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

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INTRODUCTION

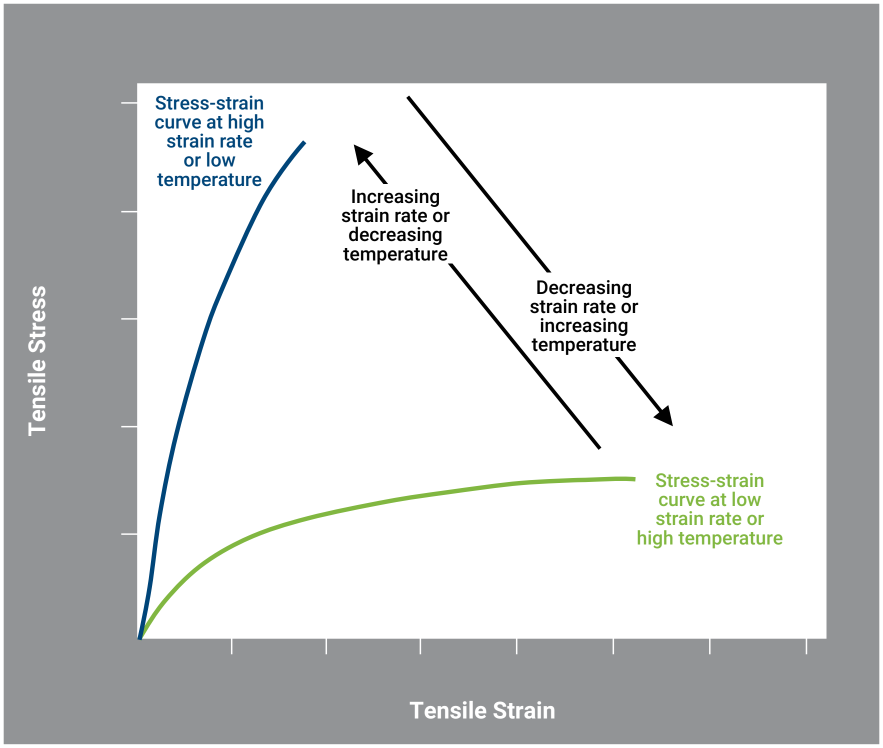
One of the most challenging issues that plastic part designers contend with is specifying materials for use throughout an operating temperature range. Material properties sheets will often include a “maximum continuous service temperature” for a plastic, but this is at best a rough guideline. In many cases, this value does not provide rich enough information to determine if a material will perform throughout a particular operating temperature range for the required service life of a part. Additionally, material properties sheets rarely include data for cold temperature performance, which presents a challenge for designers of devices such as LNG valves or cryogenically cooled superconducting magnets that operate at cold temperatures.

The purpose of this paper is to provide some design considerations when selecting plastics for use throughout an operating temperature range.

MECHANICAL PROPERTIES

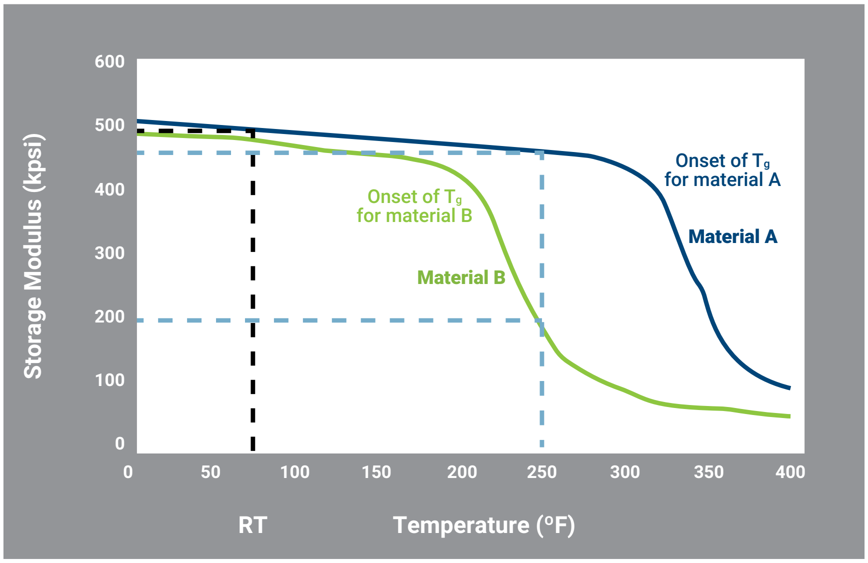
Plastics are viscoelastic materials that behave in some ways like elastic solids and in some ways like viscous liquids. Because of this, their responses to mechanical stresses are dependent on both temperature and strain rate. Plastic materials generally exhibit stronger, stiffer, and more brittle behavior at cold temperatures and lower strength, lower stiffness, and greater ductility at elevated temperatures. They also have strong, stiff, less ductile responses to mechanical stresses at high strain rates, and lower strength, lower modulus, and more ductile responses to mechanical stresses at low strain rates. The stress-strain curves shown in Figure 1 illustrate this principle.

Figure 1. Tensile Stress-Strain Curves for a Typical Thermoplastic at Various Temperatures and Strain Rates



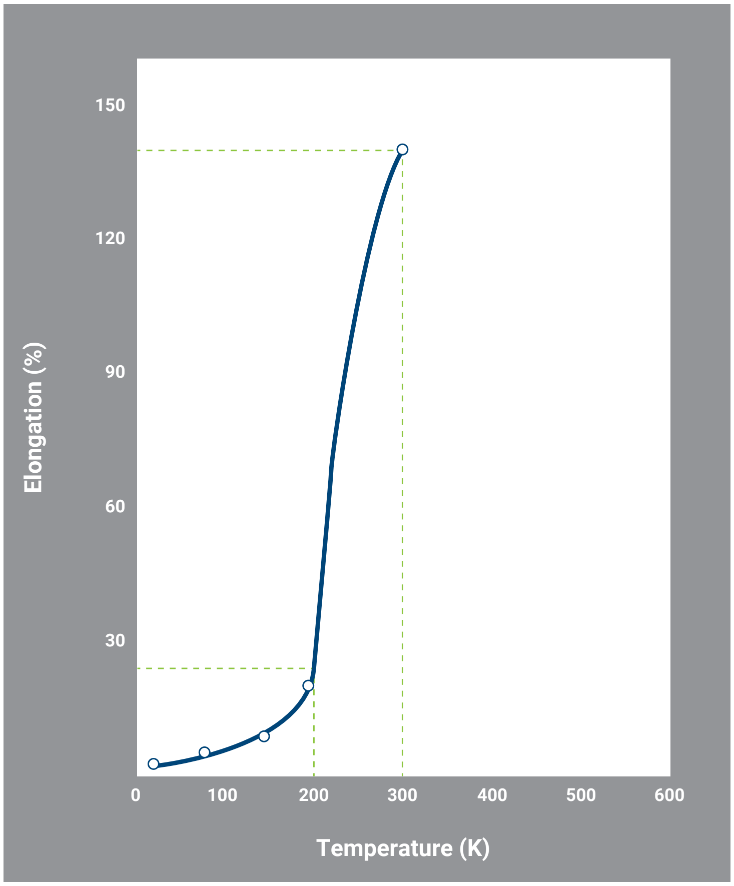
Because the mechanical properties of plastics are dependent on temperature, it is helpful to review graphs that show the strength, modulus, and tensile elongation (a measure of ductility) as a function of temperature. Figure 2 compares the storage modulus (stiffness) of two plastic materials over a temperature range from 0°F to 400°F. Both materials have similar storage moduli at room temperature. However, at 250°F material A has only slightly lower modulus than it has at room temperature and material B exhibits less than half of its room temperature modulus. In this example, material A may be more suitable for an application that requires a plastic part to support mechanical loads at 250°F.

