AVOIDING COMMON PLASTIC PART FAILURES

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Premature product failures can result in costly redesign and potentially product recalls, which can damage a company's brand.

Plastic materials offer many advantages over other industrial materials including light weight, low cost, and outstanding aesthetics. For these reasons, plastics have seen increased use for a wide range of applications. That being said, designers and engineers are sometimes disappointed when plastic parts don't perform as expected. Premature product failures can result in costly redesign and potentially product recalls, which can damage a company's brand.

The purpose of this paper is to provide a brief overview of the ten most common plastic part failures and offer some suggestions for avoiding them.

DIMENSIONAL STABILITY ISSUES

Plastic materials typically require more open dimensional tolerances compared with metals, wood products, or ceramics. This is largely due to their high rates of thermal expansion. Additionally, some plastics absorb moisture from the atmosphere, which can result in dimensional changes. Finally, plastic parts may change dimensions due to the relief of internal stresses or from being placed under mechanical loads for extended periods of time. For these reasons, designs that include both metal and plastic components must allow for dimensional changes of the plastic parts based on the operating temperature range, the varying levels of humidity in the environment, and the mechanical loads on the device.

The picture below provides an example of how plastic parts can fail when these factors are not accounted for in a design. The photograph shows an enclosure constructed from acrylic sheet bolted to a metal frame. The unit was assembled at ambient temperature and then exposed to hot summer conditions. The mismatch between the low CTE (coefficient of thermal expansion) of the metal and the high CTE of the acrylic sheet resulted in the plastic warping due to thermal expansion.

CTE mismatch between the steel structure and the acrylic glazing caused the plastic to warp in warm summer conditions.

One possible way to avoid this failure would be to allow for CTE mismatch in the design with features such as slotted holes in the plastic sheet and controlled torque of the fasteners to allow the acrylic to freely expand and contract with changes in temperature.

FAILURE AT EXTREME TEMPERATURES

Plastic materials are useful throughout a defined operating temperature range. Most plastics become somewhat stiff and brittle at cold temperatures. The picture below left shows a polypropylene sled that became brittle at winter temperatures and then cracked during use.

This polypropylene sled became brittle in cold winter temperatures and cracked during use.

This plastic spatula softened when it came into contact with a hot metal cooking surface.

When designing plastic parts for use at cold temperatures, it is useful to review data on the cold temperature ductility of the materials being considered for the application. Graphs showing notched Izod impact strength and tensile elongation at various temperatures can help to determine if a material will have sufficient toughness and ductility at the low end of the operating temperature range.

Plastics tend to exhibit soft, ductile behavior at elevated temperatures. The photograph above right shows a plastic spatula that came into contact with a metal frying pan at a temperature above the melting point of the polymer. The spatula softened and deformed.

In addition to softening, polymer materials will also degrade if exposed to high temperatures for extended periods of time. The photograph below shows a phenolic handle for a cooking pot that became brittle after years of use at elevated temperatures. Note the degraded surface on the bottom side of the part.

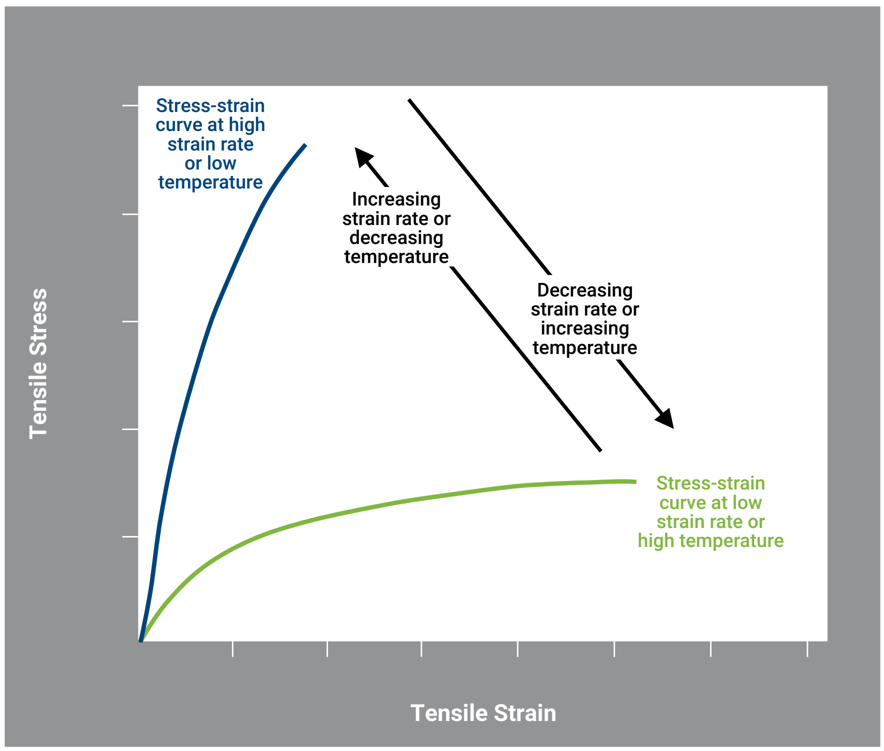
This phenolic cooking pot handle degraded and became brittle after long-term exposure to elevated temperatures during use.

