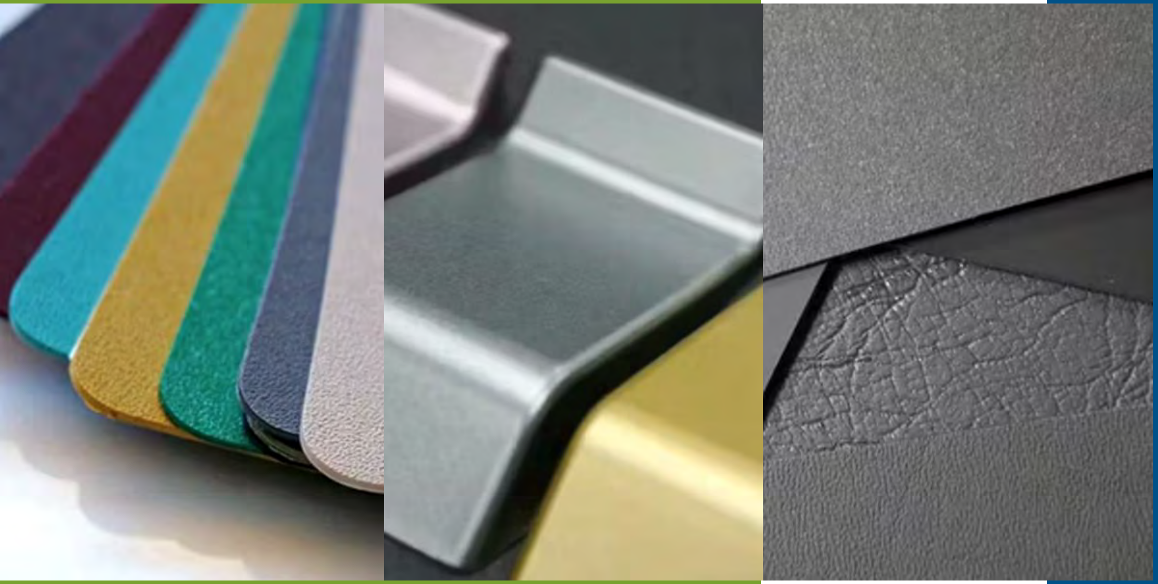
This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers polyetheretherketone (PEEK) thermoplastic materials suitable for injection molding or extrusion (See 6.1).

1.2 Classification. The PEEK thermoplastic materials shall be of the following types and classes (see 6.2):

Appearance



- Color
- Gloss
- Surface texture
- Ease of painting / coating

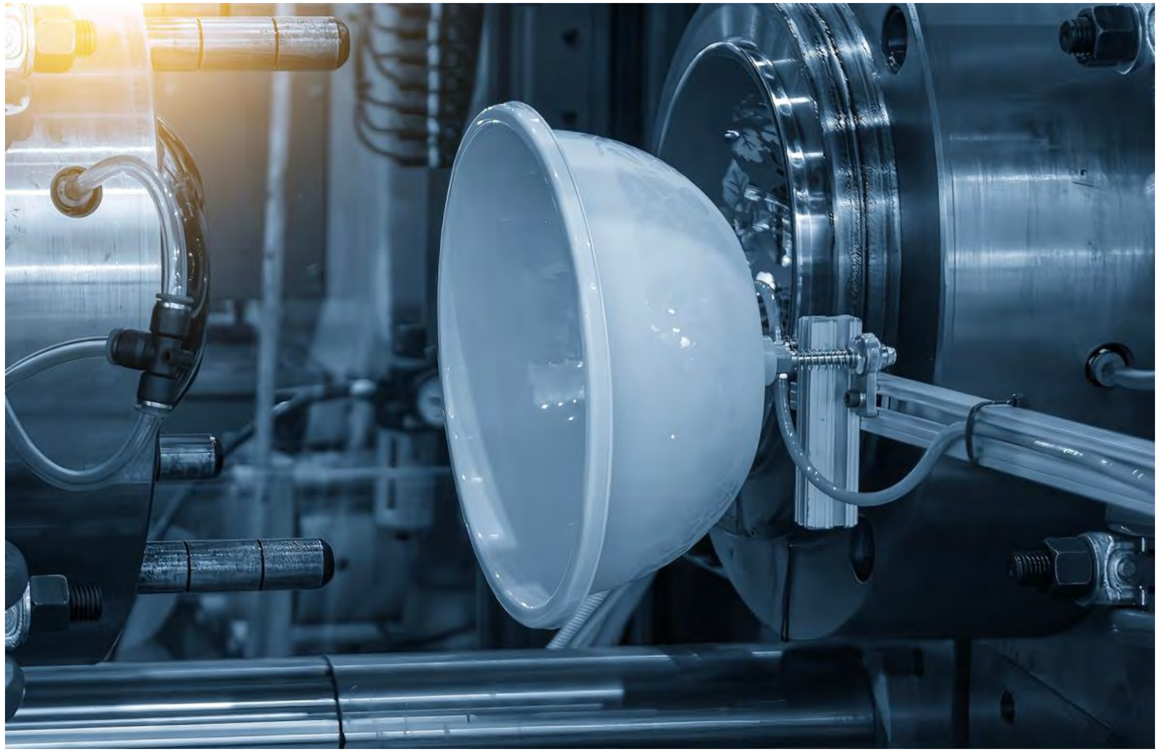
Geometry, Quantity, and Manufacturing Considerations

