

A DESIGN GUIDE

ENGINEERING PLASTICS
MATERIAL SELECTION

LANXESS
Energizing Chemistry

INTRODUCTION

Because of improved quality and cost competitiveness, plastic materials are displacing traditional materials in a myriad of diverse and demanding industries. Today, engineering plastics can be found in virtually every aspect of our lives. From food containers to automobiles, appliances, toys, office equipment, and life-saving medical devices, plastics affect each and every one of us. Product designers and consumers alike acknowledge that today's advanced plastics, in tandem with proper design, add to product value and versatility.



The growing number of thermoplastics – with their combinations of physical and mechanical properties – makes the proper material selection difficult. A resin is judged by any number of criteria – strength, toughness, aesthetics, etc. – depending upon a part's final use. Any particular plastic's performance across these criteria can vary widely.

This manual is designed to help you – the design engineer, product engineer, process engineer, and others who work with plastic materials – select materials for your specific application. It begins with a basic overview of the nature of plastics, then explains the specific tests used to compare and evaluate engineering plastics. We hope this information helps you develop parameters to consider when selecting a group of plastics for further investigation. Many rules of thumb appear in the text. Naturally, there may be some exceptions to these rules of thumb or times when one conflicts with another. If this happens, talk with your mold maker/designer and LANXESS Corporation personnel for appropriate action.

Specific resin data and typical property information have not been included in this manual except as examples for general information. All values that appear in this manual are approximate and are not part of the product specifications. Do not use this data for product specification. For more specific information on a particular resin, please read the appropriate LANXESS Product

Information Bulletin (PIB) as a preliminary step for material selection. Ultimately, material selection must be based upon your prototype testing under actual, end-use conditions. This brochure does not cover part design. While design and material selection are interrelated, we have chosen to discuss part and mold design in a separate manual, *Engineering Plastics: Part and Mold Design Guide*.

Throughout this manual, relevant tests from the American Society for Testing and Measurement (ASTM), the International Standards Organization (ISO), Underwriters' Laboratories (UL), German Standards Institute (DIN), and the International Electro-Technical Commission (IEC) are given, where possible. Efforts were made to include the pertinent tests specified in ISO 10350 – the emerging international standard for polymer properties and test procedures.

While providing a good overview of the topics you should consider when selecting a plastic, this manual does not provide all the information you'll need to make a final resin choice. Final material selection must be based upon prototype testing information and final part testing in actual, in-use settings prior to commercialization. Published data should be used only to screen potential candidate materials.

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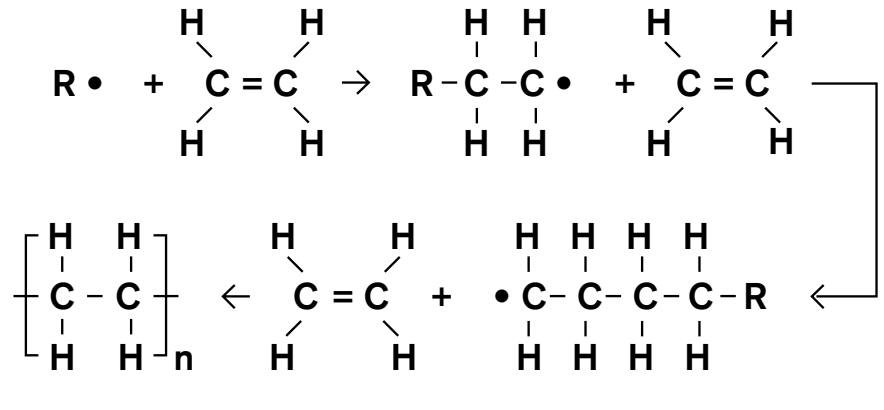
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Figure 1-1

Addition polymerization of ethylene into polyethylene. The growing molecules become commercial-quality polyethylene when the number of repeat units (n) reaches approximately 100,000.



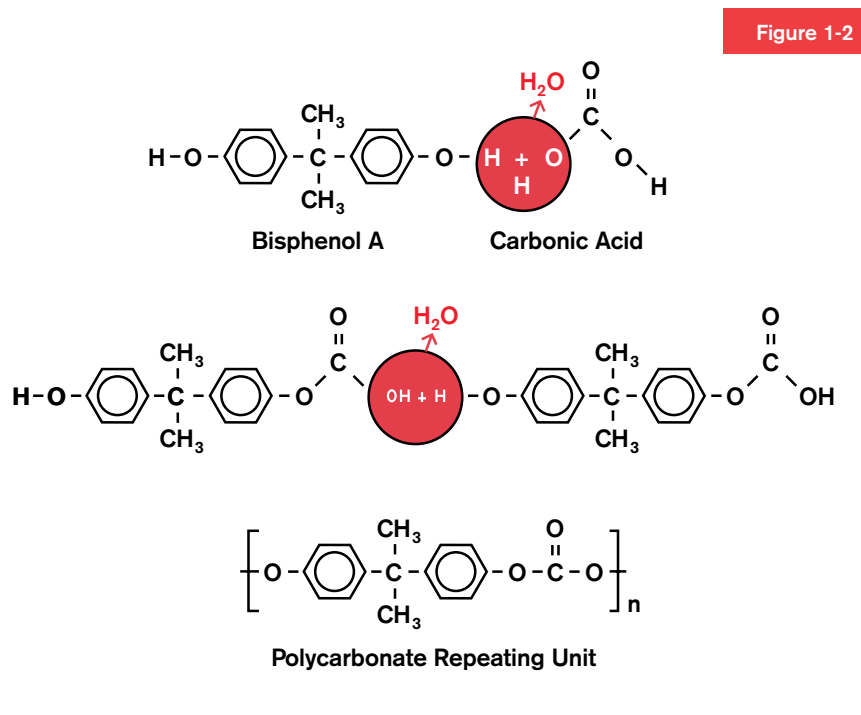
Although plastics appear in nearly every industry and market, few people have training in polymer chemistry and structure. Understanding this basic information will help you select the right resin. This section explains the concepts of polymer chemistry and structure, and shows how these elements affect material properties.

PLASTICS: ORIGINS AND DEFINITIONS

To understand plastic materials, you should have some insight into **polymers**, the building blocks of plastics. Polymers, derived from the Greek term for “many parts,” are large molecules comprised of many repeat units that have been chemically bonded into long chains. Silk, cotton, and wool are examples of natural polymers. In the last 40 years, the chemical industry has developed a plethora of synthetic polymers to satisfy the materials needs for a diversity of products: paints, coatings, fibers, films, elastomers, and structural plastics are examples. Literally thousands of materials can be grouped as “plastics,” although the term today is typically reserved for polymeric materials, excluding fibers, that can be molded or formed into solid or semi-solid objects. **Polymerization**, the process of chemically bonding monomer building blocks to form large molecules, can occur by one of several methods. In **addition polymerization**, a chain reaction adds new monomer units to

the growing polymer molecule one at a time. Each new unit added creates an active site for the next attachment (see figure 1-1). In **condensation polymerization**, the reaction between monomer units or chain end groups releases a small molecule, often water (see figure 1-2). This reversible reaction will reach equilibrium and halt unless this small molecular by-product is removed. Commercial polymer molecules are usually thousands of repeat units long.

Understanding the polymerization process gives insight into the nature of the resulting plastic. For example, plastics made via condensation polymerization, in which water is released, can degrade when exposed to water and high temperatures. Under these conditions, depolymerization occurs, severing the polymer chains.



Condensation polymerization of polycarbonate (PC) via condensation of water. Although not a common commercial process, the reverse of this reaction is the mechanism by which PC can degrade in the presence of water and high heat.

THERMOPLASTICS AND THERMOSETS

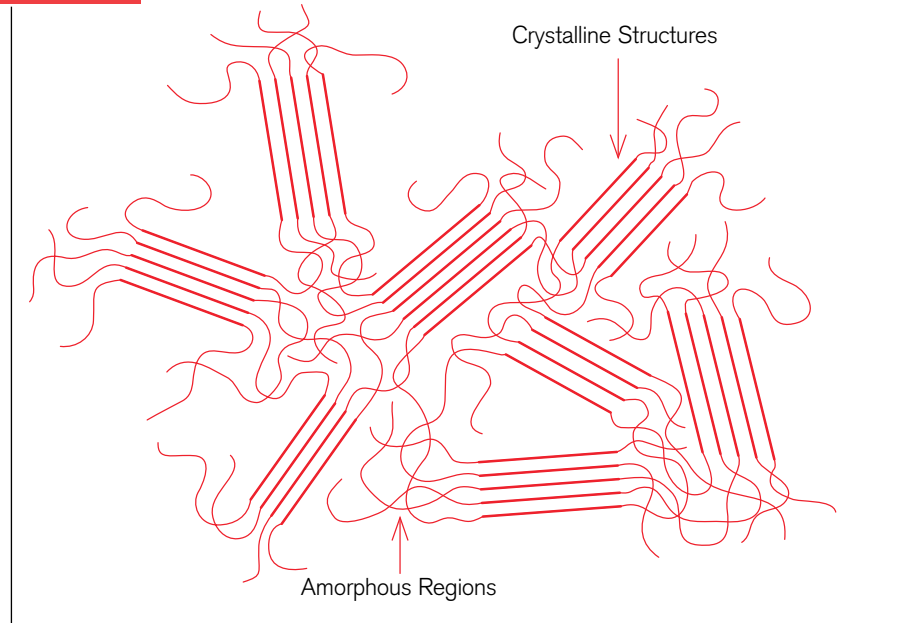
How a polymer network responds to heat determines whether a plastic falls into one of two broad categories: thermoplastics or thermosets. **Thermoplastics** soften and melt when heated and harden when cooled. Because of this behavior, these resins can be injection molded, extruded or formed via other molding techniques. This behavior also allows production scrap – runners and trimmings, for instance – to be reground and reused. Because some degradation or loss of mechanical properties can occur during subsequent remelting, you should limit the amount of recycled resin in the production resin mix. This is particularly true if processing conditions are harsh. See specific LANXESS Product Information Bulletins for the

recommended maximum regrind for a given resin.

Unlike thermoplastics, **thermosets** form cross links, inter-connections between neighboring polymer molecules that limit chain movement. This network of polymer chains tends to degrade, rather than soften, when exposed to excessive heat. Until recently, thermosets could not be remelted and reused after initial curing. Today's most-recent advances in recycling have provided new methods for remelting and reusing thermoset materials.

Figure 1-4

In crystalline resins, a percentage of the polymer chains orient into ordered, crystalline structures.



CRYSTALLINE AND AMORPHOUS

Thermoplastics are further classified by their **crystallinity**, or the degree of order within the polymer's overall structure. As a crystalline resin cools from the melt, polymer chains fold or align into highly ordered crystalline structures (see figure 1-4). Generally, polymer chains with bulky side groups cannot form crystalline configurations.

The degree of crystallinity depends upon both the polymer and the processing technique. Because of molecular structure, some polymers – such as polyethylene – crystallize quickly and reach high levels of crystallinity. Others, such as PET polyester, require longer times in a hot mold to crystallize. If cooled

quickly, PET polyester remains amorphous in the final product, such as in beverage bottles. Because most crystalline polymers have both amorphous and crystalline regions, they exhibit both a **glass transition temperature**, the melting temperature range in the non-crystalline region, and a **crystalline melt temperature**, the typically distinct melting temperature in the crystalline region. Crystalline thermoplastics must be heated above the resin's crystalline-melt temperature for extrusion and injection molding.

Amorphous polymers, ones with little or no crystallinity, have random chain entanglements and lack a discrete melting point. As they are exposed to heat, these polymers soften and become more fluid-like, allowing the polymer chains to slide past one another. As the polymer cools, chain movement diminishes, and the polymer's viscosity increases. Generally, the higher a polymer's glass transition temperature, the better it will perform at elevated temperatures. As a rule, **transparent plastics** – those used in headlight lenses and lighting fixtures, for example – are amorphous rather than crystalline. The most common transparent thermoplastics include polycarbonate, polystyrene, and poly(methyl)methacrylate.

Crystalline and amorphous plastics have several characteristic differences. The force to generate flow in amorphous materials diminishes slowly as the temperature rises above the glass transition temperature. In crystalline resins, the force requirements diminish quickly as the material is heated above its crystalline melt temperature (see figure 1-5). Because of these easier flow characteristics, crystalline resins have an advantage in filling thin-walled sections, as in electrical connectors. Additionally, these resins generally have superior chemical resistance, greater stability at elevated temperatures and better creep resistance. Amorphous plastics typically exhibit greater impact strength, less mold shrinkage, and less final-part warping than crystal-

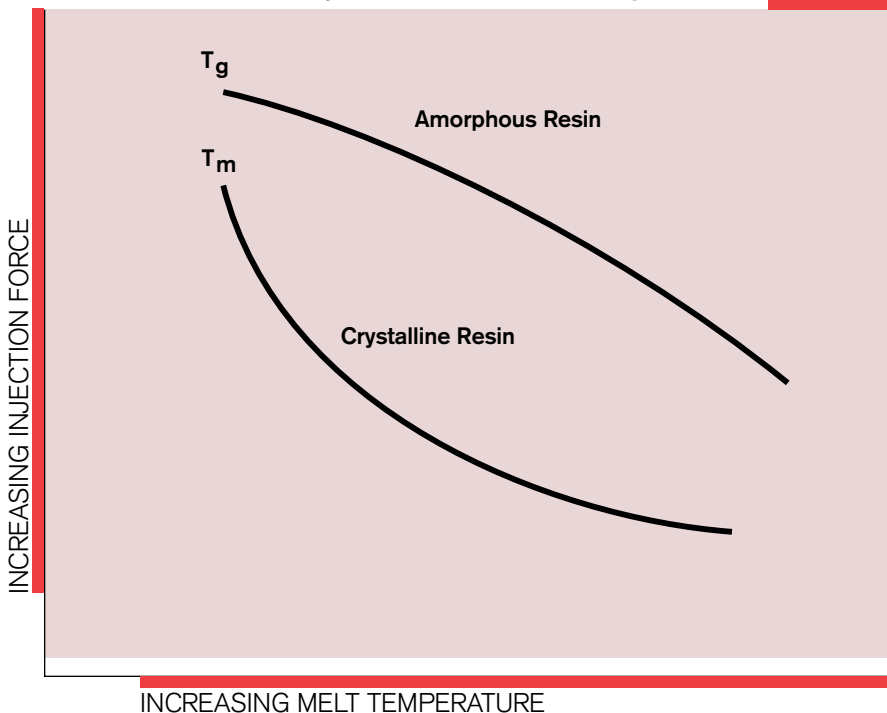
line counterparts. End-use requirements usually dictate whether an amorphous or crystalline resin is preferred.

BLENDS

Blending two or more polymers offers yet another method of tailoring resins to your specific application. Because blends are only physical mixtures, the resulting polymer usually has physical and mechanical properties that lie somewhere between the values of its constituent materials. For instance, an automotive bumper made from a blend of polycarbonate resin and a thermoplastic polyurethane elastomer gains rigidity from the polycarbonate resin and retains most

Injection Force vs. Temperature

Figure 1-5



The force required to generate flow in a mold diminishes slowly above the glass transition temperature (T_g) in amorphous thermoplastics, but drops quickly above the crystalline melt temperature (T_m) in crystalline resins.

of the flexibility and paintability of the polyurethane elastomer. For business machine housings, a blend of polycarbonate and ABS resins offers the enhanced performance of polycarbonate – flame retardance and UV stability – at a lower cost.

Occasionally, blended polymers have properties that exceed those of the constituents. For instance, blends of polycarbonate resin and PET polyester, originally created to augment the chemical resistance of polycarbonate, actually have fatigue resistance and low-temperature impact resistance superior to either of the individual polymers.

COPOLYMERS AND TERPOLYMERS

Unlike blends, or physical mixtures of different polymers, **copolymers** contain repeat units from two polymers within their molecular chain structure, such as acetal resin, styrene acrylonitrile (SAN), and styrene butadiene. In **terpolymers**, polymers with three different repeat units, individual components can also be tailored to offer a wide range of properties. An example is ABS, a terpolymer containing repeat units of acrylonitrile, butadiene, and styrene.

MOLECULAR WEIGHT

A polymer's molecular weight, the sum of the weights of individual atoms that comprise a molecule, indicates the average length of the bulk resin's polymer chains. Low-molecular-weight polyethylene chains have backbones as small as 1,000 carbon atoms long. Ultrahigh-molecular-weight polyethylene chains can have 500,000 carbon atoms along their length. Many plastics – polycarbonate, for instance – are available in a variety of chain lengths, or different molecular-weight grades. These resins can also be classified by an indirect viscosity value, rather than molecular weight. Within a resin family, higher-molecular-weight grades have higher viscosities. For example, in the viscosity test for polycarbonate, the **melt flow rate** ranges from approximately 4 g/10 min. for the highest-molecular-weight, standard grades to more than 60 g/min. for lowest-molecular-weight, high-flow, specialty grades.

Selecting the correct molecular weight for your injection-molding application generally involves a balance between filling ease and material performance. If your application has thin-walled sections, a lower-molecular-weight/ lower-viscosity grade offers better flow. For normal wall thicknesses, these resins also offer faster mold-cycle times and fewer molded-in stresses. The stiffer-flowing, high-molecular-weight resins offer the ultimate material performance, being tougher and more resistant to chemical and environmental attack.

FILLERS AND REINFORCEMENTS

Often, fibrous materials, such as glass or carbon fibers, are added to resins to create reinforced grades with enhanced properties. For example, adding 30% short glass fibers by weight to nylon 6 improves creep resistance and increases stiffness by 300%. These glass-reinforced plastics usually suffer some loss of impact strength and ultimate elongation, and are more prone to warping because of the relatively large difference in mold shrinkage between the flow and cross-flow directions.

Plastics with non-fibrous fillers – such as spheres or powders – generally exhibit higher stiffness characteristics than unfilled resins, but not as high as glass-reinforced grades. Resins with particulate fillers are less likely to warp and show a decrease in mold shrinkage. Particulate fillers typically reduce shrinkage by a percentage roughly equal to the volume percentage of filler in the polymer, an advantage in tight-tolerance molding. When considering plastics with different amounts of filler or reinforcement, you should compare the cost per volume, rather than the cost per pound. Most fillers increase the material density; therefore, increasing filler content usually reduces the number of parts that can be molded per pound.

SHRINKAGE

As a molded part cools and solidifies, it usually becomes smaller than its mold cavity. Shrinkage characteristics affect molding costs and determine a part's dimensional tolerance limit. Materials with low levels of isotropic shrinkage typically provide greater dimensional control, an important consideration in tight-tolerance parts. The exact amount of this **mold shrinkage** depends primarily upon the particular resin or system used. For instance, semi-crystalline thermoplastics generally show higher levels of shrinkage than amorphous thermoplastics because of the volume reduction during crystallization.

Other factors – including part geometry, wall thickness, processing, use and

type of fillers, and gate location – also affect shrinkage. For instance:

- Holes, ribs and similar part features restrain shrinking while the part is in the mold and tend to lower overall shrinkage.
- Shrinkage generally increases with wall thickness and decreases with higher filling and packing pressures.
- Areas near the filling gate tend to shrink less than areas further away.
- Particulate fillers, such as minerals and glass spheres, tend to reduce shrinkage uniformly in all directions.
- Fibrous fillers, such as glass or carbon fibers, decrease shrinkage primarily in the direction of flow. Fiber-filled parts often shrink two to three times more in the cross-flow versus the flow direction.

Post-mold shrinkage, additional shrinking that may appear long after molding, occurs often in parts that were processed to reduce initial shrinkage and later are exposed to elevated temperatures. Over time, molded-in stresses will relax, resulting in a size reduction. Elevated temperatures can also lead to solid-state crystallization and additional shrinkage in some semi-crystalline materials.



ADDITIVES

Additives encompass a wide range of substances that aid processing or add value to the final product, including antioxidants, viscosity modifiers, processing aids, flame retardants, dyes and pigments, and UV stabilizers. Found in virtually all plastics, most additives are incorporated into a resin family by the supplier as part of a proprietary package. You can select some additives by specifying optional grades to maximize performance for your specific application. For example, you can choose standard polycarbonate resin grades with additives for improved internal mold release, UV stabilization, and flame retardance; or nylon grades with additives to improve impact performance.

Additives often determine the success or failure of a resin or system in a particular application. Two common additives are discussed below. Before making your final material selection, you should discuss your part and its requirements with your LANXESS representative.

Combustion Modifiers

Combustion modifiers are added to polymers to help retard the resulting parts from burning. Generally required for electrical and medical-housing applications, combustion modifiers and their amounts vary with the inherent flammability of the base polymer.

Flammability results are based upon small-scale laboratory tests. Use these ratings for comparison purposes only, as they may not accurately represent the hazard present under actual fire conditions.

Release Agents

External **release agents** are lubricants, liquids or powders that coat a mold cavity to facilitate part removal. Internal release agents, usually proprietary to the system producer, find use in many plastic materials.





VISCOELASTICITY

Plastics offer a wide range of mechanical properties, as well as some unusual mechanical behaviors. Changes in the polymer repeat units, chain length, crystallinity, or level of cross-linking can yield materials with properties ranging from strong to weak, brittle to tough, or stiff to elastic. Under certain conditions – such as elevated temperatures and/or long-term loading – plastics behave quite differently from other engineering materials. This section discusses the unusual mechanical behavior of plastics and how to address these issues when designing parts for your application.

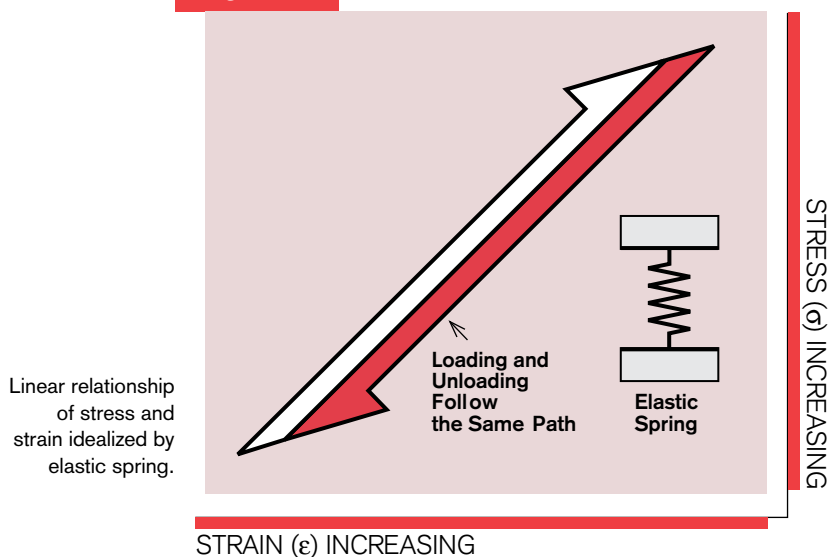
Plastics have a dual nature, displaying characteristics of both a viscous liquid and a spring-like elastomer, or traits known as **viscoelasticity**. This duality accounts for many of the peculiar mechanical properties found in plastics. Under mild loading conditions – such as short-term loading with low deflections and small loads at room temperatures – plastics usually respond like a spring, returning to their original shape after the load is removed. No energy is lost or dissipated during this purely **elastic behavior**: Stress versus strain remains a linear function (see figure 2-1). Increasing the applied load adds a proportional increase to the part's deflection.

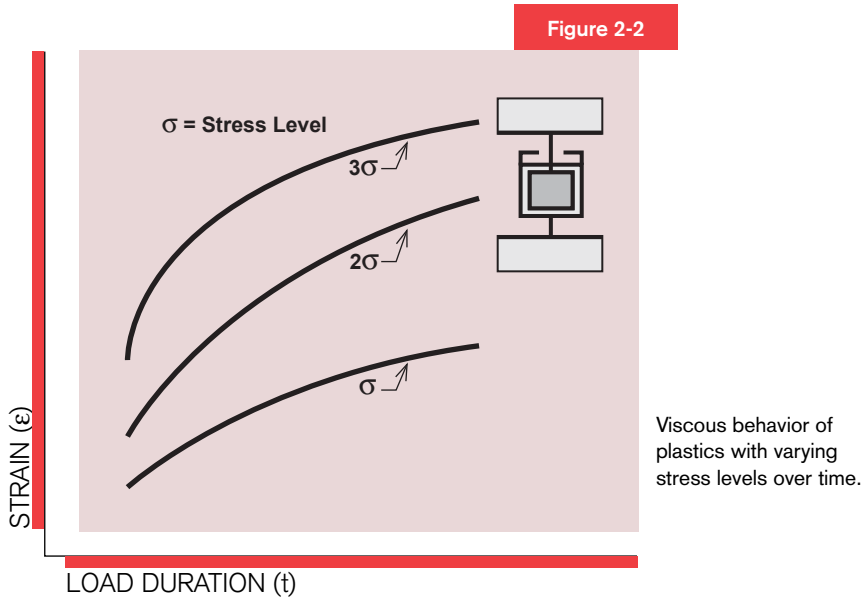
Many plastics exhibit a **viscous behavior** under long-term heavy loads or elevated temperatures. While still solid, plastics will deform and flow similarly to a very high-viscosity liquid. To understand this viscous

behavior, you must understand two terms: **strain**(ϵ) and **stress**(σ). Strain is measured in percent elongation; stress is measured in load per area. Typical viscous behavior for tensile loading shows that strain resulting from a constant applied stress increases with time as a non-linear response to these conditions (see figure 2-2). This time-and-temperature-dependent behavior occurs because the polymer chains in the part slip and do not return to their original position when the load is removed.