When designing plastic parts for use at elevated temperatures, it is useful to review data on the strength and modulus of the polymers being considered for the application at the upper end of the operating temperature range for the device. It is also useful to review thermal degradation curves that show the time that a plastic material can operate at a given temperature before losing strength and becoming brittle.

FAILURE AT HIGH AND LOW STRAIN RATES

Since plastics are viscoelastic materials, their responses to mechanical stresses depends on strain rate (the rate at which a load is applied) as well as temperature. Figure 1 shows stress-strain curves for a typical thermoplastic material. The black arrows indicate how the material exhibits stiffer, more brittle behavior at high strain rates or colder temperatures and softer, more ductile behavior at low strain rates or warmer temperatures. This characteristic of polymers has important implications for design.

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



The blue stress-strain curve describes the behavior of a typical thermoplastic material at high strain rates, such as a plastic part being dropped or struck with a hammer. The polymer will exhibit stiffer more brittle behavior, which can result in part failure. The photograph on page 8 shows the extreme case of a plastic bottle that was shot with a bullet from a rifle. At this extremely high strain rate (2500 feet per second), the plastic bottle, which is quite soft and ductile at moderate strain rates, failed in a brittle manner. Interestingly, this mimics the behavior of the material at extremely cold temperatures (perhaps cryogenic conditions), where the plastic container would also respond to stress in a stiff, brittle manner.

This PET bottle, which is tough and ductile in normal use, exhibited brittle fracture when exposed to the high strain rate impact of a bullet fired from a rifle.

This HDPE decking was installed with insufficient support underneath, which resulted in the deck failing due to flexural creep strain.

The green stress-strain curve in Figure 1, shows the behavior of a thermoplastic at low strain rates. Deformation at an extremely low strain rate is referred to as creep strain, where the plastic part changes shape when placed under a mechanical load for long periods of time. The photograph above right shows plastic outdoor decking that was installed without adequate support underneath. The deck boards exhibited flexural creep strain (slow sagging over time) under the load from their own weight.

It is important to note that creep strain can happen at much lower stresses than the values reported on material property sheets since standardized testing is done at moderate strain rates per ASTM and ISO standards.

Reviewing stress-strain curves that reflect the actual strain rates that a part will be exposed to during its service life can help to avoid unexpected failure from high strain rate impact or low strain rate creep.

CREEP RUPTURE

In some cases, a plastic part may crack as a result of creep strain. This is referred to as creep rupture. The plastic filter housing on the left side in the photograph below failed from creep rupture due to the pressure of the process fluid. The housing on the right shows how the manufacturer redesigned the part with reinforcing ribs to increase its resistance to creep rupture.