Plastic Sheet Extrusion

Thermoforming

Machining

Injection Molding



Reinforced Thermoset Fabrication

Overview of Plastic Materials

Acrylic

Advantages

- Optical clarity (or can be made opaque)
- UV stable
- Easy to thermoform
- Easy to bond
- Some colors available

Limitations

- Somewhat brittle

Polycarbonate

Advantages

- Transparent, translucent, or opaque
- Higher temperatures than acrylic
- Available in UV stable grades
- Can be cold formed and thermoformed
- High impact strength
- Some colors available

Limitations

- Prone to environmental stress cracking
- Brittle in extreme cold

Room Temperature Electrical Properties of Polycarbonate and Acrylic at Various Frequencies

	Relative Permittivity @ 11 GHz	Loss Tangent @ 11 GHz	Relative Permittivity @ 200 GHz	Loss Tangent @ 200 GHz
Acrylic	2.62	0.0080	2.52	0.0100
Polycarbonate	2.77	0.0005	2.92	0.0530

Source for 11GHz Data: Riddle, W. & Baker-Jarvis, J. (2003). Complex permittivity measurements of common plastics over variable temperatures. IEEE Transactions on Microwave Theory and Techniques, VOL., 51, NO. 3.

Source for 250 GHz Data: Liu, T. (2022). Permittivity and Loss Characterization of Polymer Films for Terahertz Applications. Highlights in Science, Engineering, and Technology, VOL 15, pages 159-168.

KYDEX® Thermoplastics

Advantages

- Good electrical properties
- Easy to thermoform
- Colors
- Flammability
- Durability

Limitations

- Brittle in extreme cold
- Not for elevated temperature applications

KYDEX® Thermoplastics

Technical Brief

KYDEX THERMOPLASTICS

SEKISUI SPI Thermoplastic Sheet for Radomes (Antenna Covers)

For information applicable to KYDEX® FST please refer to 300 series technical briefs.

TB - 122-A

Frequency Tables

Grade	60 Hz	100 Hz	1 KHz	800 MHz	1 GHz
KYDEX® 100	K=3.4 DF=0.022	K=2.9 DF=0.030	K=3.13	K=2.5 DF=0.023	K=2.8 DF=0.013
KYDEX® 510	K=2.9 DF=0.011	K=2.9 DF=0.012	K=2.9 DF=0.009	K=2.7 DF=0.004	K=2.7 DF=0.005

Grade	60 Hz	100 Hz	1 KHz	800 MHz	1 GHz
ALLEN® 2185HG	K=3.1 DF=0.007	K=3.1 DF=0.007	K=3.1 DF=0.008	K=2.7 DF=0.010	K=2.7 DF=0.009
ALLEN® 2185HG (UV film)	K=3.0 DF=0.006	K=3.0 DF=0.006	K=3.0 DF=0.007	K=2.7 DF=0.007	K=2.7 DF=0.007

Grade	1.9 GHz	2.5 GHz	5 GHz	20 GHz	40 GHz
KYDEX® 100	K=2.42	K=2.6 DF=0.011	K=2.7 DF=0.010	K=2.7 DF=0.009	K=2.82 DF=0.014
KYDEX® 510	K=2.6 DF=0.016	K=2.6 DF=0.016	K=2.6 DF=0.016	K=2.5 DF=0.017	K=2.8 DF=0.007

