

# Polymer Performance in Extreme Temperatures: Designing for Hot and Cold Environments

Webinar Presented by Curbell Plastics

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*Today's Presenters:*

**Dr. Keith Hechtel**, 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.

**Nicole Marek**, Technical Services Engineer

Nicole applies her polymer science expertise to guide customers in material selection and compliance, solving complex challenges such as extreme temperatures and harsh chemical environments.



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# Agenda

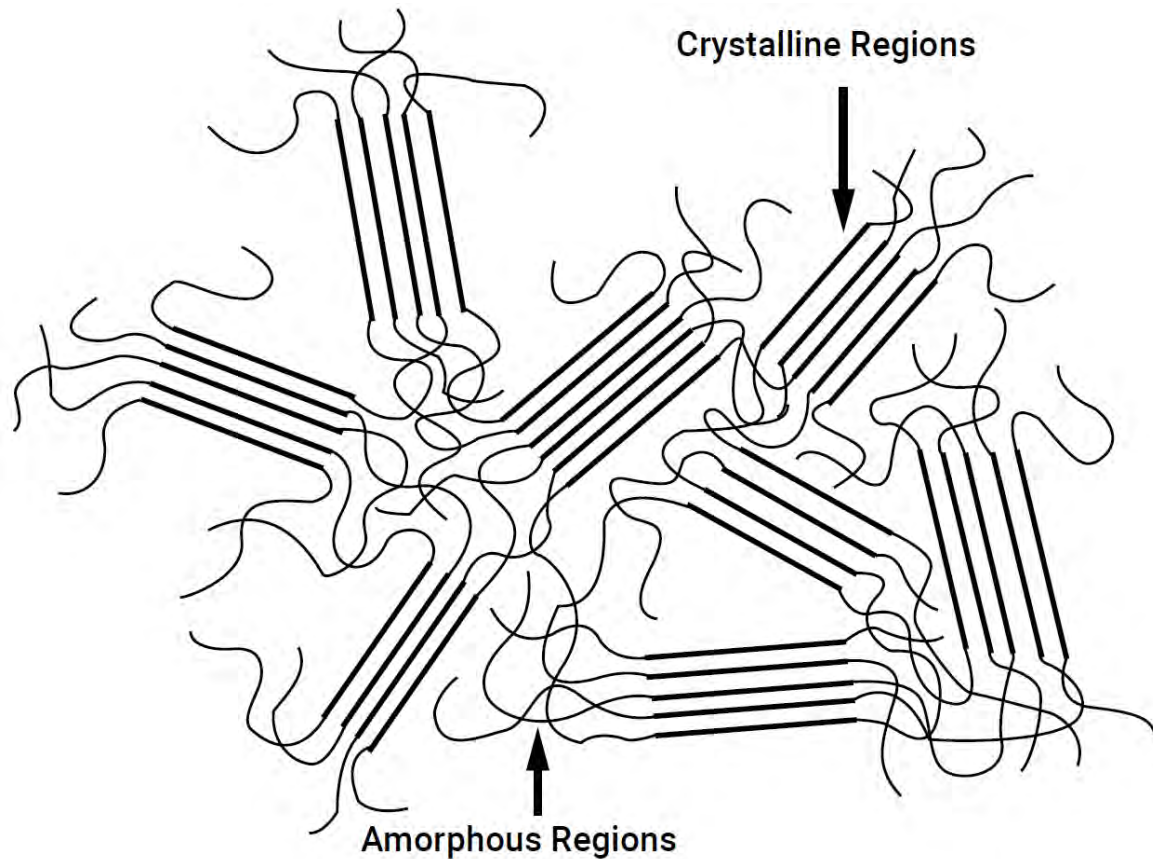


- Background
- Mechanical properties
- Dimensional stability
- Thermal conductivity
- Thermal degradation
- Tribological properties
- Electrical properties
- Creep, fatigue, and relaxation
- Chemical resistance
- Cryogenic behavior



## Why Does Temperature Matter?

- Datasheets versus real-world performance



## Why Does Temperature Influence Properties?

- Molecular Structure
  - Chain mobility
- Transition Temperatures
  - $T_g$  - glass transition temperature
  - $T_m$  - melting temperature or melting point



## Mechanical Properties: Strength, Stiffness, and Ductility

# Stress-Strain Relationships

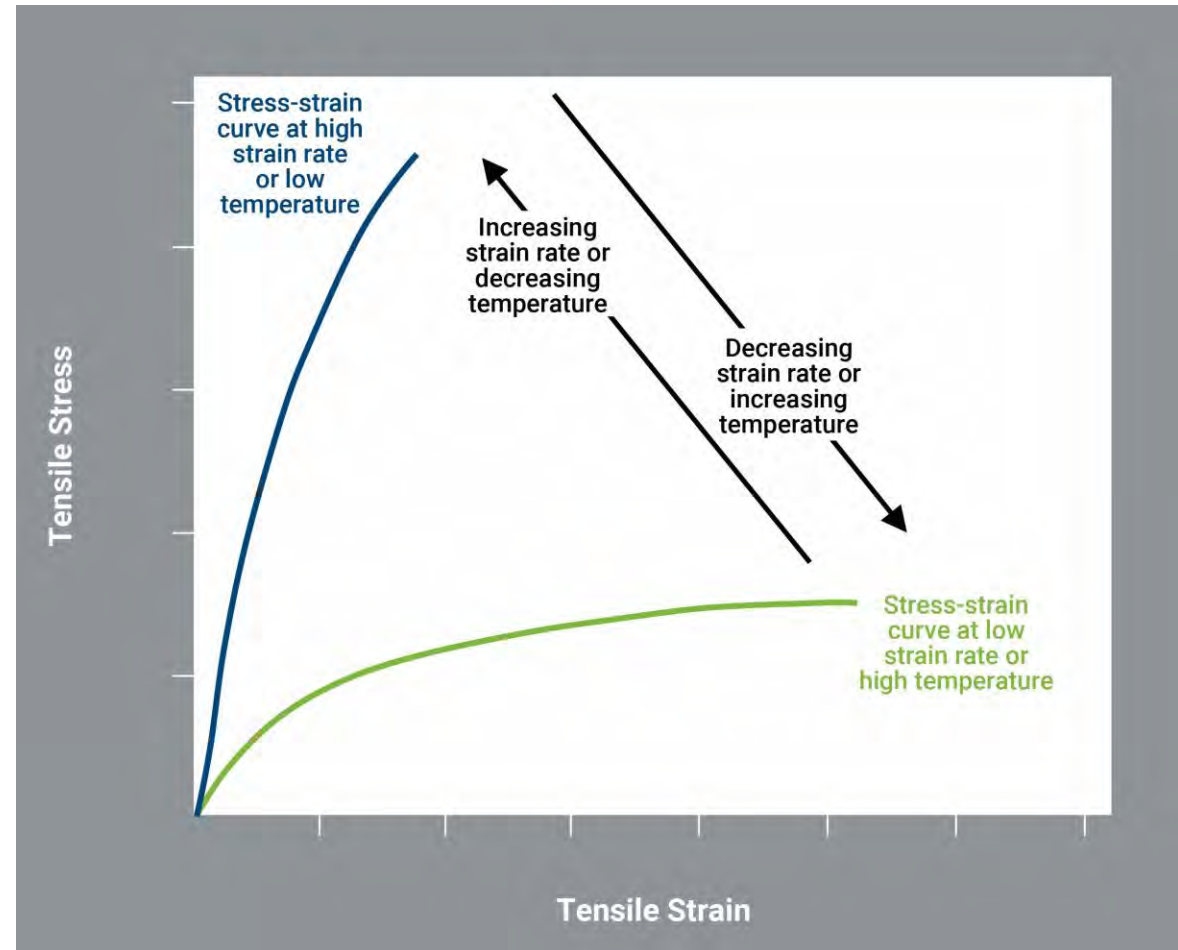
## Viscoelastic behavior

- Responses to mechanical stresses depend on:
  - Strain rate
  - Temperature



# Stress-Strain Relationships

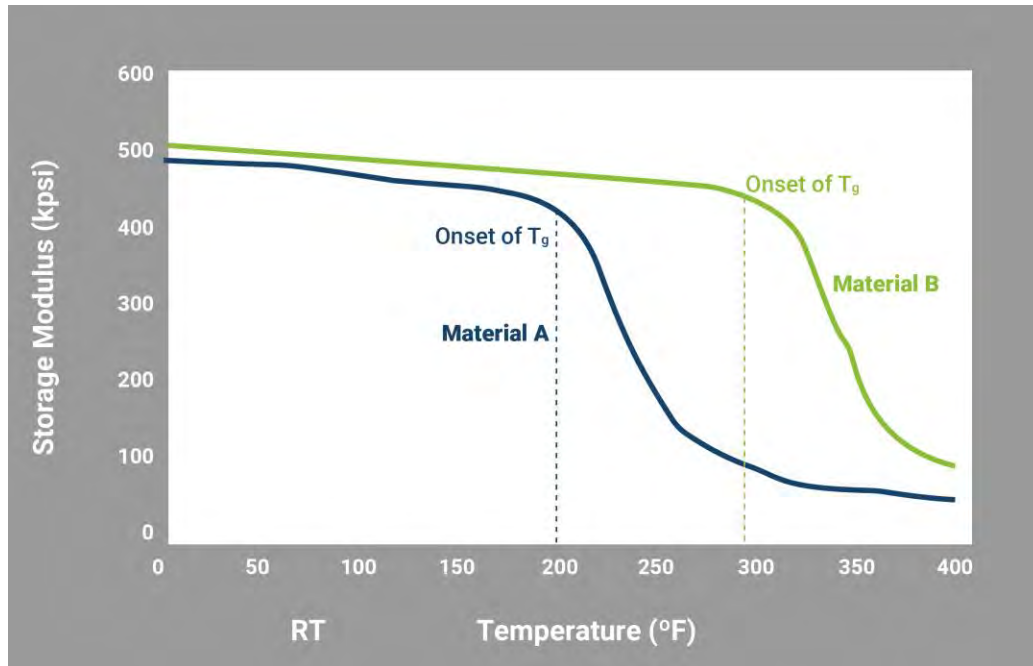
Tensile Stress-Strain Curves for a Typical Thermoplastic at Various Temperatures and Strain Rates



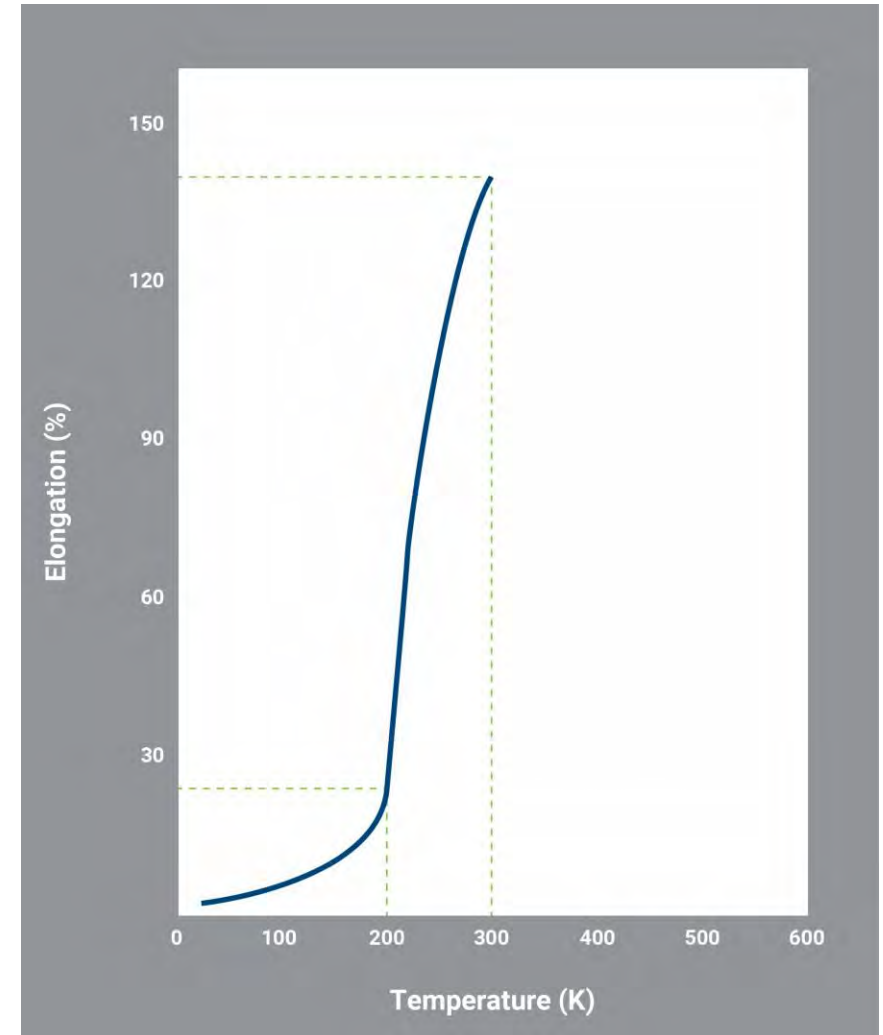
Viscoelasticity – temperature and strain rate dependence

