Chapter 5

PROPERTIES OF PLASTICS

Mechanical and Physical Properties of Plastics

This section will acquaint the reader with the technical terms and concepts used to describe the properties or performance of a material. It is important to understand these standard terms since they are used by suppliers and users to communicate how a material behaves under specific conditions. This also allows comparisons of different materials.

Design

A designer or engineer will often use design equations that work with metals while a part is being designed. Metals behave like a spring; that is, the force generated by the spring is proportional to its length. A plot (Figure 5.1) of the force as a function of length is a "straight line."

When a material actually works this way it is called "linear" behavior. This allows the performance of metals and other materials that work like a spring to be quite accurately calculated. A problem occurs when the designer tries to apply these same equations directly to plastics. Plastics do not behave like a spring (not a straight line), that is they are "non-linear." Temperature changes the behavior even more. The equations should be used only with very special input. A material supplier may have to be consulted for the correct input.

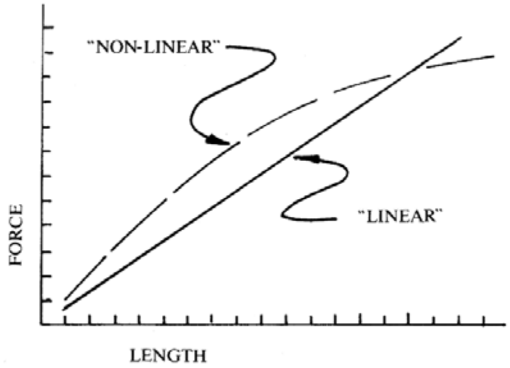

Figure 5.1

How much load or force will the part be required to carry? How will the part be loaded? What are the direction and size of the forces in the part? These are but a few of the questions that a designer tries to answer before a material is selected. (See material selection, page 32.)

Stress

How does one know if a material will be strong enough for a part? If the loads can be predicted and the part shape is known, then the designer can estimate the worst load per unit of cross-sectional area within the part. Load per unit area is called "stress." (Figure 5.2)

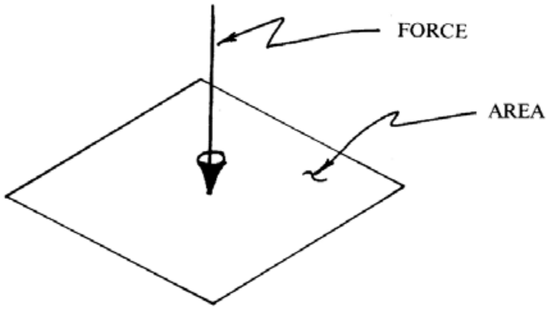

Figure 5.2

If force or load is in pounds and area is in square inches, then the units for stress are pounds per square inch.

Stiffness (Modulus)

Sometimes a designer knows a part can only bend or deflect a certain amount. If the maximum amount of bending and the shape of the part are known, then the designer can often predict how stiff a material must be. The measurement of the stiffness of a material is called the "modulus" or "modulus of elasticity." The higher the modulus number, the stiffer the material; conversely, the lower the number, the more flexible the material. The modulus also changes as the temperature changes. Modulus numbers are also given in pounds per square inch.

TYPICAL TENSILE MODULUS VALUES (PSI) at Room Temperature

Graphic-epoxy composites	40,000,000
Steel	30,000,000
Aluminum, 1000 series	10,000,000
Epoxy-glass laminates	5,800,000
Polyester-glass reinforced	2,000,000
Nylons, 30% glass reinforced	1,400,000
Acrylics	500,000
Cast epoxy	450,000
Polycarbonate	450,000
Acetal, copolymer	410,000
Polyethylene; high molecular weight	100,000

Strain

The measurement of how much the part bends or changes size under load compared to the original dimension or shape is called "strain." Strain applies to small changes in size.

STRAIN = (Final Length – Original Length) ÷ Original Length
= Change in Length or Deformation ÷ Original Length

If the change in size is in inches and the original dimension is in inches, then the units for strain are inch per inch.

Stress, strain and modulus are related to each other by the following equation. The modulus or stiffness of a material can be determined when the material is loaded in different ways, such as tension, compression, shear, flexural (bending) or torsion (twisting). They will be called tensile modulus, also known as plain modulus, flexural modulus or torsional modulus.