Ultem®

Advantages

- High service temperature
- High dielectric strength
- Strong and stiff
- Glass filled grades available
- Good flammability characteristics
- UV stable

Limitations

- Prone to ESC
- Somewhat brittle

Polyethylene

Advantages

- Good dielectric properties
- Inexpensive
- Chemical resistance

Limitations

- Low strength and stiffness
- High CTE
- Not suitable for elevated temperatures
- Needs to be formulated for weatherability
- Challenging to thermoform

Polypropylene

Advantages

- Good dielectric properties
- Inexpensive
- Outstanding chemical resistance
- Easy to weld
- Slightly stronger and higher operating temperature than HDPE

Limitations

- Less ductile than HDPE
- Not suitable for elevated temperatures
- Very difficult to bond with adhesives
- Challenging to thermoform

TPO

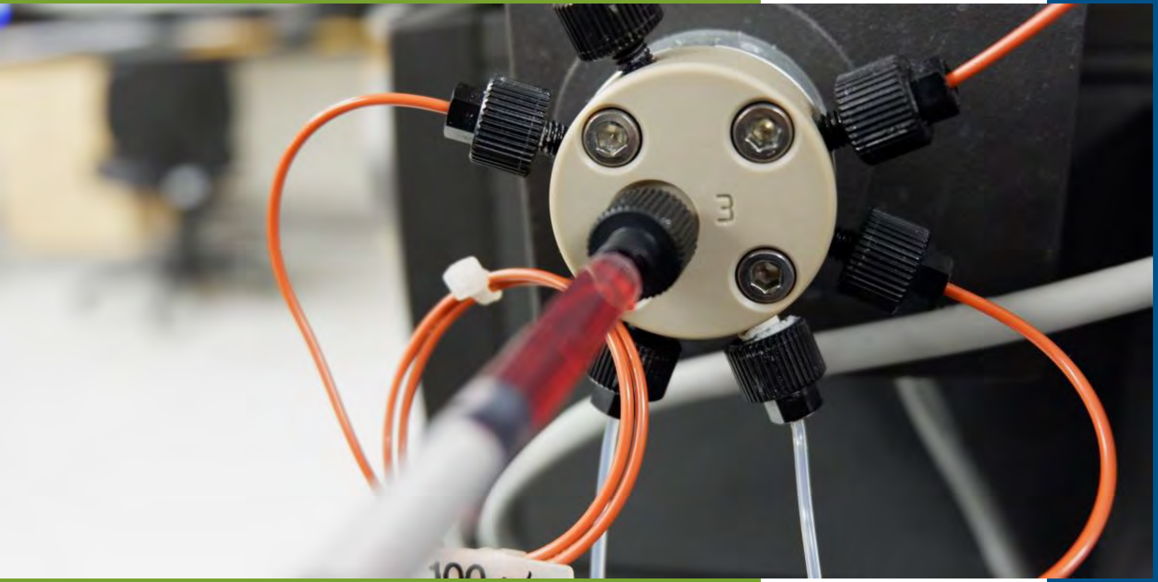
Advantages

- Good dielectric properties
- Available capped for outdoor weatherability
- Durable

Limitations

- Challenging to thermoform
- Availability / minimums
- Not for elevated temperatures

PEEK



Advantages

- Suitable for high temperatures
- Steam resistant
- Outstanding chemical resistance
- Strong and stiff
- FDA compliant grades available