# Mechanical Properties vs. Temperature

Storage Modulus for Two Different Thermoplastic Materials from 0°F to 400°F

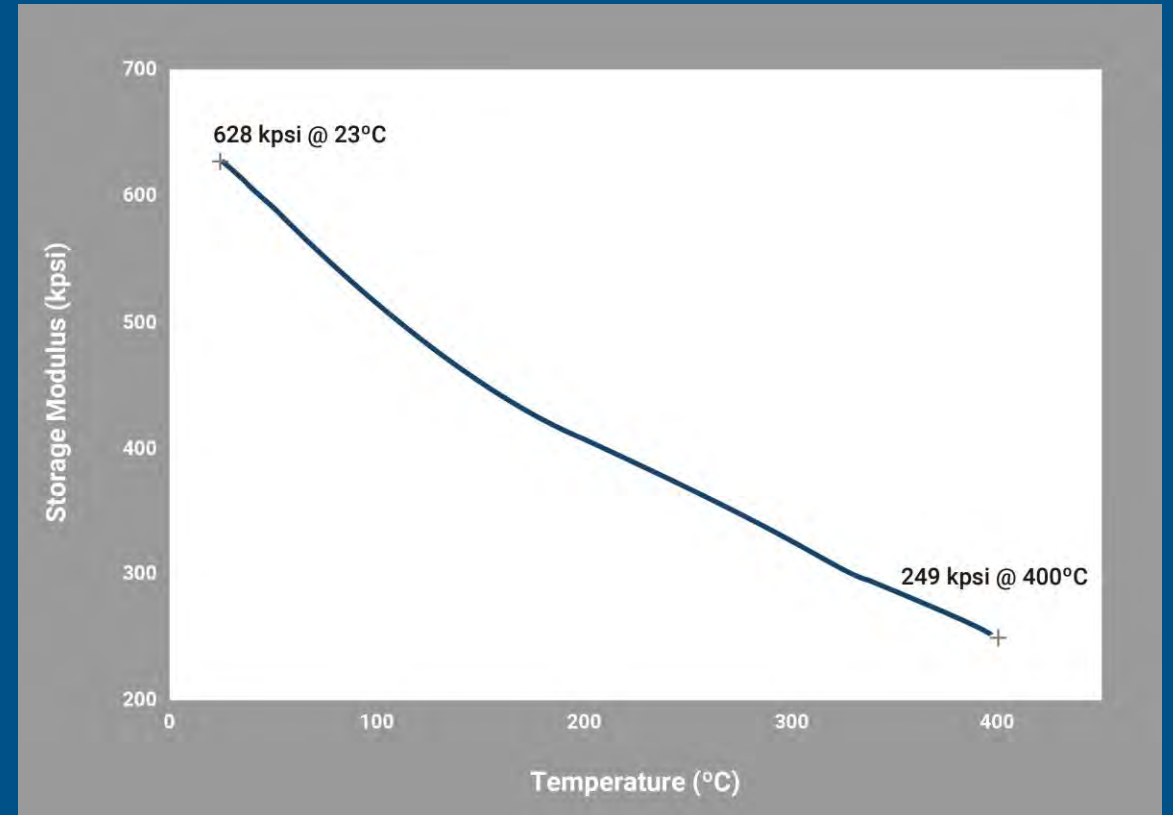


Tensile Elongation of PCTFE with 40% Crystallinity at Various Temperatures



Source: Adapted from Schramm, 1973

# Featured Material: DuPont™ Vespel® SP-211



Source: Adapted from Wingard, 2013



## Dimensional Stability with Temperature Variation

# Dimensional Changes with Temperature

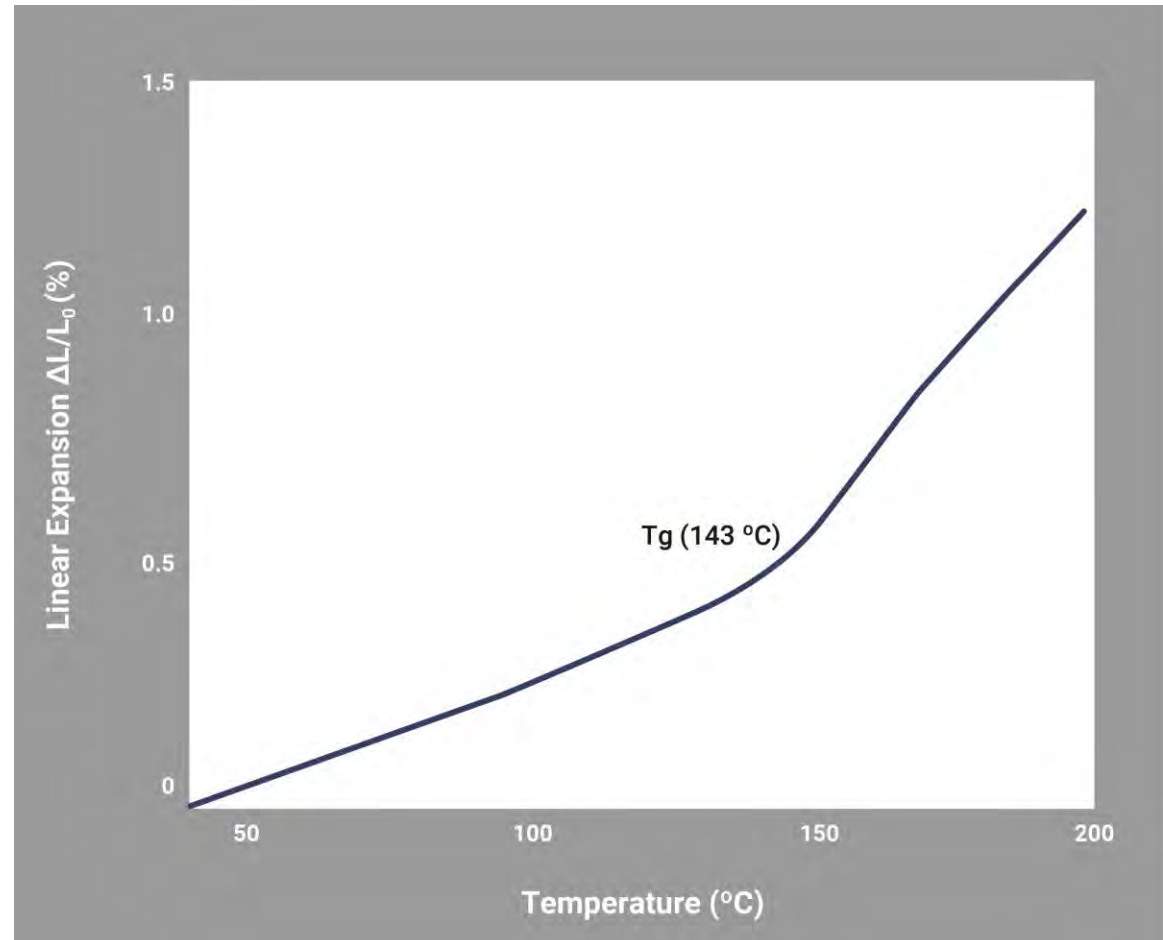


HDPE tool chest top after being placed outside on a warm day

- HDPE has a higher CTE than steel
- HDPE exhibited larger dimensional change due to increasing temperature

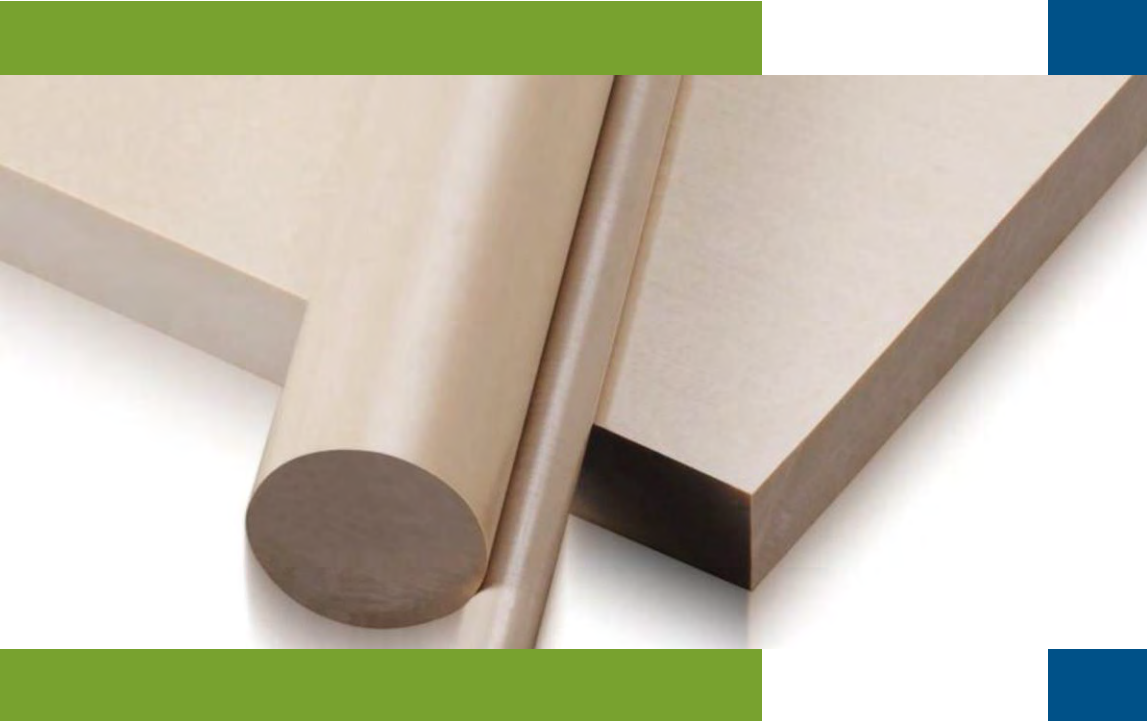
# Dimensional Changes with Temperature

Thermal Expansion of PEEK Below and Above the Material's Glass Transition Temperature