The “**Voigt-Maxwell**” model of springs and dashpots illustrates these viscoelastic characteristics (see figure 2-3). The spring in the Maxwell model represents the instantaneous response to loading and linear recovery when the load is removed. The dash-pot connected to the spring simulates the permanent deformation that

Figure 2-1 Stress-Strain Behavior





occurs over time. The Voigt model shows the slow deformation recovery after the load is removed. While it is not a practical model for structural design use, the “Voigt-Maxwell” model offers a unique way to visualize viscoelastic characteristics.

CREEP

One of the most important consequences of plastics' viscoelastic behavior, **creep**, is the deformation that occurs over time when a material is subjected to constant stress at a constant temperature. Under these conditions, the polymer chains slowly slip past one another. Because some of this slippage is permanent, only a portion of the creep deformation can be recovered when the load is removed.

The tensile test in figure 2-4 clearly demonstrates creep. A weight hung from a plastic tensile bar will cause initial deformation “d” increasing the bar’s length. Over an extended period of time, the weight causes more elongation, or creep “c.”

If you are designing parts for long-term loading, particularly for elevated-temperature service, you must account for creep characteristics. See LANXESS’ manual, *Engineering Plastics: Part and Mold Design Guide* for using long-term creep data in designing plastic parts.

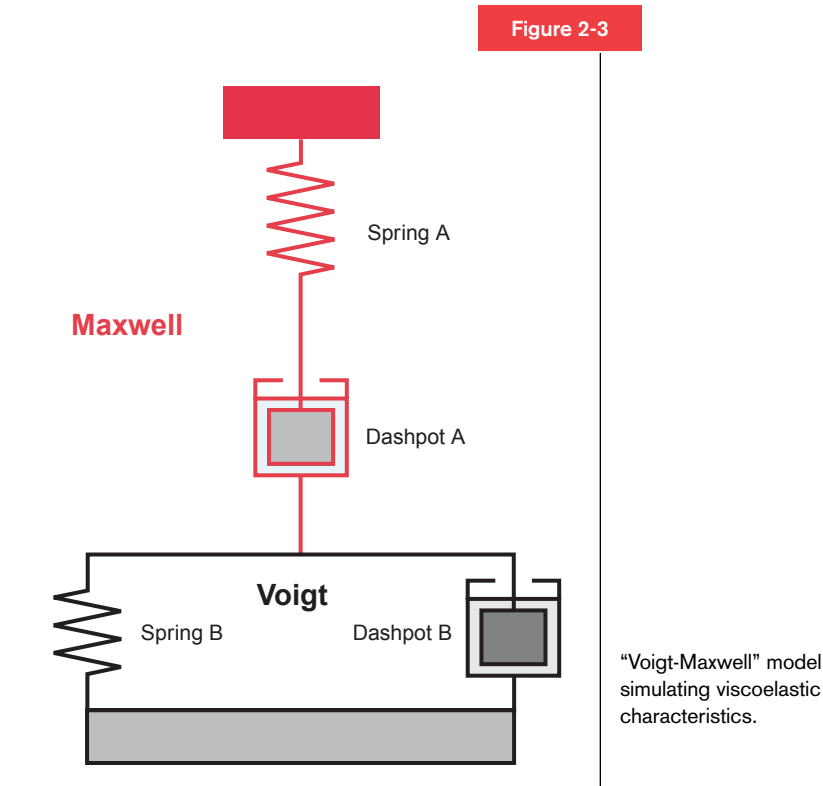
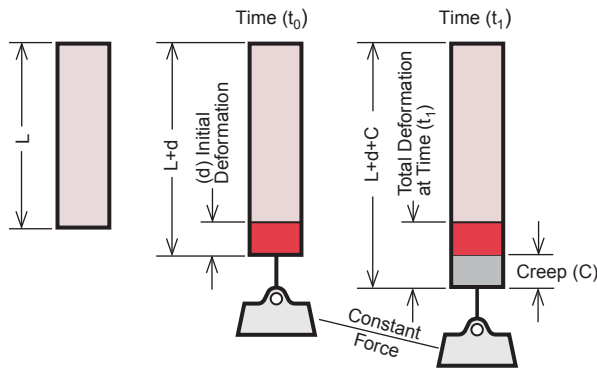


Figure 2-4

Creep Phenomenon



Under a constant load, deformation increases over time.

STRESS RELAXATION

Another viscoelastic phenomenon, **stress relaxation**, is defined as a gradual decrease in stress at constant strain and temperature. Because of the same polymer-chain slippage found in creep, stress relaxation occurs in simple tension, as well as in parts subjected to multi-axial tension, bending, shear, and compression. The degree of stress relaxation depends upon a variety of factors, including load duration, temperature, and types of stress and strain.

Figure 2-5 shows that a large weight initially produces elongation “d” and a strain, d/L (L = original length). To maintain the same elongation and strain in the test bar over time, less weight is needed because of stress relaxation.

Simply stated:

- In the creep example, elongation continues as the weight remains constant;

- In the stress relaxation example, the weight is reduced to maintain the elongation.

If you are designing parts that will be subjected to a constant strain, you should account for stress relaxation. A typical press fit, such as a metal insert in a plastic boss, relies upon stresses from the imposed strain of an

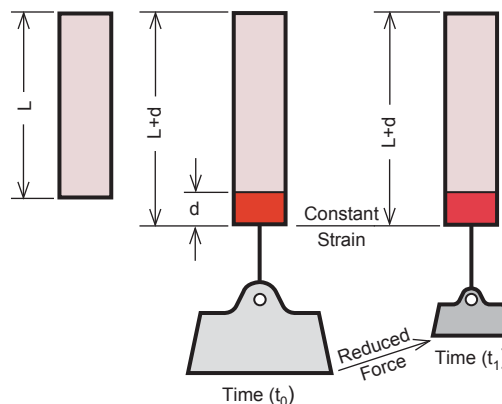
interference fit to hold the insert in place. However, polymer-chain slippage can relax these stresses and reduce the insert retention strength over time. A method for calculating the degree of stress relaxation for simple shapes is explained in LANXESS' *Engineering Plastics: Part and Mold Design Guide*.

RECOVERY

The degree to which a plastic material returns to its original shape after a load is removed is defined as its **recovery**. Involving many factors, most of which are shape- and application-specific, recovery characteristics are extremely difficult to predict. By way of example, refer to figure 2-6. In this example, strain is plotted versus time. The strain (deformation) from a load applied to a plastic part produces an initial strain (point A). Over time, creep causes the strain to increase (point B). When the load is removed, the strain immediately drops (point C). From this point, if full recovery

Stress Relaxation

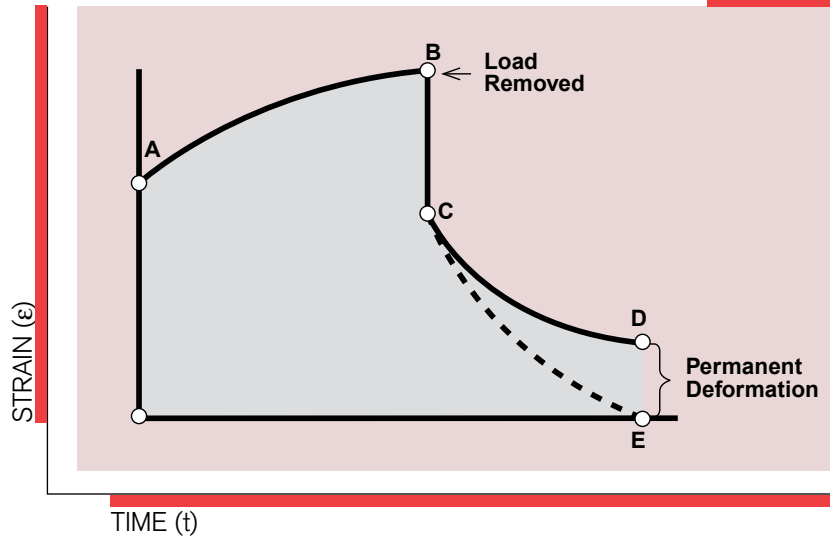
Figure 2-5



Over time a smaller load is required to maintain constant deformation.

Load and Recovery Behavior

Figure 2-6



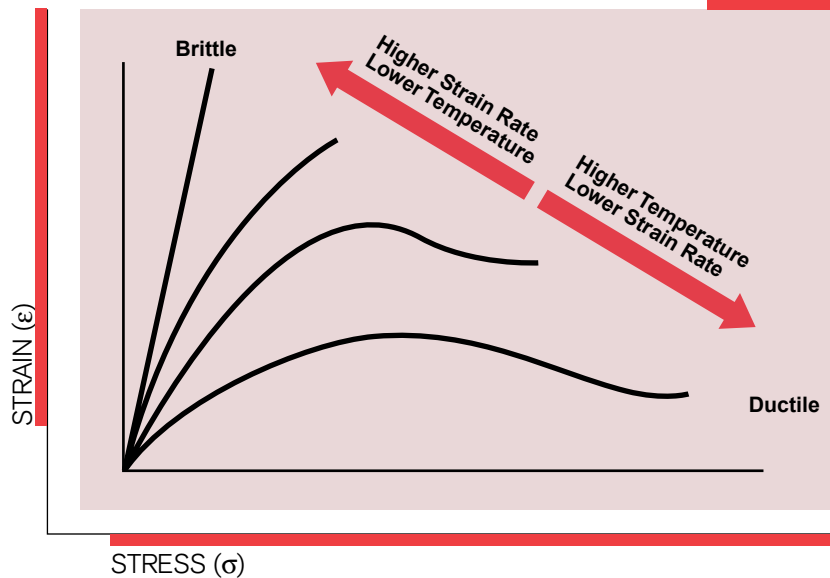
were possible, the part might return to original size (point E). More commonly, the part retains some permanent deformation (point D).

LOADING RATE

The rate at which a part is stressed, the **loading rate**, greatly affects the mechanical behavior of plastics. Parts are exposed to a variety of loading rates throughout their life cycle: from very low, static loading to high-speed impact loading. In general, thermo-plastics become stiffer and fail at smaller strain levels as the strain rate increases (see figure 2-7). Increasing the plastic's temperature usually has the opposite effect: At higher temperatures, plastics lose their stiffness, becoming more ductile. When selecting materials, you will normally have to compromise between having acceptable impact strength at the lower end of the application's temperature range, and maintaining the proper stiffness and creep resistance at the upper end of the temperature range.

Brittle and Ductile Behavior

Figure 2-7



Effects of strain rate and temperature on material behavior.

"Voigt-Maxwell" model
simulating viscoelastic
characteristics.

FACTORS AFFECTING
MECHANICAL PROPERTIES

Most of this manual defines and explains material property data found in material-specific data sheets. These Product Information Bulletins (PIBs), which describe the general properties of the materials, are useful for screening materials, and provide data for estimating finished-part performance. You should remember that these data are generated in a laboratory under a

narrow set of conditions and cannot cover all production environments. Many factors encountered in actual production and final use can alter material performance, in particular the mechanical properties. This section discusses the major factors that affect the mechanical properties of plastic parts.

Processing

Published property data is derived from testing standardized test plaques, molded under optimum processing conditions. Improper processing can degrade plastics, changing certain mechanical-property performance, such as impact strength and elongation at break. If material is improperly processed, the resulting mechanical performance may differ significantly from published values.

Common thermoplastic molding errors that can affect mechanical properties include excessive melt temperature, inadequate resin drying prior to molding, excessive residence time in the press barrel, and inadequate gate size. Keep injection speeds, as well as mold and melt temperatures, within published parameters. Insufficient injection speed or cold melt temperature causes cold flow fronts that can lead to weak weld lines and high levels of molded-in stress. Additionally, crystalline resins usually require higher mold temperatures to fully crystallize. Using lower mold temperatures can decrease crystallinity, as well as reduce stiffness and chemical resistance, while increasing ductility and impact strength.

Published data applies to material processed within recommended parameters. If you have questions, call your LANXESS representative.

Thermoplastic Regrind

Scrap thermoplastic produced during the molding process – sprue and runner systems, partially filled parts, rejected parts, etc. – can be reused. Typically, this scrap is chopped up into small pellet-sized pieces, called **regrind**, and mixed with virgin material to produce more parts.

When regrind has been remelted several times, as can happen when scrap and runners are repeatedly fed back into the press, it can become badly degraded. **Regrind** is also vulnerable to contamination and/or abusive processing, which can adversely affect the mechanical and cosmetic properties. For these reasons, you should limit the ratio of regrind to virgin material and completely avoid using it in critical applications or when resin properties must be equivalent to virgin-material properties. Closely monitor part quality when using regrind in the mix to assure adequate material and end-use properties.

Weld Lines

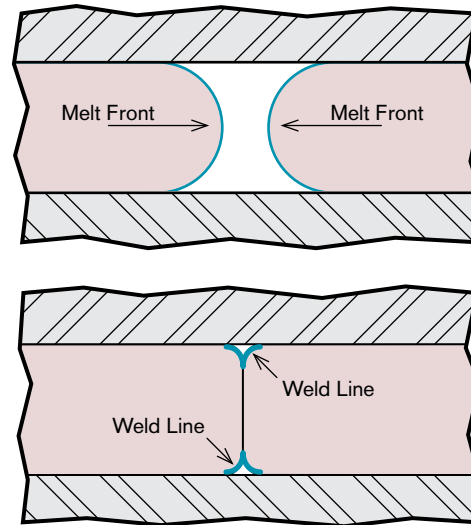
The hairline grooves on the surface of a molded part where flow fronts join during filling, called **weld lines** or **knit lines**, cause potential cosmetic flaws and reduced mechanical performance (see figure 2-8). Because few polymer chains cross the boundary when the flow fronts butt, the tensile and impact strength in the weld-line area is reduced. The resulting notches on the weld line also act as stress concentrators, further reducing impact strength.

Additionally, if the flow fronts are covered with a film from additives or a layer of impurities, they may not bind properly, which again can reduce impact and tensile strength.

Weld-line strength in thermoplastics varies with specific resin and processing parameters, such as flow-front temperature, distance from the gate, filling pressure, and level of packing.

Figure 2-8

Weld Lines

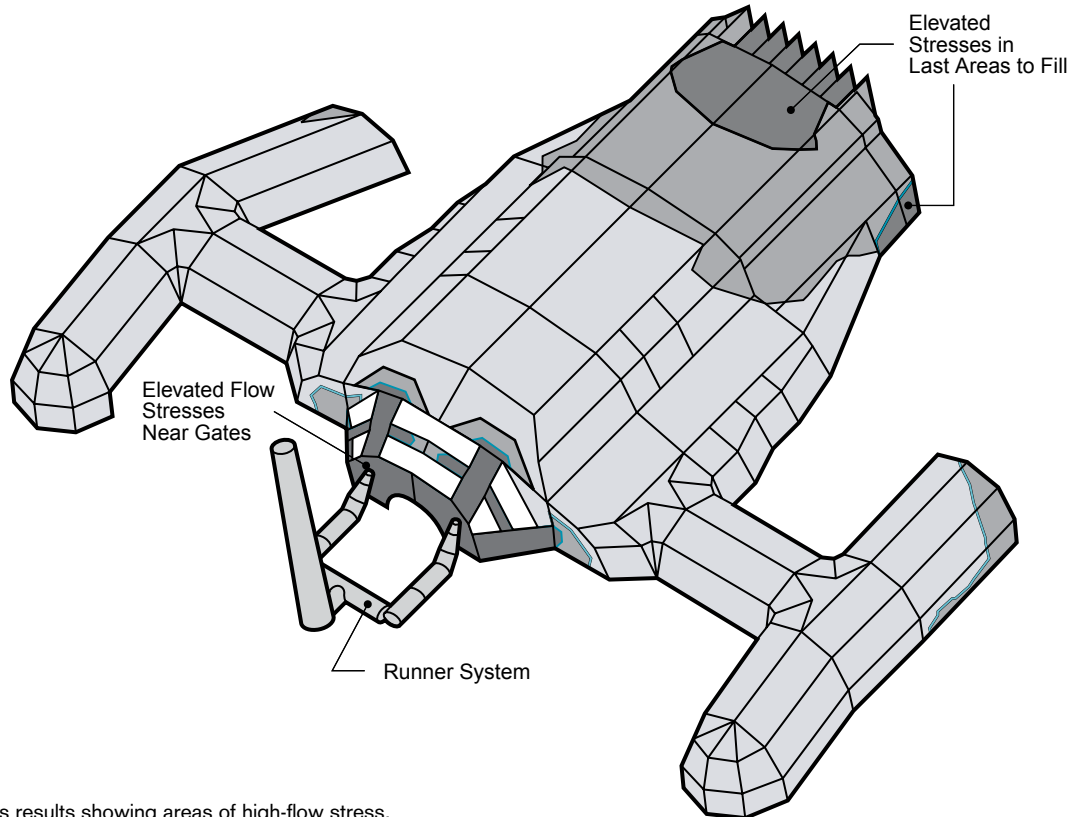


Merging melt fronts (cross-sectional view).



Flow Stresses

Figure 2-9



Filling-analysis results showing areas of high-flow stress.

Use published tensile and impact strength data cautiously, because most is based upon test samples molded without weld lines. Contact your LANXESS representative for this data or if you have any questions regarding weld line strength for a specific resin and application.

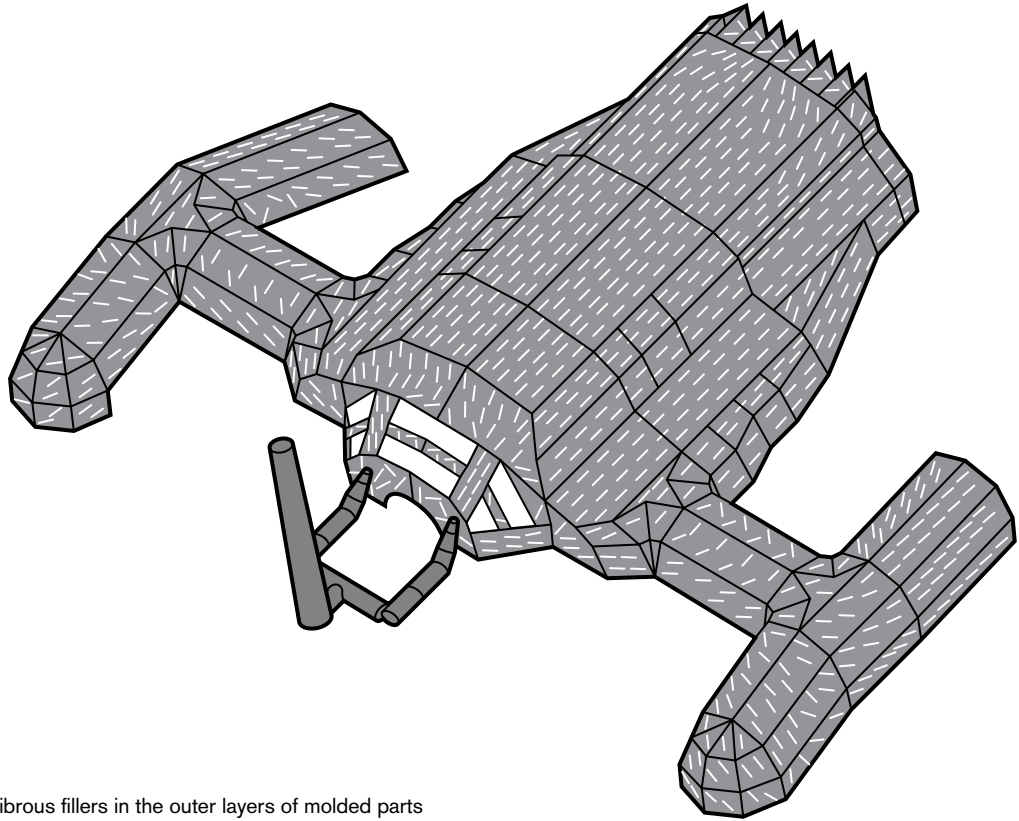
Residual Stress

Molding factors – such as uneven part cooling, differential material shrinkage, or “frozen-in” flow stresses – cause undesirable residual stresses in molded thermoplastics (see figure 2-9). High levels of residual stress can adversely affect certain mechanical properties, as well as chemical resistance and dimensional stability. Based upon simple injection-molded samples, published property data reflects relatively low levels of residual stress.

When molded-in tensile stresses on a part’s surface are exceptionally high, as in parts where the geometry has extremely thin walls or dramatic thickness variations, impact and tensile strength can be reduced. Avoid high-stress features, because the molded-in stresses and their ultimate effect on mechanical performance can be difficult to predict. Certain stress-analysis techniques, such as solvent-stress testing, locate areas of high residual stress, but only after the mold has been built and mechanical problems may have developed.

Figure 2-10

Fiber Orientation



Polymer chains and fibrous fillers in the outer layers of molded parts tend to align in the direction of flow during molding.

Orientation

As a molten thermoplastic fills a mold, its polymer chains tend to align with the direction of the flow (see figure 2-10). Part thickness and a variety of processing variables – injection speed, mold temperature, melt temperature, and hold pressure – determine how much of this flow orientation remains in the solidified part. Most molded parts retain enough orientation to show small but noticeable differences in material properties between the flow and cross-flow directions at any

location. Generally, mechanical properties in the cross-flow direction are lower than those in the flow direction. Although usually unnoticed in the aggregate, directional differences can affect mechanical performance in parts where polymer chains align uniformly along or across structural features.

The glass fibers in outer layers of glass-reinforced plastics tend to align in the direction of flow, resulting in higher tensile strength and stiffness in

this direction. They also exhibit greater resistance to shear forces acting across the fibers. Generally, fiber-filled materials have much higher shrinkage in the cross-flow than in the flow direction. Cross-flow shrinkage can be as much as two to three times greater. Address these orientation effects in both mold and part design. In many cases, careful processing and optimum gate placement can reduce or eliminate mechanical problems associated with orientation in injection-molded parts.

Water Absorption

Many plastics are hygroscopic: Over time they absorb water. Too much moisture in a thermoplastic resin during molding can degrade the plastic and diminish mechanical performance. Follow your resin supplier's drying procedures to prevent this problem.

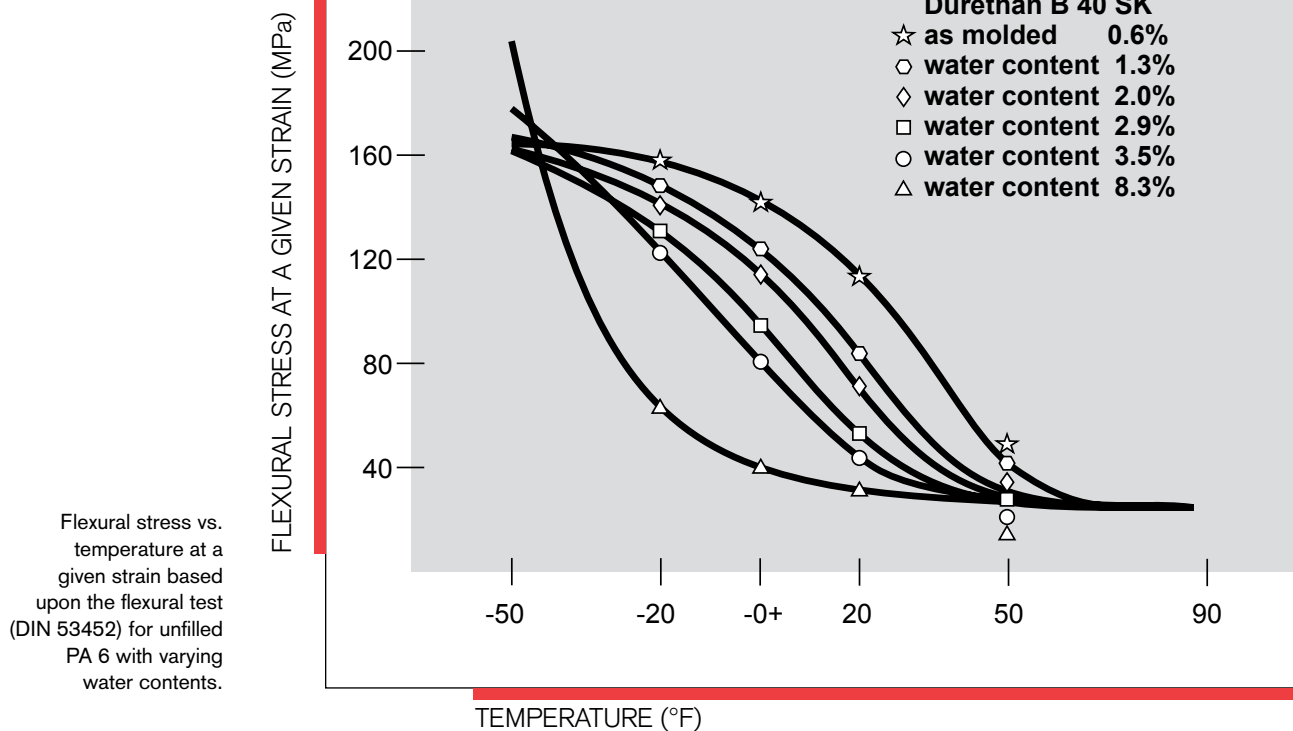
Additionally, water absorbed after molding can harm mechanical properties in certain resins under specific conditions. Through a process called

hydrolysis, water in the resin severs the polymer chains, reduces molecular weight, and decreases mechanical properties. Longer exposure times at elevated temperatures and/or loads worsen hydrolytic attack.