Figure 2. Storage Modulus for Two Different Thermoplastic Materials from 0°F to 400°F



Material selection often includes identifying plastics with sufficient ductility (tensile elongation and impact strength), especially if the application involves the part having to withstand impacts at high strain rates. Figure 3 shows tensile elongation for PCTFE with 40% crystallinity as a function of temperature.

Figure 3. Tensile Elongation of PCTFE with 40% Crystallinity at Various Temperatures



Source: Adapted from Schramm, 1973

At room temperature (294 Kelvin), PCTFE has stretchy, ductile behavior with 140% tensile elongation. When cooled to 200 Kelvin, the material has considerably less ductility, with tensile elongation of only 24%. Reduced ductility and increased modulus at cold temperatures are important considerations for applications such as the seals for cryogenic valves, where actuation torque increases with increasing compressive modulus. Brittle behavior at low temperatures can also result in plastic parts cracking and failing in cold conditions, especially when the parts experience impact.

CREEP AND STRESS RELAXATION

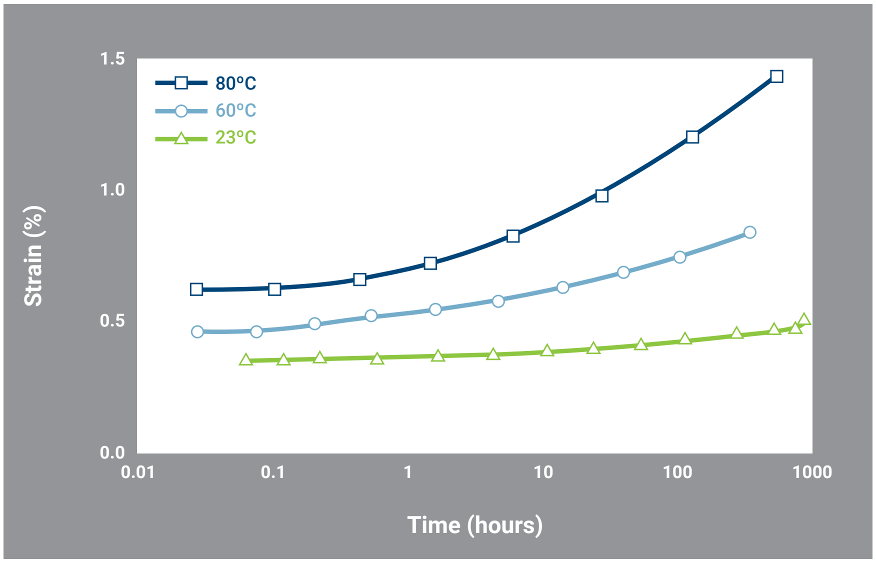
Plastic materials can continue to deform when placed under mechanical loads for extended periods of time. This may happen under loads well below the yield stress of a plastic at the strain rates specified in the ASTM or ISO testing reported on material properties sheets. This long-term deformation under load is referred to as creep strain. The photograph below shows plastic shelving in a warm attic that deformed under the load of heavy tools after several years of use.

Plastic shelving that deformed over time due to flexural creep strain.

When the shelving was initially loaded, it deflected only slightly as a function of the material's flexural modulus. However, it continued to deform and bend over time due to flexural creep. Creep strain in thermoplastics happens more rapidly at elevated temperatures. In this case, the shelving exhibited greater deformation in the summer months than during the winter months due to the higher ambient temperature during the summer.

The creep strain characteristics of thermoplastics at various temperatures can be represented graphically as shown in Figure 4. The graph shows creep stain for an unfilled polyphenylene ether-polystyrene blend at 23°C, 60°C, and 80°C.

Figure 4. Creep Curves for an Unfilled PPE-Polystyrene Blend at Various Temperatures at a Stress of 10 MPa



Source: McKeen, 2015

At room temperature (23°C), this material exhibits only 0.5% creep strain after 1000 hours under a load of 10 MPa. At 80°C, the material exhibits a much higher 1.4% creep strain after 1000 hours. This example illustrates the importance of considering creep strain when selecting plastics for applications that involve elevated temperature environments, mechanical loads, and long service life.

Stress relaxation is related to creep strain in that it describes a long-term response of plastic materials under mechanical stresses. While creep strain describes deformation under a constant load over time, stress relaxation describes a reduction of stress over time without a change in part geometry. The photographs below provide an intuitive way to think about stress relaxation. The picture on the left shows a water hose being sealed with firm pressure from the operator's thumb. The picture on the right shows the hose and the thumb in the same position, but with the operator applying much less pressure, resulting in leak paths.

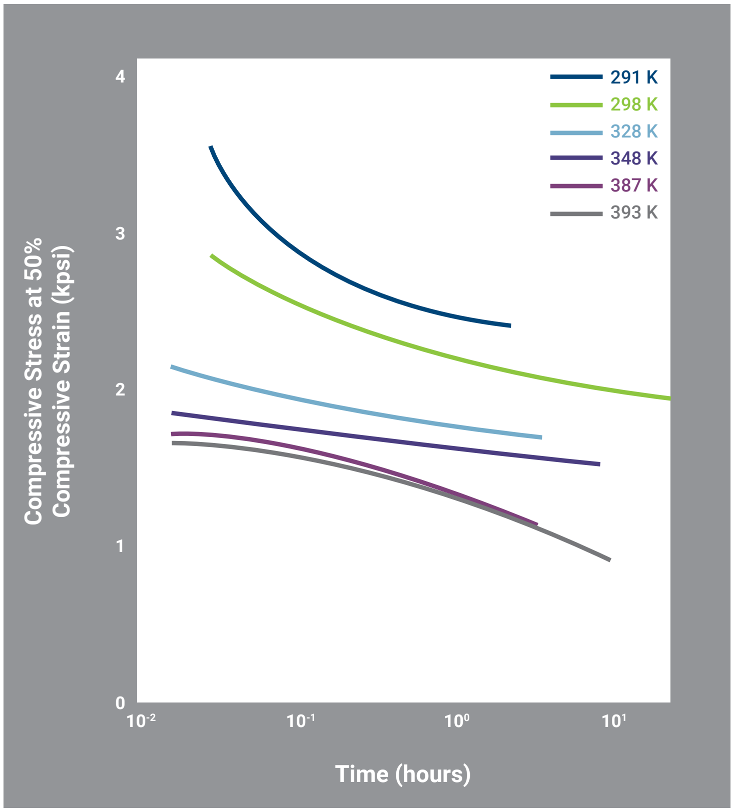
Relaxing thumb pressure on a garden hose releases water. This is analogous to the failure of a plastic seal due to stress relaxation.

This is analogous to the plastic part failure due to stress relaxation shown in the photograph below. The PTFE gasket between the metal flanges was able to seal the pressurized process fluid when the system was first installed. The PTFE then relaxed over time resulting in leak paths.

This metal piping system was assembled using a PTFE gasket which exhibited stress relaxation over time resulting in leak paths.