Limitations

- Relatively expensive
- Challenging to thermoform

Fluoropolymers

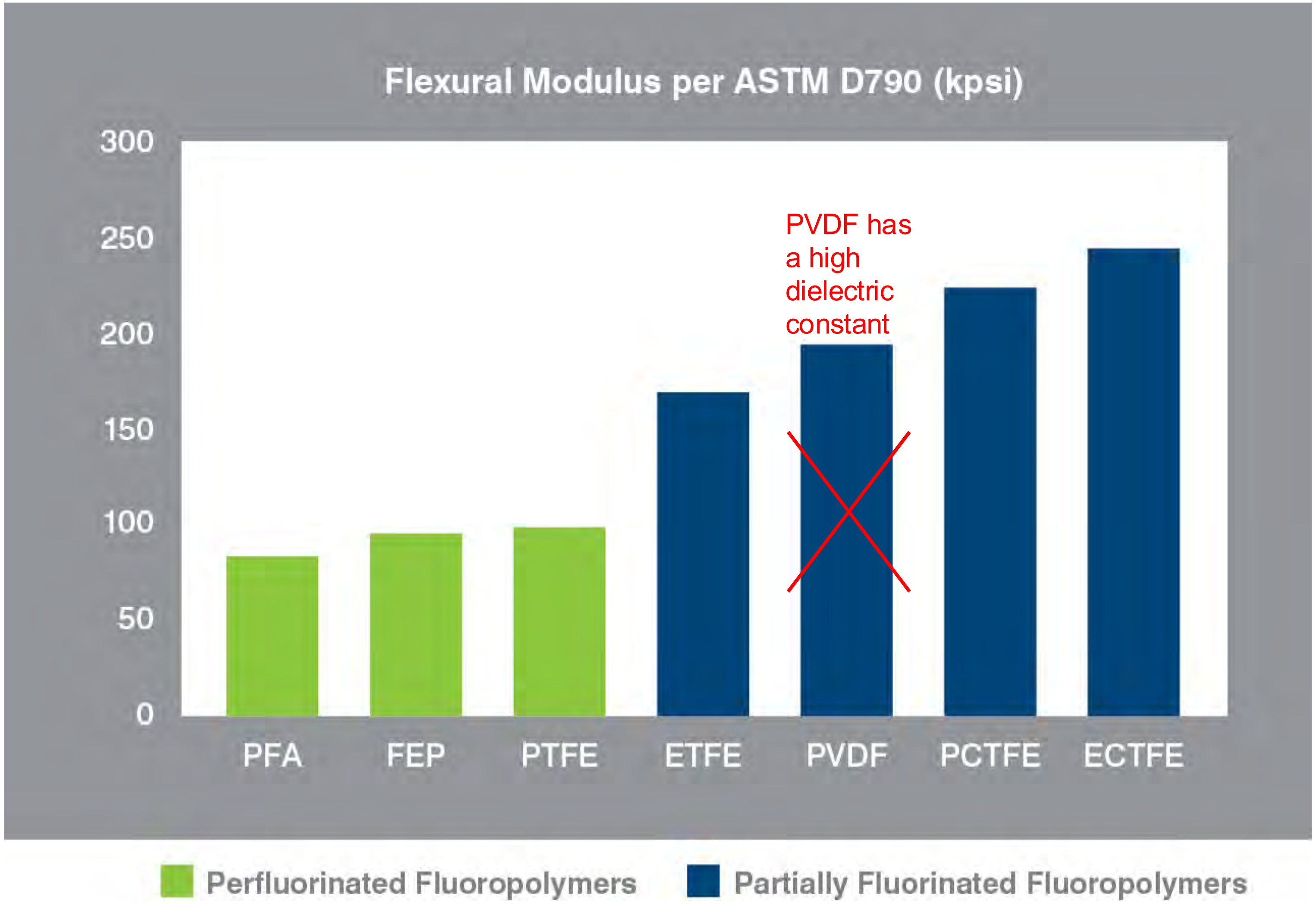
Advantages

- Good chemical resistance
- Stable at elevated temperatures
- Some have excellent dielectric properties
- Outstanding UV stability

Limitations

- Relatively expensive
- Unfilled PTFE has poor creep characteristics and high CTE

Fluoropolymers



DuPont™ Vespel® Polyimide

Advantages

- Good mechanical properties throughout a broad temperature range
- High operating temperature
- Dimensional stability