Water absorption can also change the physical properties of **polyamide resins** (nylons) without degrading them. Some polyamides absorb relatively large amounts of moisture, causing them to swell. Volumetric and linear increases of 0.9% and 0.3% respectively, for each 1% of absorbed

water are common. At the same time, these materials show increased toughness and reduced stiffness (see figure 2-11). Other mechanical and electrical properties may also change significantly with increased moisture content. These changes are reversible: The mechanical properties will revert to their original values when the part is dried. For more information, read the technical data sheet for your Durethan® polyamide resin for property data on both dry and moisture-conditioned samples.

Figure 2-11



Chemical Exposure

The effects of chemical exposure on a specific resin can range from minor mechanical property changes to immediate catastrophic failure. The degree of chemical attack depends upon a number of factors: the type of resin, the chemical in contact, chemical concentration, temperature, exposure time, and stress level in the molded part, to name a few of the more common. Some plastics can be vulnerable to attack from families of chemicals,

such as strong acids or organic solvents. In other instances, a resin may be vulnerable to a specific or seemingly harmless chemical. Verify a material's resistance to all the chemicals to which it will be exposed during processing, assembling, and final use.

Weathering

The effects of outdoor weather – particularly ultraviolet (UV) radiation – on a plastic's appearance and properties

can range from a simple color shift to severe material embrittlement. After several years in direct sun, most plastics show reduced impact resistance, lower overall mechanical performance, and a change in appearance. LANXESS has weathering data for aesthetic properties. Data for mechanical degradation is less common.

If you are designing a structural part that will be exposed to sunlight, contact your LANXESS representative for weathering data.





Mechanical properties – stiffness, hardness, toughness, impact strength, and ability to support loads – are important in most plastic applications. Mechanical property data is used regularly to preselect materials, estimate part performance, and predict deformations and stresses from applied loads. Examples of these and other calculations showing the use of this data can be found in LANXESS' Engineering Plastics: Part and Mold Design Guide.

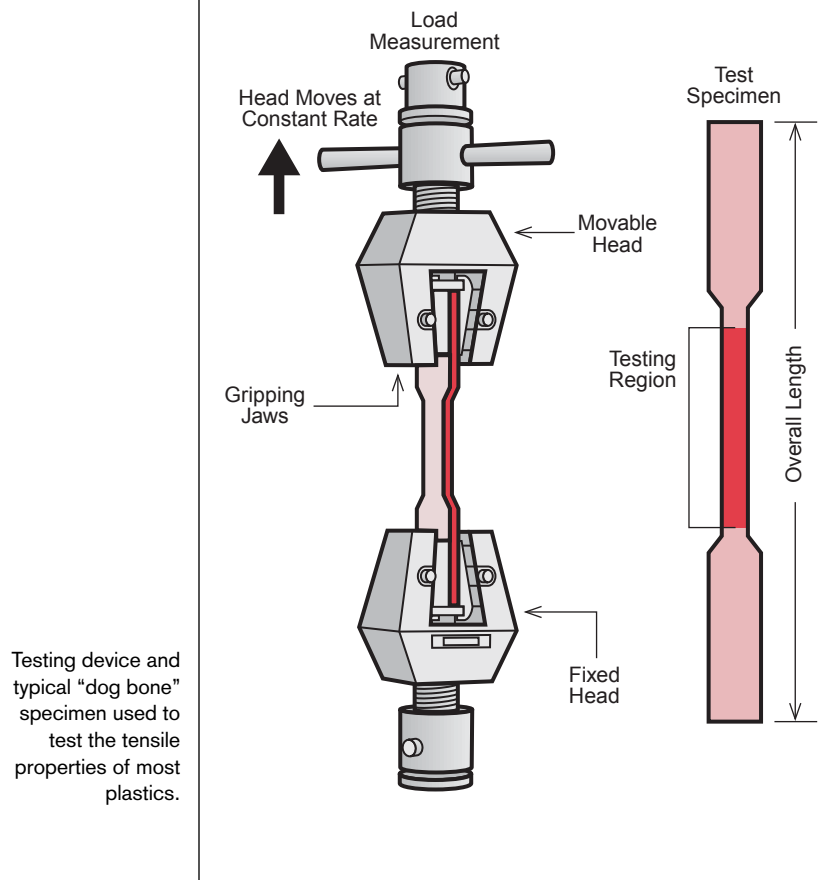
As previously mentioned, test results found in most technical data sheets have been derived from laboratory tests and may not directly apply to your specific part or application. This data should be used for comparison purposes only, because real-world application factors such as environment, temperature, and loading rate also affect material performance.

LANXESS' material property values and limits are given at face value – no safety factors or margins for error have been built-in. Use these data conservatively with appropriate safety margins to account for:

- Differences between testing and end-use conditions;
- Material and processing variability;
- Unforeseen environmental or loading stresses.

See LANXESS' part and mold design guide for further discussions of design and application safety factors.

Figure 3-1 Tensile Tester

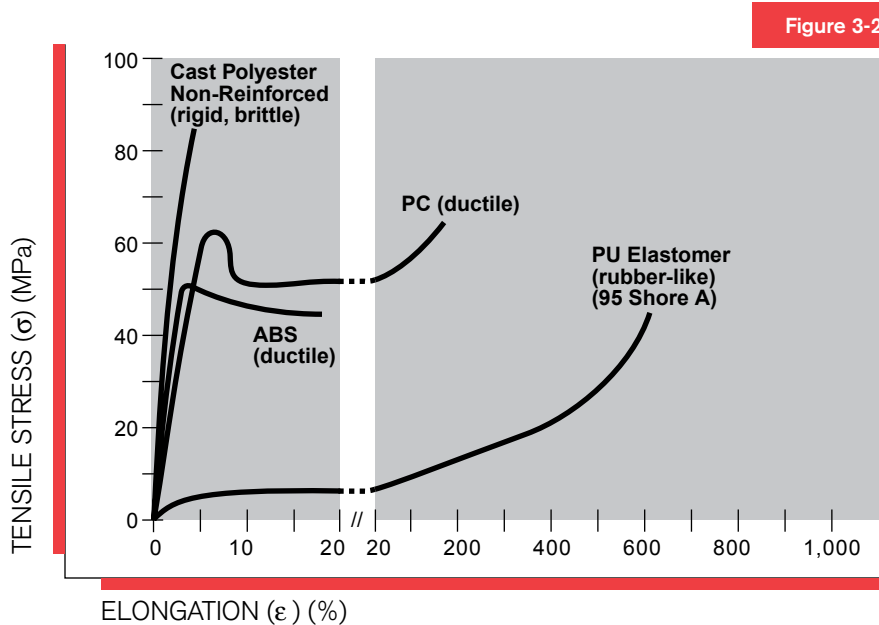


SHORT-TERM MECHANICAL PROPERTIES

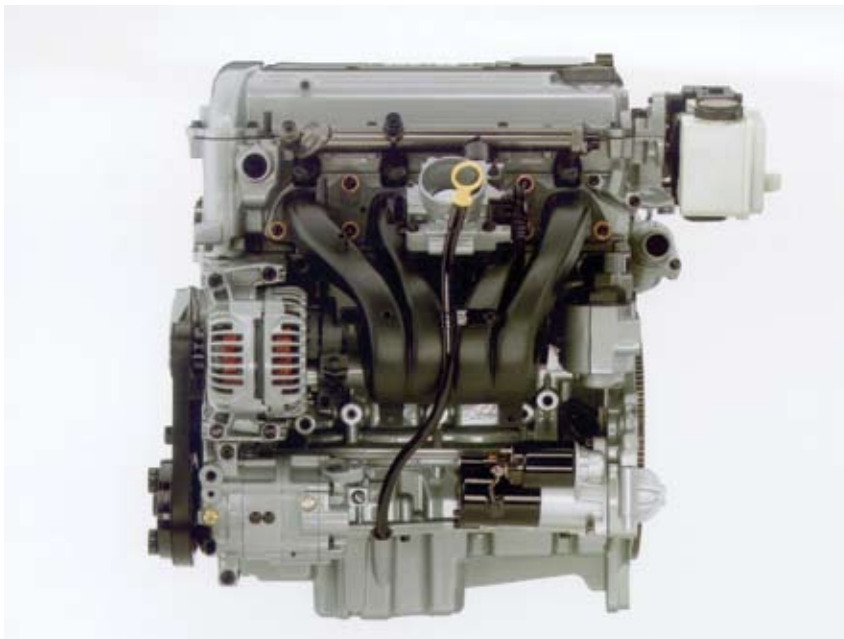
Short-term mechanical data, based upon testing done over a short period of time, does not account for long-term phenomena, such as creep or stress relaxation. This information should be used only when loading or other stress is applied for such a short period of time that the long-term effects are insignificant. All mechanical properties are tested at room temperature (73°F or 23°C) unless otherwise stated.

Tensile Properties

Tensile properties, important in structural design, are used to compare the relative strength and stiffness of plastics. The standard tensile tests for rigid thermoplastics (**ASTM D 638** and **ISO 527**) or soft plastics and elastomeric materials (**ASTM D 412**) involve clamping a standard molded tensile bar into the test device (see figure 3-1). The device's "jaw" then moves at a constant rate of separation between the clamps, typically 5 mm/min. for glass-filled

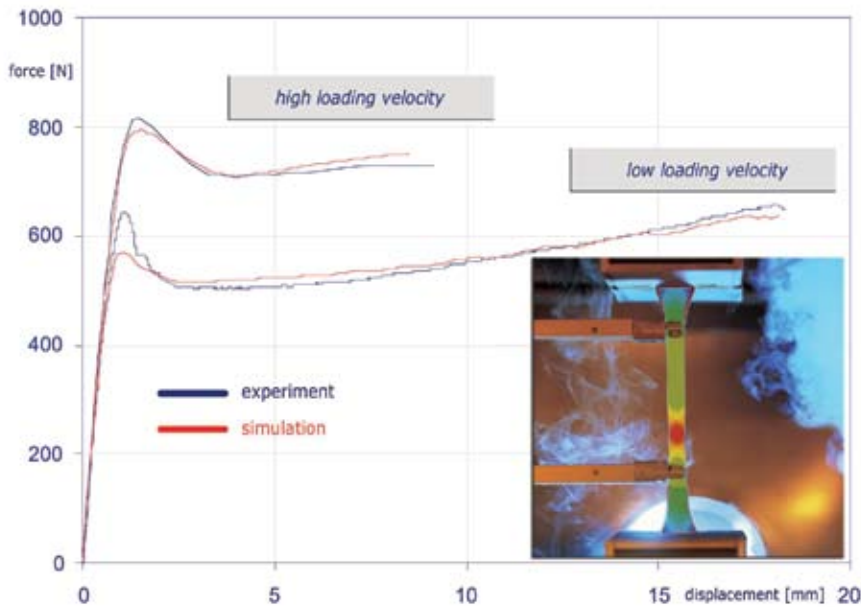


These curves illustrate the characteristic differences in the stress-strain behavior of various plastics.



materials and 50 mm/min. for unfilled plastics. The result – usually expressed as a curve illustrating the relationship between stress, or the force per original cross-sectional area, and the strain, defined as percentage change in length – yields a wealth of information about a resin’s behavior under tensile load (see figure 3-2).

Tensile stress-strain curves graphically illustrate transitional points in a resin’s stress-strain behavior (see figure 3-4). Point A, the **proportional limit** for the material, shows the end of the region in which the resin exhibits linear stress-strain behavior. Point B is the material’s **elastic limit**, or the point after which the part will be permanently deformed even after the load is removed. Applications that cannot tolerate any permanent deformation must stay below the elastic limit. Point C, the **yield point**, marks the beginning of the region in which ductile plastics continue to deform without a corresponding increase in stress. Elongation at yield gives the upper limit for applications that can tolerate the small permanent deformations that occur between the elastic limit and yield point, but not the larger deformations occurring during yield. Point D, the **break point**, shows the strain value at which the test bar breaks. Point E, the highest value after yield, is known as the **ultimate strength**. These five transitional points, important in plastics part design, are the basis for several common tensile properties.



Tensile Stress at Yield

The **tensile stress at yield**, the stress level corresponding to the point of zero slope on the stress-strain curve, generally establishes the upper limit for applications that can only tolerate small permanent deformations (see point C in figure 3-4). Tensile-stress-at-yield values can only be measured for materials that yield under testing conditions.

Elongation at Yield

Elongation at yield, the strain value at the yield point, is a more convenient limit than stress at yield if you know the part's strain levels. Much like stress at yield, elongation at yield determines the upper limit for applications that can tolerate the small permanent deformations that occur before yield.

Tensile Modulus

Used commonly to compare various materials and make structural calculations, the **tensile modulus** measures a resin's stiffness. Higher modulus values indicate greater stiffness. Because of plastic's viscoelastic tensile behavior, determining tensile modulus is more subjective and less precise for plastics than it is for metals or other materials. Mathematically, you can determine the tensile modulus by taking the ratio of the stress to strain as measured below the proportional limit on the stress-strain curves. When dealing with materials with no clear linear region, you can calculate the modulus at some specified strain value, typically at 0.1% (secant modulus). For some applications, buckling analysis for example, it may be more appropriate to derive a tensile modulus from the slope of a straight

line drawn tangent to the curve at a point on the stress-strain diagram (tangent modulus).

Typical stress-strain behavior of unreinforced plastics.

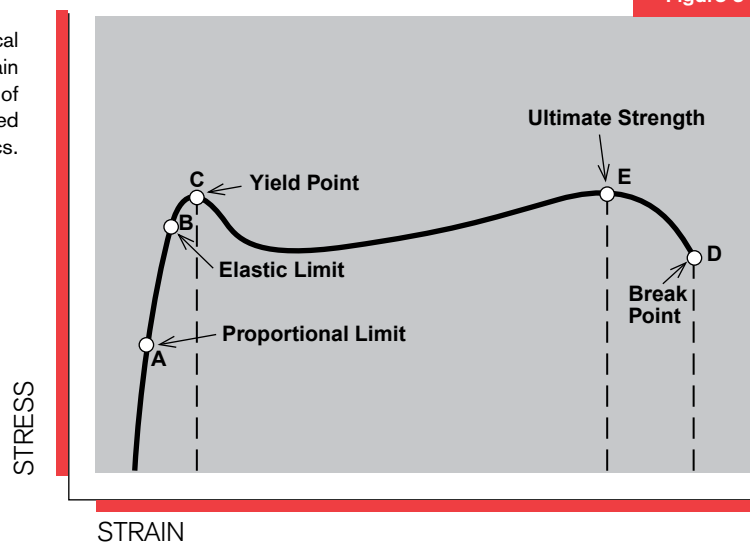


Figure 3-4

Tensile Stress at Break

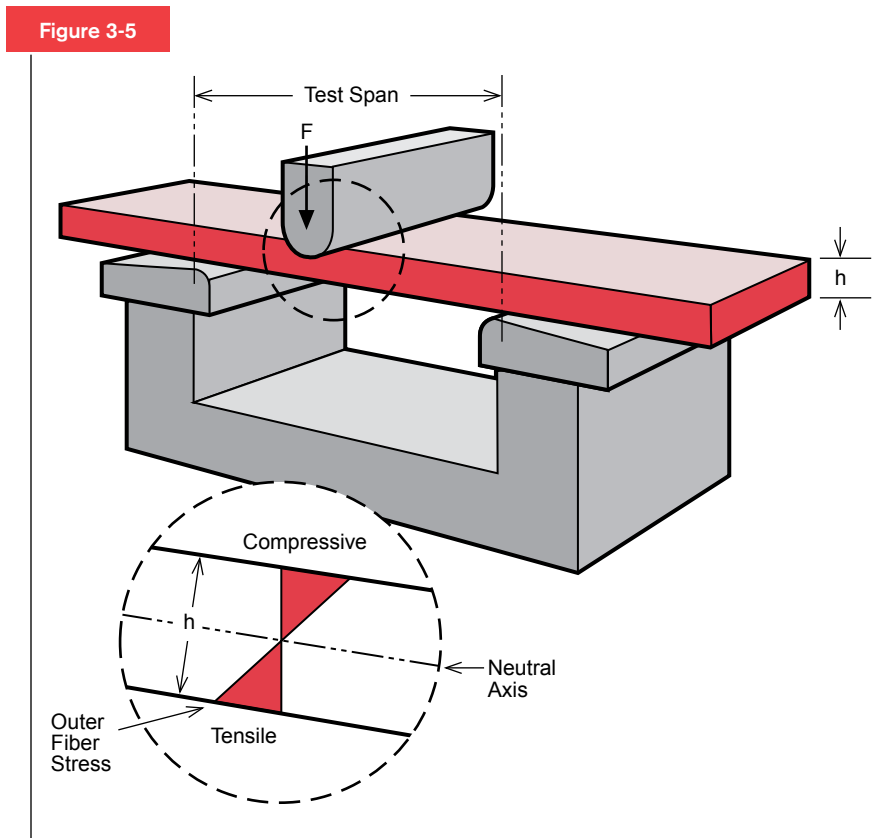
Defined as the stress applied to the tensile bar at the time of fracture during the steady-deflection-rate tensile test, data for **tensile stress at break** establishes upper limits for two types of applications: one-time-use applications, which normally fail because of fractures; and those parts that can still function with the large deformations that occur beyond the elastic limit.

Elongation at Break

Most useful for one-time-use applications that fail by fracture rather than by deformation, **elongation at break** measures the strain at fracture as a percentage of elongation. Brittle materials break at low strain levels; ductile and elastic materials attain high strain levels before breaking.

Ultimate Strength

Ultimate strength measures the highest stress value during the tensile test. This value should be used in general strength comparisons, rather than in actual calculations. Ultimate strength is usually the stress level at the breaking point in brittle materials. For ductile materials, it is often the value at yield or a value slightly before the breaking point (see point E in figure 3-4).



Flexural test set-up (ISO method) and stress distribution in specimen under load.

Poisson's Ratio

Parts subjected to tensile or compressive stresses deform in two directions: with the load and perpendicular to it. This physical characteristic is easy to visualize with a rubber band. As you stretch the band, its cross section becomes narrower. **Poisson's ratio** measures the ratio of lateral to longitudinal strains.

Poisson's ratio usually falls between 0.35 and 0.42 for engineering resins. Some rubbery materials have ratios approaching the constant-volume value of 0.50. For many structural analysis equations, Poisson's ratio is a required constant. A Poisson's ratio of 0.38 generally gives satisfactory results.

Flexural Properties

Flexural properties relate to a plastic's ability to bend or resist bending under load. In the tests for most flexural properties (**ASTM D 790** and **ISO 178**), a test bar placed across two supports is deflected in the middle at a constant rate, usually 2 mm/min. for glass-reinforced materials and 20 mm/min. for unfilled plastics (see figure 3-5). You can use standard beam equations to convert the force-versus-deflection data into an outer-fiber, stress-versus-strain curve.

Flexural Modulus

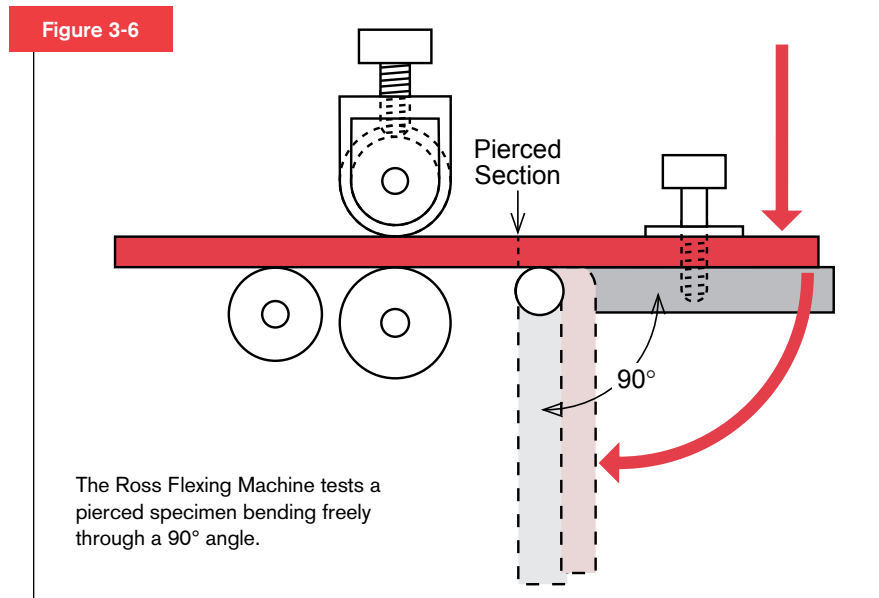
Defined as the ratio of stress to strain in the elastic region of a stress-strain curve, **flexural modulus** measures a resin's stiffness during bending. A test bar subjected to the bending loads distributes tensile and compressive stresses through its thickness. Because stress varies through the cross section, the flexural modulus is based upon the outer fiber stress, whereas tensile modulus is based upon a stress which is constant through the cross section.

Test values for tensile modulus typically correlate well with those of the flexural modulus in solid plastics. Although flexural modulus is more applicable for simple bending calculations, tensile modulus usually can be substituted when flexural data is unavailable.

Ultimate Flexural Stress

The **ultimate flexural stress**, taken directly from the stress-strain curve, measures the level after which severe deformation or failure will occur. For brittle materials, it is usually the stress value at break. In ductile materials, the ultimate flexural stress value usually corresponds to the yield point, or the point at which additional deflection does not cause increasing stress. Because this stress level is beyond the resin's elastic limit, some permanent deformation is likely.

A resin's resistance to bending, or ultimate flexural strength, cannot always be determined using the flexural test, because many resins do not yield or break in bending. For these materials, LANXESS's data sheets list flexural stress at a stated strain, often 5%.



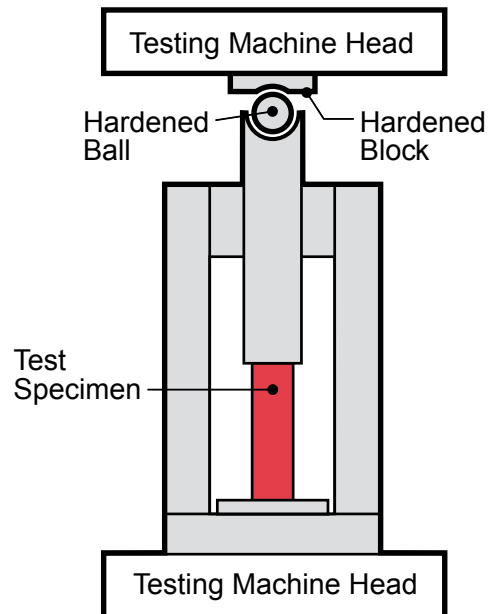
Compressive Properties

How a resin responds to compression may also be important in some applications. **Compressive properties** include modulus of elasticity, yield stress, deformation beyond yield point and compressive strength: important considerations to part designers.

In the standard tests for compressive properties (**ASTM D 695** or **ISO 604**), a specimen is compressed at a constant strain rate between two parallel platens until it ruptures or deforms by a certain percentage (see figure 3-7). Because thermoplastic parts rarely fail in compression, this data is of limited use in part design for thermoplastics.

Figure 3-7

Compression Tester



Compressive Strength

Useful for load-bearing applications, **compressive strength** testing measures the maximum compressive stress recorded during testing. Data from **ASTM D 695** or **ISO 604** also can be used to calculate **compressive modulus**, the ratio of stress to strain below the proportional limit.

Shear Strength

Shear strength measures the shearing force required to make holes or tears in various specimens. Also useful in structural calculations for parts that may fail in shear, this data should be used cautiously, as testing does not account for stress concentrators and molded-in stresses.

In the shear strength test (**ASTM D 732**), a punch tool is pressed at a fixed speed into a standard-sized disc mounted on the testing device. Shear strength, the force needed to make the hole, divided by the sheared area is measured in units of force per area.

Impact Properties

Important in a variety of applications, impact properties, particularly impact strength, will help you select the proper material. **Impact strength**, a plastic part's ability to absorb and dissipate energy, varies with its shape, thickness and temperature. While impact properties can be critical in some applications, test results are among the most difficult to relate to actual part performance. Variables such as part geometry, temperature, stress concentration points, molding stresses, and impact speed reduce the accuracy of general impact data for quantitative calculations. The complex and

dynamic nature of resin performance during impact has led to the development of a variety of tests that more closely represent different in-use conditions. The most common of these tests are described in this section.