MODULUS = STRESS ÷ STRAIN

or in other words

MODULUS = Load ÷ Change in shape when loaded
(STIFFNESS)

Choose the type of modulus in the property sheet that most nearly duplicates what the customer expects the major load to be. If the load is unknown, use the lowest moduli value of the two. These numbers can be used for short-term loading if the load is to be applied for only a few days at the most.

The stress/strain equation is the equation used by designers to predict how a part will distort or change size and shape when loaded. Predicting the stress and strain within an actual part can become very complex. Fortunately, the material suppliers use tests that are easy to understand.

THE PERFORMANCE OF A PLASTIC PART IS AFFECTED BY:

- What kind of load the part will see (tensile, impact, fatigue, etc.)
- How large the load is
- How long or often that load will be applied
- How high and/or low a temperature the part will see
- How long it will see those temperatures
- The kind of environment the part will be used in. Will moisture or other chemicals be present?

This is where plastics differ in their behavior when compared to other materials, such as metals and ceramics. Choosing stress and/or modulus values that are too high and do not account for time and temperature effects can lead to failure of the part.

Some additional terms that are used to describe material behavior:

Yield Point

The yield point is that point when a material subjected to a load, tensile or compression gives and will no longer return to its original length or shape when the load is removed. Some materials break before reaching a yield point, for example, some glass-filled nylons or die cast aluminum.

To try to further visualize this property, take a piece of wire and slightly bend it. It will return to its original shape when released. Continue to bend and release the wire further and further. Finally, the wire will bend and not return to its original shape. The point at which it stays bent is the yield point. The yield point is a very important concept because a part is usually useless after the material has reached that point.

Tensile Strength

The maximum strength of a material without breaking when the load is trying to pull it apart is illustrated in Figure 5.3. This is the system used by the suppliers to report tensile properties in their literature, such as strength and elongation.

A good way to visualize this property is to think of pulling a fresh marshmallow apart and then pulling a piece of taffy apart. The force or pounds required to pull the taffy apart would be much greater than required to pull the marshmallow apart. If that force is measured and the taffy and marshmallow each had a cross-sectional area of one square inch, then the taffy has the higher tensile strength in terms of pounds per square inch (psi). Plastics may demonstrate tensile strengths from 1,000 psi to 50,000 psi.

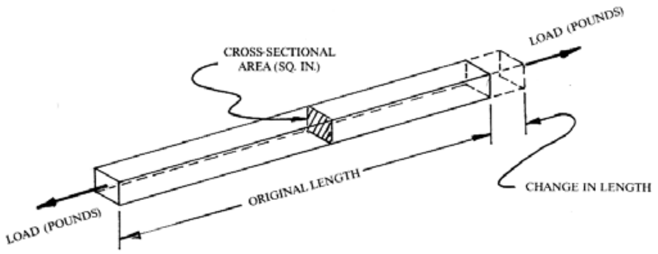

Figure 5.3

Elongation

Elongation is always associated with tensile strength because it is the increase in the original length at fracture and expressed as a percentage. An example would be to pull on a 1" wide piece of paper that is 4" long. It tears with no visible elongation or nearly 0 percent elongation. Now do the same thing to a 1" × 4" piece of taffy. It will stretch several times its original 4" length before it fractures. Assume that it is stretched to a 12" length, then (12" ÷ 4")(100) = 300 percent elongation.

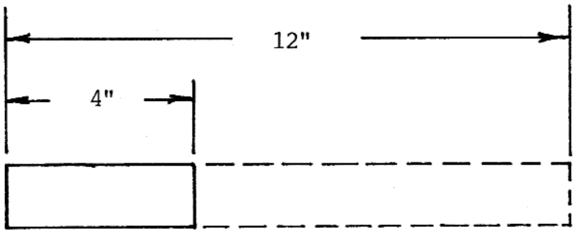

Figure 5.4

Compressive Strength

Compressive strength is the maximum strength of a material without breaking when the material is loaded as shown in Figure 5.5. Check if the material supplier has the information on compressive strength, since it is not always determined.