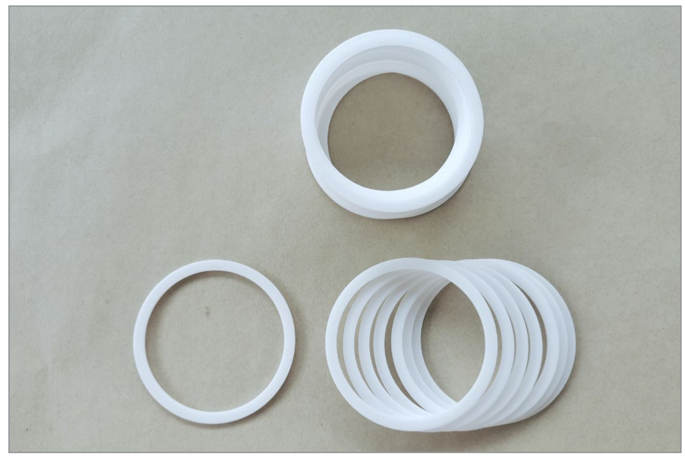
The filter housing on the left failed from creep rupture due to the internal pressure of the process fluid. The design of the housing on the right was modified to include reinforcing ribs for improved creep resistance.

As illustrated in this example, adding reinforcing ribs can dramatically improve the resistance of a plastic part to creep rupture. Adding reinforcements such as glass fibers to the resin also tends to improve the creep resistance of thermoplastic materials.

STRESS RELAXATION

For some applications, such as seals in fluid handling systems and polymer locking elements in mechanical fasteners, the function of the device depends on the material maintaining a certain level of apparent stress when pressed against a mating metal part. Thermoplastic materials will exhibit stress relaxation over time, which can result in part failure. For example, the piping system below was sealed with PTFE gaskets.

This metal piping was assembled using PTFE seals. These exhibited stress relaxation over time, which resulted in leak paths.

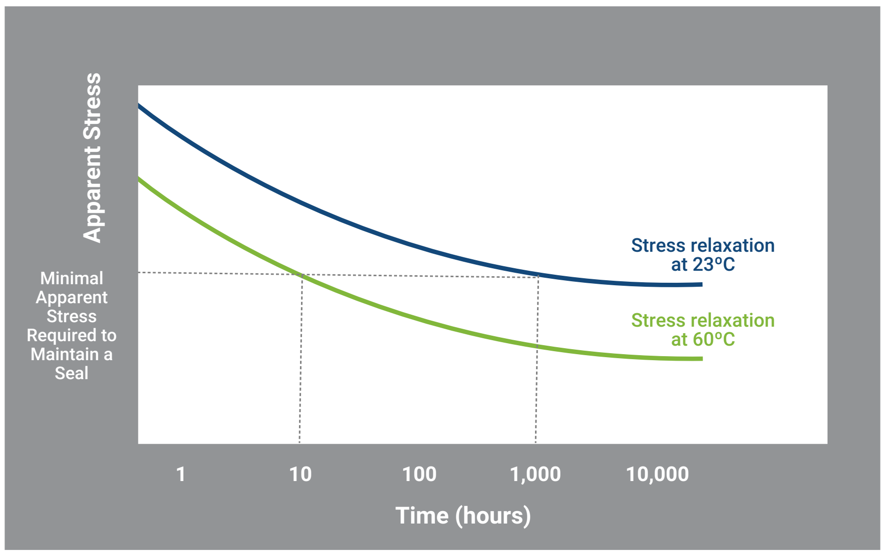


PTFE is often used for seals due to its softness and its ability to conform to mating metal surfaces. However, unfilled PTFE has relatively poor stress relaxation characteristics.

The system maintained a seal for a period of time, but the PTFE eventually relaxed, which resulted in leak paths. Stress relaxation for a plastic occurs more rapidly at elevated temperatures.

The stress relaxation behavior of a thermoplastic material is described by curves such as the ones shown in Figure 2. The minimal apparent stress required to maintain a seal for this particular application is indicated by the gray dashed line.