In one of the most widely used tests, the **Izod impact test (ASTM D 256, D 4812, or ISO 180)**, a pendulum arm swings from a specified height and hits a cantilevered piece of test material, causing the piece to break (see figure 3-8). The arm then continues traveling at a lower speed, because of the energy lost on impact. This loss of energy, calculated from the difference in beginning and ending heights, determines the Izod impact strength, measured in ft-lb/in, or J/m. Samples may be notched on the narrow face, with the notch facing the impact side as specified in the test. Results should note whether the sample was notched and list sample thickness and test temperature.

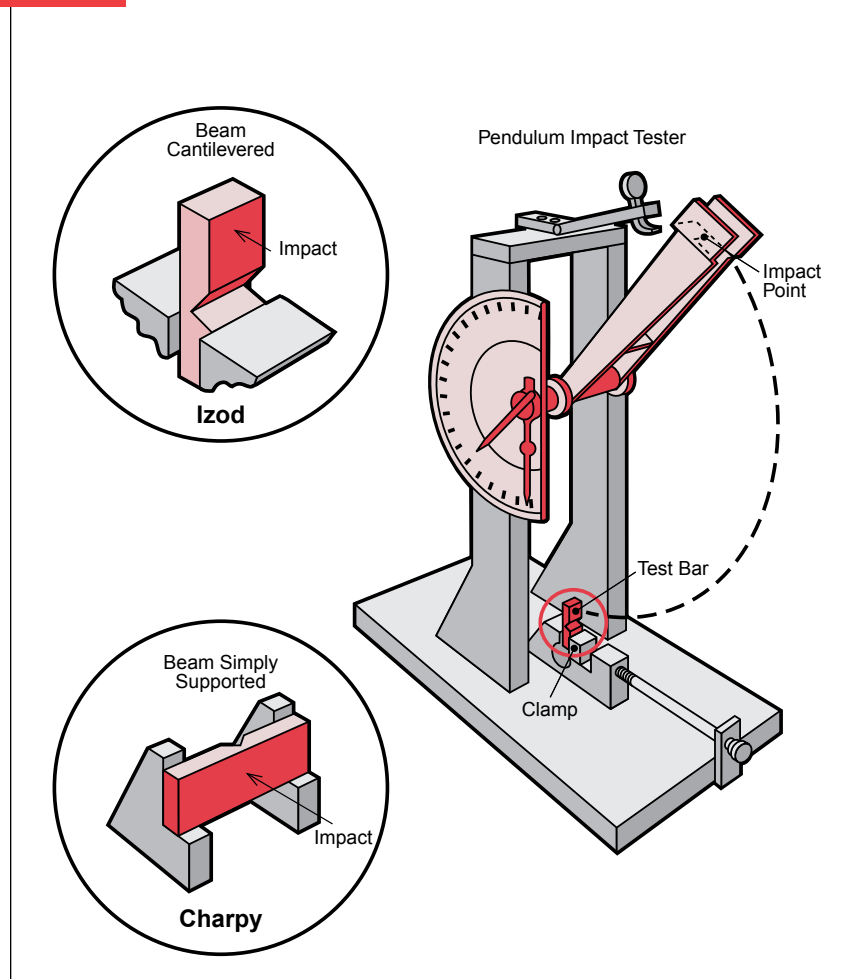
A second, less common method of measuring impact strength, the **Charpy impact test (ISO 179)**, differs from Izod impact in the way a specimen is supported and oriented in the test device (see figure 3-8). Instead of being cantilevered, Charpy samples are supported at both ends, with the notch facing away from the impact side. Charpy testing measures impact strength in kJ/m². Charpy and Izod test results generally correlate well with the behavior of solid plastics.

Sample thickness and notch radius affect the results of both tests. In fact, beyond a certain thickness, known as the **critical thickness**, further thickness increases can reduce impact strength in some materials. This phenomenon is apparent in impact-strength-versus-thickness curves at various temperatures

in polycarbonate resins (see figure 3-9). A sharp notch radius also reduces impact strength. For example, tests show that a polycarbonate resin specimen with a 0.005-inch notch radius has less than one-quarter of the Izod impact strength as compared to a specimen with a notch radius of

0.010 inch (see figure 3-10). Avoid sharp corners in all applications regardless of polymer, especially those involving high loads.

Figure 3-8



Izod and Charpy impact tests.

While neither of these tests provides impact performance data for a particular part or geometry, both are valuable for general material preselection and comparison, as well as providing good indications of a given plastic's notch sensitivity. Additionally, impact strength and **tensile modulus properties** provide insight into the plastic's basic mechanical nature.

- Generally, high impact strength coupled with large tensile modulus suggests a tough material;
- High impact strength and small tensile modulus indicate a ductile, flexible material;
- Low impact and large tensile modulus typify a brittle material.

Tensile impact tests (ASTM D 1822 or ISO 8256) measure a plastic's ability to absorb impact energy when notch effects are not a concern. This test is well-suited for evaluating impact performance of thin sheets, films, soft materials, and other plastics which cannot be easily tested via other methods (see figure 3-11). In the test, a sample is mounted on a pendulum at one end and a cross head clamp at the other. At the bottom of the pendulum swing, the clamp impacts fixed anvils, transferring large tensile stresses to the test bar, causing it to fracture. The results are recorded as the energy required to break the test piece, divided by the cross-sectional area of the necked-down region.

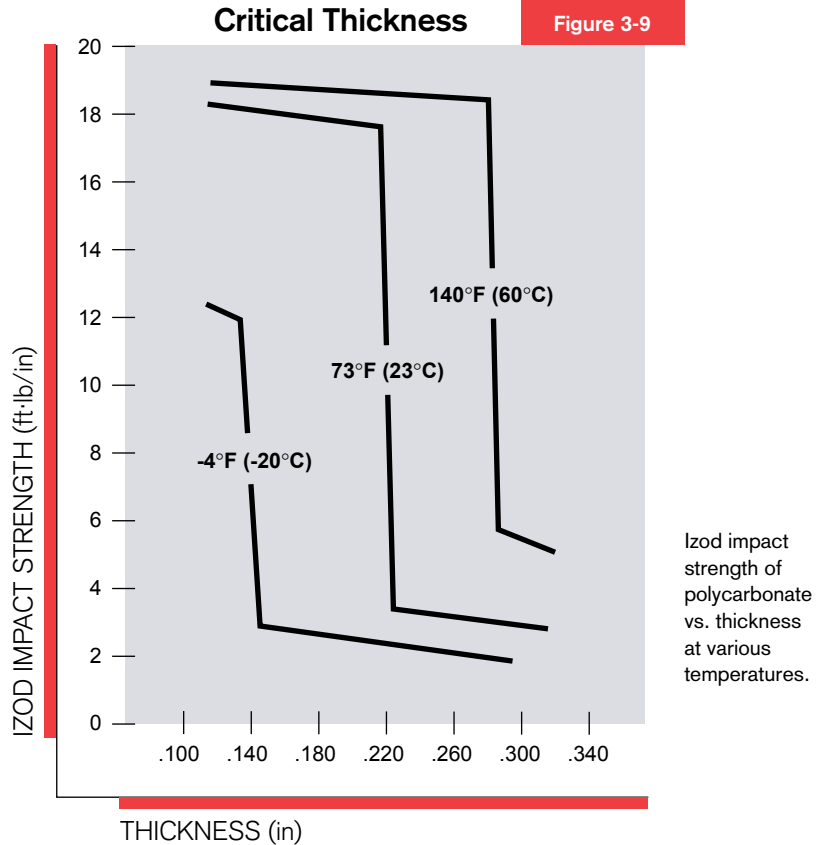
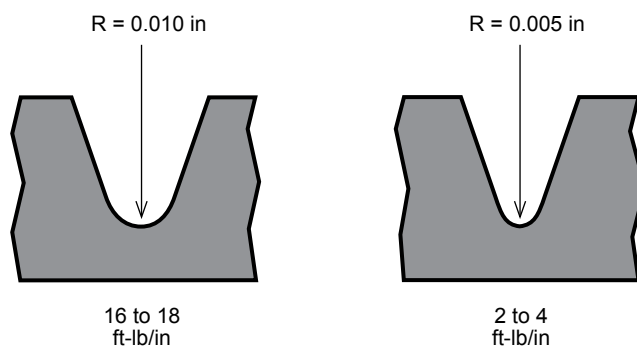


Figure 3-10

Effect of Notch Radius on the Izod Impact Strength of Polycarbonate



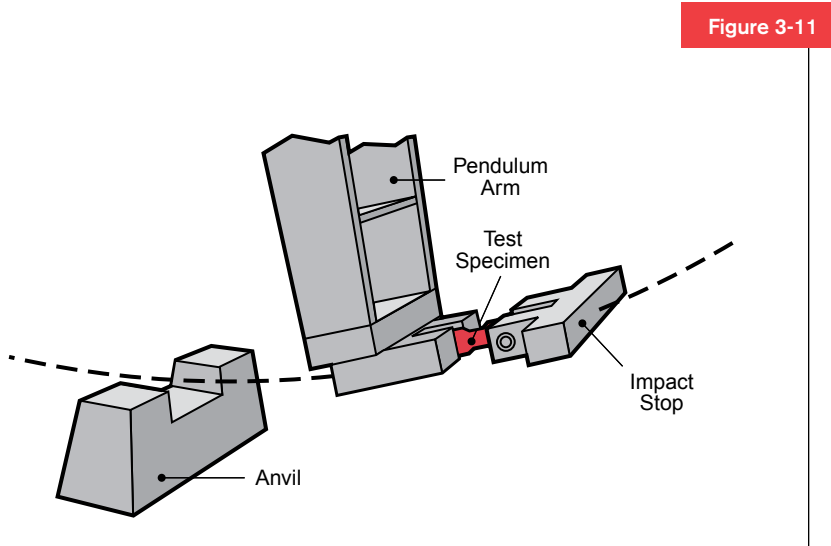


Figure 3-11

Tensile Impact test (ASTM D 1822).

Two other impact tests help to determine relative puncture-impact strength. In the **falling dart impact test**, also known as **Gardner impact test (ASTM D 3029)**, a weighted puncturing device with a standard tip diameter – usually 5/8 inch – drops onto a supported sample disc from increasing heights until the impact causes a rupture or cracking. Typically measured in foot-pounds, the falling dart impact strength is the drop energy of the average height causing rupture. The **instrumented impact test (ASTM D 3763)** gives more detailed information than the falling dart test. In this test, a high-speed dart with a rounded tip – usually 0.5 inch in diameter – impacts a sample disc. Unlike the falling dart impact test, the dart velocity remains constant throughout impact. At impact, a device measures the maximum force transmitted, the energy transmitted, the deflection at maximum force, and the

type of fracture. Dart velocity, test temperature, sample thickness, and clamp distance are usually listed with test results.

If your application has stress concentrators in anticipated impact areas, do not use either of the test values described above for material comparisons. Most suitable for comparing a plastic's relative puncture-impact strength in applications without sharp corners, notches, or other stress concentrators, these test values vary greatly with temperature, impact speed, and dart shape. Extremely valuable in applications that cannot tolerate brittle failure, these tests help to determine whether specific materials fail in brittle or ductile mode.

Hardness Properties

The hardness properties of plastics, mainly used to compare indentation resistance, may not correlate to the material's actual abrasion, scratch, or wear resistance. The two most common tests for comparing relative hardness are described in this section.

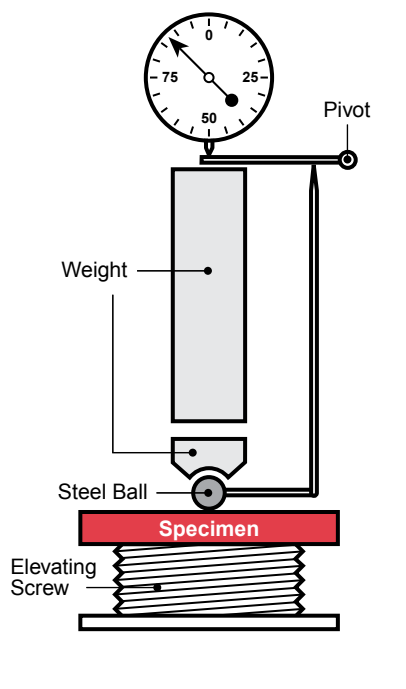
The Rockwell hardness test (ASTM D 785 or ISO 2039-2) applies loads to an indenter, which presses against a standard-sized plastic specimen (see figure 3-12). After the minimum load required to indent the sample has been established, the load is increased to a higher value for a short time and then returned to the starting value. The increase in impression depth determines the Rockwell hardness. Smaller impression depths correspond to greater hardness and higher Rockwell values. Hardness values are always listed according to the appropriate Rockwell hardness scale. For most engineered plastics, either a Rockwell “R” or more severe “M” scale is used.

If the part will be exposed to subnormal temperatures, place the test specimen and equipment in a cold box at the expected exposure temperatures. Testing procedures are the same as

for other plastics (**ASTM D 2240**). The initial (one-second) and five-second drift values – the time delays after initial indentation – are reported.

Figure 3-13 shows an approximate, relative comparison of hardness values from several common hardness tests and scales.

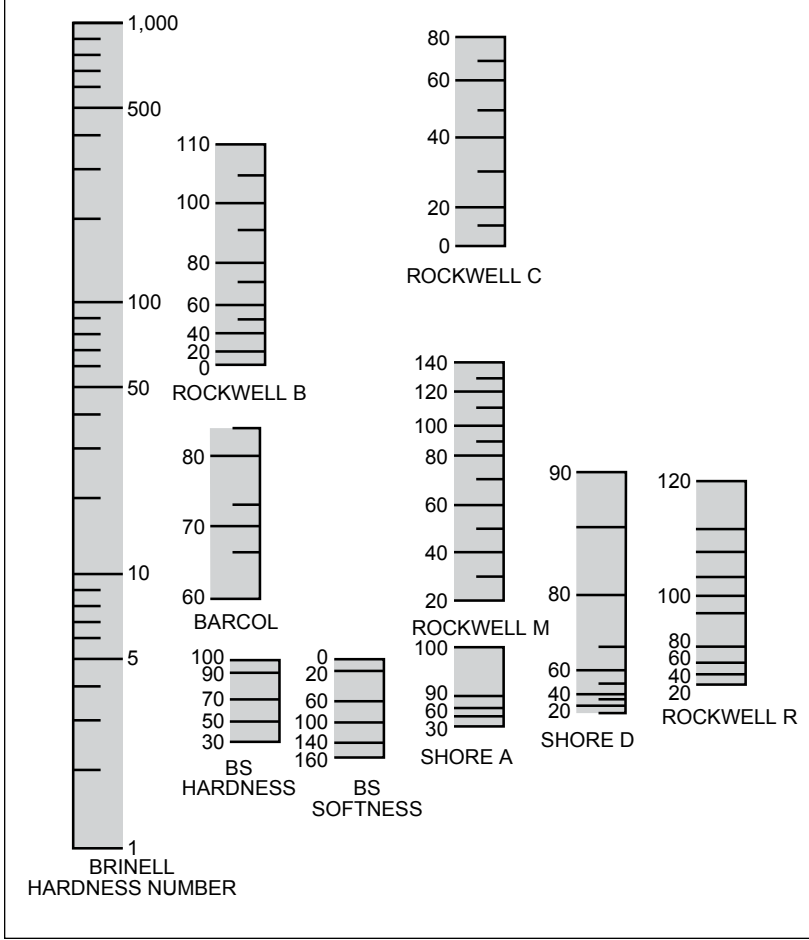
Figure 3-12



Schematic of Rockwell hardness test.

Figure 3-13

Approximate Correlation Between Various Hardness Scales

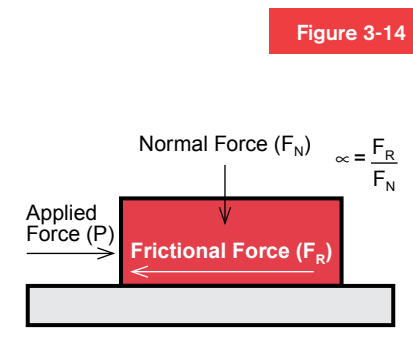


Miscellaneous Mechanical Properties

Coefficient of Friction

The **coefficient of friction** is the ratio of friction force, the force needed to initiate sliding, to normal force, the force perpendicular to the contact surfaces (see figure 3-14). Coefficients are commonly listed for two types of friction: **static friction**, the forces acting on the surfaces to resist initial movement, and **dynamic or sliding friction**, the forces acting between surfaces moving relative to each other.

Frictional property tests for plastics, such as **ASTM D 1894** or **ISO 8295**, measure coefficients for combinations of plastics and/or metals. Because of the multitude of combinations possible, finding data for specific types of plastics and/or metals can be difficult. Unless you are willing to test your specific material combination, you will have to estimate frictional forces based upon available data (see table 3-1). Frictional properties generally



The coefficient of friction is the ratio of the frictional force resisting sliding (F_R) to force acting normal to the interface (F_n).

Table 3-1

Coefficients of Friction (Static) Ranges for Various Materials

Material	On Self	On Steel
PTFE	0.10-0.25	0.10-0.25
PE rigid	0.40-0.50	0.20-0.25
PP	0.35-0.45	0.25-0.35
POM	0.25-0.50	0.15-0.35
PA	0.30-0.50	0.30-0.40
PBT	0.30-0.40	0.30-0.40
PS	0.45-0.60	0.40-0.50
SAN	0.45-0.65	0.40-0.55
PC	0.40-0.65	0.35-0.55
PMMA	0.60-0.70	0.50-0.60
ABS	0.60-0.75	0.50-0.65
PE flexible	0.65-0.75	0.55-0.60
PVC	0.55-0.60	0.55-0.60

correlate well with different grades of a particular plastic material. For applications in which the frictional force contributes a small portion of the overall forces, approximate frictional data generally suffices.

Published data on coefficients of friction should be used for estimating purposes only. In addition to being very sensitive to speed, coefficient values depend greatly upon the surface finish and the presence of lubricants and surface contaminants. Because of these factors, generating a precise friction coefficient for design calculations can be difficult.

Abrasion and Scratch Resistance

Important primarily for aesthetics and durability, a variety of application-specific tests typically measure **abrasion and scratch resistance**. The two most-common tests use a Taber abrader. Generally, a loss of volume or weight when a test piece is exposed to an abrasive surface under load determines abrasion resistance.

An optical transmission/reflectance test, **ASTM D 1044** measures the effect of wear on a transparent thermoplastic resin to establish haze and luminous transmittance. Another standard test for scratch resistance moves a specimen under a loaded diamond point. The load divided by the width of the resulting scratch gives the scratch-resistance value.

LONG-TERM MECHANICAL PROPERTIES

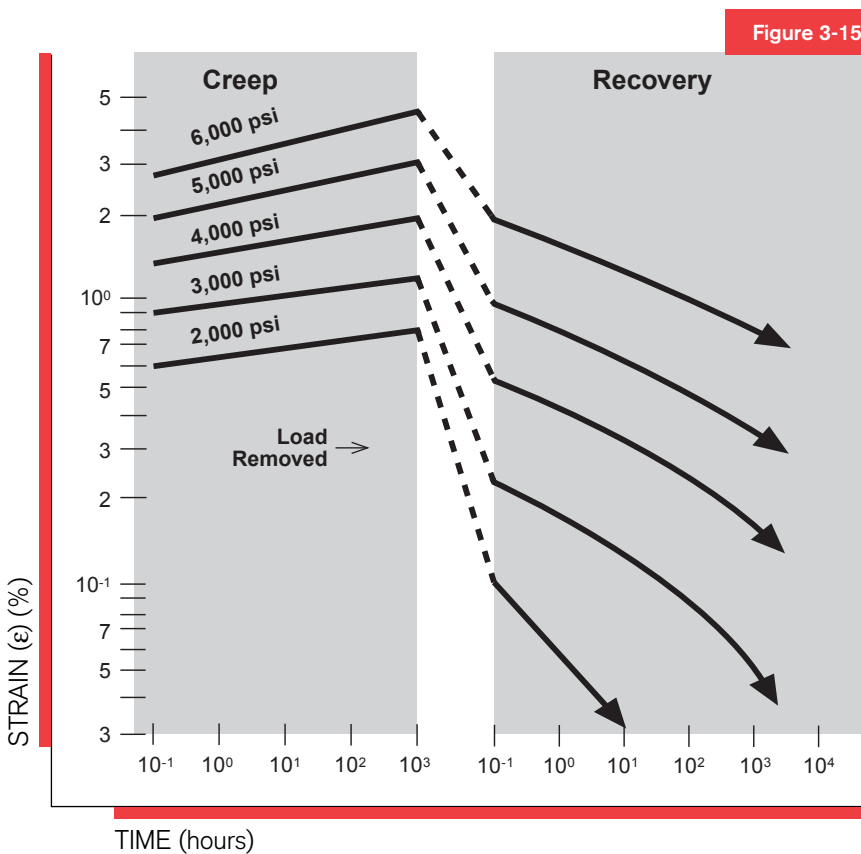
Time and ambient temperature affect the long-term mechanical properties of plastics, because they affect polymer-chain mobility. Plastic parts under constant load tend to deform over time to redistribute and lower internal stresses. The mobility of polymer chains determines the rate of this stress redistribution. Higher temperatures increase the free space between molecules, as well as the molecular-vibration energies,

resulting in a corresponding increase in polymer-chain mobility. Even at moderate temperatures, polymer chains can reorient in response to applied loads, if given enough time. Two long-term properties – creep, the added deformation in a part that occurs over time under constant stress, and stress relaxation, the reduction in stress in parts subjected to constant strain – increase significantly with time and temperature.

Although their effects are similar, time and temperature affect part performance differently. At different temperatures, a given plastic shows immediate differences in instantaneous or short-term mechanical properties. Time, however, does not significantly affect mechanical properties. Barring chemical or environmental attack, the material will have the same strength and stiffness as it did before loading. Time affects the perception of strength and stiffness: A part which has deformed after five years of constant loading appears to have lost stiffness, although, in fact, its stiffness has remained the same. Responding to the load over time, individual polymer chains have moved to redistribute and lower stresses, causing the deformation.

Because long-term loading affects part performance, most engineering plastics are tested for long-term mechanical properties. This section discusses the most common of these tests.

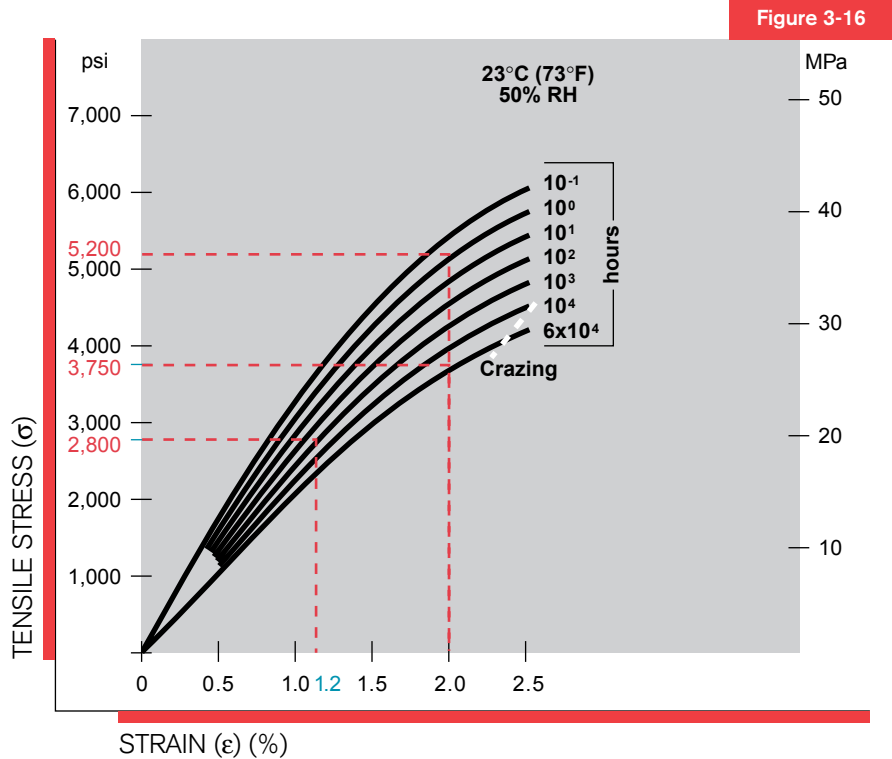
Creep and recovery of polycarbonate at 73°F (23°C).