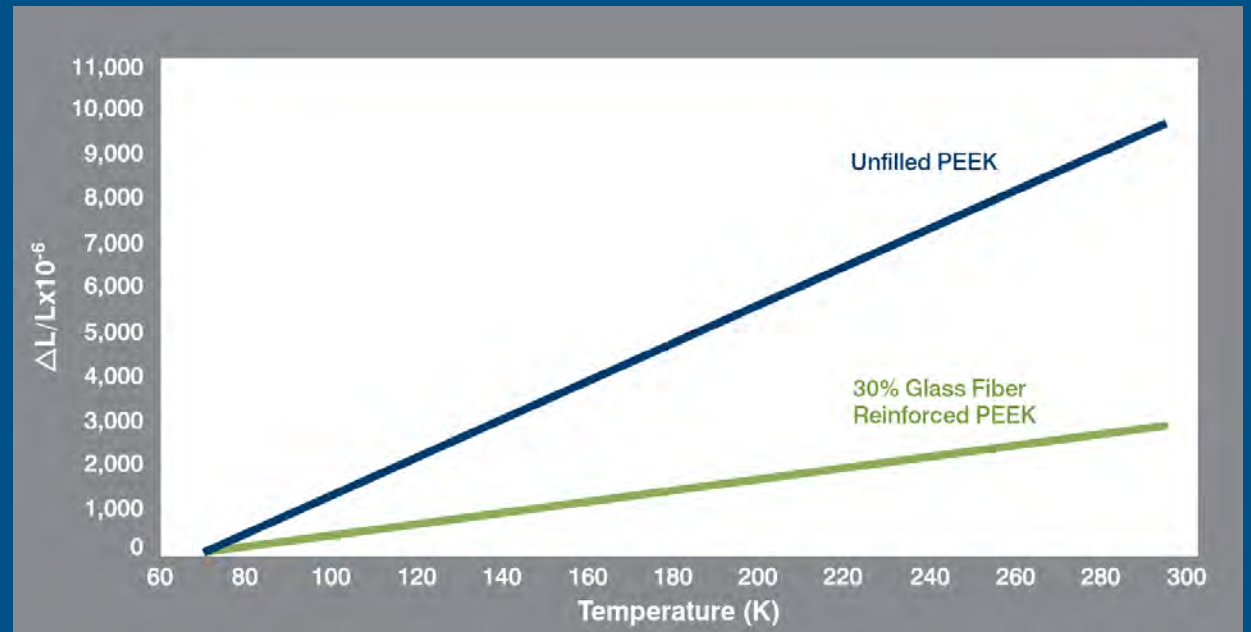


Source: Adapted from Jiang, 2021

# Featured Material: 30% Glass Filled PEEK



Linear Thermal Expansion of Unfilled VICTREX® PEEK and  
30% Glass-Filled VICTREX® PEEK



Source: Chu, X., Wu, Z., Huang, R., Zhou, Y., & Li, L., (2010)



# Thermal Conductivity

# Thermal Conductivity vs. Temperature

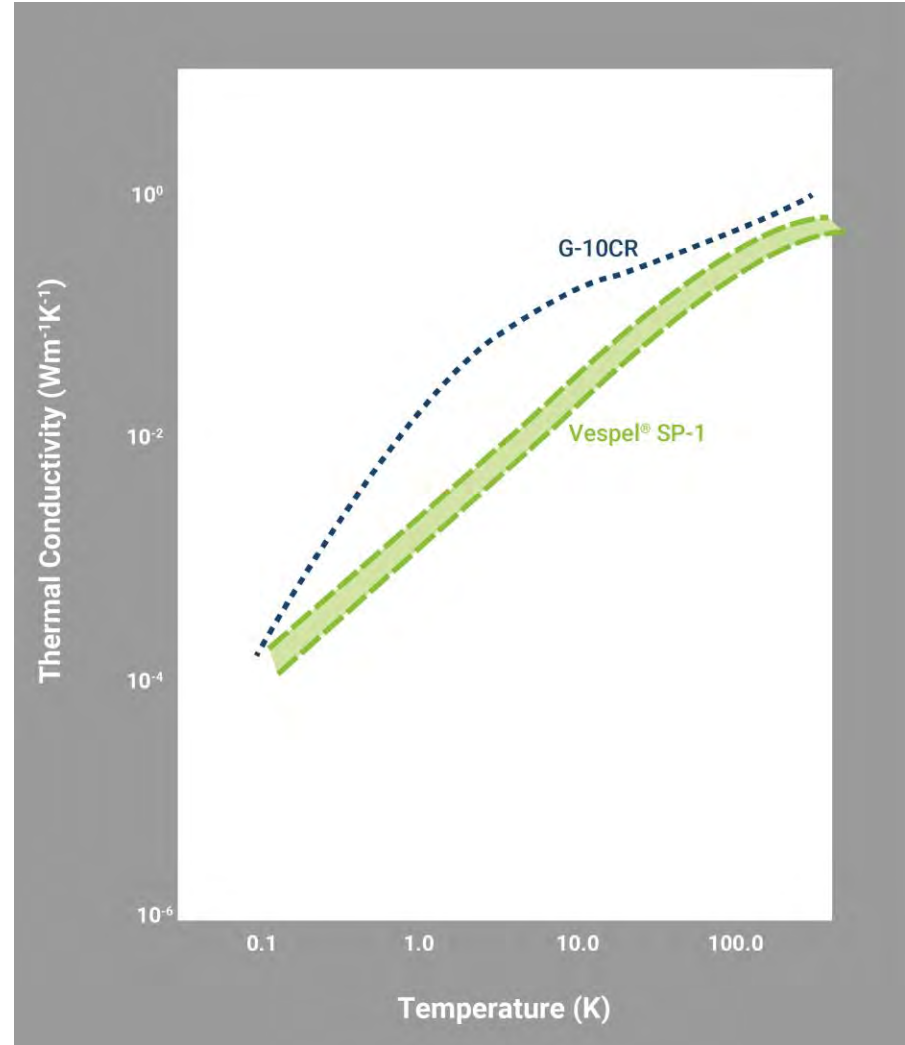


Important when plastic is used as a thermal isolator

- Phenolic handle has lower thermal conductivity – safer to touch
- Steel handle has higher thermal conductivity

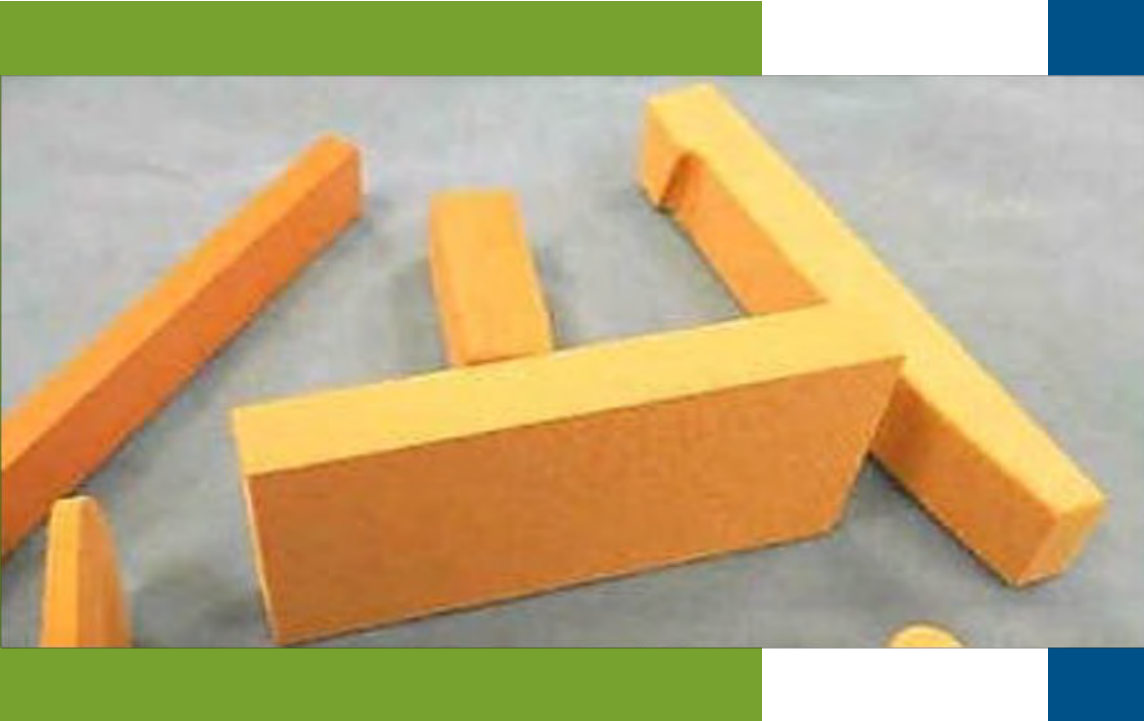
# Thermal Conductivity vs. Temperature at Cryogenic Temperatures

Thermal Conductivity of Cryogenic Grade G-10 Glass/Epoxy Composite and DuPont™ Vespel® SP-1 from Cryogenic Temperatures to Room Temperature



Source: Adapted from Woodcraft, 2009

# Featured Material: Vespel® SF Foam



## Benefits of Vespel® SF Foam:

- Low thermal conductivity
- Operating temperatures can exceed 300°C
- Acoustic insulation
- Flame resistant

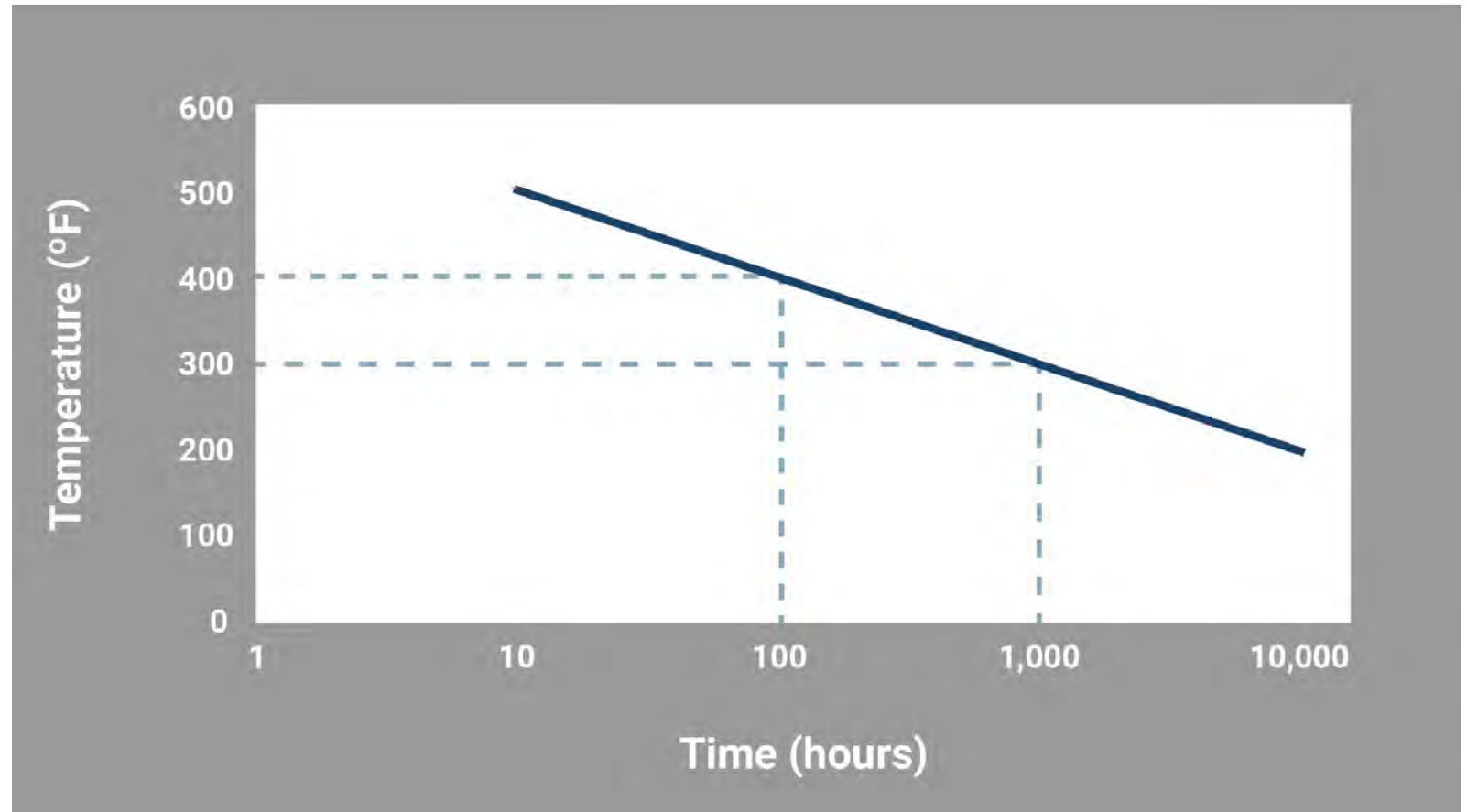
[Vespel® SF Foam Products Offer Performance at Extreme Temperatures](#)