Stress relaxation in plastic materials is more pronounced at elevated temperatures. For example, stress relaxation curves for PTFE (polytetrafluoroethylene) at various temperatures are shown in Figure 5.

Figure 5. Stress Relaxation of PTFE at Various Temperatures



Source: Schramm, 1973

In this example, specimens of PTFE are compressed to 50% of their original height at temperatures ranging from 291 K (64°F) to 393 K (248°F) and relaxation of the initial stress over time is recorded. The curves provide several important insights for designers considering PTFE for an application that has an operating temperature range from 291 K to 393 K.

- The initial compressive stress at 291 K (the lowest temperature tested) is higher than the initial stresses at the other temperatures tested due to the higher compressive modulus (stiffness) of PTFE when it is cold.
- For all of the temperatures tested, stress decreases significantly after 10 hours.
- After 10 hours, the material tested at the highest temperature (393 K) relaxed to the lowest stress level.

These behaviors have important implications for plastic seals, gaskets, washers, and mechanical fasteners, where maintaining stress over long periods of time is essential for the function of the part.

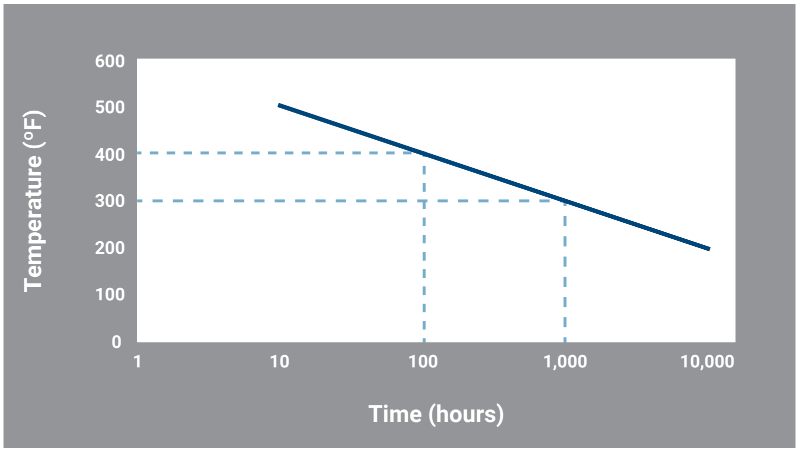
DEGRADATION

Plastic materials tend to lose strength and become brittle over time when exposed to elevated temperature environments. The photograph below shows a phenolic pot handle that became weak and brittle over time due to repeated exposure to high temperature.

This phenolic pot handle became brittle and degraded after many years of use at elevated temperatures.

This loss of strength and ductility for a plastic material happens more quickly as temperature is increased. Figure 6 on page 12 shows time to 50% loss of tensile strength for a particular thermoplastic at temperatures ranging from 200°F to 500°F.

Figure 6. Time to 50% Loss of Tensile Strength for a Thermoplastic at Various Temperatures



As highlighted by the dashed lines, at 300°F, this material loses 50% of its tensile strength after 1000 hours of exposure. However, if the temperature is increased to 400°F, the material loses 50% of its tensile strength after only 100 hours of exposure. Curves of this type provide rich information about the ability of a plastic material to perform over time when used at elevated temperatures.

THERMAL EXPANSION

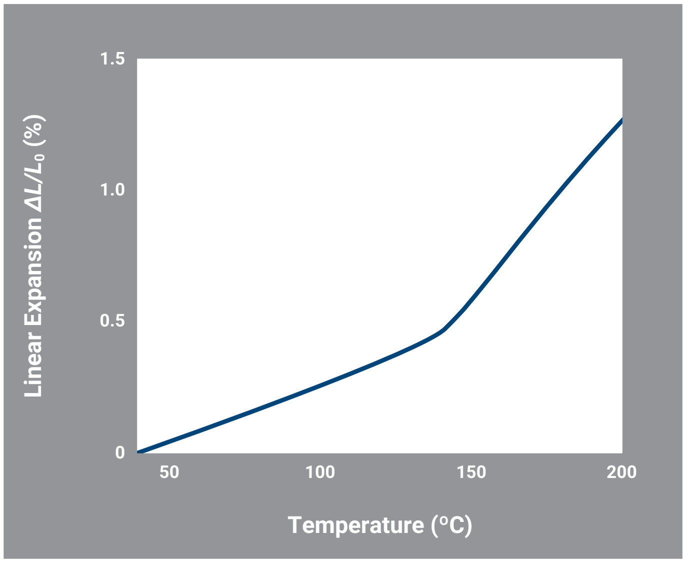
Plastics have higher thermal expansion rates than metals, which can result in design challenges when assemblies that include metal and plastic parts must operate throughout a wide temperature range. CTE mismatch between the metal and plastic components can result in the plastic growing when the device is warmed or shrinking when the device is cooled to a degree that the metal and plastic parts no longer fit together in a way that allows the assembly to function. The photograph below shows a toolbox with a steel cabinet and a high density polyethylene top.

This HDPE tool chest top warped when placed outside on a warm day due to its high rate of thermal expansion.

The toolbox was used outdoors during the summer, which resulted in both the steel and the polyethylene components growing in size as a function of their thermal expansion rates. The CTE of steel is 0.65×10^{-5} inches/inch of original length/°F of temperature change. The CTE of HDPE is much higher at 6.7×10^{-5} inches/inch of original length/°F. Due to the higher thermal expansion rate of HDPE relative to the steel mating part, the HDPE top increased in size and warped when the toolbox was exposed to elevated temperature conditions. In this example, the designer failed to allow sufficient clearance for the plastic part to expand within the expected operating temperature range.

Additionally, the thermal expansion rate of many plastics changes at different temperatures. For example, Figure 7 shows the increased thermal expansion rate of PEEK (polyetheretherketone) above its glass transition temperature of 143°C.

Figure 7. Thermal Expansion of PEEK Below and Above the Material's Glass Transition Temperature



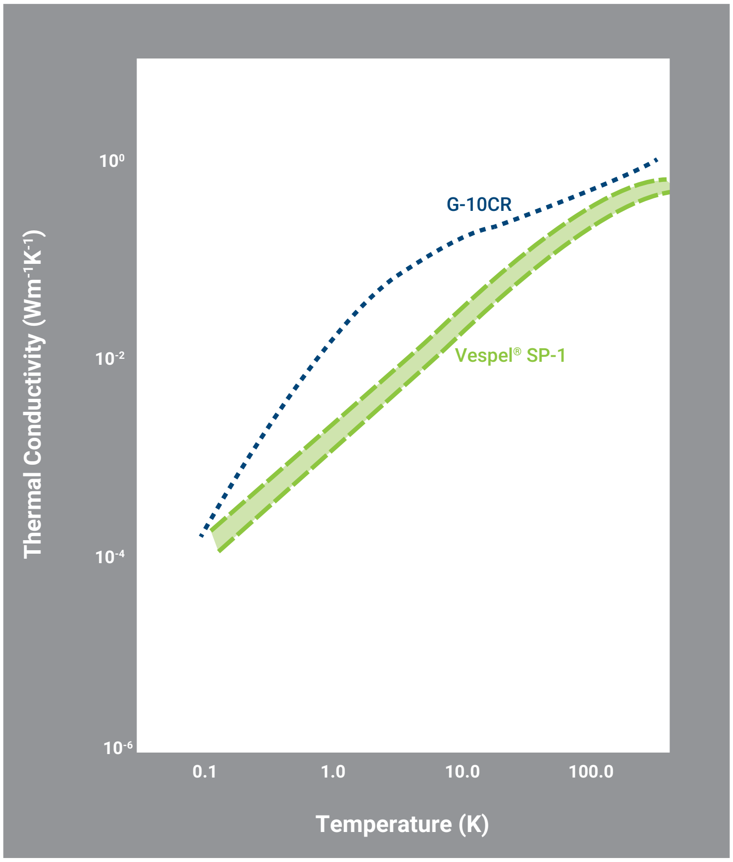
Source: Adapted from Jiang, 2021

Thermal expansion curves provide useful information about the dimensional stability of a plastic material. This can help to determine the potential suitability of a plastic for an application that requires parts to maintain certain dimensional tolerances throughout an operating temperature range.