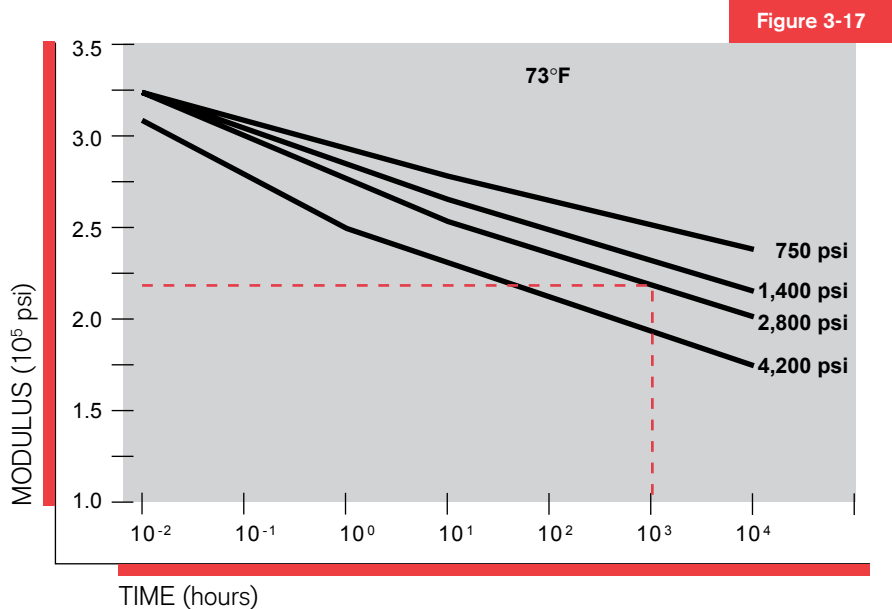
Creep Properties

Over time, parts subjected to a constant load often distort beyond their initial deformation; they creep. Long-term creep data helps designers estimate and adjust for this additional deformation. A common creep test involves hanging a weight axially on the end of a test bar and monitoring increases in the bar's length over time, as outlined in **ASTM D 2990** or **ISO 899**. Flexural creep, a more common measure for structural foam materials, measures creep performance similarly to tensile creep, using cantilevered test bars.

Presented graphically in a variety of forms, creep and recovery data is often plotted as strain versus time at various stress levels throughout the creep and recovery phases (see figure 3-15). Another popular form, the **isochronous stress-strain curve**, plots tensile stress versus resulting tensile strain at given time increments (see figure 3-16). Occasionally creep data is presented as **apparent modulus** or **creep modulus** versus time at various stress levels (see figure 3-17). To determine the apparent modulus, divide the stress by the actual strain from an isochronous strain curve after a specific load duration. For example, if we assume room-temperature conditions, a tensile stress of 2,800 psi (19 MPa), and a load duration of 1,000 hours using a strain of 1.2%, we can calculate an apparent modulus of 230,000 psi (1,590 MPa) from the isochronous stress-strain curve in figure 3-16. You can also read the apparent modulus directly from the data in figure 3-17.

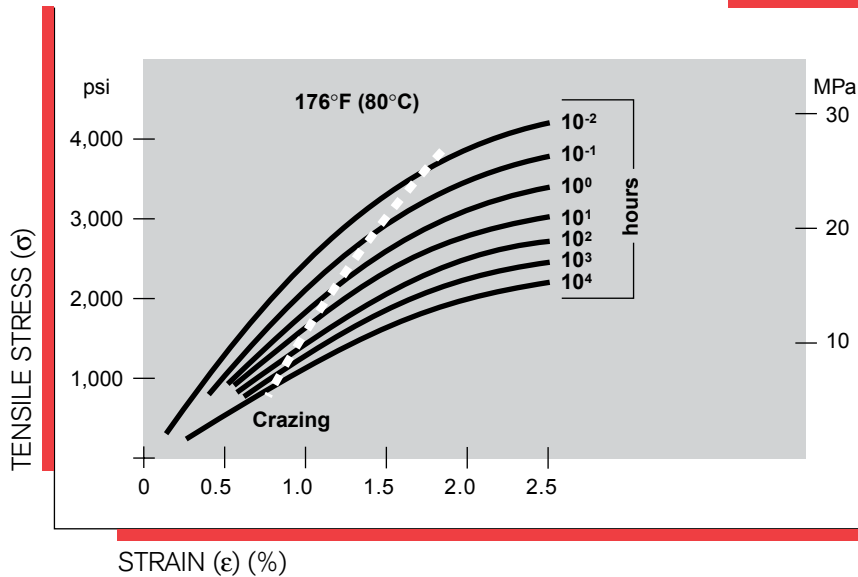


Isochronous stress-strain curves at 73°F (23°C) for polycarbonate.



Apparent modulus for unfilled polycarbonate at various stress levels.

Figure 3-18



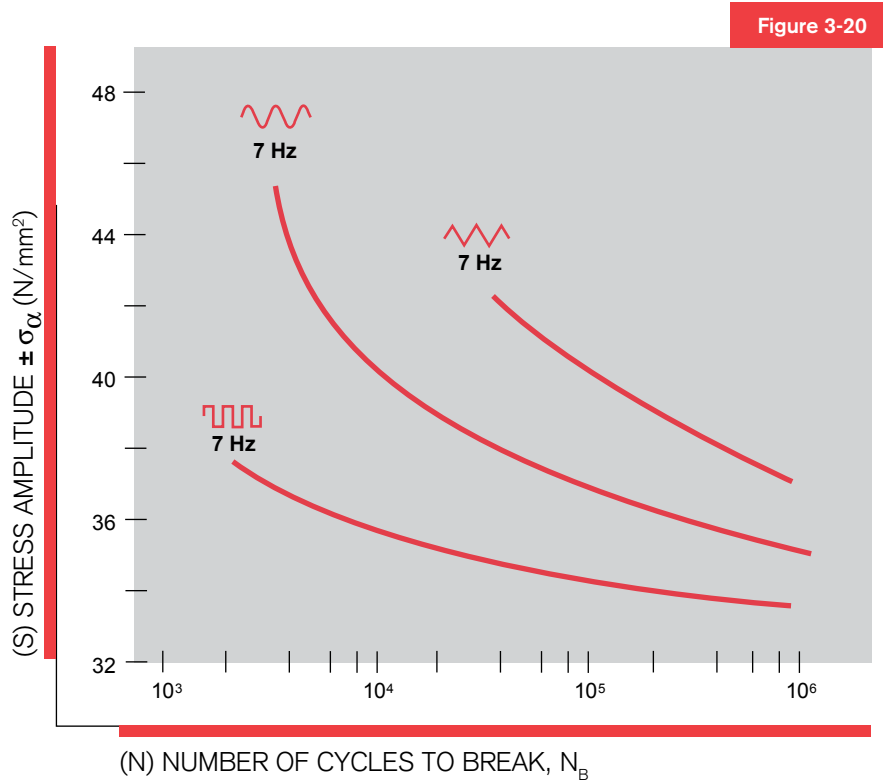
Isochronous stress-strain curves at 176°F (80°C) for polycarbonate

Temperature affects creep properties. Compare figure 3-16, showing the isochronous stress-strain curve for a polycarbonate resin at 73°F (23°C), and figure 3-18, showing the same resin at 176°F (80°C). In general, higher ambient temperatures will cause more creep deformation. See LANXESS' *Engineering Plastics: Part and Mold Design Guide* for more information on creep, test curves, apparent modulus, and effects of temperature.

Stress Relaxation

Stress relaxation, the stress reduction that occurs in parts subjected to constant strain over time, is an important design concern for parts that will be subjected to long-term deflection. Because of stress relaxation, press fits, spring fingers and similar parts can show a reduced retention or deflection force.

Stretching a test bar to a fixed length and measuring the change in tensile stress over time with a stress transducer is one method for measuring stress relaxation. Creep testing, much more prevalent than stress relaxation testing, gives similar data, is easier to do, and can be used to approximate most stress-relaxation values.



Tensile fatigue test curve for glass-filled Durethan® polyamide in three cyclic-loading modes.

Fatigue Properties

From the isochronous stress-strain creep curves (see figure 3-16), you can easily see the effects of stress relaxation by reading through the time curves for a given strain. In this figure, the tensile stress at 2% strain drops from an instantaneous value of 5,200 psi (36 MPa) to approximately 3,750 psi (22 MPa) after 10,000 hours.

These curves also may show when crazing could occur in transparent polycarbonate resins (see figures 3-16 and 3-18). **Crazing** – tiny, reflective cracks that appear when a part is subjected to long-term tensile loads – precedes

larger cracks and ultimately part failure. In figure 3-16, you can see that crazing occurs at 2.5% strain at room temperature after 10,000 hours.

Stress-relaxation modulus, calculated by dividing the stress after a specific load duration by the strain corresponding to the fixed strain, accounts for stress relaxation in standard engineering equations.

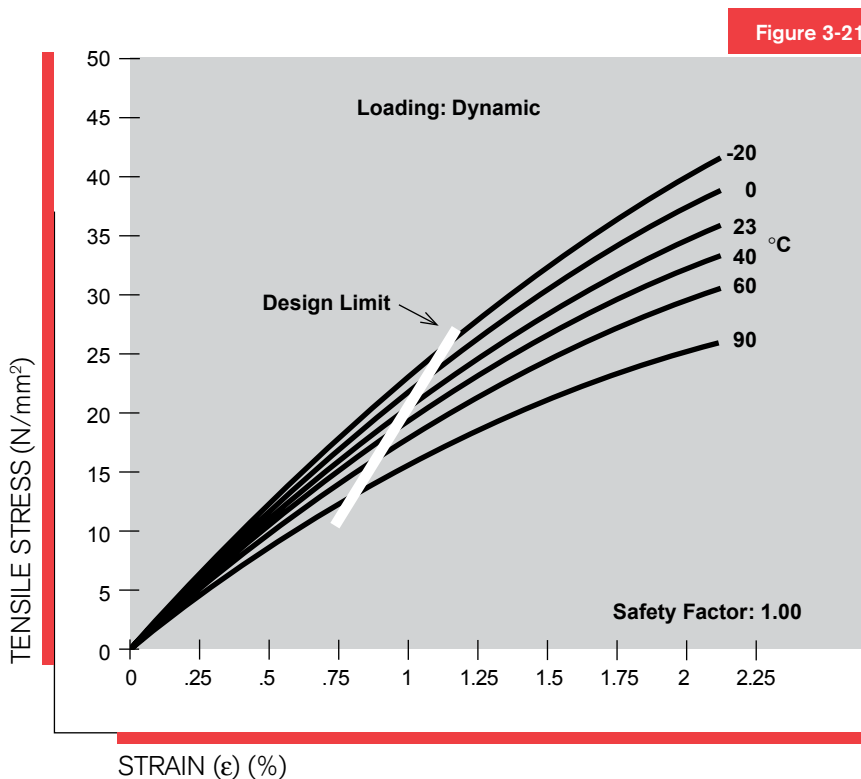
Molded plastic parts exposed to cyclic loading often fail at substantially lower stress or strain levels than parts under static loading, a phenomenon known as **fatigue**. Applications that expose parts to heavy vibrations or repeated deflections – such as snow plow headlight housings, one-piece salad tongs, and high-use snap-latch closures – need plastics with good fatigue characteristics.

Fatigue properties are sensitive to many factors, including notch effects, environmental factors, stress concentrators, loading frequency, and

temperature. In a common test for flexural fatigue, the unsupported end of a test bar is subjected to a reversing cyclic load, keeping either the deformation or the applied force constant. The number of cycles to failure is recorded. Usually defined as the fracture point, failure can also be defined as the point at which resultant stress or strain is reduced by a fixed amount, given in a percentage. Results for various stress levels are plotted against number of cycles to failure (see figure 3-20), presented as **S-N curves**.

Providing a useful means for comparing the relative fatigue endurance of various plastics, S-N curves can also be used to estimate the expected life of parts under known cyclic loading. In addition to S-N curves, fatigue data can appear as stress or strain limits on stress-strain curves (see figure 3-21). The heavy, white line in this figure shows the suggested design limit at various temperatures for a polycarbonate/ABS resin used in applications subjected to dynamic fatigue loading.

Fiber orientation also affects fatigue properties. Fatigue strength for a given fiber-filled resin is approximately 10 times greater when the fibers are aligned lengthwise, along the test bar rather than perpendicularly. Typically based upon simple test bars with lengthwise fiber orientation in controlled laboratory conditions, fatigue data represents ultimate, rather than typical, performance. When you calculate fatigue-life values using published data, always include appropriate safety factors or margins for error.



Stress-strain curves for PC/ABS showing limits at various temperatures for dynamic loading.



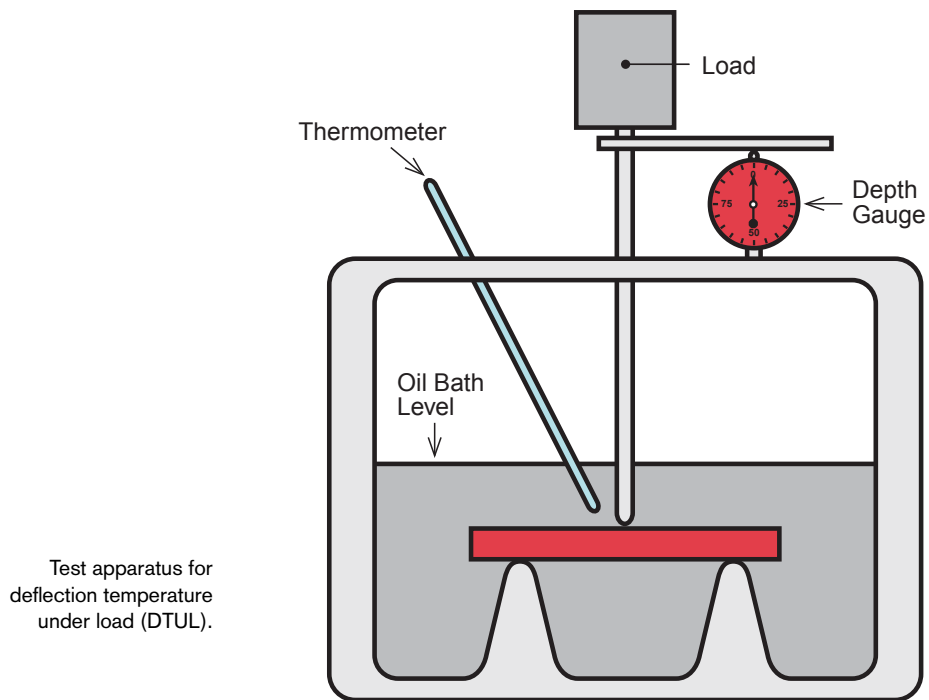
Temperature requirements often limit resin choice more than any other factor. A variety of tests measure thermal properties in plastics to help you select a resin that meets your needs. This section describes the more common thermal properties to consider, the relevance of each property in material selection, and the tests we use at LANXESS to determine these properties.

DEFLECTION TEMPERATURE UNDER LOAD (DTUL)

DTUL values are used to compare the elevated temperature performance of materials under load at the stated test conditions. Sometimes referred to as the “heat distortion temperatures” or “HDT,” they do not represent the upper temperature limit for a specific material or application. Molding factors, sample preparation and test bar thickness significantly influence DTUL values. Compare data from different test labs and suppliers cautiously.

In the **ASTM D 648** test for DTUL, the center of a test bar resting on supports four inches apart is loaded to a specified outer-fiber stress of either 66 or 264 psi (0.45 or 1.8 MPa) (see figure 4-1). The temperature in the test chamber rises at 2°C per minute until the applied load causes the bar to deflect an additional 0.010 inches. The temperature at which this deflection occurs is the DTUL. Test bar thickness varies from 1/8 to 1/2 inch (3.2 to 12.7 mm), depending upon the material specification.

Figure 4-1



In a similar test for DTUL, **ISO 75**, a 110 mm x 10 mm x 4 mm test bar rests edge wise upon supports spaced 100 mm apart. Test bars are initially loaded to an outer stress level of 0.45 or 1.8 MPa with the ambient temperature increasing 2°C per minute. The test results show the temperature when the specimen reaches a deflection corresponding to a standard strain value, typically 0.2%. A variation of this test places an 80 mm x 10 mm x 4 mm specimen flat across supports spaced 64 mm apart.

COEFFICIENT OF LINEAR THERMAL EXPANSION (CLTE)

The **coefficient of linear thermal expansion** measures the change in length per unit length of a material per unit change in temperature. Expressed as in/in/°F or cm/cm/°C, the CLTE is used to calculate the dimensional change resulting from thermal expansion. Especially important when components of an assembly have widely varying thermal expansion coefficients, CLTE values for plastics are typically much higher than those for metals. You must provide for thermal expansion differences in assemblies with metal and plastic components (see table 4-1). One common test for measuring coefficient of thermal expansion is **ASTM E 831**.

Table 4-1

Coefficients of Linear Thermal Expansion (CLTE) for Common Materials

Material	in/in/°F x 10 ⁻⁵
Glass	0.5
Steel	0.6
Composite RIM	0.8
Brass	1.1
Aluminum	1.3
Nylon GF*	1.3
Polyester GF*	1.4
PPS GF*	1.5
Polycarbonate GF*	1.7
ABS GF*	1.7
Polypropylene GF*	1.8
Acetal GF*	2.5
Acrylic	3.8
Polycarbonate	3.9
PC/ABS Blend	4.0
Elastomeric RIM GF*	4.0
ABS	4.4
Nylon	4.5
Polypropylene	5.0
Acetal	5.8
Polyester	6.0
Polyethylene	7.0
Elastomeric RIM Unfilled	7.8

*glass-filled resins



THERMAL CONDUCTIVITY

Thermal conductivity, typically measured as Btu•in/(hr•ft²•°F) or W/K•m, indicates a material's ability to conduct heat energy. Thermal conductivity is particularly important in applications such as headlight housings, pot handles, and hair curlers that require thermal insulation or heat dissipation properties. Computerized mold-filling analysis programs require special thermal conductivity data derived at higher temperatures than specified by most tests.

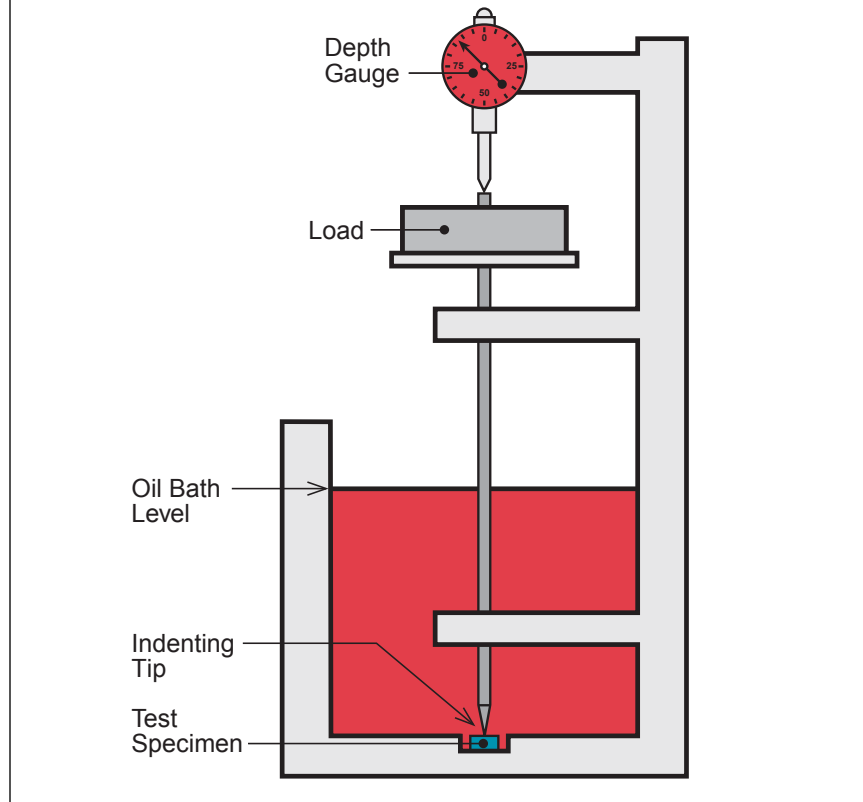
SPECIFIC HEAT

Usually measured in Btu/lb•°F or kJ/kg•°C, **specific heat** reflects the heat required to cause a one-degree temperature change in a unit mass of material. Occasionally, specific-heat values are shown as a ratio of heat required to raise the temperature of 1g of a substance 1°C to the heat required by the same mass of water. Most mold-filling and cooling analysis programs need a resin's specific heat for heat-transfer calculations.

RELATIVE TEMPERATURE INDEX (RTI)

Exposure to elevated temperatures can reduce a plastic's electrical and mechanical properties over time. The **UL Relative Temperature Index (RTI, UL 746)**, also known as the continuous-use temperature, gives values for approximate temperature limits for continuous use in air and without additional external loading. The RTI correlates with the temperature above which the heat aging causes the loss of certain critical properties, such as dielectric strength, tensile strength and tensile impact. Helpful in comparing a resin's thermal endurance and property characteristics over time, RTI is required for products needing UL recognition. If RTI testing has not been performed on your material, you can apply for a Generic Temperature Index (GTI), the minimum, long-term service temperature that materials of these types have been found to withstand. The GTI is usually considerably lower than RTI values.

Figure 4-3



Vicat softening point test apparatus.

VICAT SOFTENING TEMPERATURE

By definition, the **Vicat softening temperature** ranks the thermal performance of plastics according to the temperature that causes a specified penetration by a lightly loaded probe. Often used as a general indicator of short-term, high-temperature performance, the Vicat softening temperature is less sensitive to sample thickness and molding effects than DTUL.

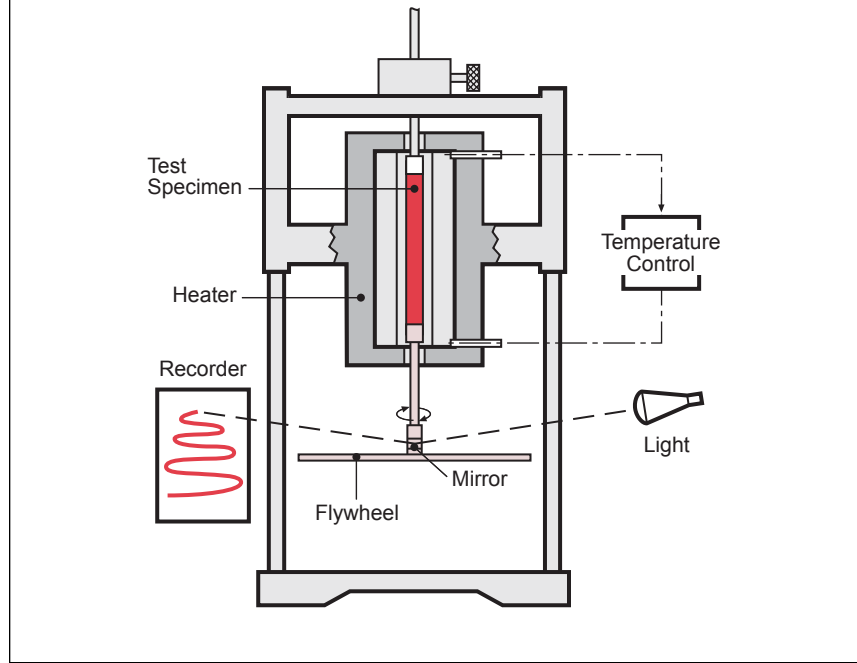
In the standard test (**ASTM D 1525** or **ISO 306**), a flat-ended probe

with a 1 mm² cross section contacts a plastic specimen submerged in a heating bath (see figure 4-3). After a specified load is applied to the probe, the oil bath temperature rises at a slow, steady rate. The Vicat softening temperature is the temperature of the oil bath when the probe reaches a 0.04-inch (1-mm) depth.

TORSIONAL PENDULUM

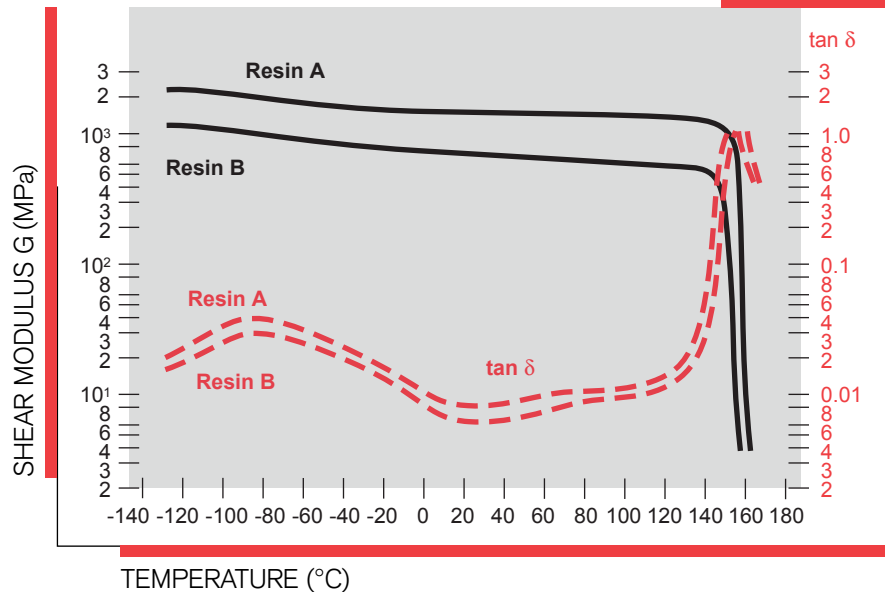
The torsional pendulum test (**DIN 53445 or ASTM D 4065**) determines shear modulus and mechanical power factor over a wide range of temperatures. In this test, an attached flywheel torsionally deforms a specimen, which is allowed to oscillate in free vibration (see figure 4-4). The shear modulus, calculated from the resultant oscillation frequency and $\tan \delta$, an indicator of vibration damping due to internal energy losses, can be plotted on the same graph over a range of temperatures as in figure 4-5. This figure shows that the tested resin grades remain mechanically stable up to approximately 284°F (140°C) and do not suddenly become brittle at low temperatures. This bulk-property, shear-modulus data, coupled with the surface-response, Vicat data, gives a good indication of a material's upper-use temperature limit for short-term exposure.