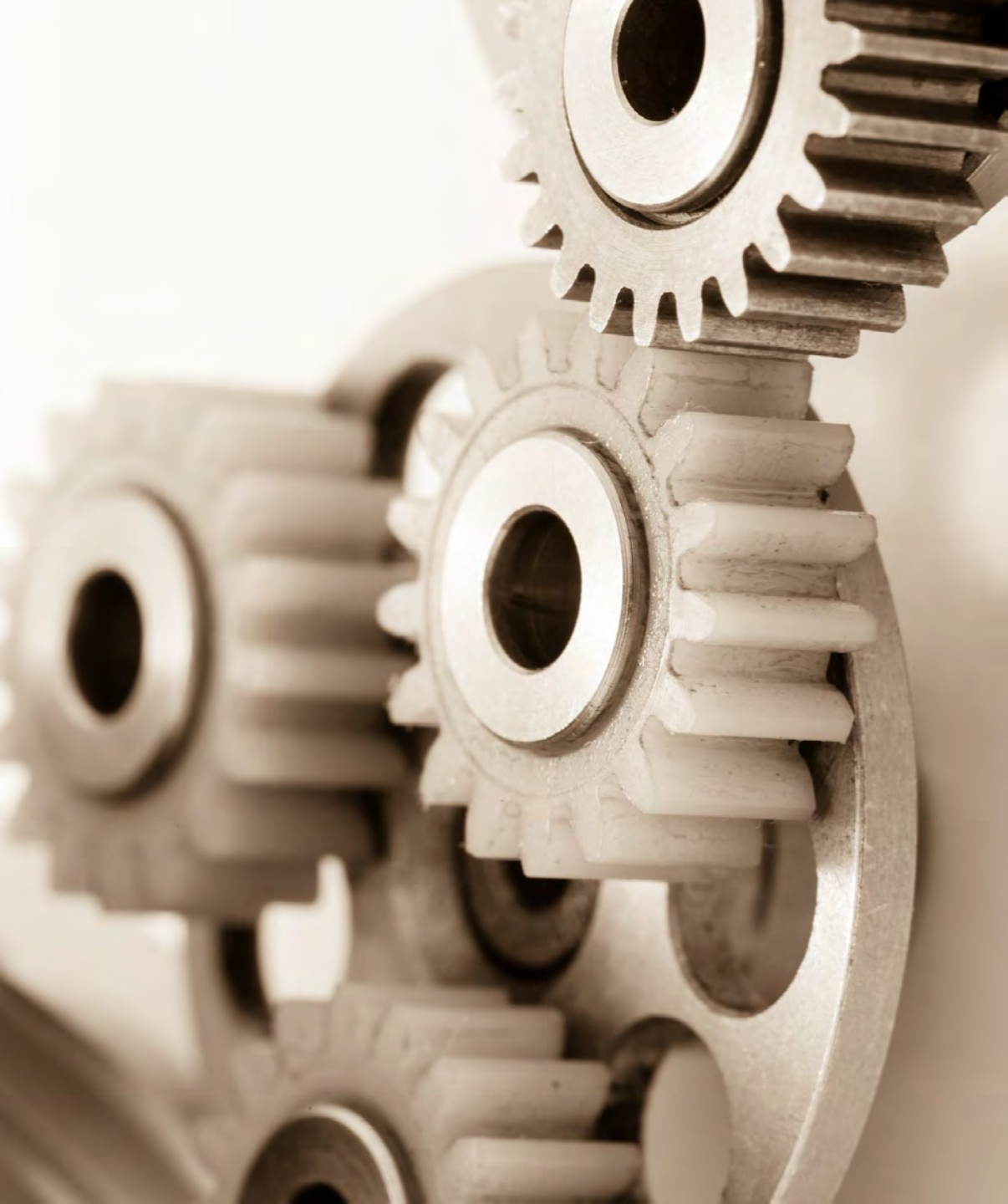


# Thermal Degradation

# Thermal Degradation

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





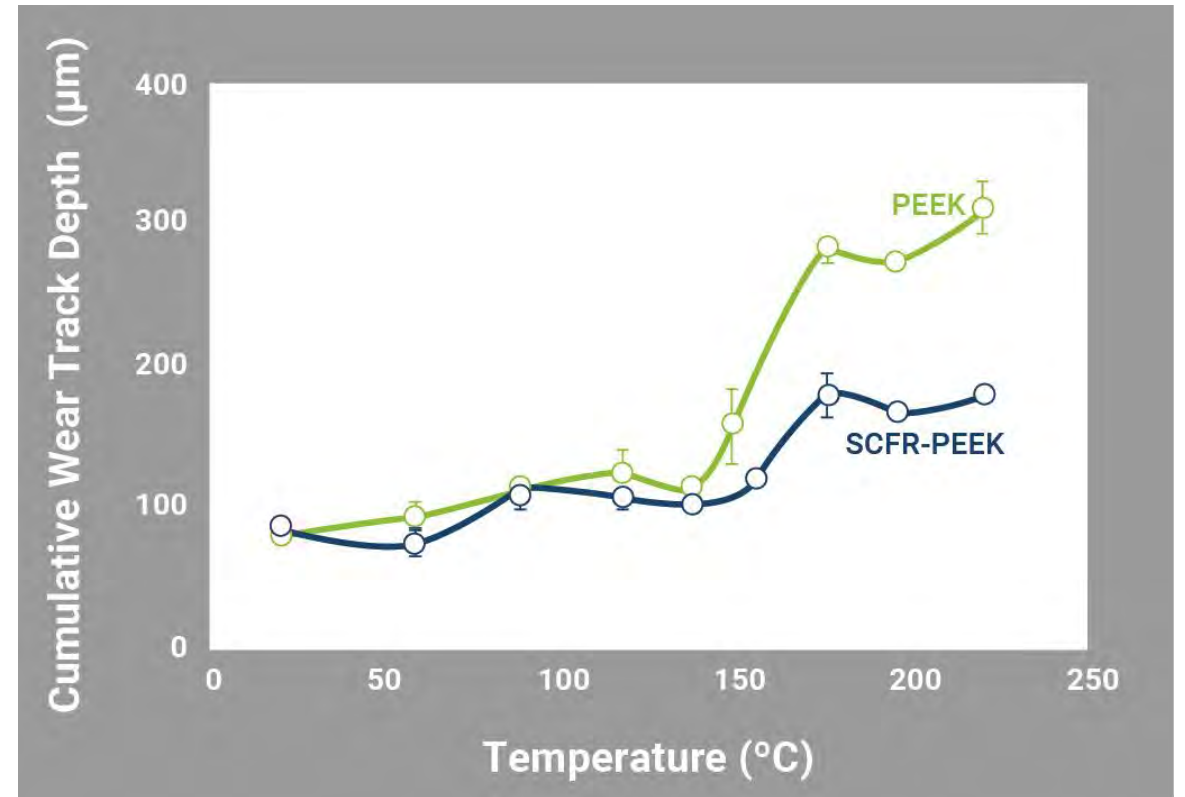
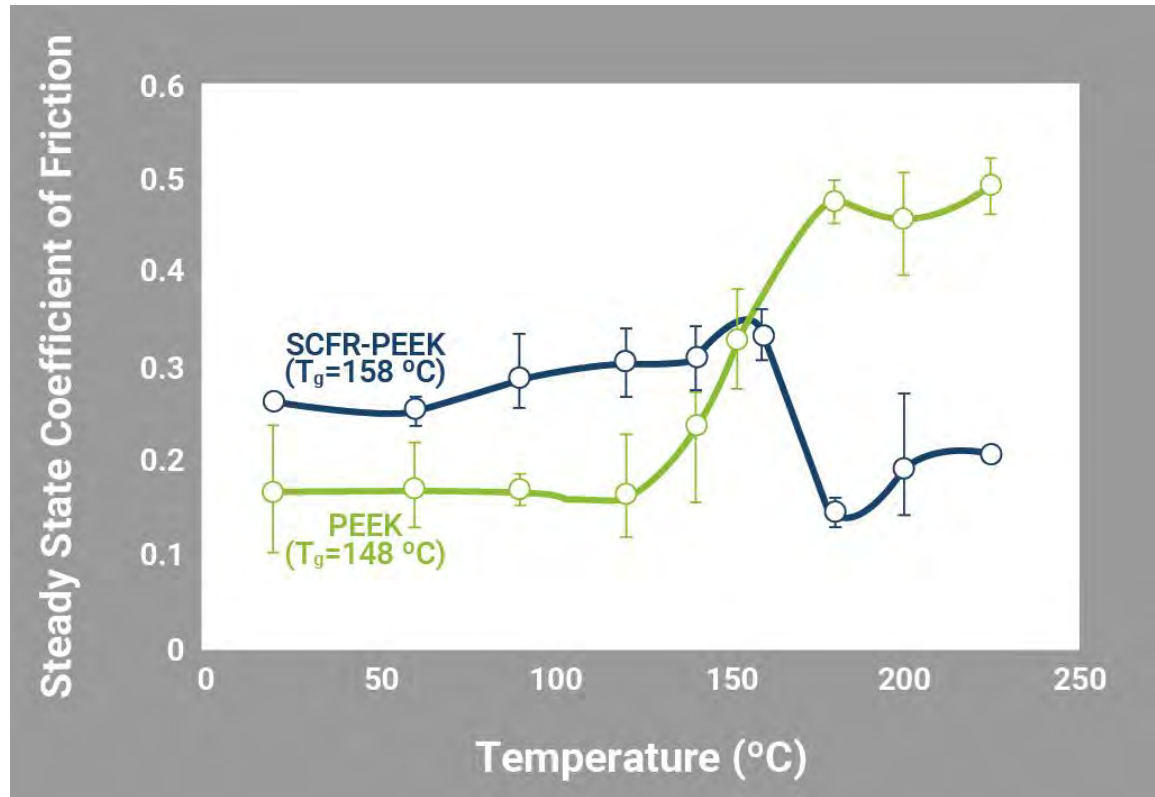
## Tribological Behavior: Friction and Wear

# Factors Influencing Tribology



- Wear mechanism
- Molecular weight
- Crystallinity
- Glass transition temperature
- Additives
- External lubricants
- Operating temperature range
- Chemistry, surface finish, and hardness of mating components

### Friction and Wear Performance of Virgin PEEK and 30% Short Carbon Fiber Reinforced PEEK Sliding Against AISI52100 Steel from 20°C to 225°C



Source: Hanchi, 1997

# Featured Material: Fluorosint™ 207



## Benefits of Fluorosint™ 207 PTFE

- Outstanding friction and wear properties – even against soft metals
- Service temperatures up to 500°F
- FDA compliant