Limitations

- Very expensive
- Can't be injection molded or thermoformed

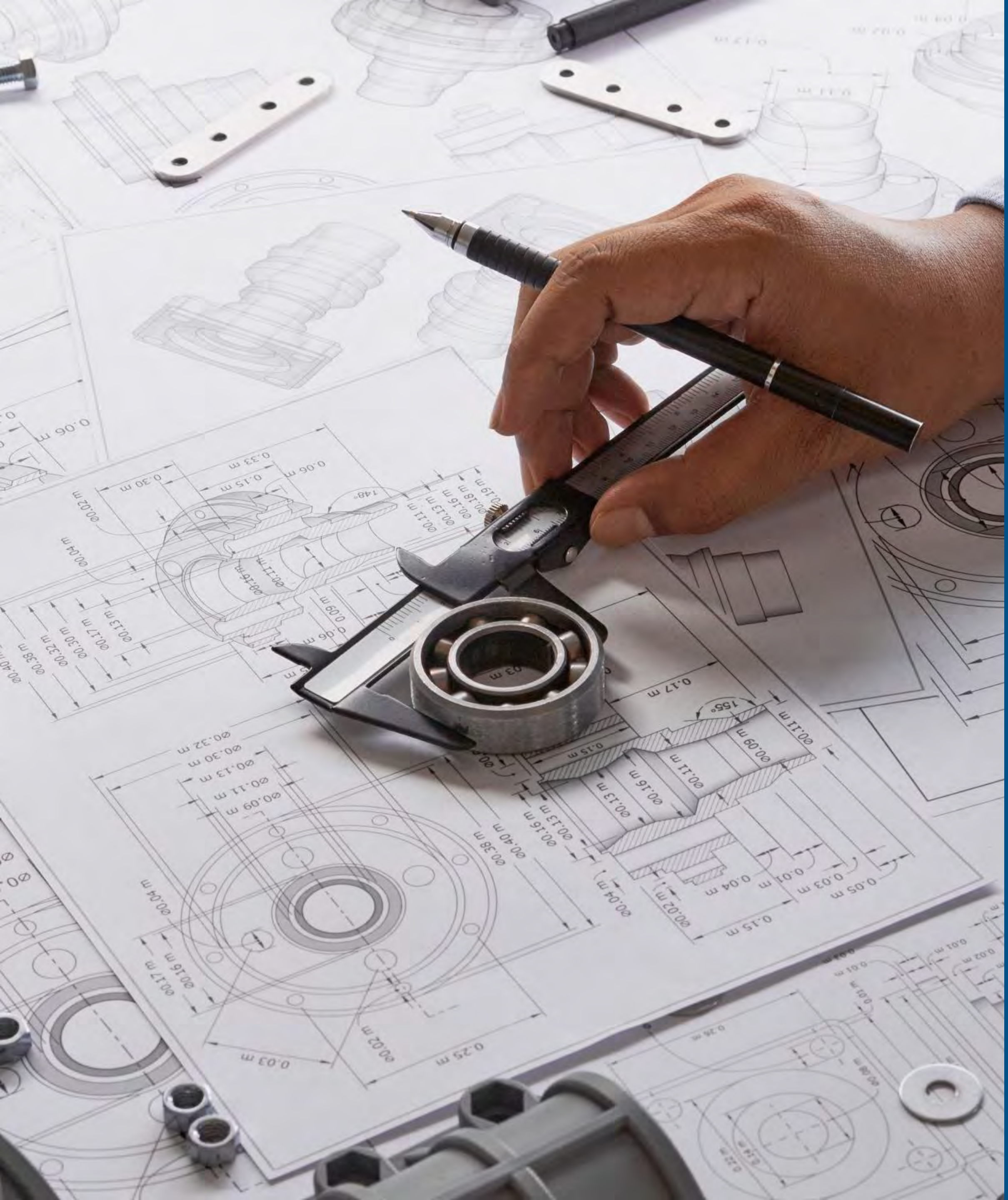
Thermoset Composites

Advantages

- Strong and stiff
- Durable
- Can be painted
- Moderately good electrical properties