THERMAL CONDUCTIVITY

Applications in devices such as spacecraft, superconducting magnets, and fusion power generation equipment often require plastic materials with low thermal conductivity to serve as thermal isolators. The operating temperature range for these plastic parts may extend from cryogenic conditions to temperatures up to 300°C. The thermal conductivity values for plastic materials can vary significantly throughout a given temperature range as shown in Figure 8 below.

Figure 8. 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

The figure reinforces the idea that data represented graphically often provides a more complete picture of the behavior of a plastic throughout a given operating temperature range compared to the limited information given by a single value on a material properties sheet.

POST-PROCESSING CRYSTALLIZATION

A molded or extruded semicrystalline plastic part may continue to crystallize and shrink if used at temperatures above the material’s glass transition temperature and below its melting point. This has important implications for devices made from semicrystalline plastics that have to operate at elevated temperatures. For example, if a PEEK part was molded to only a moderate level of crystallinity and then used at a temperature above its glass transition temperature of 143°C, it could continue to crystallize resulting in the part shrinking over time. This could potentially be problematic for plastic parts where tight dimensional tolerances are required. Annealing the PEEK part prior to putting it into service would allow the material to achieve a higher level of crystallinity and thereby have greater dimensional stability when used at elevated temperatures.

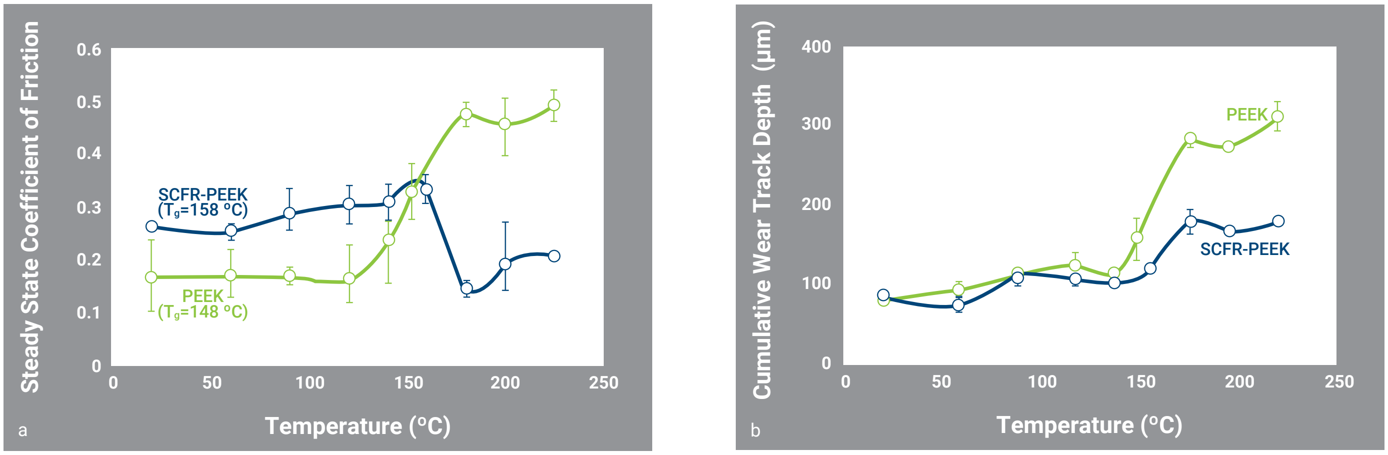
TRIBOLOGICAL PROPERTIES (FRICTION AND WEAR)

The friction and wear behavior of a plastic material in a given application is a complex topic that involves a number of variables including:

- The mechanism of wear (sliding wear, abrasive wear, rolling contact fatigue, etc.)
- The molecular weight, crystallinity, and glass transition temperature of the plastic
- Additives in the formulation
- The chemistry, surface finish, and hardness of the mating components
- The presence or absence of external lubrication
- The operating temperature range of the device (including frictional heat generated at the contacting surfaces)

It is difficult to make generalizations about the coefficient of friction and the wear rate as functions of temperature for a given tribological system with one or more plastic components due to the unique nature of each application. That being said, operating temperature can influence tribological performance. An example of this is shown in Figures 9a and 9b.

Figures 9a and 9b. 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

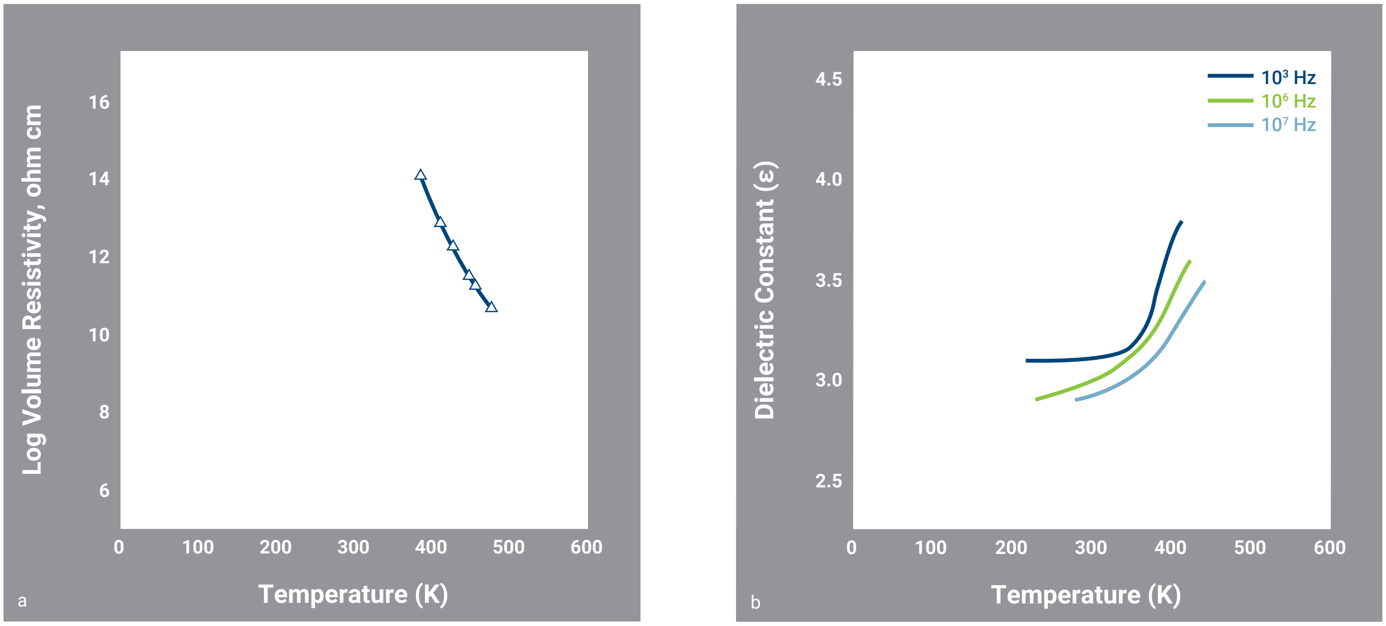
In this example, virgin PEEK has a similar wear rate to SFCR (short carbon fiber reinforced) PEEK and a lower coefficient of friction than SFCR PEEK from 20°C up to the polymer's glass transition temperature of 148°C. Above its T_g, virgin PEEK has a higher COF and a higher wear rate compared with SCFR PEEK. This example illustrates how additives and fillers can enhance friction and wear performance throughout a particular operating temperature range under certain conditions. As previously noted, it would be erroneous to generalize the effects of short carbon fiber reinforcement in thermoplastics for tribological performance based on this single example.