Figure 2. Stress Relaxation Curves for a Typical Thermoplastic Material



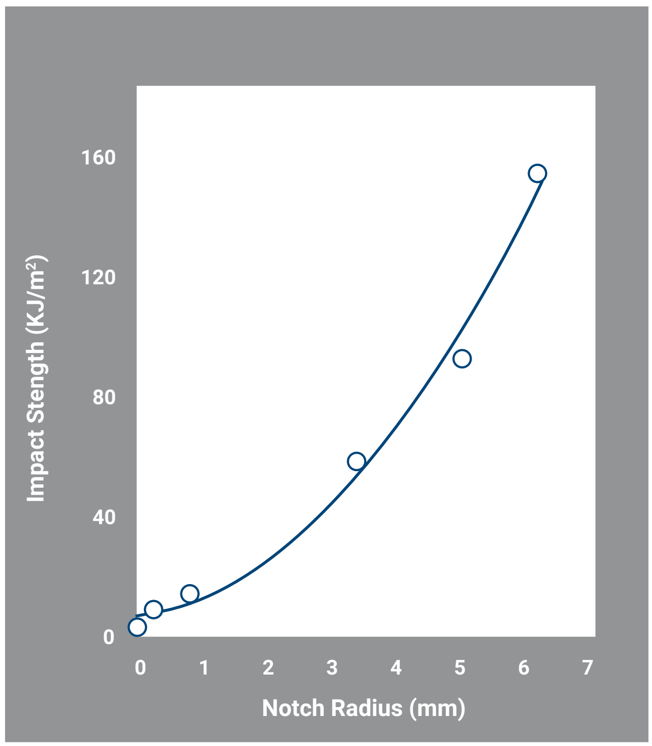
In this example, at room temperature (23°C), the polymer seal would fail due to stress relaxation after 1,000 hours of operation. At 60°C, the seal would fail after only 10 hours.

Reviewing stress relaxation data for the plastics being considered for an application can help to reduce the chance of premature failure due to stress relaxation.

STRESS CONCENTRATIONS

Polymers are very sensitive to stress concentrations from elements of the part geometry and also from assembly fasteners. Figure 3 shows the impact strength of polycarbonate as a function of notch radius. As the notch approaches a sharp corner, the impact strength of the material drops dramatically.

Figure 3. Impact Strength of Polycarbonate as a Function of Notch Radius



Source: Adapted from Notch Sensitivity of Polycarbonate and Toughened Polycarbonate by Kilwon Cho, JaeHo Yang, Byung Il Kang, and Chan, Eon Park. Journal of Applied Polymer Science 89(11): 3115 – 3121.

The broken plastic construction barrier shown below left failed due to the stress concentration associated with a sharp 90 degree internal corner. Adding a generous radius to the corner would dramatically improve the toughness and impact resistance of the part.

This construction barrier failed due to a stress concentration at a sharp 90 degree internal corner.

This plastic floor trim failed due to high hoop stresses from flat head screws.

Stress concentrations from fasteners can also lead to premature plastic part failure. Flat head screws are particularly problematic with plastics since the tapered heads create high levels of hoop stress at the assembly holes. The photograph above right shows plastic floor trim that cracked due to stress concentrations from flat head assembly screws.

Changing to a more “plastic-friendly” fastener such as a pan head or cap head screw with a flat washer to spread the load over a wider area would help to avoid this type of failure.

PREMATURE WEAR

Premature wear is a common cause of plastic part failure for a wide range of applications including plastic bearings, wheels, and the sealing surfaces of actuated valves. A good first step to prevent failure from excessive wear is to identify the mechanism (or mechanisms) of wear that will be operating on the device.

Sliding wear involves two surfaces in direct contact and in relative motion. Putting a low friction additive such as PTFE or oil in the plastic formulation can dramatically improve the wear life of plastic parts that experience this type of wear.

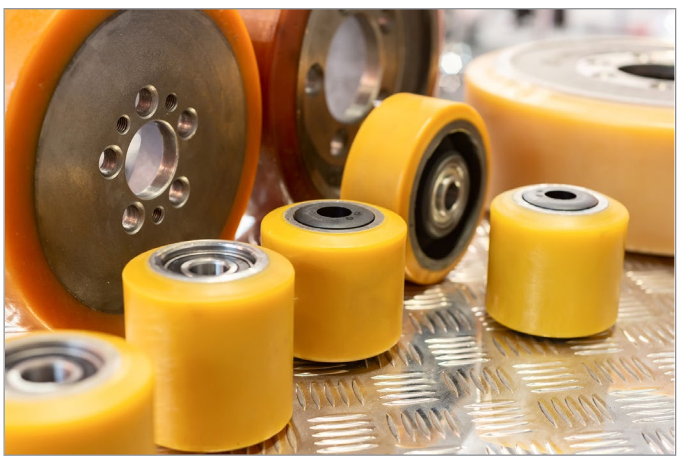
Abrasive wear involves contact with rough surfaces and/or an abrasive materials such as sand or wood chips. Certain polymers such as ultra-high molecular weight polyethylene and harder grades of polyurethane have outstanding resistance to abrasive wear.