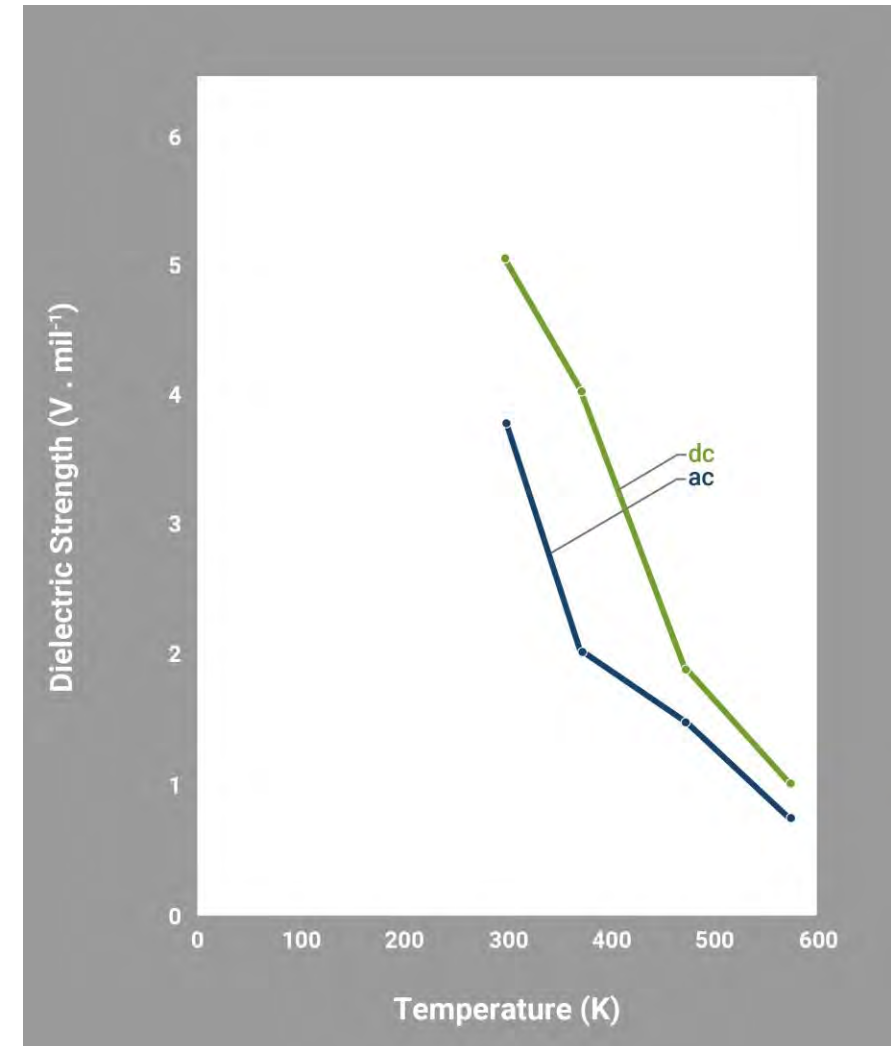
[Fluorosint™ 207 - Food contact compliant PTFE | MCG](#)



# Electrical Properties

- Resistivity
- Dielectric constant
- Dielectric strength
- Arcing resistance
- Dissipation factor

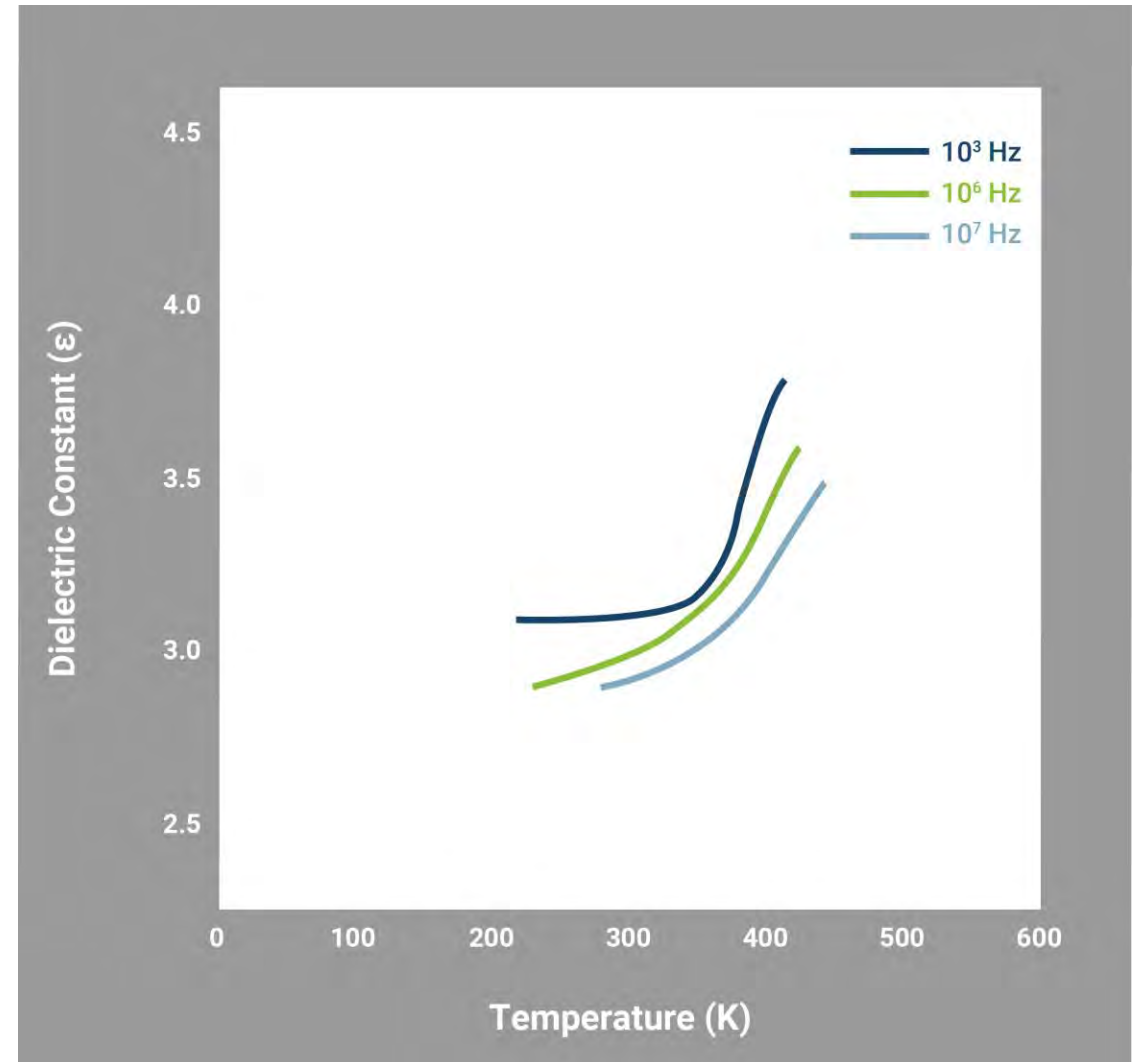
# Dielectric Strength of PTFE at Various Temperatures



Source: Adapted from Schramm, 1973

# Dielectric Constant of Semicrystalline PET at Various Temperatures and Frequencies

Note: Electrical properties are dependent on the molecular structure of the polymer. The changes to the volume resistivity and the dielectric constant of semicrystalline PET at various temperatures can't necessarily be generalized to other plastic materials.

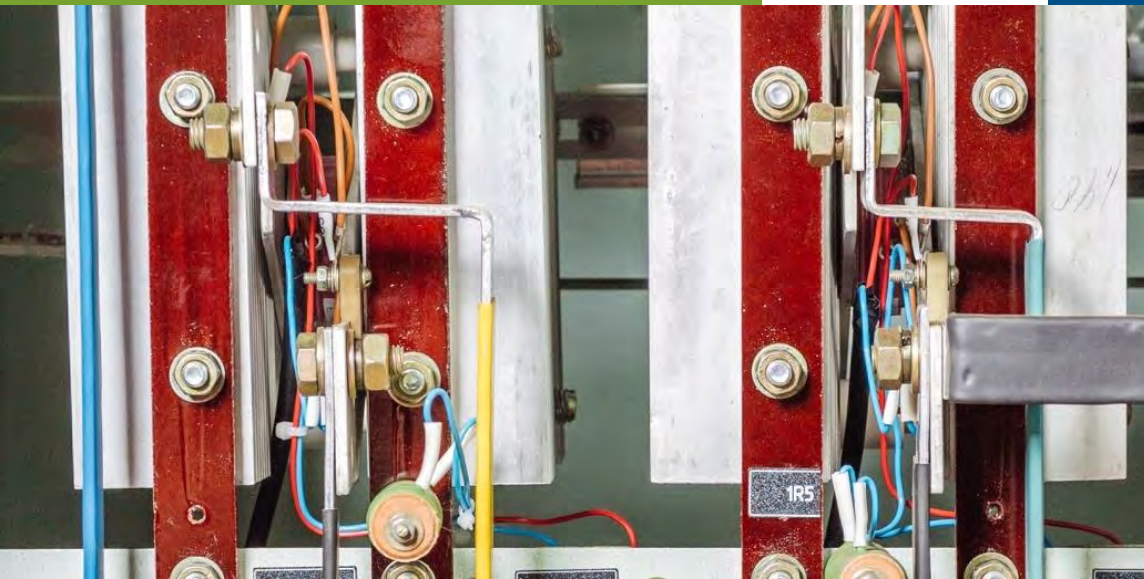


Source: Adapted from Schramm, 1973

# Featured Material: GPO-3

## Benefits of GPO-3

- Glass reinforced polyester composite
- Outstanding electrical insulator
- Arc and track resistance





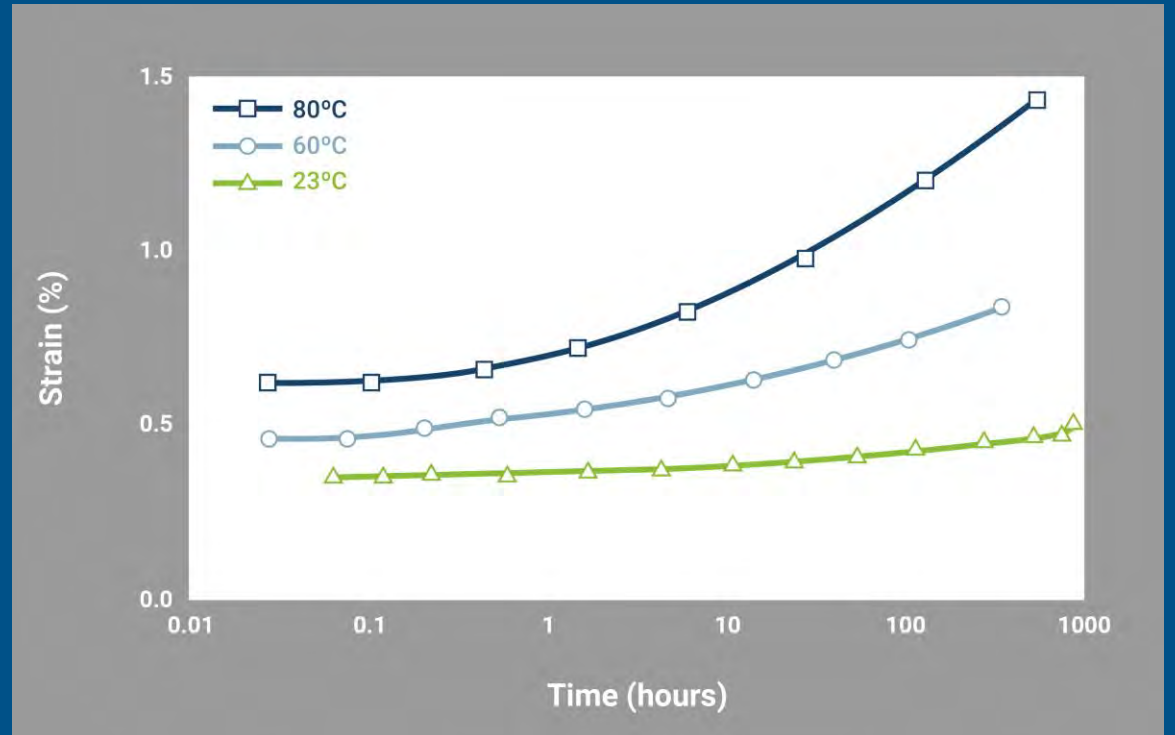
## Effect of Temperature on Creep, Stress Relaxation, and Fatigue