Figure 4-4



Torsion pendulum tester for determining shear modulus in plastic materials.

Figure 4-5



Shear modulus and mechanical power factor ($\tan \delta$)



LANXESS materials are often used in applications that need electrical insulation. Our Product Information Bulletins (PIBs) list the electrical properties for plastics used in the electrical and electronic industries. To use this information properly, you need to have a good understanding of the terminology and testing methods. This section describes the most common methods for determining electrical properties and explains how these properties are used to select materials for electrical and electronic components.

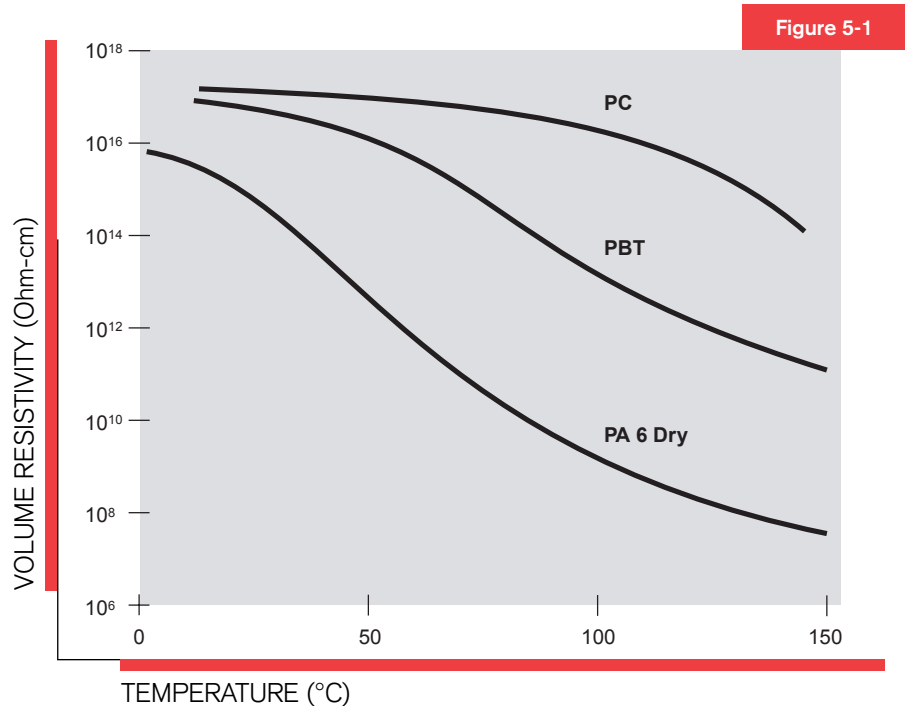


Figure 5-1

Volume resistivity of three plastics as a function of temperature.

VOLUME RESISTIVITY

Volume resistivity, a measure of a resin's electrical insulating properties, provides a means to compare plastics used as insulators. A resin's volume resistivity should be at least 10^8 ohm-cm to be considered an insulating material. While plastics generally have excellent insulating properties, their electrical resistance decreases with increasing temperature and moisture content, sometimes by orders of magnitude within a part's given service range (see figure 5-1). Always evaluate your product's volume resistivity at in-use environmental conditions.

A measure of the electrical resistance between opposite faces of a unit

cube of material, volume resistivity indicates current-leakage resistance through an insulating body. The tests for volume resistivity (**ASTM D 257** or **IEC 93**) measure resistance in ohms between electrodes mounted on opposite specimen faces (see figure 5-2). This resistance is multiplied by the electrode's area, then divided by the sample thickness, to give the volume resistivity in ohms-cm.

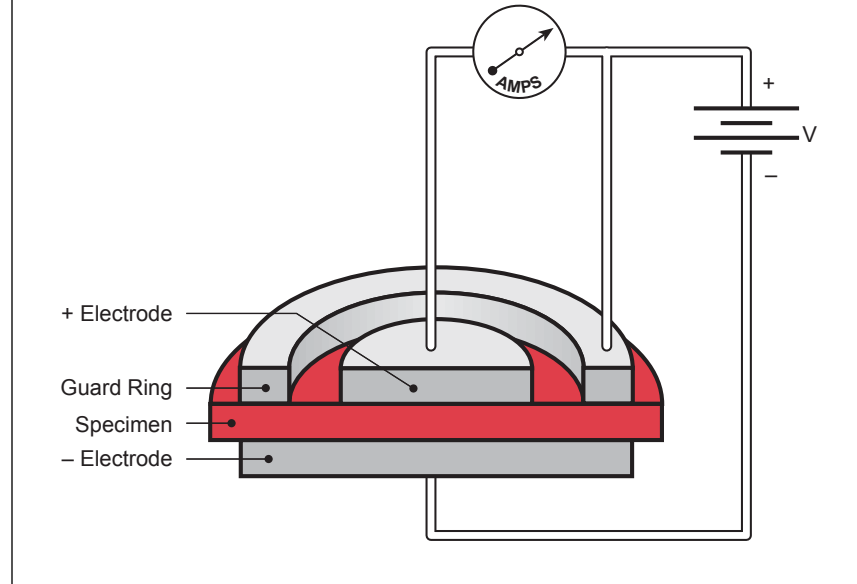
SURFACE RESISTIVITY

Important in applications with closely-spaced conductors such as terminal blocks, **surface resistivity** measures a resin's surface-insulating performance.

As with volume resistivity, higher values indicate better insulating properties. Because test results are sensitive to humidity, surface contamination and surface contour, accurate and reliable measurements are difficult to obtain.

In the tests (**ASTM D 257** or **IEC 93**), the resistance between two straight conductors pressed onto opposite edges of the test specimen determines the current leakage along the surface of a 0.4-inch (1-cm) square of the insulating material. Because the length and width of the path are the same, the centimeter terms cancel, leaving ohms as the standard measurement unit.

Figure 5-2



Cross sectional schematic for typical volume-resistivity test apparatus.

DIELECTRIC STRENGTH

A resin's **dielectric strength**, the best single indicator of a material's insulating capability, measures the voltage an insulating material can withstand before electrical failure or breakdown occurs. Expressed as a voltage gradient, typically volts per mil of thickness, higher dielectric-strength values indicate

better insulating characteristics. The dielectric strength of plastics varies inversely with thickness: thinner specimens yield higher values. The values also tend to be higher at elevated temperatures. Always note the specimen

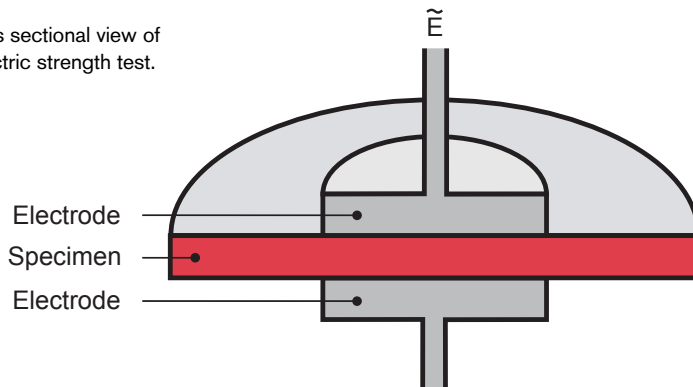
thickness and testing temperature when comparing dielectric strength values.

In the test for dielectric strength (**ASTM D 149** or **IEC 243**), a flat sheet or plate is placed between cylindrical brass electrodes, which carry electrical current (see figure 5-3). Generally, at LANXESS, we use the **short-time test** for dielectric strength. In this test, the voltage increases at a uniform rate from 0.5 to 1.0 kV/sec until breakdown.

For finer measurements, the **step-by-step test** applies an initial voltage equal to 50% of the breakdown voltage as determined by the short-term test. The voltage increases at a rate specified for each type of material until breakdown. Test specimens for this latter testing method must be large enough to prevent flashing over, and often are immersed in transformer oil during testing

Figure 5-3

Cross sectional view of dielectric strength test.



for this reason. Because temperature and humidity affect test values for both methods, specimens must be carefully conditioned.

DIELECTRIC CONSTANT

An important factor in high-power and/or high-frequency applications, the dielectric constant is dimensionless and varies with temperature, moisture levels, frequency and part thickness. Specifically, the **dielectric constant** is the ratio of the capacitance of a plate electrode system with a test specimen as the dielectric to the capacitance of the same system with a vacuum as the dielectric. A schematic of the standard tests for measuring dielectric constants (**ASTM D 150** or **IEC 250**) is shown in figure 5-4. Lower values indicate better insulating characteristics.

DISSIPATION FACTOR

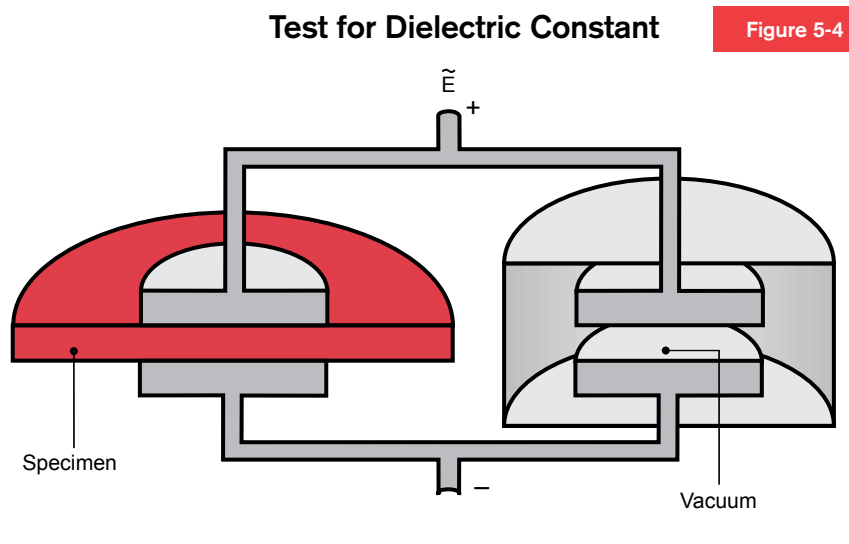
Measuring a resin's tendency to convert current into heat, the **dissipation factor**, is particularly important in applications such as radar and microwave equipment that run at high frequencies. Some resins subjected to these reversing fields convert a high percentage of the energy to heat, making the process inefficient and possibly leading to part failure. Lower dissipation values, desirable for electrical insulation materials, indicate less power loss and heat generation.

Dissipation factors generally increase with increasing temperature. Excessive heat can cause a cascading effect: Increasing losses generate higher temperatures and further losses. This effect can lead to material breakdown and possible thermal ignition.

Tested on the same apparatus as dielectric constant, the dissipation factor measures the ratio of the parallel reactance to the parallel resistance of a test material at specified frequencies and temperatures. To avoid an excessive level of implied precision and bias, **UL 746 A** records results from this electrical test and other tests that follow as **Performance Level Category (PLCs)** based upon the mean test results rather than recording the exact numerical results.

ARC RESISTANCE

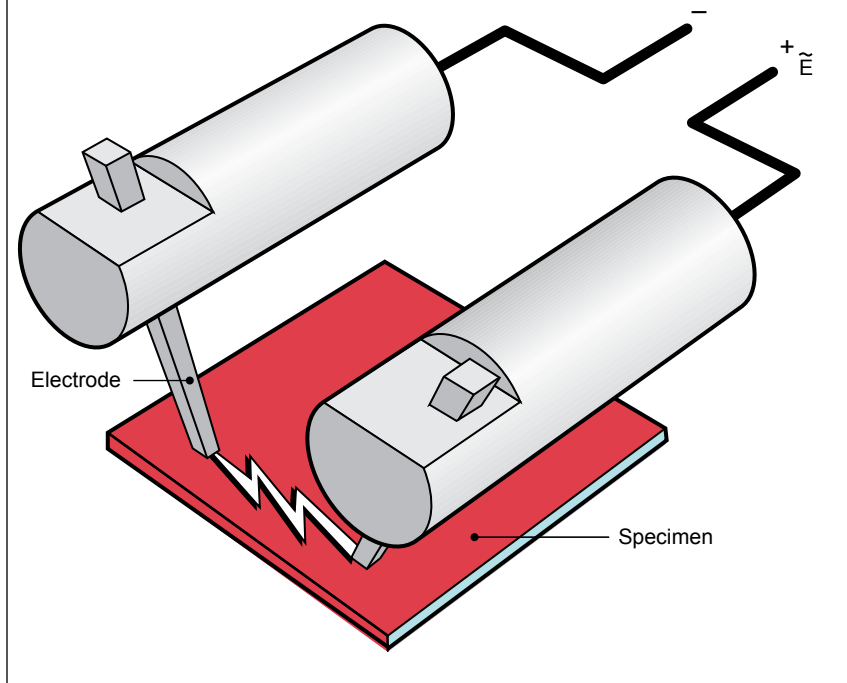
Arc resistance measures the number of seconds a plastic specimen's surface will resist forming a continuous conductive path while being exposed to a high-voltage electric arc. Materials with higher arc-resistance values are used in components with closely spaced conductors that project above the plastic's surface, and in applications such as circuit breakers and distributor caps where arcing may occur.



Dielectric constant is the ratio of the system capacitance with the plastic specimen as the dielectric to the capacitance with a vacuum as the dielectric.

The mechanism for forming the conductive path across the sample varies with resin. Burning, carbonization, heating to incandescence or a breakdown in the material's surface usually determine the failure point. In the standard tests (**UL 746 A** and **ASTM D 495**), electrodes intermittently emit an arc on the specimen surface with increasing severity until the specimen fails (see figure 5-5). Because test results are sensitive to surface moisture and contamination, arc-resistance values may not correlate directly to the surface conditions of your final part. See table 5-1 for PLC ratings.

Figure 5-5



Arc-resistance electrodes intermittently subject the specimen surface to a high-voltage arc until a conductive path is formed.

COMPARATIVE TRACKING INDEX (CTI)

Much like arc resistance, the **comparative tracking index** tests (**UL 746 A**, **ASTM D 3638**, or **IEC112**) measure the voltage needed to make a conductive path between electrodes on the surface of a specimen. The difference between these tests is that in CTI the sample is exposed to 50 drops of an electrolytic liquid, to account for surface contamination. In the **IEC 112** test for CTI, the electrolyte drips onto a specimen at a rate of 50 or 100 drops per minute and the tracking voltage increases in 25-volt increments, up to a maximum of 600 volts.

Materials with higher CTI values should be considered in applications where arcing is possible. When surface contamination is likely, CTI values may be more useful than arc-resistance values. PLC ratings are shown in table 5-2.

Table 5-1

ASTM D 495 Test Results

Range-Mean Time of Arc Resistance	Assigned PLC
420 and greater	0
360 and up to 420	1
300 and up to 360	2
240 and up to 300	3
180 and up to 240	4
120 and up to 180	5
60 and up to 120	6
Less than 60	7

Table 5-2

PLC Values for CTI

CTI Range-Tracking Index (TI in Volts)	Assigned PLC
600 and greater	0
400 and up to 600	1
250 and up to 400	2
175 and up to 250	3
100 and up to 175	4
Less than 100	5

HOT-WIRE IGNITION (HWI)

Simulating a situation in which a current-carrying component in direct contact with a plastic part becomes heated due to overloading, this test measures the number of seconds before the material ignites.

In the standard test (**UL 746 A** or **ASTM D 3874**) plastic specimens are wrapped with resistance wire that dissipates a specified level of electrical energy (see figure 5-6). The UL material card lists results in PLCs as shown in table 5-3.

HIGH-CURRENT ARC IGNITION (HAI)

Measuring the number of arc applications applied either to the specimen surface or at some specified distance from it until the sample ignites, this test (**UL 746**) subjects specimens to high-intensity arcs at regular intervals. Results show the number of arcs needed to initiate combustion under standardized conditions. The UL card lists results as a PLC rating as shown in table 5-4.

HIGH-VOLTAGE ARC-TRACKING RATE (HVTR)

In this test (**UL 746 A**), a specimen's surface is subjected to high-voltage arcs for two minutes. During this time, the electrode spacing increases to the maximum distance that will sustain the arc. The tracking rate, defined as the length of the conductive leakage path after the two minutes, divided by the two-minute test length, receives a PLC rating as shown in table 5-5.

Standard setup for hot-wire-ignition test.

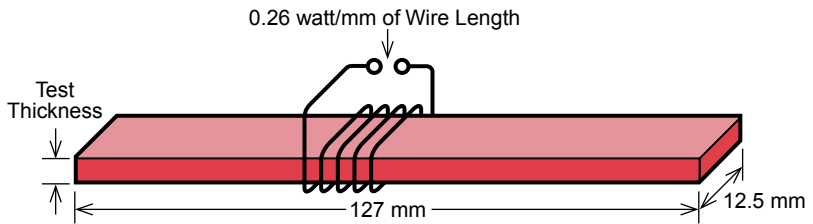


Figure 5-6

Table 5-3

PLC Values for HWI

HWI Range-Mean Ignition Temp (IT in sec)	Assigned PLC
120 and longer	0
60 and up to 120	1
30 and up to 60	2
15 and up to 30	3
7 and up to 15	4
Less than 7	5

Table 5-4

PLC Values for HAI

HAI Range-Mean Number of Arcs to Cause Ignition	Assigned PLC
120 and greater	0
60 and up to 120	1
30 and up to 60	2
15 and up to 30	3
7 and up to 15	4

Table 5-5

PLC Values for HVTR

HVTR Range-TR (in mm/min)	Assigned PLC
0 through 10	0
Over 10 through 25.4	1
Over 25.4 through 80	2
Over 80 through 150	3
Over 150	4



When designing plastic parts, pay close attention to the environment to which the part will be exposed during processing, secondary operations and assembling, as well as end-use. Chemical exposure and weather conditions may determine which resin you choose. In this section, we discuss several of the more important environmental properties, as well as the tests done to measure these characteristics.

WATER ABSORPTION

Plastics absorb water to varying degrees, depending upon their molecular structure and the fillers and additives they contain. In addition to adversely affecting both mechanical and electrical properties, high levels of moisture can cause parts to swell, an important consideration in close-tolerance applications or when a plastic part is joined with parts made of other materials.

Standard tests (**ASTM D 570** or **ISO 62**) measure moisture absorption by the weight gained in oven-dried samples after they have been immersed in distilled water for a minimum of 24 hours at 73°F (23°C). An alternative method involves immersing samples for 30 minutes at 212°F (100°C). Generally listed along with the temperature and duration of immersion, the weight-gain percentage can be important when designing parts in which water absorption could affect a key property or dimension.

Moisture content in plastic resins during processing can also be important. Improper moisture levels can cause problems, such as degradation and cosmetic flaws in thermoplastics. Always follow your resin supplier's procedures for drying pellets before processing.

HYDROLYTIC DEGRADATION

Exposing plastics to moisture at elevated temperatures can lead to hydrolytic attack, decreasing the material's physical properties.

Hydrolysis, a chemical process that severs polymer chains by reacting with water, reduces molecular weight and degrades the plastic. The degree of degradation depends upon a number of factors, including exposure time, type of exposure (intermittent or continuous), environmental temperature, stress levels in the part, and other chemicals in the water such as chlorine or detergents. Because of the number of factors that affect hydrolytic attack, plastics should always be tested at in-use environmental conditions.

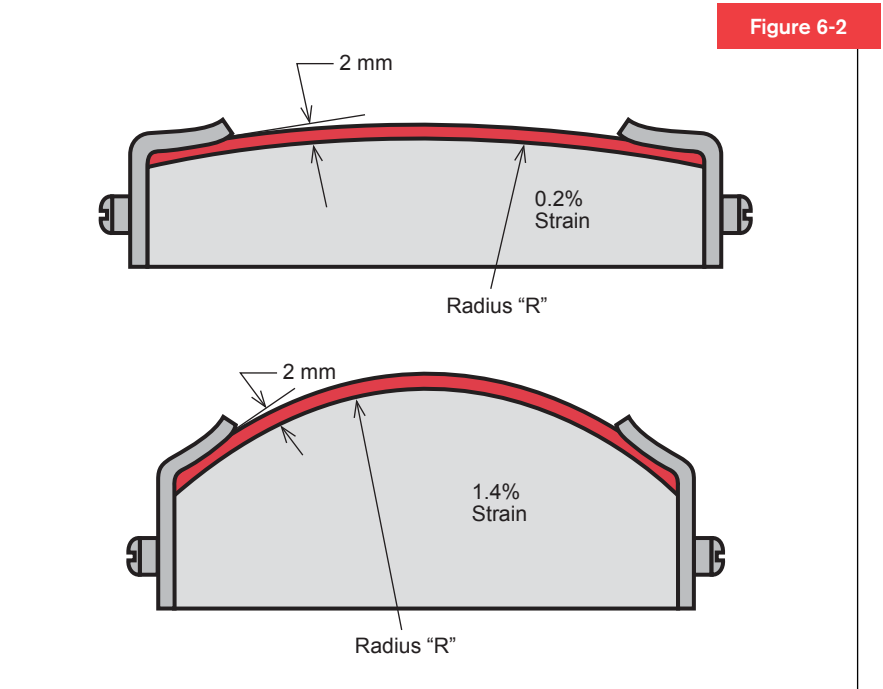
CHEMICAL RESISTANCE

A difficult and complex topic, the chemical resistance of any given plastic depends upon many factors including the chemical and its concentration, exposure time and temperature, and stress levels in the part.

The type of chemical attack varies with the plastic and the chemical involved. In some cases, the chemical will cause a progressive breakage of the polymer chains over time, reducing the molecular weight and physical properties. Other parts will **stress-crack**, a process in which small cracks or crazes develop in areas that are stressed from molding or applied load. Acting as stress concentrators, these cracks can lead to mechanical failure. When attacked by a weak solvent, a plastic part can swell and also experience a change in mechanical properties.

When designing parts, consider all the substances a part will encounter, including intentional and accidental exposure. Also review the chemicals to which a part may be exposed in manufacturing and assembling, such as cutting oils, degreasers, cleaning solvents, printing dyes, paints, adhesives and lubricants.

Some published chemical-resistance data lists substances in generic or general terms, such as aliphatic hydrocarbon or lubricating oil. Use this data cautiously, as additives or impurities in a specific brand can cause chemical attack.



Multi-strain fixtures. Radius "R" is varied to give strain values from 0.2% to 1.4%.

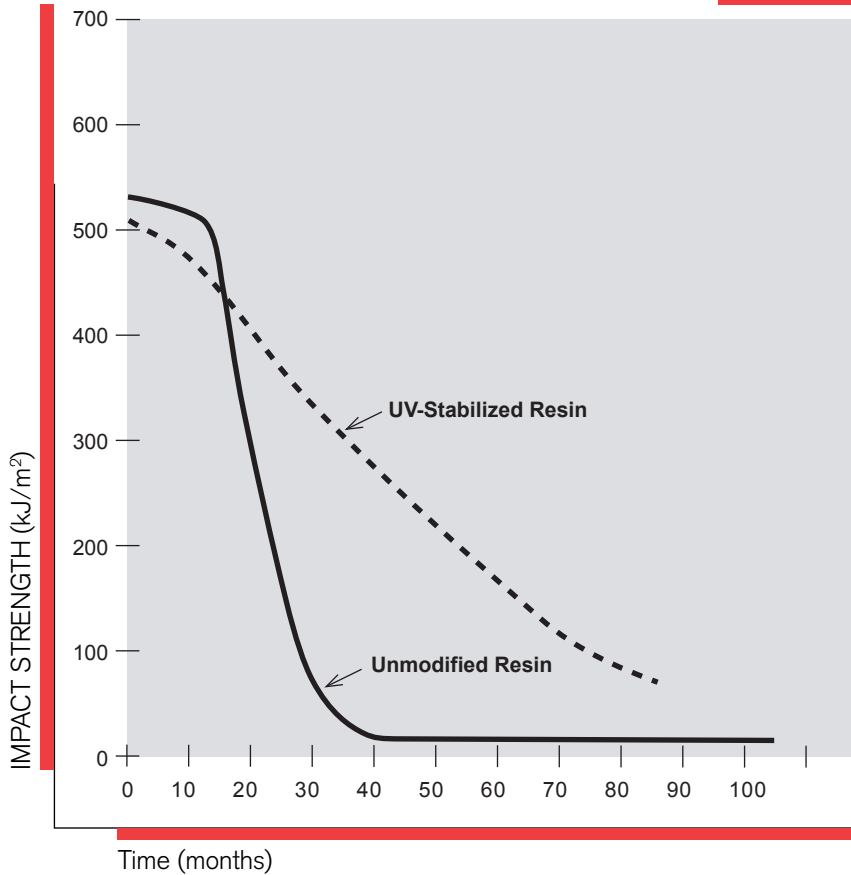
Additionally, elevated temperatures and chemical concentrations will affect chemical resistance: A material that withstands a 10% concentration of a solvent at room temperature may not withstand a 5% concentration at 150°F (66°C).