ELECTRICAL PROPERTIES

Plastic materials are often selected in electrical applications due to their insulating properties including their resistivity, dielectric strength, and resistance to electrical arcing. Additionally, some polymers are used for radomes due to their transparency to radio frequency signals as evidenced by their low dielectric constants and low dissipation factors throughout certain frequency ranges.

The operating temperature can influence the electrical performance of plastics as illustrated in Figures 10a and 10b. The figures show the lower volume resistivity and the higher dielectric constant of semicrystalline PET as the material is heated.

Figures 10a and 10b. Volume Resistivity and Dielectric Constant of Semicrystalline PET at Various Temperatures



Source: Adapted from Schramm, 1973

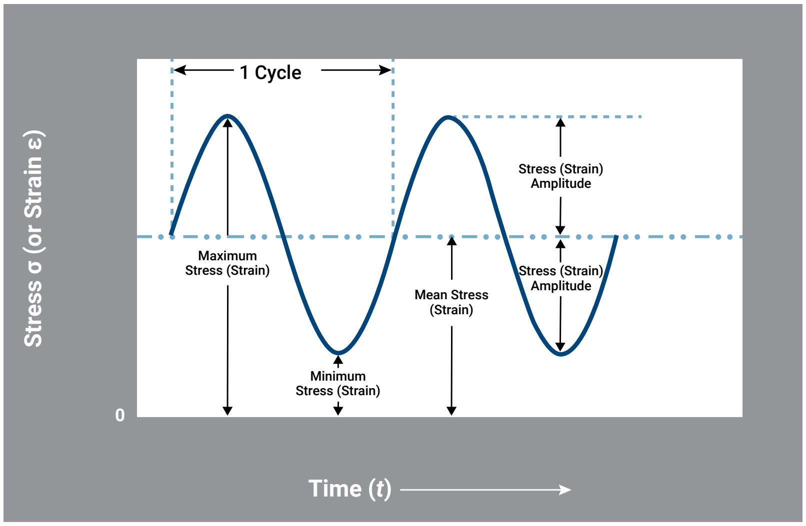
It is important to note that electrical properties are dependent on the molecular structure of the polymer and the changes to the volume resistivity and the dielectric constant of semicrystalline PET at various temperatures can't necessarily be generalized to other plastic materials.

FATIGUE

Fatigue refers to the progressive damage and eventual failure of a plastic material over time, with exposure to repeated cycles of stress or strain. Rather than measuring the ultimate strength that a material can withstand in a one-time event, fatigue accounts for the effect of repeated events over the life of a plastic part. A material can fail, even at loads much lower than the yield strength, with these repeated cycles [Regel].

The applied stress may come in a variety of forms, for instance, tensile (pulling apart), compressive (pushing down), shear (parallel), torsional (twisting), or flexural (bending). Important parameters in the measurement of fatigue include the amplitude (amount of stress applied), cycle frequency (the speed at which stress is applied), and the number of cycles before failure. Figure 11 provides a visual for the cyclic nature of fatigue testing [McKeen].

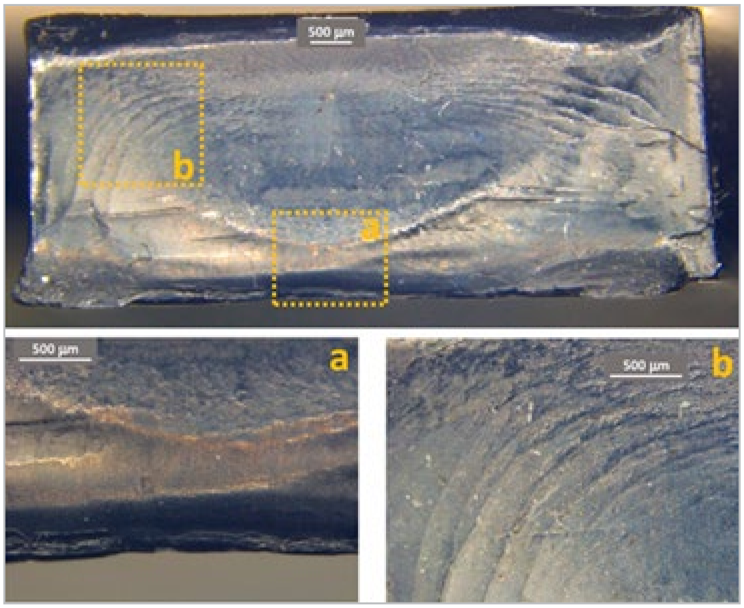
Figure 11. General Shape of a Sinusoidal Curve Generated by Cyclic Fatigue Testing



Source: Adapted from McKeen, 2010

In the first stage of the fatigue process, crack initiation (nucleation) occurs. The cause for this initial crack may be from cyclic loading, material defects, thermal expansion/contraction, or even chemical attack. Regardless of the cause, a crack will then continue to grow (propagate) with exposure to repeated stresses in cyclic loading. The rate of crack propagation will determine how quickly the material approaches failure. Failure occurs when the cracks reach a critical size and the material fractures, unable to withstand the applied load [McKeen]. Figure 12 shows an example of the fracture surface of ABS, after cyclic fatigue testing at room temperature.