Limitations

- Challenging to machine



Tips for a Successful Plastic Part Design

Considerations for Plastic Part Design

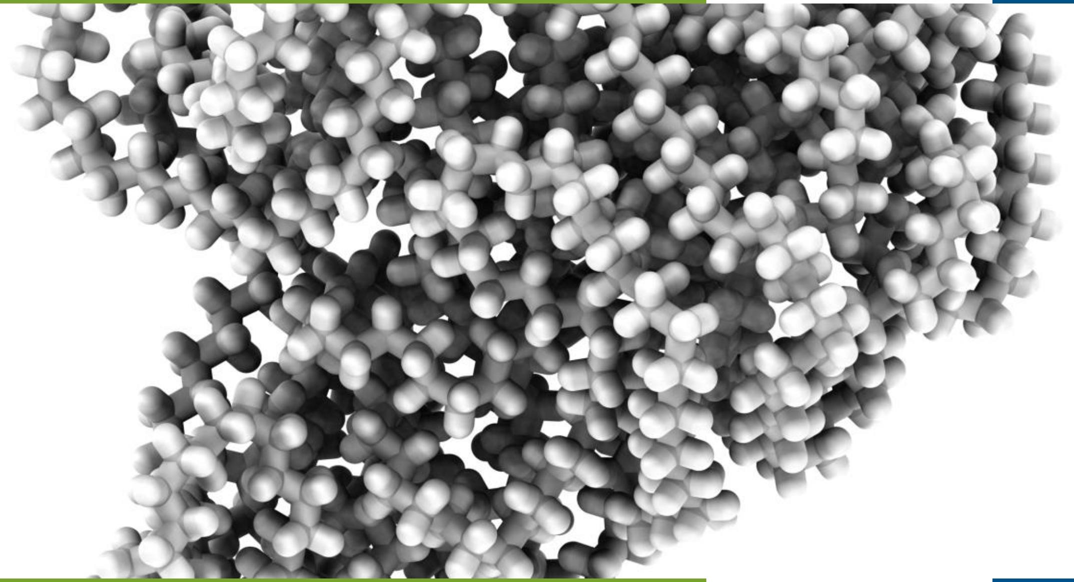
Immediate failure

- Mechanical loads
- Impact

Failure over time

- Fatigue
  - Flexural fatigue
  - Impact fatigue
  - Thermal cycling
- Creep / stress relaxation
- Wear / erosion

Significance of Molecular Weight



Improves impact resistance

Lowers brittleness temperature

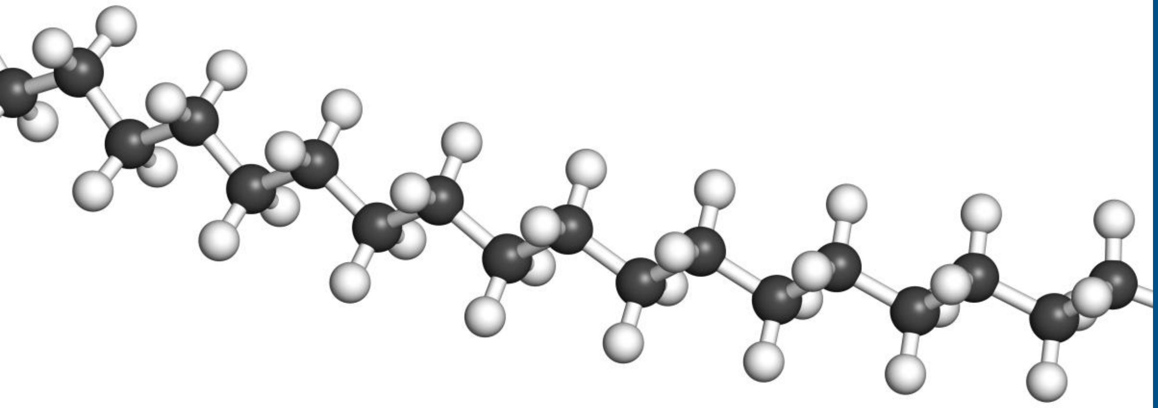
Increases melt viscosity

- Ketchup ⟷ Tomato paste
- Limits processability at both the upper and lower end of the range