# Increased Creep with High Temperatures



Flexural Creep Strain in Plastic Shelving

Creep Curves for an Unfilled PPE-Polystyrene Blend at Various Temperatures at a Stress of 10 MPa



Source: Mckeen, 2015



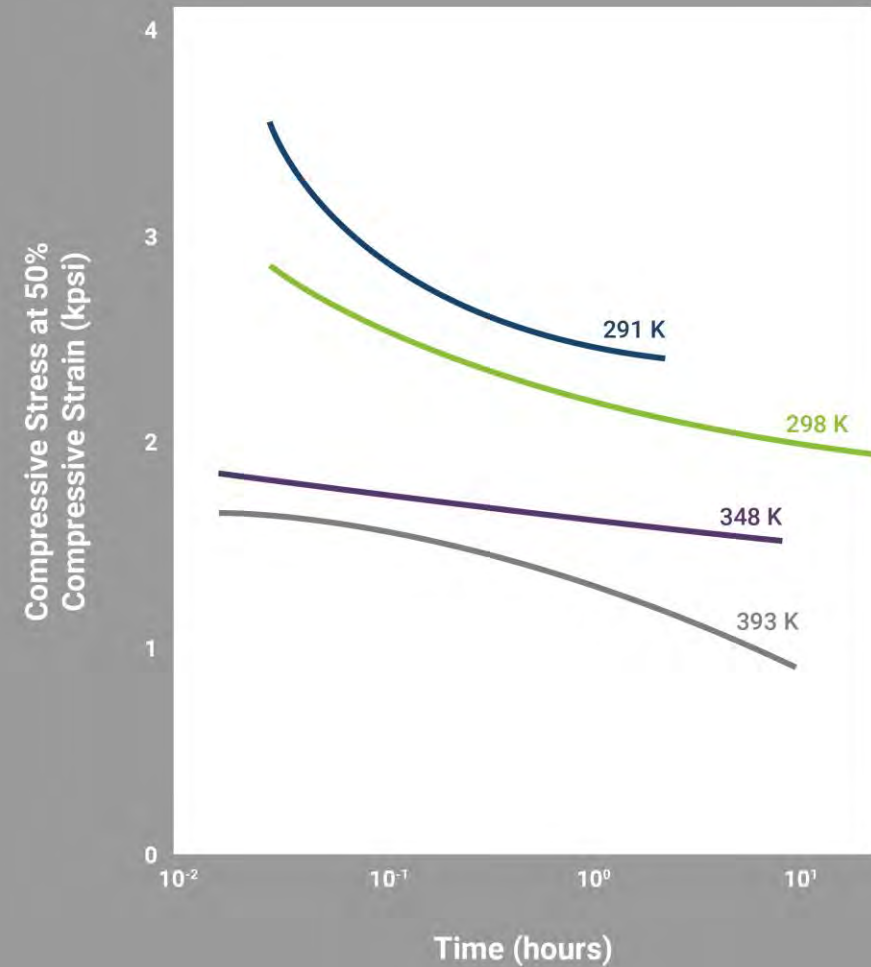
## Increased Stress Relaxation With High Temperatures