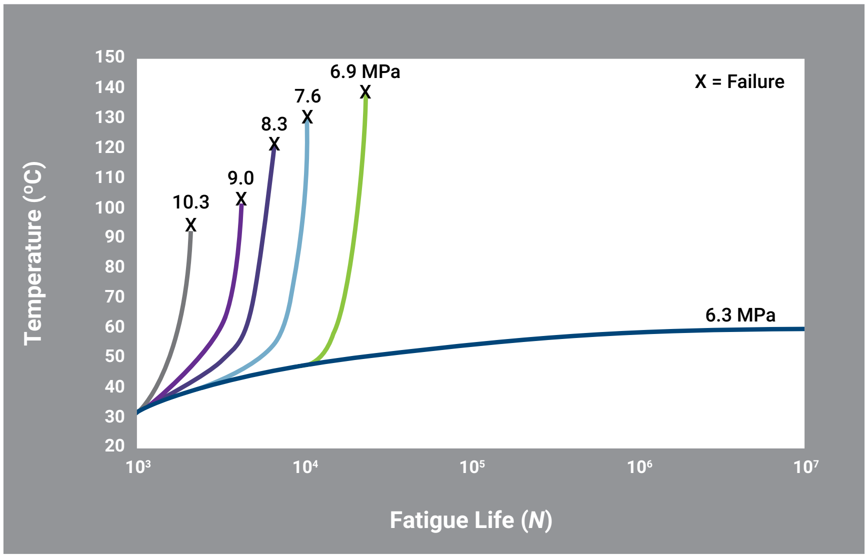
Figure 12. Fracture Surface of an ABS Test Specimen After Fatigue Failure (a) Crack Initiation Point; (b) Propagation Bench Marks



Source: Mura, 2018

Before considering the effects of environmental temperature, it should be noted that polymeric test specimens often experience a phenomena called hysteretic heating during fatigue testing. When a mechanical load is applied to a polymer, the mechanical energy is converted to heat due to internal friction. Polymers tend to be thermal insulators, so this generated heat can have trouble dissipating. This can lead to the amount of dissipated heat being lower than the amount of heat generated, causing self-heating of the polymer [Regel]. Hysteretic heating can be a complicating factor in fatigue testing and the temperatures of specimens need to be carefully observed and controlled to avoid inaccurate evaluation. Figure 13 demonstrates the drastic decrease in fatigue life that PTFE samples see with hysteric heating [McKeen].

Figure 13. Measured Temperature of PTFE Samples Undergoing Fatigue Testing at Various Constant Stress Levels at a Frequency of 30Hz

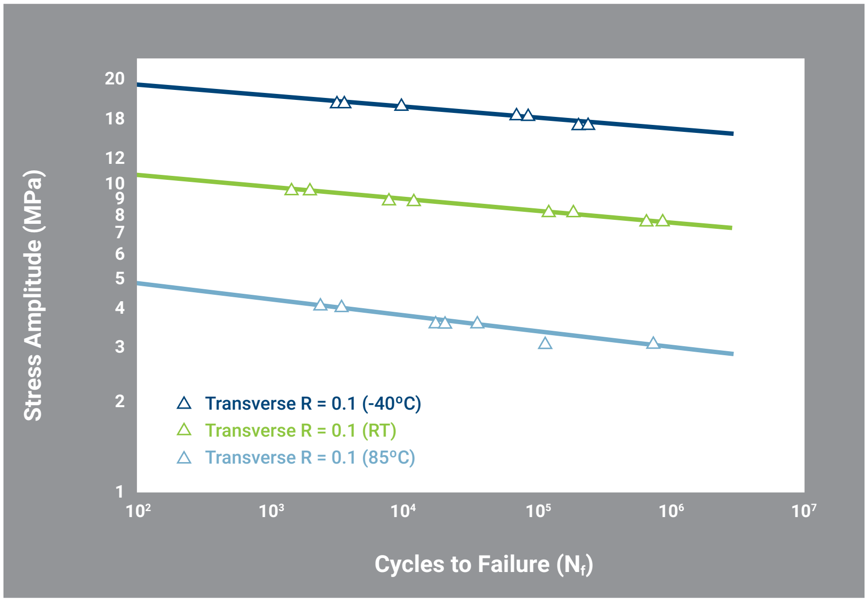


Source: McKeen, 2010

Molecular mobility increases and the material becomes softer as it heats up, especially near or above the glass transition temperature. This leads to easier crack formation, crack propagation, deformation, and generally lower fatigue life [Regel].

Fatigue life is also greatly influenced by the external environmental temperature. Compared to room temperature, polymers tend to exhibit lower fatigue lives at elevated temperatures. This effect is attributed to a combination of self-heating and further material softening. The effects of low temperatures on fatigue however, can vary. Figure 14 shows fatigue testing results for PP samples at -40°C, room temperature, and 85°C. These tests were conducted at a stress ratio (R) of 0.1, indicating a largely tensile cycle, with a small compressive component. The stress amplitude was adjusted to create similar fatigue lives for each temperature tested [Mellott].

Figure 14. Effect of Fatigue Testing Temperature on PP Samples



Source: Adapted from Mellot, 2014

The high temperature tests yielded notably lower stress amplitudes, indicating a drastic decline in fatigue life compared to room temperature. The low temperature tests yielded higher stress amplitudes compared to room temperature, indicating an enhanced fatigue life [Mellott]. It is typical behavior for the rate of crack propagation to be decreased in stiffer thermoplastics with less chain mobility [Mura]. Although, fatigue life may also be impacted by other factors such as molecular weight or plastic composition. Typical fatigue behavior may see exceptions in extreme environmental conditions, or for some formulations.

CHEMICAL RESISTANCE

Chemical resistance refers to the capacity of a material to withstand exposure to a given substance, without degradation or property loss. The question of chemical compatibility does not have a simple “yes” or “no” answer – a polymer may be greatly affected by a chemical, not affected at all, or somewhere in between. Factors such as chemical structure (of both the polymer and the chemical medium), concentration, and exposure time all play a role.

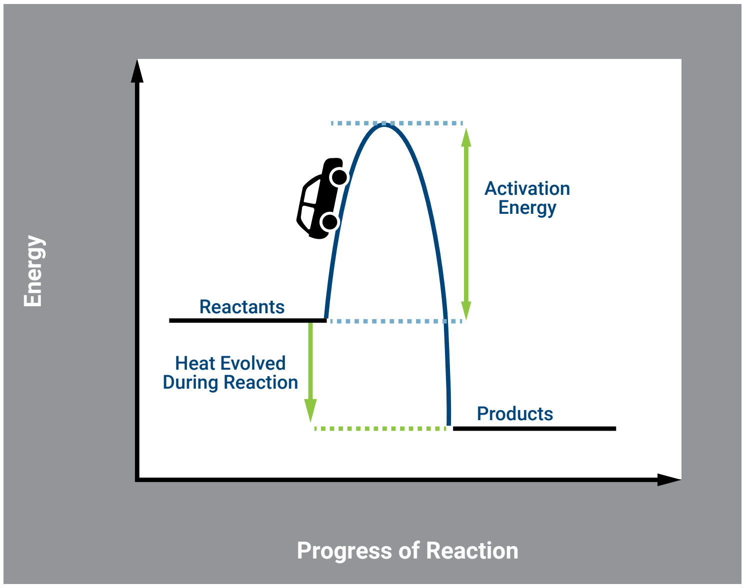
Temperature also plays a critical role in chemical compatibility. Exposure at room temperature may show little to no effect while exposure at high temperatures may be detrimental to a material. For example, hydrofluoric acid is a very strong oxidizer – it tends to steal electrons from materials and it causes degradation in many polymers. Polyethylene is commonly used to store hydrofluoric acid, due to a high resistance to chemical attack. However, past about 60ºC (depending on the acid concentration), polyethylene will begin to show increasing incompatibility and is not recommended for use [Eurofluor]. This section will cover the two main mechanisms of chemical attack to explain the reasoning for this variable behavior.

CHEMICAL EFFECTS

Chemical effects refer to actual reactions that degrade and alter the chemical structure of a polymer. This can result in the breaking down of polymer chains (molecular degradation), reactions with functional groups, or a combination of both [Ebnesajjad]. The exact chemical reactions that occur will vary by polymer and interacting chemical species.