At LANXESS, we typically collect chemical-resistance data by applying the substance to five tensile bars bent across fixtures that generate five different strain levels from 0.2 to 1.4% (see figure 6-2) for either 24 hours at 73°F (23°C) or 16 hours at 150°F (66°C). Bars without cracks or crazing are then tested for tensile elongation at break. The **strain limit** for a given resin, the highest strain

level without cracks or a large drop in elongation values, determines its chemical-resistance rating. Given in general terms, such as "resistant," "limited resistance" or "non-resistant," these ratings serve only as guidelines for screening candidate materials. **ISO 175** specifies a similar test performed on 50-mm circular or square test plaques.

If you have any questions regarding a LANXESS resin and a specific chemical environment, please call your LANXESS representative. Final material selection should be evaluated with production parts under actual application conditions.

Figure 6-3



This graph shows the significant differences in impact strength reduction of standard and UV-stabilized resin grades after months of outdoor exposure.

WEATHERABILITY

Plastics in outdoor use are exposed to weather extremes that can be devastating to the material. The most harmful weather component, exposure to the sun's **ultraviolet (UV) radiation**, can cause embrittlement, fading, surface cracking and chalking.

Weatherability in plastics varies with polymer type and within grades of a particular resin. While many resin grades are available with UV-absorbing additives to boost weatherability, generally the higher-molecular-weight grades of a resin fare better than

lower-molecular-weight grades with comparable additives. Additionally, some colors tend to weather better than others. Contact your LANXESS representative when selecting materials for outdoor use.

To test weatherability (**ASTM G 5377 or ISO 4892**), resin suppliers normally expose the material to actual outdoor conditions, usually in Arizona or Florida. Mounted for optimum sun exposure, samples are tested for mechanical and physical properties after a series of exposure times (see

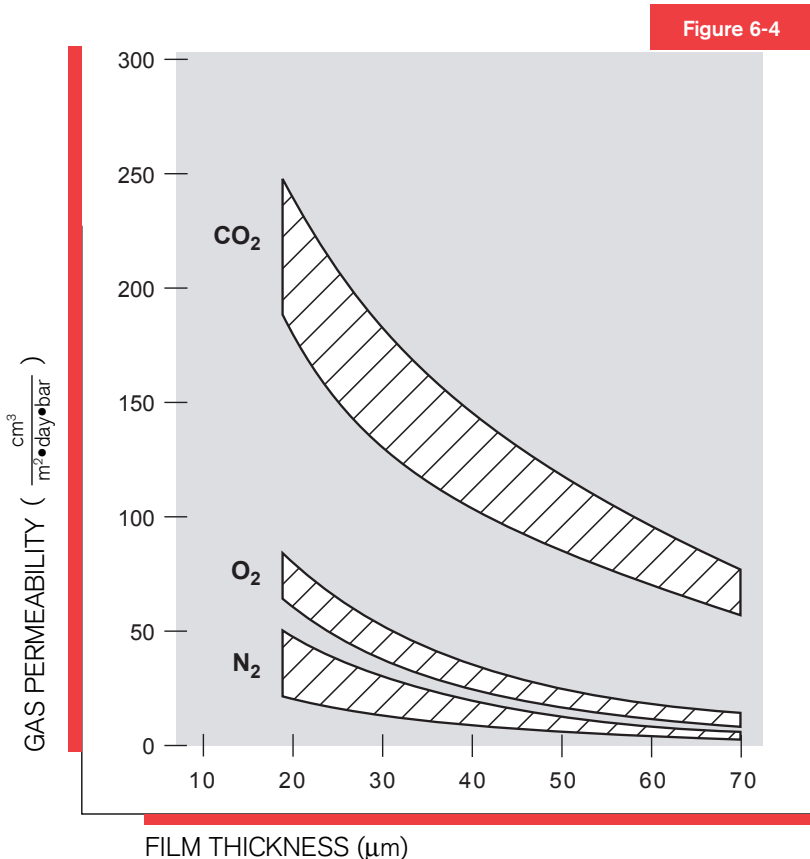
figure 6-3). Because it shows how specific properties are affected over time, this data is extremely useful when designing parts for outdoor use.

Although outdoor testing is most common, accelerated data can be generated in special test chambers with UV lights and climate controls. Because of the more severe environment in these testing chambers, the results are usually listed at 1,000 hours, rather than years.

GAS PERMEABILITY

Gas permeability measures the amount of gas – typically carbon dioxide, oxygen or nitrogen – that passes through a material in a given time. Permeability is an important concern in many packaging and medical applications where the plastic must form a barrier to gasses. Usually graphed as permeability versus film thickness (see figure 6-4), gas permeability also can be shown as a single value for each gas at a standard film thickness and temperature.

Standard permeability tests exist for a variety of conditions, such as for a pressure-driven system with just one gas present or for a constant-pressure system driven by a gas concentration gradient. Standard tests include **DIN 53380**, **ISO 2556** and **ASTM D 1434**.



Gas permeability as measured by DIN 53380 with test temperature at 22°C (72°F) for Durethan® B38F polyamide resin.



There are a variety of other properties – such as optical transmittance and flammability – that you, the designer, have to address when developing plastic parts. These properties further help you determine which material is best suited for a given application. This section discusses some of these properties and relevant testing.

DENSITY

Density, the mass-per-unit volume of a material, is useful when converting part volume into part weight, or cost per pound into cost per cubic inch, and other calculations involving weight and volume conversions. Usually expressed in pounds per cubic inch (lb/in³) or grams per cubic centimeter (g/cm³), density measurements for solid plastics are often conducted according to **ISO 1183**.

SPECIFIC VOLUME

The reciprocal of density, **specific volume** can be used instead of density for weight and volume conversions. Typically, it is measured in cubic inches per pound (in³/lb) or cubic centimeters per gram (cm³/g).

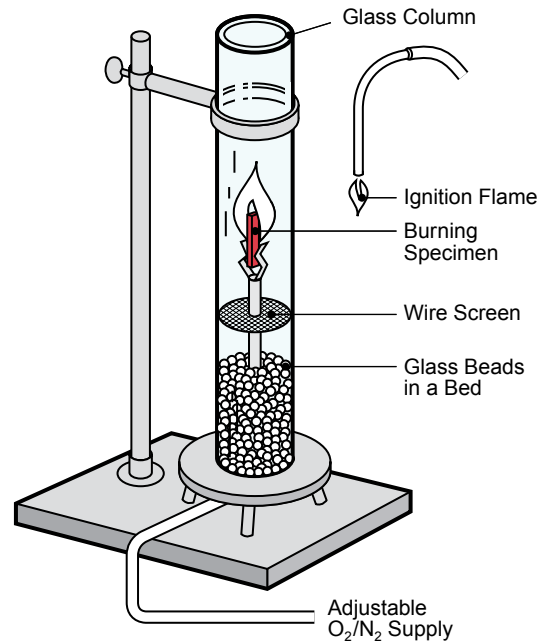
SPECIFIC GRAVITY

Specific gravity, the ratio of a material's density to the density of water at 73°F (23°C), is used in a variety of calculations and comparisons when relative weight matters. A dimensionless value, specific gravity can be converted into density in grams per cubic centimeter (g/cm³) at 73°F (23°C) if you multiply specific gravity by 0.99756. The conversion factor accounts for the fact that the density of water is less than 1 g/cm³ at 73°F (23°C). Performed on most plastic systems, **ASTM D 792 (ISO 1183)** measures specific gravity.

HAZE AND LUMINOUS TRANSMITTANCE

Haze and luminous transmittance, commonly tested according to **ASTM D 1003**, measure a material's transparency. Haze is the percentage of transmitted light passing through a sample that is scattered more than 2.5 degrees. Luminous transmittance, the ratio of light transmitted through the sample to the incident light directed at the sample, is listed either as a percentage or a ratio. Surface reflection accounts for nearly the entire light-transmission loss in optically transparent plastics and approximately 10% for polycarbonate. Plastic grades with low-haze and high-transmittance values are best for applications requiring transparency.

Figure 7-1



Oxygen-index test apparatus.

REFRACTIVE INDEX

Light passing through a gas, liquid or solid travels slower than light passing through a vacuum. The **refractive index**, important in a variety of optical-lens and light-pipe calculations, indicates the ratio of light's velocity in a vacuum to its velocity as it passes through a given substance. Published values from **ASTM D 542** or **ISO 489** are for testing at room temperature. The refractive index of plastics generally decreases with increasing temperatures.

OXYGEN INDEX

The **oxygen index (ASTM 2863 or ISO 4589)** measures the minimum percentage of oxygen, by volume, in a mixture of oxygen and nitrogen needed to support flaming combustion in a plastic sample at room temperature (see figure 7-1). Open-air combustion is more likely in materials with oxygen-index ratings of less than 21, the oxygen percentage in the atmosphere. Not intended as an indicator of fire risk under actual conditions, the oxygen index measures a resin's contribution to the combustion process.

FLAMMABILITY CLASS

Except for a few that are inherently flame retardant, most plastics require an additive to meet higher flame-resistance ratings. Because these additives can:

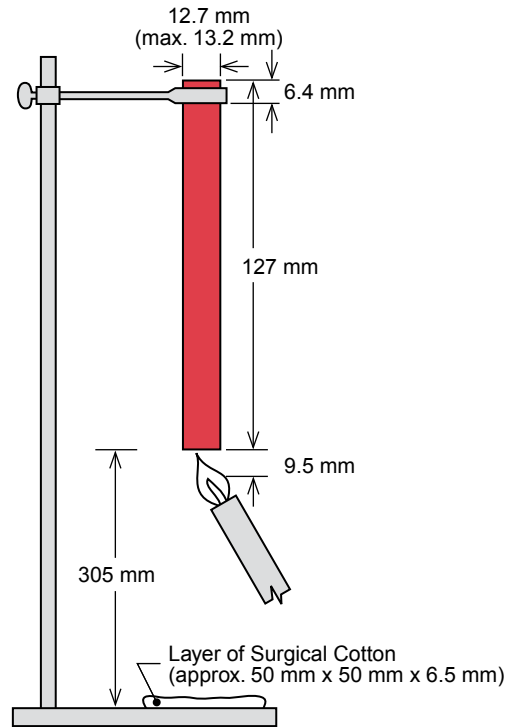
- Add to the material cost;
- Cause a variety of molding problems, and;
- Result in lower mechanical properties;

avoid over-specifying the degree of flame resistance required.

Underwriters Laboratories has established flammability classes for plastics (**UL 94**). Classes range from “HB,” the least flame resistant, through more resistant ratings of “V-2,” “V-1” and “V-0.” Additionally materials can receive a “5VA” or “5VB” rating based upon a separate test covered under UL 94 for the more stringent flammability requirements in electrical and electronic enclosures. Because thicker specimens typically exhibit greater flame resistance, flame-class ratings listed on the UL card for the resin list the minimum thicknesses for which the rating was obtained. *Flammability results are based upon small-scale laboratory tests. Use these ratings for comparison purposes only, as they do not necessarily represent the hazard present under actual fire conditions.*

The vertical-flame test subjects the lower end of a sample to two applications of a 19-mm, high-blue flame from a Bunsen burner for a duration of 10 seconds each (see figure 7-2). The horizontal test applies a 25-mm flame from a Bunsen burner to the free end of a test specimen for 30 seconds (see figure 7-3). The flame-class criteria for the test results are listed in tables 7-2 and 7-3.

Figure 7-2 Vertical Burn Test

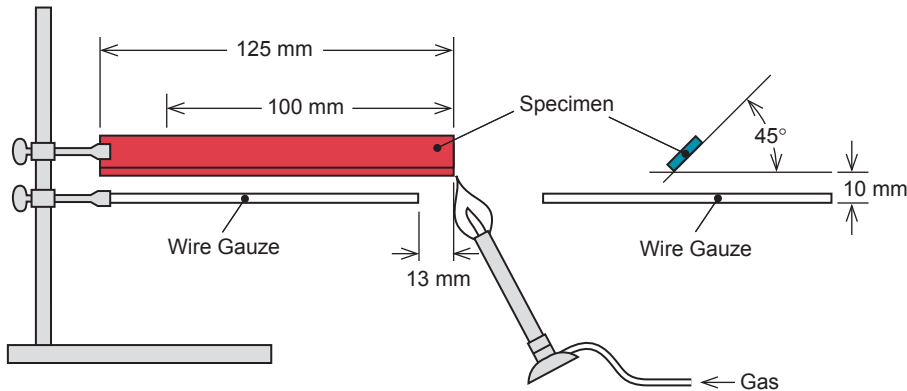


Flammability of solid specimens according to UL 94.

Flammability standards for a variety of electrical products are listed in **UL 746 C**. To avoid costly tests to prove conformance to this standard, consider resins that have been pre-tested and meet the requirements indicated.

Horizontal Burn Test

Figure 7-3



Flammability of solid specimens according to ASTM D 635 (similar to UL 94).

Table 7-2

Vertical Burning Test for UL Flammability Classifications 94V-0, 94V-1, 94V-2

Test Criteria	Flammability Classification		
	94V-0	94V-1	94V-2
Flaming combustion time after each application of flame	≤ 10 s	≤ 30 s	≤ 30 s
Total flaming combustion time for each set of 5 specimens (10 flame applications)	≤ 50 s	≤ 250 s	≤ 250 s
Flaming or glowing combustion up to the holding clamp	no	no	no
Duration of glowing combustion after second removal of test flame	≤ 30 s	≤ 60 s	≤ 60 s
Ignition of surgical cotton by dripping flaming particles	no	no	yes

Table 7-3

Horizontal Burning Test for Flammability Classification 94HB

Specimen Thickness	Burning Rate
≥ 1/8 in	≤ 1 – 1-1/2 in/min
≤ 1/8 in	≤ 3 in/min

or material ceases to burn before flame reaches the second reference mark



When selecting a resin, you should also consider processing properties. Information for thermoplastic resins – such as melt flow rates, viscosity versus shear-rate curves and spiral flow data– help determine if a given resin is right for your application and processing techniques. In each section, we define relevant terms, their importance, and their testing methodology.

GENERAL PROCESSING PARAMETERS

Part designers and mold makers must address two common processing parameters – shrinkage and viscosity – when planning to make any part out of plastic. These two processing properties are discussed below.

Mold Shrinkage

Plastics shrink significantly during the cooling cycle in molding. A mold designer uses mold-shrinkage values to compensate for part shrinking during molding. To determine mold shrinkage values, use the following formula:

$$\text{Shrinkage} = \frac{[(\text{Mold Dimension}) - (\text{Part Size})]}{(\text{Mold Dimension})}$$

Results are typically listed as length-per-unit-length or as percentages. Always measure part and mold dimensions at room temperature.

Standard tests such as **ASTM D 955**, **ISO 294** and **DIN 16901** give ranges of values based upon simple mold shapes and standard molding conditions. The exact shrinkage for a given application depends upon many processing and design factors and may differ dramatically from published values. Measuring actual shrinkage from parts with similar geometries molded under anticipated processing conditions may give more accurate predictions. Finite-element shrinkage analysis software can provide specific predictions based upon your part geometry, runner and gating system, mold-cooling design,

and processing conditions. When possible, the mold designer should anticipate changes based upon initial molding trials and allow for adjustments for critical dimensions.

Viscosity

A material's viscosity, its internal resistance to flow, determines mold-filling rates in both thermoplastic and polyurethane resins. Viscosity as it relates to these different types of resins is discussed in this section.

Solution Viscosity

The viscosity of a polymer dissolved in solvent provides an indirect measure of molecular weight and relative melt flow behavior of the base resin. The viscosity measured at a series of concentrations can be plotted against concentration and the graph extrapolated to infinite dilution to determine the limiting viscosity number or **intrinsic viscosity**. This value, coupled with constants for the polymer and solvent at a given temperature can be applied to the semi-empirical Mark-Houwink equation to calculate molecular weight.

The ratio of the viscosity of the dilute polymer solution of specified concentration to the viscosity of the solvent yields the viscosity ratio or **relative viscosity**. Most commonly used as a quality control guide during resin production, **relative viscosity** measurements can also detect polymer degradation caused by improper molding.

Viscosity Versus Shear-Rate Curves

Viscosity versus shear-rate curves, more relevant than melt flow rates for comparing moldability in thermoplastic materials, are seldom used directly in resin selection. Used increasingly in computerized mold-filling simulation programs, these curves are used in curve-fitting equations and as constants. Software can then interpolate (and extrapolate) viscosity data for more temperatures and shear rates than the original test data.

The capillary viscometer (**ASTM D 3835**) measures a thermoplastic's viscosity over a range of temperatures and shear rates. The pressure, and therefore the shear rate acting on the melt, increase in stages for each test temperature. You can calculate the shear rate and corresponding viscosity from the die geometry and the amount of extruded material at each pressure setting. The results, usually plotted on log/log graph paper, create curves of apparent viscosity versus shear rate at various temperatures. Figure 8-1 shows viscosity curves of common engineering thermoplastics.

The capillary viscometer measures a range of shear rates from approximately one-tenth to several thousand reciprocal seconds, the range of shear rates normally encountered in extrusion and injection molding.

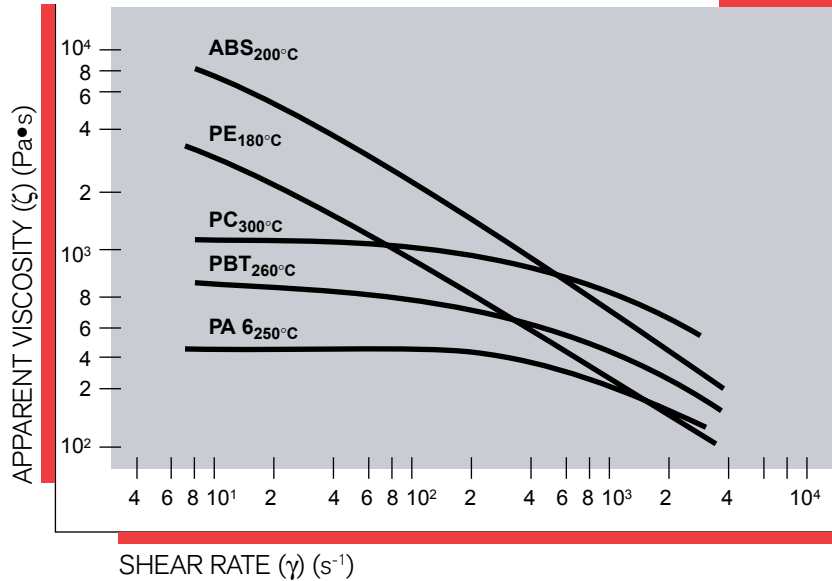


Figure 8-1

Apparent viscosity as a function of shear rate.

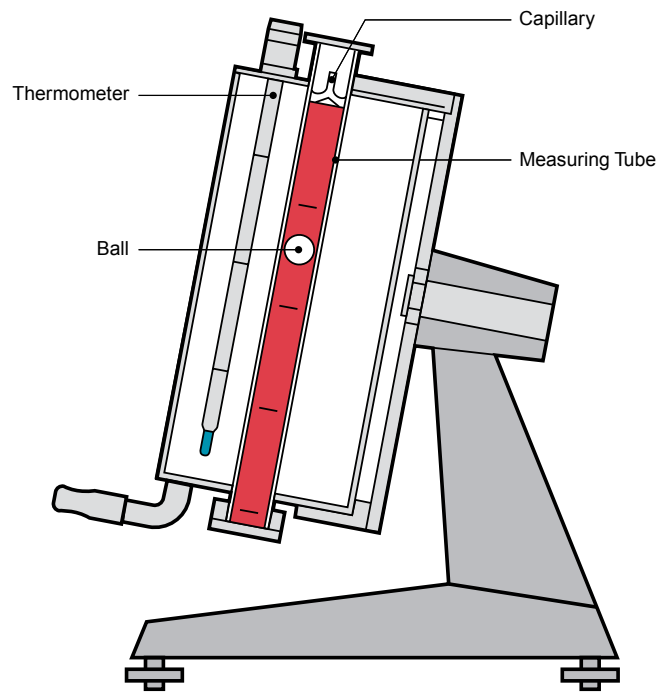


Figure 8-2

Haake-Hoepler falling ball viscometer.

Figure 8-3

THERMOPLASTICS

Most of the concerns for processing thermoplastic resins involve flow rates and ability to properly fill molds. This section outlines the relevant tests to check flow properties, viscosity curves and other processing parameters for thermoplastic resins.

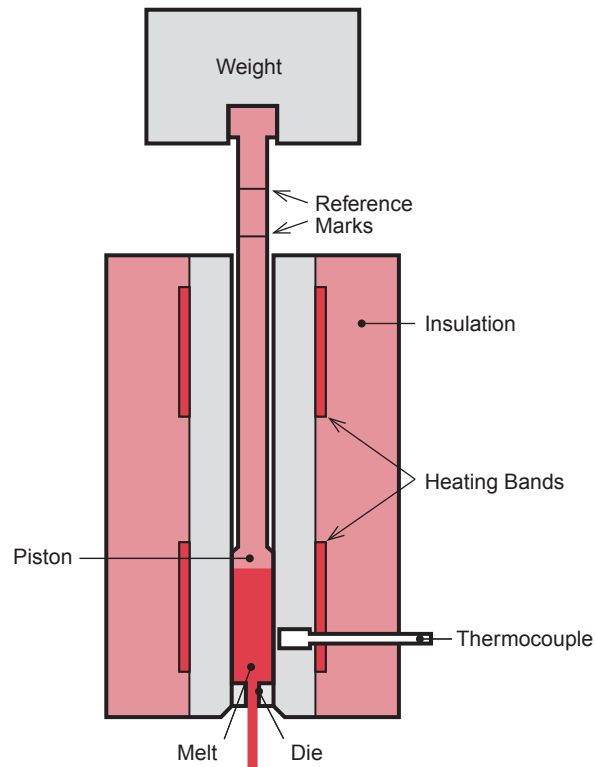
Melt Flow Rate

The amount of a resin extruded through a standard die in ten minutes by a weight-driven plunger determines the **melt flow rate**, one of the most-common methods to test the flow properties of thermoplastics (see figure 8-3). In the common tests (**ASTM D 1238** or **ISO 1133**), an appropriate load and melt temperature for the resin are selected from a standard set of test conditions. Higher melt flow rates indicate lower resistance to flow and lower viscosity.

Because the test for melt flow is performed at a single temperature and single load value, it does not account for the relationship of viscosity as a function of shear rate and temperature. Melt flow rates do not reliably predict the ease of flow in a mold and should not be used to judge the relative flow ability of dissimilar resins, because the shear rates used in testing are generally lower than those found during actual injection molding.

Melt flow rate is useful for differentiating grades of a resin family according to viscosity and molecular weight. For

general-purpose polycarbonate resins, melt flow rates identify at least six viscosity grades within the 4 to 19 g/10 min melt flow range. Also, because melt flow rate is a good measure of viscosity differences or changes for a specific resin, you can use it to check uniformity in production batches or as a quick check for degradation in molded plastic parts. If the melt flow rate in molded material has significantly increased from that found in unmolded pellets from the same batch, processing-related degradation may have occurred.



Schematic of melt flow rate test apparatus.

Spiral Flow

Spiral-flow testing measures the distance a plastic travels through the long, spiral-shaped channels of a special test mold to determine a resin's mold-filling capability (see figure 8-4). The test mold typically consists of a center sprue gate feeding a 1/2-inch wide, rectangular cross-section flow channel that spirals outward to a length of approximately 50 inches.

The spiral-flow length records the resin's flow length at the stated thickness and processing conditions. Graphs of flow length versus thickness (see figure 8-5) provide a quick method for estimating such molding parameters as gate spacing and required part thickness for filling.

Consider this test's conditions and limitations when applying spiral flow data to actual molded parts. Difficult-to-fill features and non-uniform thicknesses can limit this data's usefulness in many applications. Additionally, flow in molds with

Cavity half of spiral-flow mold.