Analogy for a plastic seal failure  
due to stress relaxation

# Increased Stress Relaxation with High Temperatures



Stress Relaxation of PTFE at Various Temperatures



Source: Schramm, 1973

# Increased Fatigue with High Temperatures

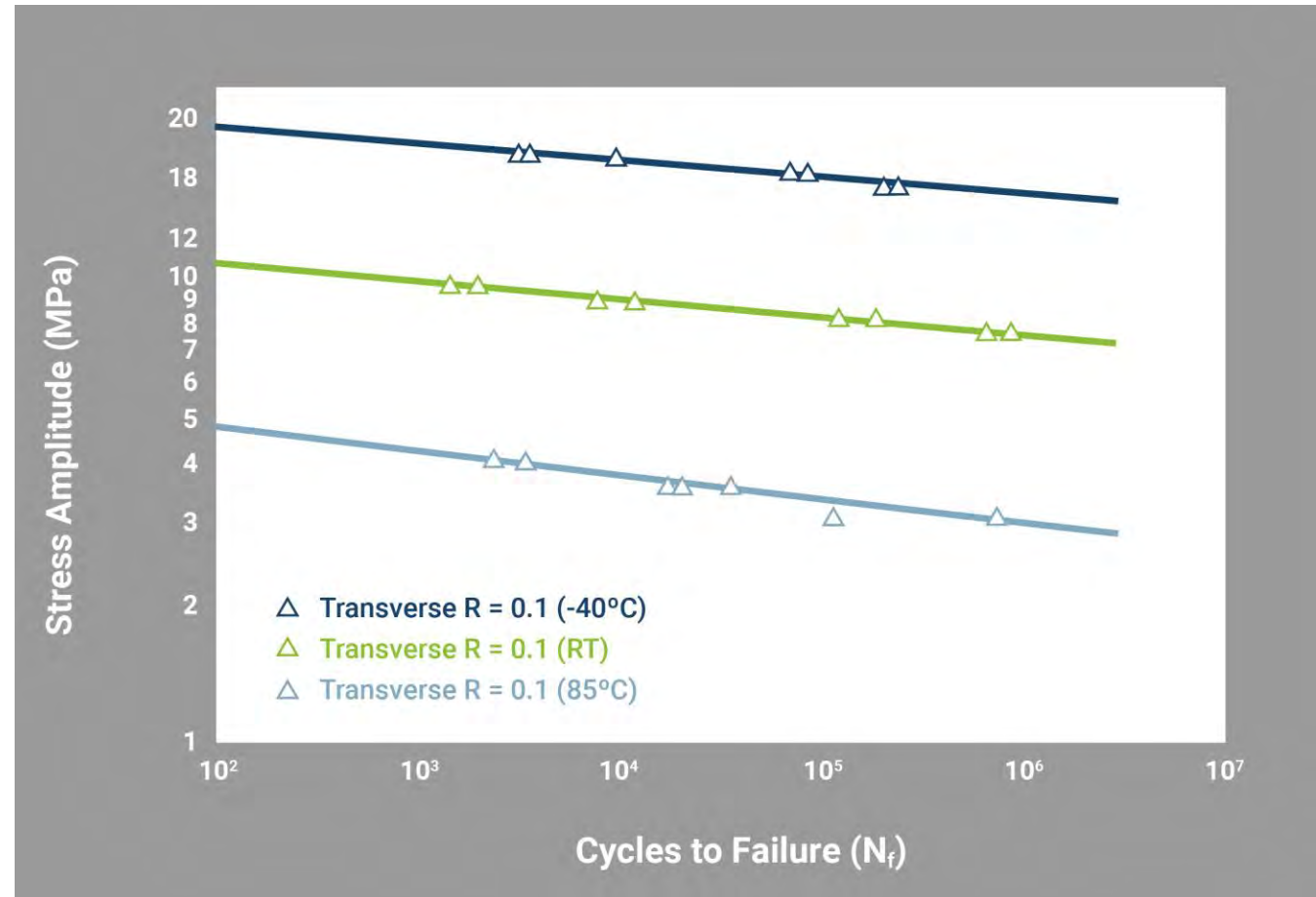


Fatigue failures from repeated cyclic stresses

- Thermoplastics generally have shorter fatigue life at elevated temperatures

# Increased Fatigue with High Temperatures

Effect of Fatigue Testing Temperature on PP Samples

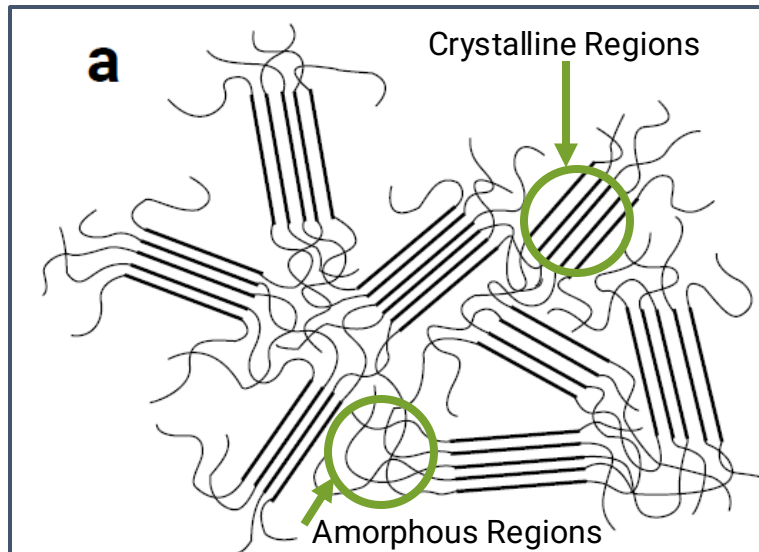


Source: Adapted from Mellot, 2014

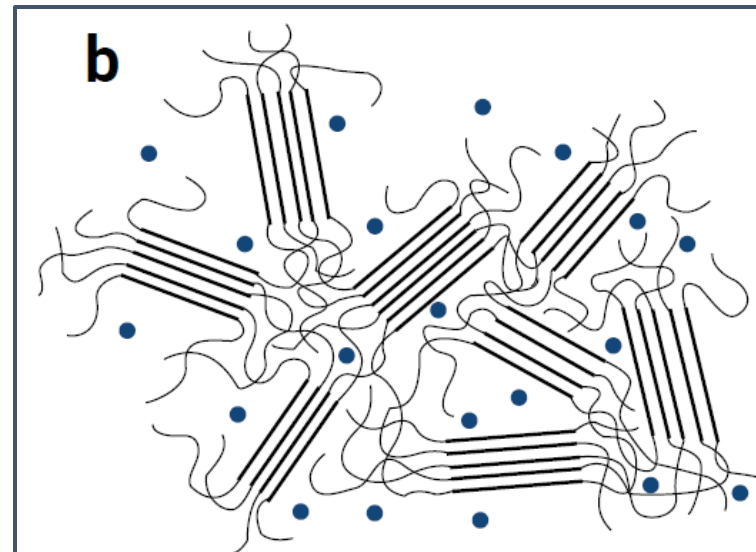


## Chemical Resistance – Physical and Chemical Effects

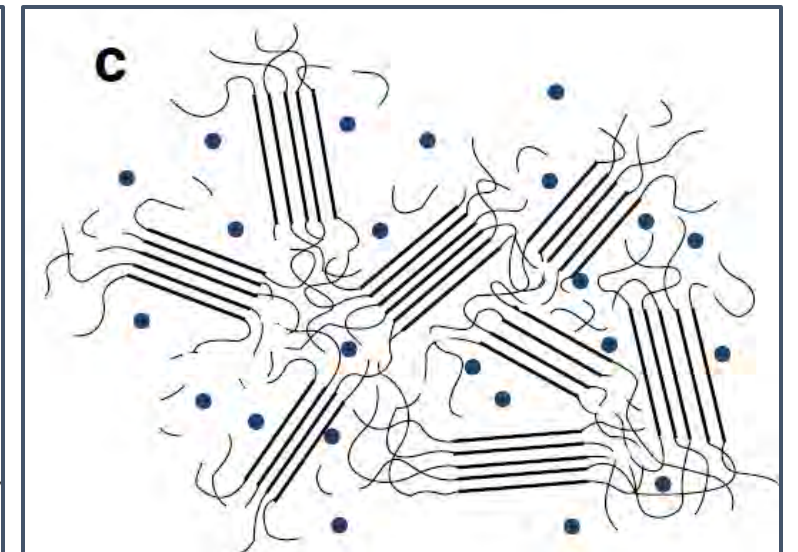
# Chemical Attack Mechanisms



(a) Crystalline and Amorphous Phases Before Immersion



(b) Plasticization



(c) Chain Scission Due to Hydrolysis

# Chemical Attack Mechanisms

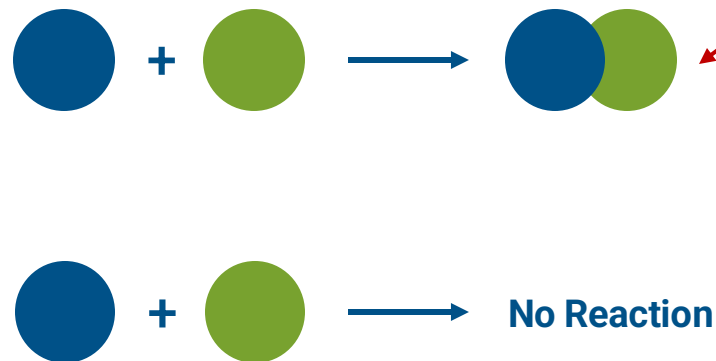


Cross section of PEX piping after oxidation from chlorine exposure

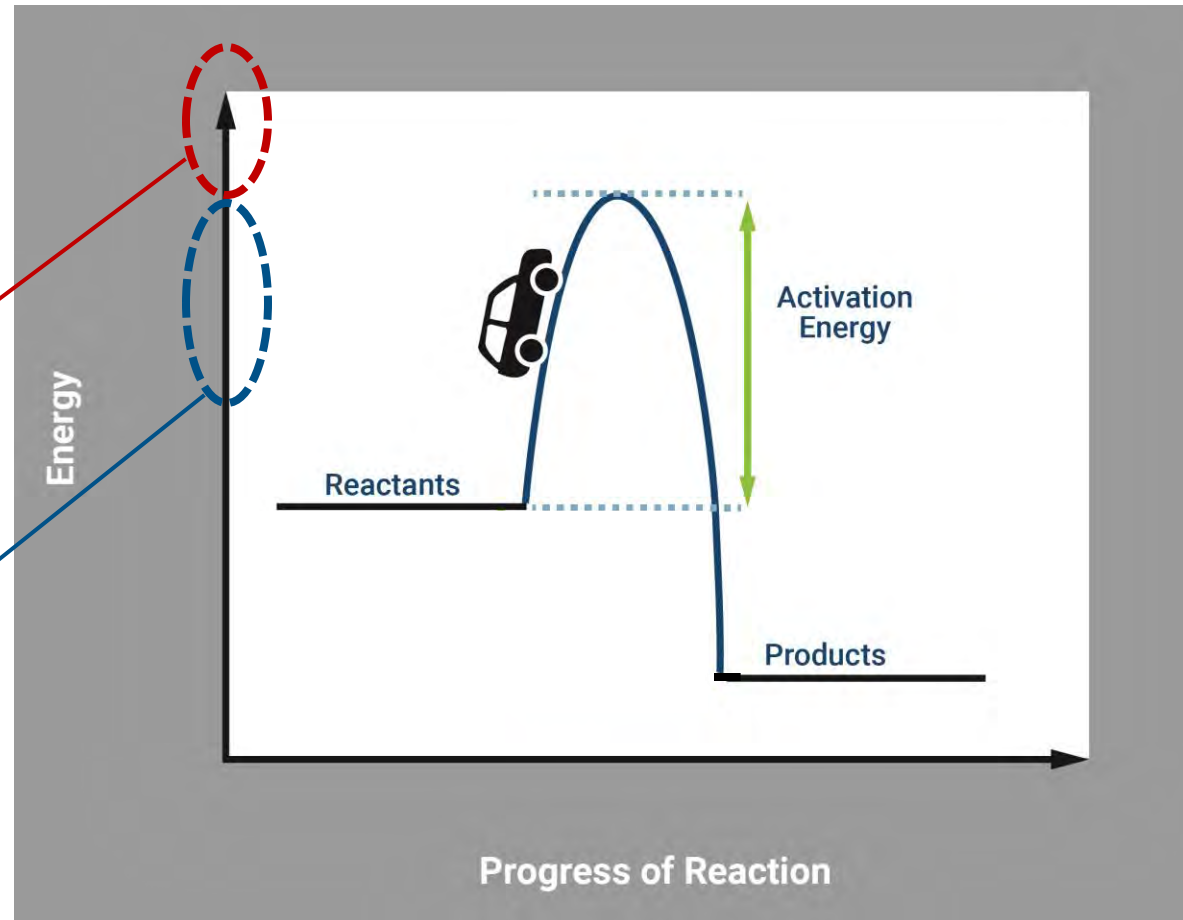
- Initiation
- Propagation
- Branching
- Termination

Source: Adapted from Samarth, 2021

# How Does Temperature Influence Chemical Responses?

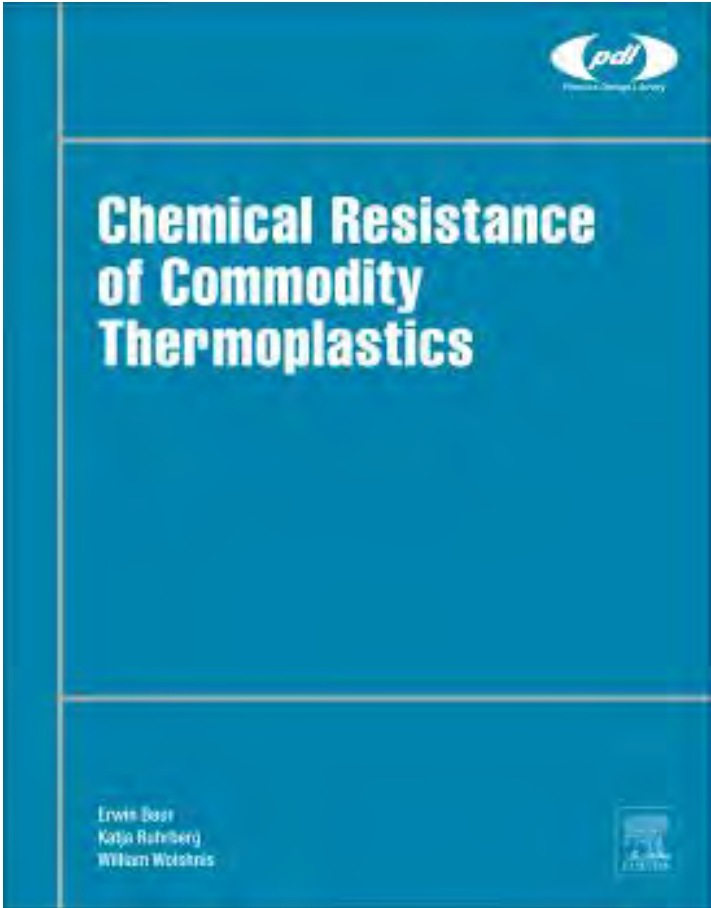


Typical Activation Energy Curve for an Exothermic Reaction



Source: Adapted from Clark, 2023

# Resistance Data for Temperature Ranges



Source: Baur, 2016

# Resistance Data for Temperature Ranges Cont.

Weighted Value	Weight Change*	Diameter; Length* Change	Volume Change*	Mechanical** Property Retained	Visual/Observed*** Change
10	0–0.25	0–0.1	0–2.5	>=97	No change
9	>0.25–0.5	>0.1–0.2	>2.5–5.0	94–<97	
8	>0.5–0.75	>0.2–0.3	>5.0–10.0	90–<94	
7	>0.75–1.0	>0.3–0.4	>10.0–20.0	85–<90	Slightly discolored, slightly beached
6	>1.0–1.5	>0.4–0.5	>20.0–30.0	80–<85	Discolored yellows, slightly flexible
5	>1.5–2.0	>0.5–0.75	>30.0–40.0	75–<80	Possible stress crack agent flexible, possible oxidizing agent, slightly crazed
4	>2.0–3.0	>0.75–1.0	>40.0–50.0	70–<75	Distorted, warped, softened, slight swelling, blistered, known stress crack agent
3	>3.0–4.0	>1.0–1.5	>50.0–70.0	60–<70	Cracking, crazing, brittle, plasticizer, oxidizer, deteriorated
2	>4.0–6.0	>1.5–2.0	>60.9–90.0	50–<60	Severe distortion, oxidizer, and plasticizer deteriorated
1	>6.0	>2.0	>90.0	>0–<50	Decomposed
				0	Solvent dissolved disintegrated

\*All values are given as a percentage change from original.

\*\*Percentage mechanical properties retained include tensile strength, elongation, modulus, flexural strength, and impact strength. If the % retention is greater than 100%, a value of 200 minus the % property retained is used in the calculations.

\*\*\*Due to the variety of information of this type reported, this information can be used only as a guideline.

Source: Baur, 2016

# HDPE's Resistance to Xylene at Various Temperatures



Exposure Medium	Temperature (°C)	PDL #	Notes
Xylene	23	6	Fair resistance
Xylene	60	1	Poor resistance, loss of mechanical properties, swelling
Xylene	104	NA	Dissolution

# Featured Material: Kynar® PVDF



## Benefits of Kynar® PVDF:

- Outstanding chemical resistance at elevated temperatures
- Easy to weld into chemical tanks and tank liners