For a given reaction to occur successfully, the reactants must collide with the proper orientation and sufficient energy to break and form chemical bonds. Every chemical reaction has an associated activation energy that it is required to overcome [OpenStax]. This energy barrier is the hill seen in Figure 15 below. Imagine this figure represents a road, and you want to drive from point A (the reactants) to point B (the products). The higher the hill, the more difficult it will be to drive over. If two reactants collide with insufficient energy, then no reaction will occur.

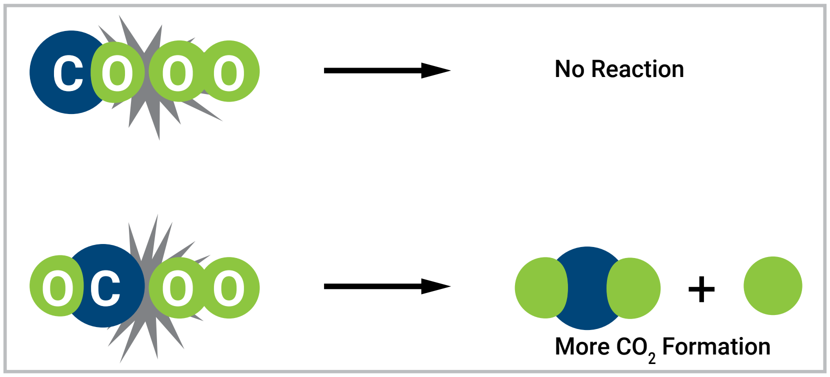
Figure 15. General Activation Energy Curve for an Exothermic Reaction



Source: Adapted from Clark, 2023

Some reactions are also able to occur only if the reacting species collide with a certain orientation, often seen with asymmetrical molecules. If reactants collide with improper orientation, they will bounce off of each other and, even with sufficient energy, no reaction will occur (see Figure 16). The required activation energy and molecular orientation will vary by reaction.

Figure 16. Potential Outcomes of Two Collisions with Different Orientations Occurring Between Carbon Monoxide and Oxygen Molecules



Source: OpenStax, 2022

As temperature increases, molecules move with greater kinetic energy – they move more and with greater speed. This has two major impacts – more collisions are able to occur so the chances of a successful collision increase, and the reactions tend to collide with more energy making it more likely for the activation energy to be overcome. Reactions are typically able to occur more rapidly and more aggressively with increasing temperature [OpenStax].

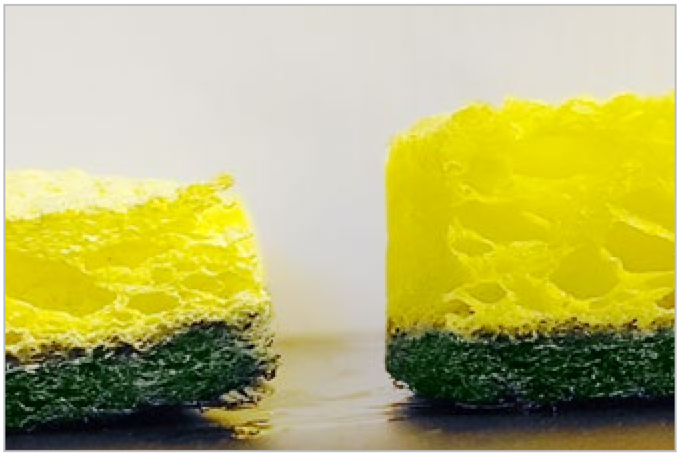
For example, polyethylene pipes may come into contact with chlorinated water while in service. Over time, it has been observed that the chlorinated water attacks the pipe surface, eventually causing the degradation of molecular chains. Cracks may form in the material and propagate, decreasing the strength of the pipe walls and increasing the risk for catastrophic bursting and failure. This effect is accelerated with increasing temperatures, leading to a decrease in material life [Samarth].

Figure 17. Cross Section of PEX Piping After Chlorine Attack

Source: Adapted from Samarth, 2021

DIFFUSION

Solvent effects refer to the physical diffusion of a chemical into the polymer structure. This transport is driven by the existence of a concentration gradient. Fluids will tend to move from areas of high concentration into areas of low concentration [Ebensajjad]. Imagine a dry sponge. All of the small holes and pores of the sponge are not empty, they are filled with the surrounding medium (air). If you drop the sponge into a bucket of water, the water will enter the sponge through these small openings and displace the air. The dimensions of the sponge will grow, as seen in the image below, and it will feel softer.



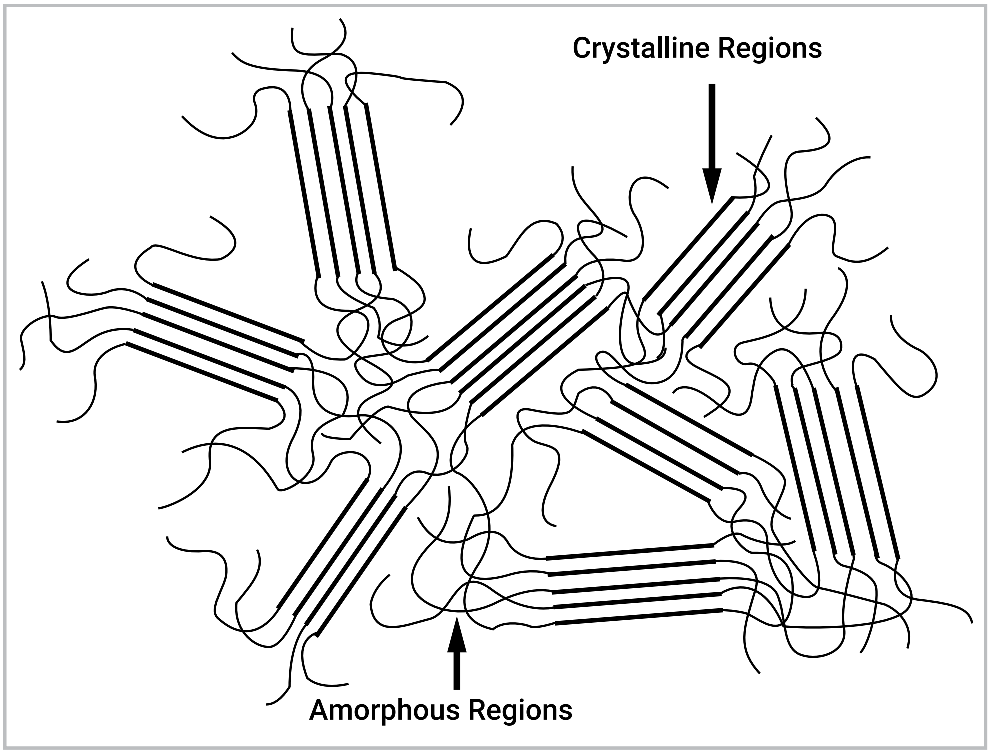
Comparison of a sponge before and after exposure to water.

This is a simplified visualization of the solvent effects seen in polymers. It is unfavorable for a chemical to stay in one concentrated area when there is space for it to spread out and diffuse. When the surrounding medium changed, it became more favorable for the water to diffuse into the sponge. The system became stable once again when the concentration of water within the sponge was in equilibrium with the water concentration of the exterior environment.

There are a number of models for solvent diffusion into a polymer. This process is much more complex than the porous sponge example, but can be broken down into some key concepts. The extent to which this molecular transport happens depends greatly on the size, molecular forces, and polarity (relative charge) of the diffusing molecules, compared to the structure of the polymer [Ebnesajjad].