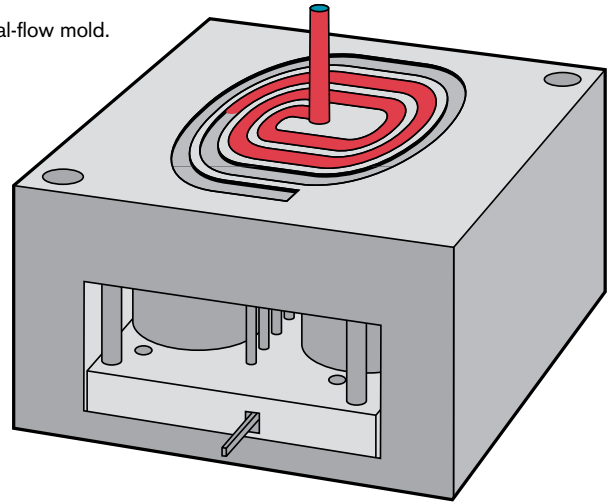


Figure 8-4

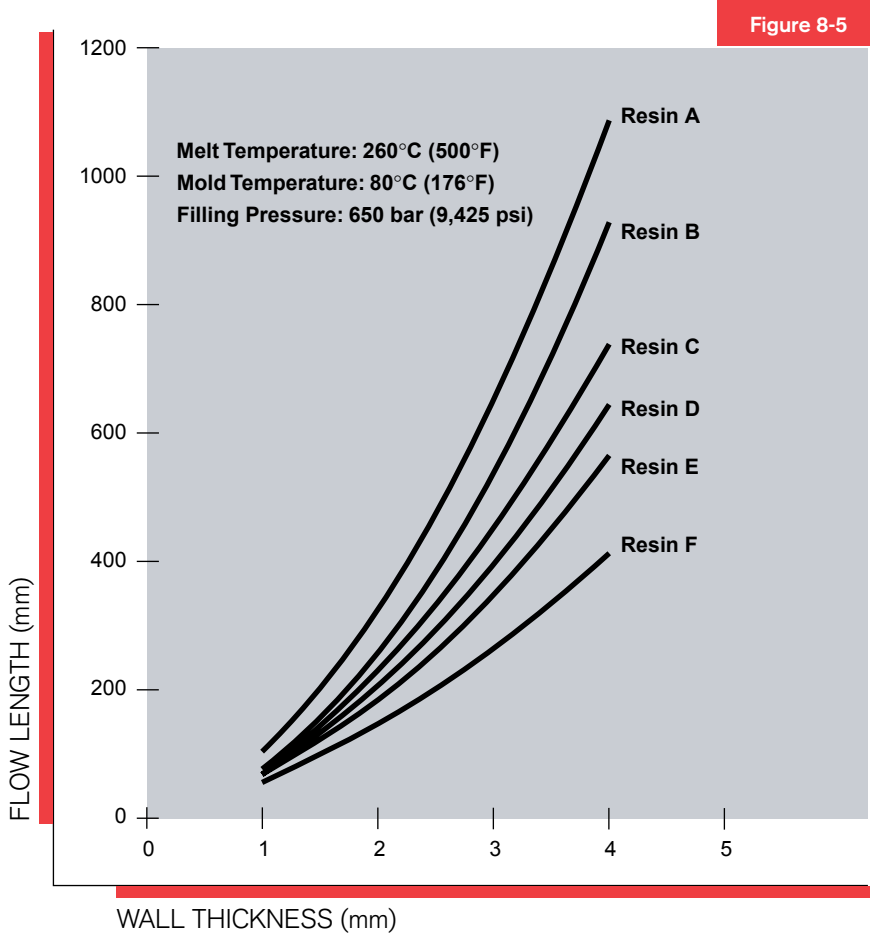


Figure 8-5

restrictive runner systems may be shorter than this data indicates. You will also need to know if spiral-flow data is based upon maximum or typical processing conditions. In these situations, consider using computerized, mold-filling analysis.

Spiral flow lengths for various PC/ABS resins at typical processing conditions.



Getting the optimum balance of performance, quality, and cost requires a careful combination of material and plastic part design. As the demands on plastic parts grow and the number of grades increases, selecting the most-effective plastic becomes more difficult. This section explains some things to consider when selecting your material.

COST CONSIDERATIONS

A plastic's contribution to final product cost involves more than the per-pound cost of the resin. Different materials have different costs associated with processing, finishing, productivity, and quality control, which can alter costs dramatically. For example:

Deflashing costs and longer cycle times often make a compression-molded, low-cost thermoset resin less economical than its higher-cost thermoplastic counterparts.

Other material differences also affect final part cost. As a general rule, crystalline materials have faster cycle times than amorphous resins. Some materials show corrosive or abrasive behavior that could lead to higher-than-normal mold and press maintenance costs. Differing shrinkage

and warpage characteristics could lead to high scrap costs in parts with tight tolerances if you use the wrong resin. Other materials prone to cosmetic defects could contribute to high scrap costs.

Because the part's shape, not its weight, is fixed in the design, you should always compare the cost per volume ($\$/\text{in}^3$) instead of cost per pound. A ton of low-density material will produce more parts than a ton of high-density material.

Part geometry also plays an important role. When comparing resins for a load-bearing application, optimize part geometry for each resin's characteristics. For example, you may be able to design a part with thinner walls and fewer ribs and achieve the required stiffness with a higher-modulus resin.



ENVIRONMENTAL CONSIDERATIONS

Environmental conditions – mechanical loading, temperature extremes, exposure to chemicals and the elements, for instance – play crucial roles in material selection. When evaluating these conditions, consider more than just the intended, end-use environment: Plastic parts are often subjected to harsher conditions during manufacturing and shipping than in actual use. To assure longevity and durability, always test plastic parts under all manufacturing, transportation and end-use conditions.

Load

Successful material selection often depends upon satisfying some not-so-obvious mechanical requirements. For example, a plastic chosen for a snow plow headlight assembly may meet the support and impact requirements, but fail in-use because of vibrational fatigue. Likewise, a plastic used in a computer housing may support a monitor initially, but sag over time because of inadequate creep resistance. Apparently similar plastics may exhibit quite different performance under certain types of long-term or dynamic loading. Carefully evaluate a material's performance under all types of anticipated load.

Temperature

Many material properties in plastics – impact strength, modulus, tensile strength and creep resistance, to name

a few – depend upon ambient temperature in final use. Thermoplastics tend to become more ductile and flexible as the temperature increases. As the temperature decreases, these materials become stiffer and more brittle. Additionally, many plastics suffer permanent losses in mechanical characteristics when exposed to long-term, elevated temperatures. Select materials that satisfy part requirements throughout the expected temperature range.

Chemical Resistance

A key factor in material selection, resistance to chemical attack varies greatly from plastic to plastic. Individual plastics are usually vulnerable to attack from families of chemicals, such as strong acids or organic solvents. Resins tend to show either resistance or vulnerability to broad classes of chemicals such as weak acids or organic solvents. However, within these classes, there are often surprising exceptions. Additionally, the complete list of harmful substances may include an odd collection of apparently unrelated chemicals. You should verify a material's resistance to all the chemicals it will be exposed to in processing, assembling and final use. You should also check a

material's resistance under the harshest anticipated conditions, because chemical resistance tends to diminish with increasing temperature, exposure and concentration. Finally, be wary of different brand-name products. A resin may respond differently to two cleaners with the same major ingredients, because of minor differences in their chemical composition.

Weather Resistance

A resin's ability to withstand exposure to weather extremes and UV radiation from the sun greatly affects its selection for outdoor applications. UV exposure severely degrades many



plastics, leaving them discolored and brittle after a short time in service. Although most engineering plastics are available in UV-stabilized grades, they differ in their level of UV resistance. High-molecular-weight grades of polycarbonate, inherently more UV resistant than lower-molecular-weight grades, demonstrate better resistance when modified with UV additives.

Radiation from indoor fluorescent lighting can also cause yellowing in many plastics. Applications exposed to other types of artificial radiation, such as from high-intensity discharge lamps or gamma sterilization, may require special resin grades. Contact your LANXESS representative for assistance in selecting grades for these applications.

MATERIAL PROPERTIES

To help you select and use plastics, resin suppliers publish property data for various materials. This data can be helpful in initial selection,

but should not be the sole basis for choosing a plastic. Good for comparing the relative performance of similar resins, data should not be extrapolated to higher temperatures or loads. For example, a material with high modulus at room temperature may not have a correspondingly high modulus at elevated temperatures.

Many times published data does not cover your precise, end-use conditions. If you understand the trends for each property, this data can still be useful. For example, tensile modulus decreases as temperature increases. If your application requires a modulus of at least 300,000 psi (2,069 MPa) at 122°F (50°C) and you have reliable data showing a modulus greater than this for any temperature over 50°C, you can be confident that the material is stiff enough. Clear property trends have been stated in the materials property descriptions in this manual.

Computerized, material-database programs quickly screen large numbers

of resin grades according to selected sets of performance criteria. Unfortunately, because of the differences in test methods or specimen preparation, direct comparisons of property data from different sources are often not valid. To help solve this problem, a consortium of resin suppliers, including LANXESS, helped develop Computer-Aided Material Preselection by Uniform Standards (CAMPUS®), a plastics database system now in use worldwide. CAMPUS provides an international, uniform system for testing and selecting plastic materials from different suppliers. Contact your LANXESS representative for information on the availability of CAMPUS material data.

Published material properties, based upon testing done in a lab, do not necessarily reflect the complexities encountered in actual production parts. Therefore, published data is more appropriate for eliminating unsuitable materials than for identifying



the best material. *You should select your final material only after testing in actual production and end-use conditions.*

PROCESSING

Processing and moldability concerns should be identified and addressed early in the design process. For instance, materials with good flow properties and broad processing windows should be considered for parts with thin sections or long flow lengths. Spiral-flow data showing flow lengths at various thicknesses may help you screen potential materials in this situation. If you're designing a part with difficult geometries, you may want to perform a computerized mold-filling analysis to address mold-filling concerns.

Within any resin family, improved processing characteristics often compromise mechanical properties. Knowing this early in the design stage will help you adjust part geometry to account for this compromise. A material's shrinkage factor and warpage



characteristics should also be considered during the design process. Materials with low-shrinking and low-warping tendencies are best suited for large parts, as well as parts with tight tolerances and critical flatness requirements. Finally, difficult part geometries may necessitate using a material with an internal mold release to help eject the part without distortion or cycle interruption.

APPEARANCE

The aesthetics of a finished part directly affect the perception of quality. For toys, housewares and medical applications, Lustran® ABS resins are desirable, because of their high-gloss finish, wide range of colors and toughness.

Certain grades of Durethan® Nylon 6 resin have largely overcome the nonuniform, swirly appearance found in some glass-reinforced resins. These grades, used in structural appearance parts such as chair star bases, maintain a resin-rich surface with the glass hidden below.

Color availability and consistency also factor into aesthetics. Because of the natural color of their base polymers, some plastics can not be made in light colors. Standard colors cost less than custom colors. Check with your LANXESS representative to see what colors are readily available. For optimum color matching and uniform color retention over time, consider specifying the same resin for components of cosmetically critical assemblies.

AGENCY APPROVALS

Some applications require that plastic parts be approved by or conform to specifications developed by a variety of government and private agencies. Additionally, companies have their own specifications that must be considered when selecting a plastic. Many resin suppliers have test data to prove compliance with these various specifications. If you select a resin that has been pre-tested and meets specifications, you can save time and money. Among the most common agencies and approvals are:

- **Underwriters' Laboratories, Inc. (UL)** needs to approve most general-sale, electrical devices sold in North America. Many LANXESS resins meet or exceed the flame-class ratings indicated by the appropriate UL standard.
- **Military (MIL)** specifications regulate and certify plastics used in all military applications according to the exact specification and type designation.
- **Food and Drug Administration (FDA)** compliance is needed for plastics that could come in contact with food. When evaluating medical and surgical devices, the FDA examines the resin's composition, quality, and uniformity, as well as the device's structural integrity and bio-compatibility. These regulations generally pertain to substances that could migrate into food through contact with the plastic.

- **United States Department of Agriculture (USDA)** approves plastics used in packaging federally inspected meat and poultry, and plastics used in meat and poultry-processing equipment.
- **National Sanitation Foundation Testing Laboratory, Inc. (NSF)** regulates the use of some plastics used in food processing equipment, and pipes and fittings for potable water. Materials and equipment must meet standards for taste, odor, toxicity and clean ability, as well as other tests specific to the finished part.

ACTUAL REQUIREMENTS

Take time to ascertain your true part and material requirements. Although the problems associated with underestimating these specifications can be serious, they usually can be identified and corrected during prototype testing. On the other hand, because parts perform as designed, the costs of over-specifying for an application normally go uncorrected. Such oversights can increase part costs, while reducing product competitiveness.

Some material requirements – such as product feel or appearance – can be subjective and imprecise. Others – such as flammability ratings or key thermal or electrical properties – are clearly specified by industry standards. Parts should be designed with appropriate safety factors. Calculations and/or computer analysis may help determine some mechanical

or processing requirements. When determining less-precise requirements, you may want to use comparisons to known properties of existing materials. While these comparisons do not precisely define the material requirements, they help narrow your choices.

PROTOTYPE TESTING

Final material selection must be based upon thorough product testing. Even with the most complete planning and engineering, opportunities for oversight and miscalculations exist for any project. Prototype testing gives you an opportunity to test and optimize part design and material selection before investing in expensive production tooling. Good prototype testing duplicates the production conditions as closely as possible, including prototype molds that simulate production tooling; processing and assembling techniques that are identical to production; and testing under the same range of mechanical, chemical and environmental conditions that the final part will endure.

Simplifying or eliminating prototype testing increases the chances of unexpected problems that could lead to delays and expensive modifications in production tooling. You should thoroughly prototype test all new designs.

RESIN SUPPLIERS

Your resin supplier is an important member of your design team, providing

technical and engineering support, as well as test results and processing, design and computer-aided engineering (CAE) services to help you. While many suppliers offer these services, they can differ significantly in quality and availability. LANXESS has a reputation for providing quality service throughout the project's life.

SYSTEMS APPROACH

In the systems approach, your team – consisting of designers, production and processing engineers, and others who have input on new products – considers and optimizes all of the steps involved in taking an idea from design to production. This approach develops more options and opportunities for improved material selection, design, and final production and processing techniques simultaneously. For instance, selecting an easier-flowing material and modifying a part's design to maintain performance levels could solve processing problems before they develop.

Additionally, because the design is not set in concrete when material selection begins, you can compare designs that have been optimized for the properties of each material candidate. For instance, a material with higher tensile modulus and good processing characteristics might be used in a design with thinner wall sections. This systems approach may help you select material, because it compares the cost and performance of the complete system.



**DESIGN AND
ENGINEERING EXPERTISE**

To get material selection and/or design assistance, just call your **LANXESS** representative or **1-800-LANXESS**. To best help you, we will need to know the following information:

- Physical description of your part(s) and engineering drawings or CAD geometry, if possible;
- Current material being used;
- Service requirements, such as mechanical stress and/or strain, peak and continual-service temperature, types and concentrations of chemicals to which the part(s) may be exposed, stiffness required to support the part itself or another item, impact resistance, and assembly techniques;
- Applicable government or regulatory agency test standards;
- Tolerances that must be held in the functioning environment of the part(s);

- Any other restrictive factors or pertinent information of which we should be aware.

Upon request, **LANXESS** will furnish such technical advice or assistance it deems to be appropriate in reference to your use of our products. It is expressly understood and agreed that because all such technical advice or assistance is rendered without compensation and is based upon information believed to be reliable, the customer assumes and hereby releases **LANXESS** from all liability and obligation for any advice or assistance given or results obtained. Moreover, it is your responsibility to conduct end-use testing and to otherwise determine to your own satisfaction whether **LANXESS** products and information are suitable for your intended uses and applications.

TECHNICAL SUPPORT

We provide our customers with design and engineering information in several ways: applications advice, available by phone, at **1-800-LANXESS**; processing assistance, through a nationwide network or regional field technical service representatives; technical product literature; and periodic presentations and seminars.

The types of expertise you can obtain from **LANXESS** include:

Design Review Assistance

- Concept development
- Product/part review
- Mold design review
- Part failure analysis
- Finite element stress analysis
- Mold filling and cooling analysis
- Experimental stress analysis
- Shrinkage and warpage analysis

Application Development Assistance

- Product development
- Part cost estimates
- Color matching
- Prototyping
- Material selection
- Molding trials
- Physical testing
- Secondary operation advice

Product Support Assistance

- Dryer audits
- On-site processing audits
- Start-up assistance
- On-time material delivery



- Troubleshooting
- Processing/SPC Seminars
- Productivity audits

REGRIND USAGE

For each grade of thermoplastic resin, there is an upper limit on the amount of regrind that may be used with virgin material, depending upon end-use requirements of the molded part and provided that the material is kept free of contamination and is properly dried. These limits are published in Product Information Bulletins and data sheets. Any regrind used must be generated from properly molded parts, sprues, and/or runners. All regrind used must be clean, uncontaminated, and thoroughly blended with virgin resin prior to drying and processing. Under no circumstances should degraded, discolored, or

contaminated material be used for regrind. Materials of this type should be discarded.

Improperly mixed and/or dried resin may diminish the desired properties of **LANXESS** thermoplastics. You must conduct testing on finished parts produced with any amount of regrind to ensure that your end-use performance requirements are fully met. Regulatory organizations (e.g., UL) may have specific requirements limiting the allowable amount of regrind. Because third-party regrind generally does not have a traceable heat history, nor offers any assurance that proper temperatures, conditions, and/or materials were used in processing, extreme caution must be exercised in buying and using regrind from third parties.

The use of regrind material should be avoided entirely in those applications where resin properties equivalent to virgin material are required, including but not limited to color quality, impact strength, resin purity, and/or load-bearing performance.

FOR MORE INFORMATION

The typical property data presented in this brochure are for general information only. They are approximate values and do not necessarily represent the performance of any of our materials in your specific application. Do not use this information for product specification. For more detailed information, contact your **LANXESS** representative or call **1-800-LANXESS**.

RELATED ISO-ASTM-IEC TEST METHODS
Based on Ascending ISO Test Number

Typical Properties for Natural Resins	ISO/IEC Test Method	SI Units	ASTM Test Method	U.S. Units
Water Uptake (Immersion): Saturation @ 23°C	ISO 62:1980	%	D 570	%
Water Uptake (Immersion): Saturation @ 23°C/50% RH	ISO 62:1980	%	D 570	%
Deflection Temperature Under Load (Unannealed): 1.80-MPa Load	ISO 75-1:1993	°C	D 648	°F
Deflection Temperature Under Load (Unannealed): 0.45-MPa Load	ISO 75-2:1993	°C	D 648	°F
Deflection Temperature Under Load (Unannealed): 8.00-MPa Load	ISO 75-3:1993	°C	D 648	°F
Flexural Stress @ 5% Strain	ISO 178:1992	MPa	D 790	lb/in ²
Flexural Modulus	ISO 178:1991	MPa	D 790	lb/in ²
Impact Resistance, Charpy, Unnotched, 23°F	ISO 179-1eU:1993	kJ/m ²	D 256	ft•lb/in ²
Impact Resistance, Charpy, Unnotched, -30°C	ISO 179-1eU:1993	kJ/m ²	D 256	ft•lb/in ²
Impact Resistance, Charpy, Notched, 23°F	ISO 179-1eA:1993	kJ/m ²	D 4812	ft•lb/in ²
Impact Resistance, Charpy, Notched, -30°C	ISO 179-1eA:1993	kJ/m ²	D 4812	ft•lb/in ²
Impact Resistance, Izod, Unnotched, 23°F	ISO 180-1eC:1993	J/m	D 256	ft•lb/in
Impact Resistance, Izod, Unnotched, -30°C	ISO 180-1eC:1993	J/m	D 256	ft•lb/in
Impact Resistance, Izod, Notched, 23°F	ISO 180-1eA:1993	J/m	D 256	ft•lb/in
Impact Resistance, Izod, Notched, -30°C	ISO 180-1eA:1993	J/m	D 256	ft•lb/in
Vicat Softening Temperature: Rate A [10N]	ISO 306:1994	°C	D 1525	°F
Vicat Softening Temperature: Rate B [50N]	ISO 306:1994	°C	D 1525	°F
Tensile Modulus	ISO 527-1 & -2:1993	MPa	D 638	lb/in ² x10 ³
Tensile Stress at Yield	ISO 527-1 & -2:1993	MPa	D 638	lb/in ²
Tensile Strain/Elongation at Yield	ISO 527-1 & -2:1993	%	D 638	%
Tensile Strain/Elongation at Break	ISO 527-1 & -2:1993	%	D 638	%
Tensile Stress at 50% Elongation	ISO 527-1 & -2:1993	MPa	D 638	lb/in ²
Tensile Stress at Break	ISO 527-1 & -2:1993	MPa	D 638	lb/in ² x10 ³
Tensile Strain/Elongation at Break	ISO 527-1 & -2:1993	%	D 638	%
Hardness, Shore	ISO 868:1985	Scale-Value	D 2240	Scale-Value
Tensile Creep Modulus @ 1 hr	ISO 899-1:1993	MPa	D 638	lb/in ² x10 ³
Tensile Creep Modulus @ 1000 hr	ISO 899-1:1993	MPa	D 638	lb/in ² x10 ³
Melt Flow/Volume Rate @ xxx°C/x.x-kg Load	ISO 1133:1991	ml/10 min	D 1238	ml/10 min
Density	ISO 1183:1987	g/cm ³	D 792	lb/in ³

RELATED ISO-ASTM-IEC TEST METHODS
Based on Ascending ISO Test Number

Typical Properties for Natural Resins	ISO/IEC Test Method	SI Units	ASTM Test Method	U.S. Units
Flammability† UL94 Flame Class, 1.6 mm Thick Specimen	ISO 1210:1992	Rating	(UL94)	Rating
Flammability† UL94 Flame Class, 6.2 mm Thick Specimen	ISO 1210:1992	Rating	(UL94)	Rating
Hardness, Ball Indentation	ISO 2039-1:1987	Scale-Value	D 785	Scale-Value
Hardness, Rockwell	ISO 2039-2:1987	Scale-Value	D 785	Scale-Value
Molding Shrinkage, Parallel	ISO 2557:1989	%	D 955	in/in
Molding Shrinkage, Normal	ISO 2557:1989	%	D 955	in/in
Melting Point	ISO 3146:1985	°C	D 1525	°F
Coefficient of Linear Thermal Expansion, Parallel	ISO 3167:1992	1/K	D 696	in/in/°F
Coefficient of Linear Thermal Expansion, Normal	ISO 3167:1992	1/K	D 696	in/in/°F
Limiting Oxygen Index	ISO 4589:1984	%	D 2863	%
Flexural Creep Modulus @ 1 hr	ISO 6602-1:1993	MPa	D 638	lb/in ² x10 ³
Flexural Creep Modulus @ 1000 hr	ISO 6602-1:1993	MPa	D 638	lb/in ² x10 ³
Impact, Multiaxial @ 23°F	ISO 6603-1:1989	mm	D 3763	ft•lb/in
Impact, Multiaxial, Instrumented @ 23°F	ISO 6603-2:1989	J	D 3763	ft•lb/in
Tensile Impact Strength, Double-Notched	ISO 8256:1991	kJ/m ²	D 1822	ft•lb/in ²
Flammability† UL94-5V Flame Class, 3.0 mm Thick Specimen	ISO 10351:1994	Rating	(UL94)	Rating
Flammability† UL94-5V Flame Class, 6.2 mm Thick Specimen	ISO 10351:1994	Rating	(UL94)	Rating
Volume Resistivity (Tinfoil Electrodes)	IEC 93:1980	ohm•cm	D 257	ohm•cm
Surface Resistivity	IEC 93	ohm	D 257	ohm
Comparative Tracking Index [CTI]	IEC 112:1979	Steps	D 3638	Steps
Dielectric Strength (Short Time Under Oil @ 73°F)	IEC 243-1:1988	kV/mm	D 149	V/mil
Relative Permittivity/Dielectric Constant (Tinfoil Electrodes): 100 Hz	IEC 250	—	D 150	—
Relative Permittivity/Dielectric Constant (Tinfoil Electrodes): 1 MHz	IEC 250	—	D 150	—
Dissipation Factor (Tinfoil Electrodes): 100 Hz	IEC 250	E-4	D 150	—
Dissipation Factor (Tinfoil Electrodes): 1 MHz	IEC 250	E-4	D 150	—
Glass Transition Temperature	IEC 1006	°C	D 3418	°F
Relative Temperature Index, Electrical	(UL746B)	°C	(UL746B)	°C
Relative Temperature Index, Mechanical with Impact	(UL746B)	°C	(UL746B)	°C
Relative Temperature Index, Mechanical without Impact	(UL746B)	°C	(UL746B)	°C

† Flammability results are based on small-scale laboratory tests for comparison purposes only and do not necessarily represent the hazard presented by this or any other material under actual fire conditions.

HEALTH AND SAFETY INFORMATION

Appropriate literature has been assembled which provides information concerning the health and safety precautions that must be observed when handling the **LANXESS** products mentioned in this publication. For materials mentioned which are not **LANXESS** products, appropriate industrial hygiene and other safety precautions recommended by their manufacturers should be followed. Before working with any of these products, you must read and become familiar with the available information on their hazards, proper use, and handling. This cannot be overemphasized. Information is available in several forms, e.g., material safety data sheets and product labels. Consult your **LANXESS** Corporation representative or contact the Product Safety and Regulatory Affairs Department at **LANXESS**.

REGULATORY COMPLIANCE INFORMATION

Some of the end uses of the products described in this publication must comply with applicable regulations, such as the FDA, NSF, USDA, CPSC and BfR. If you have any questions on the regulatory status of these products, contact your **LANXESS** Corporation representative or Regulatory Affairs Manager at **LANXESS**. As with any product, use of the products mentioned in this publication in a given application must be tested (including field testing, etc.) by the user in advance to determine suitability.

These items are provided as general information only. They are approximate values and are not considered part of the product specifications.

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