Rolling contact fatigue describes the repeated compressive stresses experienced by wheels and rollers as they travel on a surface. Certain polymers such as copolymer acetal and PEEK have excellent rolling contact fatigue resistance.

The photographs show examples of each of these mechanisms of wear.

Sliding wear

Abrasive wear



Rolling contact fatigue

Identifying the mechanisms of wear that are likely to operate for a particular application and then specifying plastic materials and additives that are resistant to those types of wear can help to avoid part failure due to premature wear.

FATIGUE

Fatigue is the result of a plastic part experiencing repeated cyclic stresses. Fatigue failures are typically characterized by the initiation and growth of microscopic cracks that eventually coalesce into larger cracks. This can be problematic if the part fails from fatigue prior to its expected service life. For example, the laundry clothespin shown in the photograph below failed after only a few weeks due to the insufficient fatigue resistance of the part.

This laundry clothespin prematurely failed from flexural fatigue.

High molecular weight plastic resins tend to exhibit longer fatigue life than lower molecular weight grades. Additionally, plastic parts that have few voids and inclusions have fewer sites for crack initiation. Finally, materials can be formulated with elastomeric particles in their formulations to help to slow the growth of micro cracks. Reviewing fatigue data represented on S-N curves for various polymers and then selecting fatigue resistant formulations can help to reduce the chance of premature failure from repeated cyclic stresses.

ENVIRONMENTAL STRESS CRACKING

Environmental stress cracking is the result of exposing a plastic part to a mechanical stress and also a chemical stress crack agent. The typical chemicals that cause ESC are cleaning solutions, adhesives, and lubricants. The chemical plasticizes the polymer and reduces its mechanical properties. The part then subsequently cracks from either external mechanical loads or from internal stresses from manufacturing processes such as molding or machining.

The picture below left shows an acrylic speedometer lens that failed due to ESC. Exposure to aggressive cleaning chemicals and the internal stress from the injection molding process resulted in the failure.

This acrylic speedometer lens failed from environmental stress cracking.

This ABS dentist office light housing failed from ESC. The sharp internal corner created a stress concentration. The cleaning chemical used in the office acted as a stress crack agent.

Part geometry plays a role in ESC since stress concentrations increase the localized stresses on a part. In the example shown above right, an ABS housing for a dentist office work light failed due to ESC. The sharp 90 degree internal corner created a stress concentration and the medical disinfectant spray used in the office acted as a stress crack agent on the material.

Semicrystalline plastics such as polyethylene or polypropylene tend to be more resistant to ESC than amorphous plastics such as polycarbonate or acrylic. Additionally, high molecular weight resins are generally more resistant to ESC than low molecular weight grades.

DEGRADATION FROM OUTDOOR EXPOSURE

Many plastic materials will change color and become brittle when exposed to ultraviolet light over long periods of time. Degradation will tend to be faster at lower latitudes where sunlight strikes the earth at a more direct angle.

The picture below shows a plastic playground slide that experienced color shift from red to pink and also became brittle from exposure to sunlight.

This polyethylene slide exhibited color shift from red to pink and it became brittle and cracked after years of exposure to sunlight.

The slide eventually failed via brittle cracking. Some plastics including acrylic materials and fluoropolymers are inherently UV resistant. For other plastics, additives can be included in their formulations to enhance their UV resistance.

Carefully selecting the base polymer and also formulating the plastic for appropriate UV resistance for the service life of the part can help to prevent premature degradation in outdoor conditions.

The purpose of this paper has been to introduce the reader to some of the more common modes of plastic part failure and to offer some suggestions for avoiding these problems. More detailed information on plastic materials and plastic part design including informative webinars and white papers can be found on Curbell Plastics' website (www.curbellplastics.com).

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

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ABOUT THE AUTHOR

Dr. Keith Hechtel is Senior Director of Business Development for Curbell Plastics. Much of his work involves helping companies to identify plastic materials that can be used to replace metal components in order to achieve quality improvements and cost savings. Dr. Hechtel has over 35 years of plastics industry experience and he is a recognized speaker on plastic materials and plastic part design.

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