Polymers contain small areas of open space, where chemical molecules are able to enter when certain conditions are met. This open space between the chains of a polymer is known as free volume – it can be imagined as small fluctuations in local density and chain packing. A chemical molecule may enter the polymer when it contacts a “hole” that is large enough to fit through [Asoltanei]. Amorphous regions within a polymer matrix are less densely packed than crystalline regions, leaving more accessible free volume for chemicals to enter. A large number of amorphous regions within a polymer, impurities, or other physical defects can provide the space for molecules to enter and move more easily through a polymer structure [Ebnesajjad]. Figure 18 provides a visual for the densely packed, highly ordered crystalline regions of a polymer, compared to the less dense, less ordered amorphous regions.

Figure 18. General Representation of Amorphous and Crystalline Regions Within a Semi-Crystalline Polymer



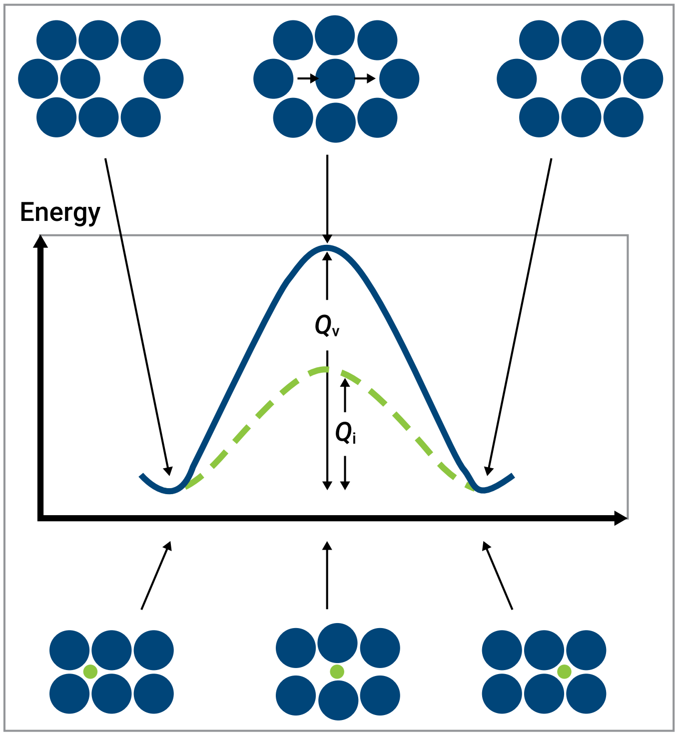
Source: Ebnesajjab, 2016

While diffusion refers to the movement of molecules, solubility refers to the capacity of one substance to dissolve another. A simple saying to understand the role that polarity and molecular forces play in solubility is “like dissolves like.” Molecules with similar polarities and/or similar molecular forces will be more drawn to each other. This is why water (polar) does not like to mix with oil (nonpolar). Depending on the solubility between the chemical species and polymer chains, one may see varying degrees of polymer swelling, softening, and even complete dissolution in some cases [Ennesajjab].

Temperature has a direct impact on polymer transport properties. The glass transition temperature (T_g) represents the temperature that a polymer will transition from a glassy, rigid structure to a rubbery, flexible structure. Below T_g, chain mobility decreases with decreasing temperature. As temperature increases above the T_g, a polymer will have a more liquid-like structure.

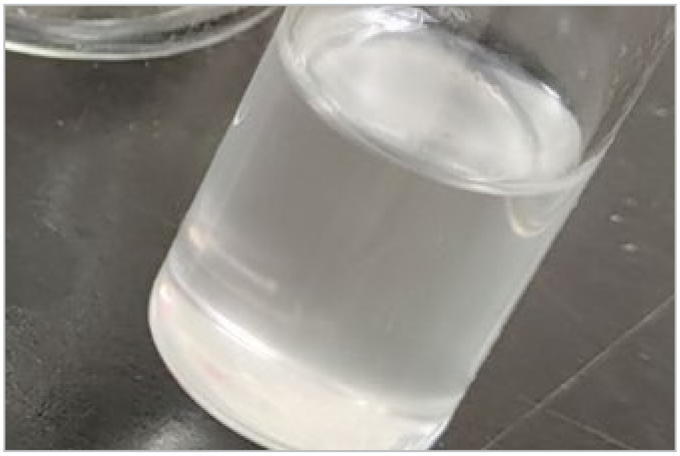
With increasing temperature, molecules and atoms become increasingly energetic. The chain mobility and free volume of polymer chains, as well as the mobility of diffusing species will increase [Karimi]. In order to move from one stable position to another, a diffusing species is required to overcome a barrier in the form of activation energy. Thermal energy can provide the required input for a diffusing species to break neighboring bonds and move into a nearby open position. This idea is visualized in Figure 19 where relative activation energies are shown for two scenarios. Larger diffusing species or more densely packed structures (crystalline versus amorphous) will tend to experience higher activation energies, or in other words, more resistance to diffusion [Freudenberger].

Figure 19. General Activation Energies of Diffusion: (Top) Through an Opening (Missing Atoms) in the Material Matrix, and (Bottom) When a Small Diffusing Species Moves Through Atomic Gaps of a Filled Matrix



Source: Adapted from Freudenberger, 2021

For example, there are no solvents capable of dissolving polyethylene at room temperature. Polymer swelling is able to occur, but only at about 30ºC below the melting point, are certain solvents (similar polarities and molecular forces) able to dissolve it. The increased energy and molecular mobility that come with a temperature increase allow the solvent molecules to have more contact with the polymer chains, and the energy to overcome the internal forces that hold the chains together. Complete dissolution would be the most extreme example of solvent effects. When the solubilities of the chemical and polymer are similar and with exposure to elevated temperatures, partial or complete polymer dissolution becomes a risk [Ebnesajjad]. The image below shows a cloudy solution containing dissolved HDPE after being heated with a solvent.



Solution of solvent (o-xylene) containing dissolved HDPE after heating for 5 minutes at 104ºC.

It is critical to consider the temperatures that a plastic will face within an application when chemical exposure is anticipated. Due to its complexity, chemical compatibility can be difficult to predict without experimental data. If existing data does not sufficiently represent the expected application conditions (similar chemicals, polymer brands, temperatures, concentrations, etc.), then it is recommended to complete testing to ensure compatibility.

CONCLUSION

The purpose of this paper is to provide plastic part designers with some considerations when selecting plastic materials for use in an operating temperature range. This involves reviewing the effect of temperature on a wide range of material properties including:

- Mechanical properties
- Creep and stress relaxation
- Thermal properties
- Dimensional stability
- Tribological properties
- Electrical properties
- Fatigue resistance
- Chemical resistance

Many aspects of plastic material behavior were illustrated using data represented graphically in lieu of the limited single point data provided on most commercial material properties sheets. This approach provides designers with more detailed information when specifying plastic materials for use in an operating temperature range.

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TECHNICAL EXPERTISE

Curbell white papers are intended to provide engineers and designers with basic information about the engineering polymers available as sheet, rod, tube, and film stock from Curbell Plastics. We invite you to contact Curbell via e-mail at **technicalsupport@curbellplastics.com** to discuss applications in detail.

ABOUT CURBELL PLASTICS

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