Improves long-term performance

- Fatigue
- Environmental stress crack resistance
- Chemical resistance

Significance of Molecular Weight

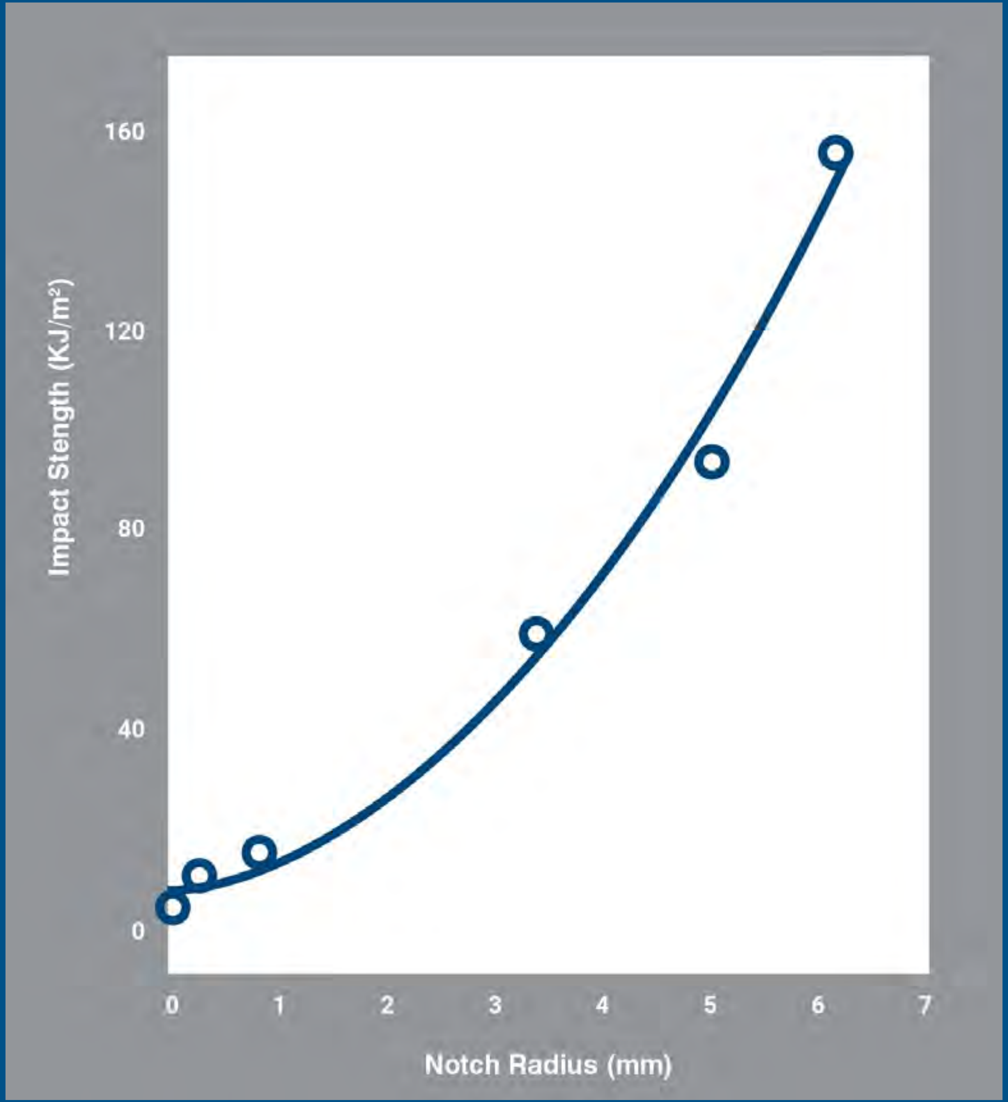


- Some degradation through normal processing
- UV light or other radiation
- Chemical attack
- Hydrolytic degradation
  - Exposure to steam
  - Improper drying of resin
- Thermal degradation
  - Excessive temperature during processing
  - Multiple heat histories, use of regrind
  - Long-term exposure to elevated temperatures
- Use of incompatible colorants