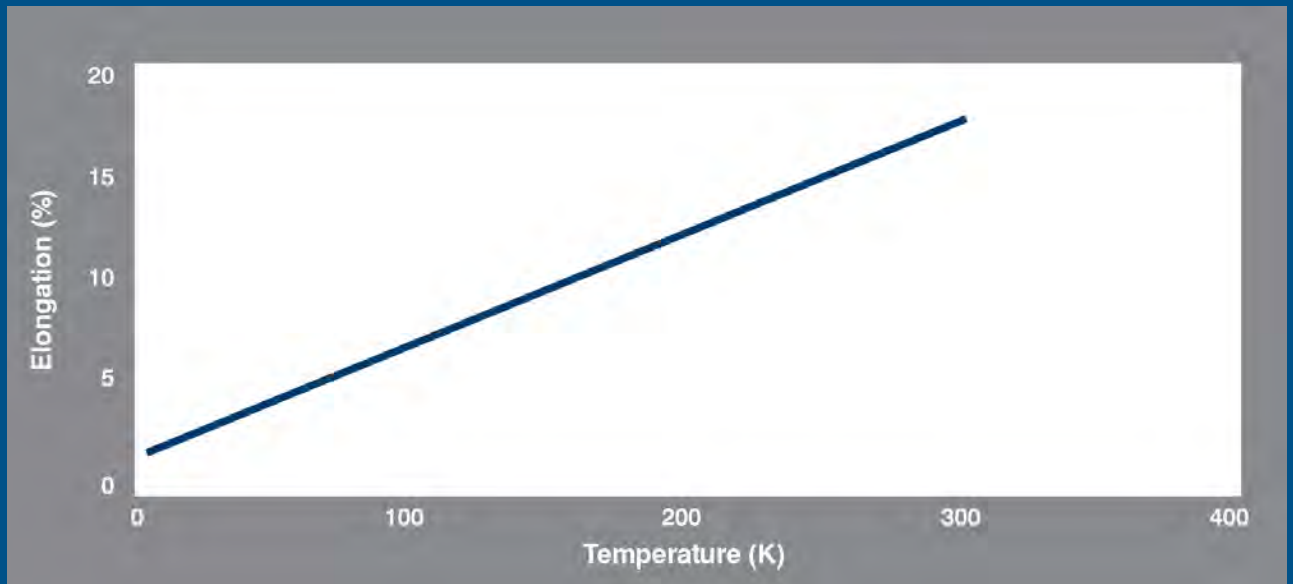


## Cryogenic Conditions – Special Considerations for Very Low Temperatures

# Low-Temperature Embrittlement



Elongation of Polycarbonate at Various Temperatures

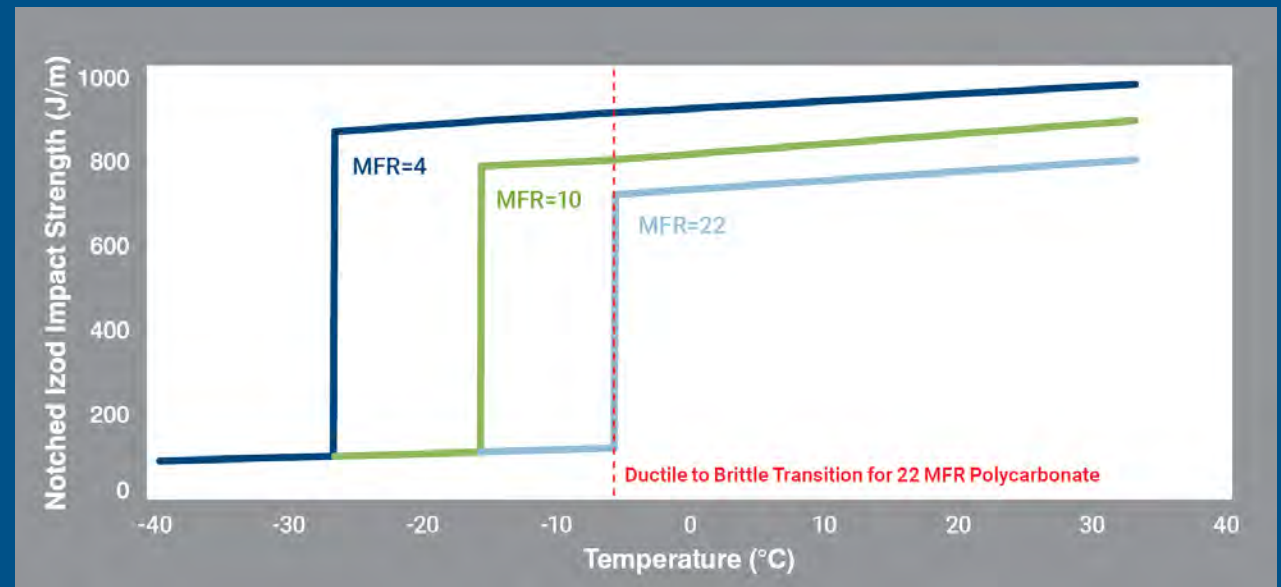


Source: Schramm et al, 1973

# Reduced Toughness at Low Temperatures



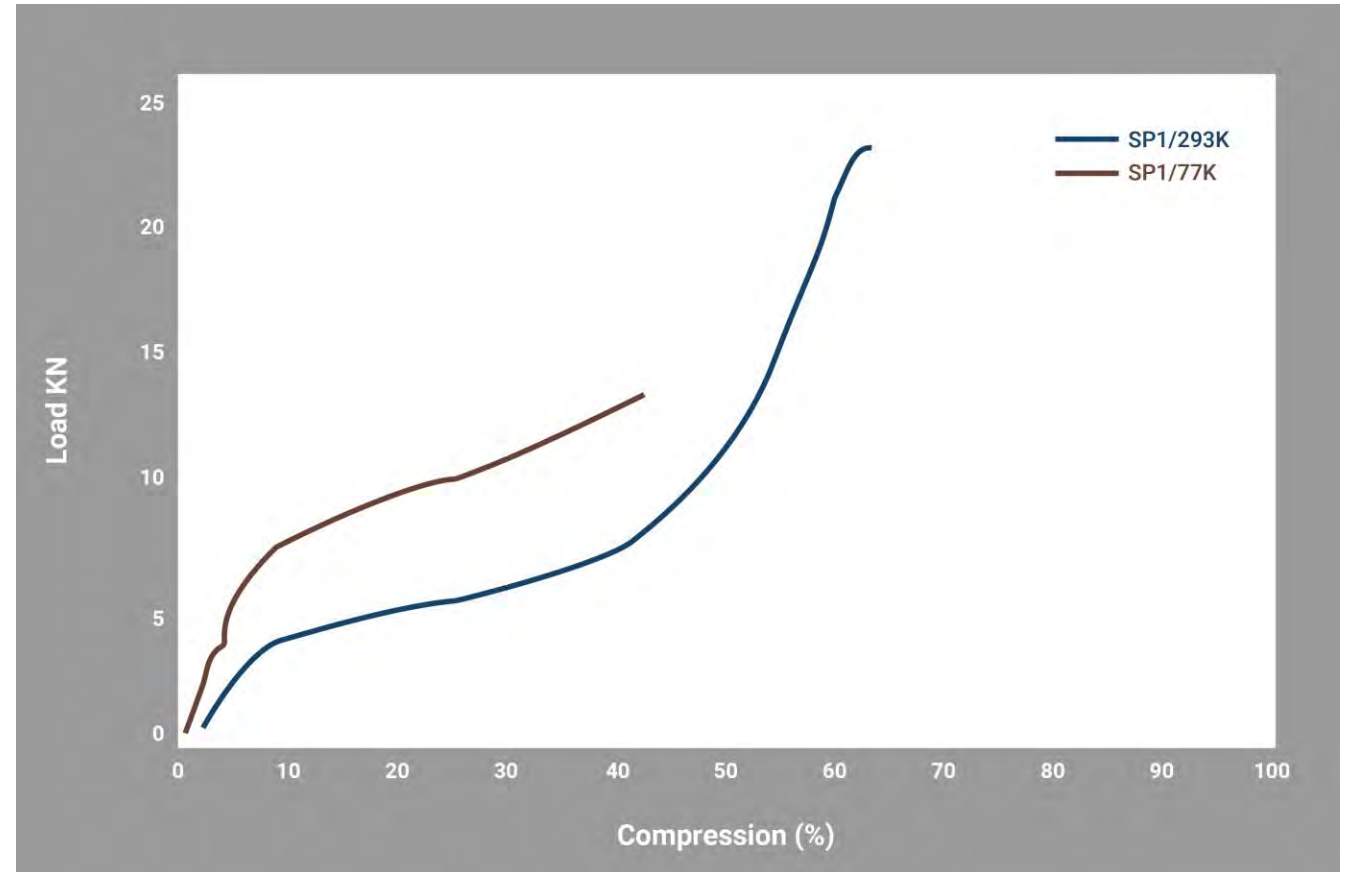
Notched Izod Impact Strength of Low, Medium, and High Molecular Weight Grades of Polycarbonate at Various Temperatures



Source: McKeen, 2008

# Vespel<sup>®</sup> SP-1 Under Compressive Loads

Compressive Strength Data for Vespel<sup>®</sup> SP-1

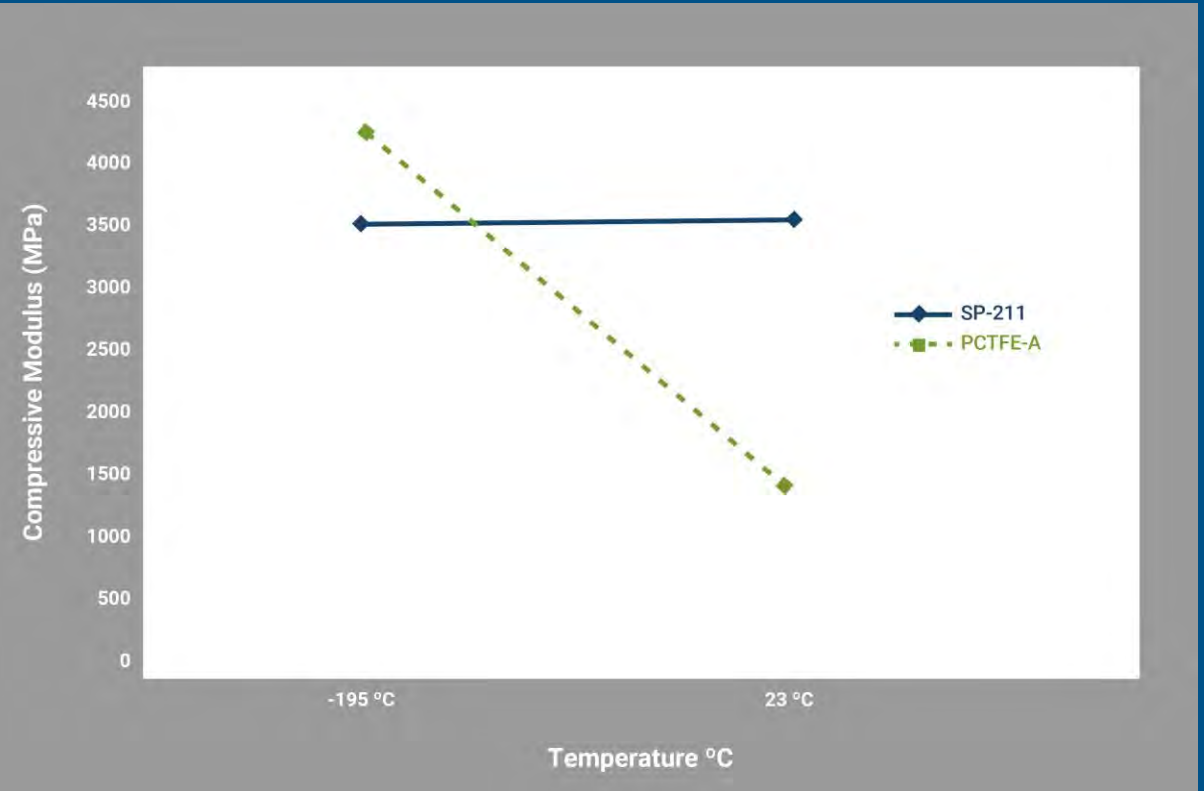


Source: Adapted from McDonald & Rao, 1987

# Low-Temperature Embrittlement



Compressive Modulus of PCTFE and Vespel® SP-211 Versus Temperature



Source: Adapted from Lewis, 2015

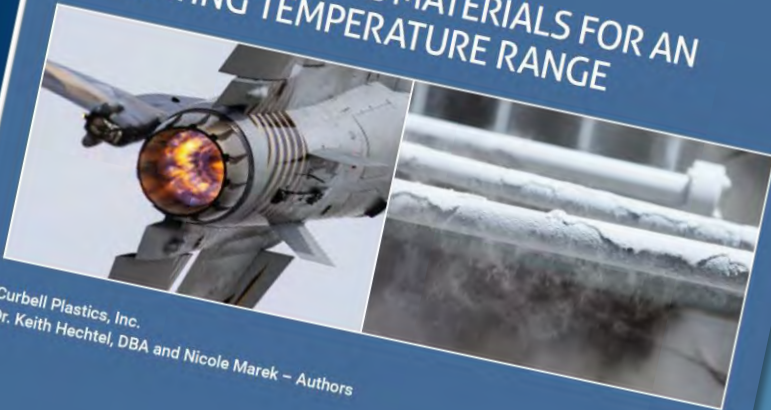


# Summary

Plastic material selection for temperature extremes requires careful consideration that extends past the reported property values on datasheets

- Operating temperature range (hot and cold)
- Mechanical loads
- Dimensional stability requirements
- Thermal properties
- Friction and wear properties
- Electrical properties
- Creep, fatigue, and relaxation
- Chemical exposure

RUNNING HOT AND COLD:  
SELECTING PLASTIC MATERIALS FOR AN  
OPERATING TEMPERATURE RANGE



Curbell Plastics, Inc.  
Dr. Keith Hechtel, DBA and Nicole Marek – Authors

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For additional information and detail read our white paper on the topic *Running Hot and Cold: Selecting Plastic Materials for an Operating Temperature Range*

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