Sharp Corners

Sharp internal corners reduce the impact resistance of plastic parts

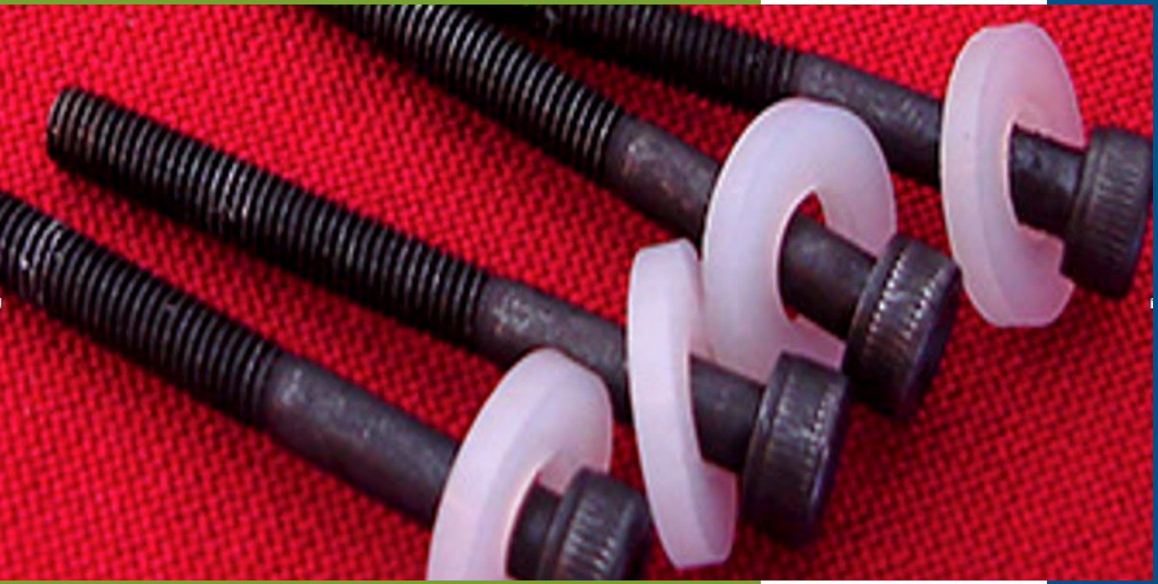
Source: Adapted from Notch sensitivity of polycarbonate and toughened polycarbonate by Kilwon Cho. Journal of Applied Polymer Science, Vol. 89, pages 3115 -3121 (2003).



Fasteners

- Avoid countersunk, flat head screws
- Use round head screws with flat washers to reduce stress concentrations
- Clean screws to remove any contaminants
- Be careful of thread lockers
- Control torque

Fasteners



- Be careful of elastomer washers that may contain stress crack agents
- Don't put holes too close to the edge of a plastic part

For additional information and detail read our white paper on the topic *Plastic Materials for High Performance Radomes*

Reference Information

				POLYOLEFINS Low dielectric constants, low strength and stiffness, not suitable for elevated temperature applications, difficult to thermoform, good chemical resistance, low cost	
	Property	**Test Method**	**Units**	**HDPE**	**Polypropylene**
Electrical Properties	Dissipation Factor (at 60 Hz)		Hz	0.002 @ 1 GHz	0.00019 @ 1 MHz
	Dielectric Constant (at 60 Hz)		Hz	2.35	2.4 @ 1 MHz
	Dissipation Factor (at GHz frequencies)		GHz	0.002 @ 1 0.001 @ 11.3	0.00008 @ 9.4
	Dielectric Constant (at GHz frequencies)		GHz	2.5 @ 1 2.4 @ 11.3	2.26 @ 9.4
	Dielectric Strength	ASTM D149	V/mil	1000	1140
Mechanical Properties	Tensile Strength at Break (or at yield, when noted)	ASTM D638	psi	4000	4700 @ yield
	Tensile Elongation at Break (or at yield, when noted)	ASTM D638	%	600	>50
	Flexural Modulus	ASTM D790	kpsi	140	225
	Notched Izod Impact Resistance (unless otherwise noted)	ASTM D256	ft-lbs/in	1.9	1.0

Reference Information

				POLYOLEFINS Low dielectric constants, low strength and stiffness, not suitable for elevated temperature applications, difficult to thermoform, good chemical resistance, low cost	
	Property	**Test Method**	**Units**	**HDPE**	**Polypropylene**
Thermal Properties	Heat Deflection Temperature @264 psi	ASTM D648	ºF	147	210
	Continuous Service Temperature		ºF	170	180
	Coefficient of Thermal Expansion	ASTM D696	in/in/ºFx10^{-5}	9.0	6.0
OTHER Properties/ MFG NOTES	Outdoor Weatherability*	–	–	Good	Poor
	Moisture Absorption (24 hours)	ASTM D570	%	0.10	<0.10
	Water Contact Angle	–	º	104 (advancing) 96 (receding)	97 (static)
	Flammability	UL-94	–	HB @ 0.118", 0.236"	HB @ 0.125"
	Availability in a wide variety of colors and surface textures	–	–	✓	✓
	Easy to Machine	–	–	✓	✓
	Easy to Thermoform	–	–		

*Outdoor weatherability depends on a number of material and environmental factors. The specific grade, color, and presence of UV stabilizers in a material will have a significant effect on weatherability.

Thank you for your time today!
Questions?

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- Ask about customized presentations
- Curbell Plastics toll free phone: 888-287-2355
- www.curbellplastics.com

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