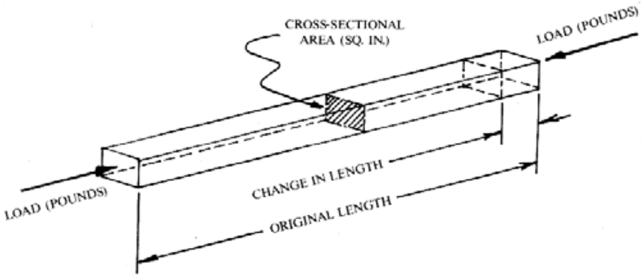

Figure 5.5

This term becomes less meaningful with some of the softer materials. PTFE, for example, does not fracture. Consequently, the compressive strength continues to increase as the sample is deforming more and more. A meaningful compressive strength would be the maximum force required to deform a material prior to reaching the yield point. The compressive term similar to "elongation" is "compressive deformation," though it is not a commonly reported term. It is easy to visualize two identical weights, one sitting on a 1" cube of fresh marshmallow and the other on a 1" cube of taffy. The marshmallow would be flattened and deformed more.

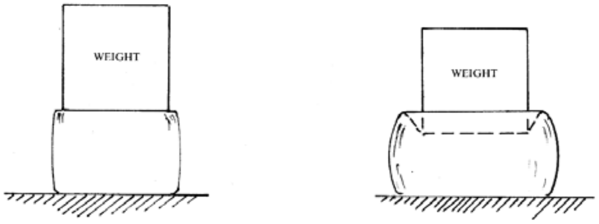

Figure 5.6

Shear Strength

Shear strength is the strength of a material when the material is loaded as shown in Figure 5.7. The surfaces of the material are being pulled in opposite directions. Some examples of items that experience shear loading are the nail holding a picture on the wall, the cleats of athletic shoes, and tire tread as a car speeds up or slows down.

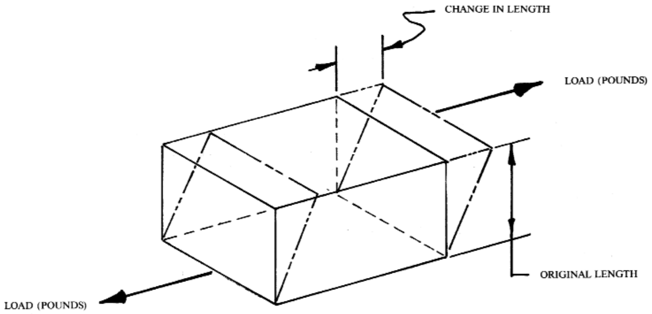

Figure 5.7

Flexural Strength

Flexural strength is the strength of a material when a beam of the material is subjected to bending as shown in Figure 5.8. The material in the top of the beam is in compression (squeezed together), while the bottom of the beam is in tension (stretched). Somewhere in between the stretching and squeezing there is a place with no stress and it is called the neutral plane. A simple beam supported at each end and loaded in the middle is used to determine the flexural modulus given in properties tables. Skis, fishing poles, pole vault poles and diving boards are examples of parts needing high flexural strength.

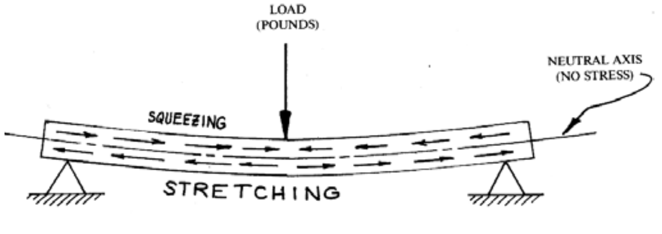

Figure 5.8

Torsional Strength

Torsional strength is the strength of a material when a shape is subjected to a twisting load as shown in Figure 5.9. An example of a part with a torsion load is a screw as it is being screwed in. The drive shaft on a car also requires high torsional strength.

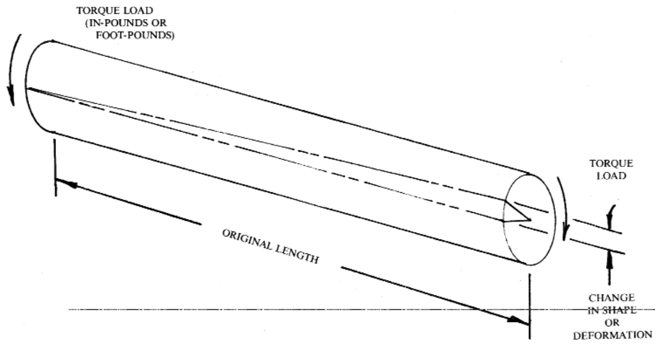

Figure 5.9

Poisson's Ratio

Sometimes a designer will need a value for Poisson's ratio. This ratio occurs in some of the more complex stress/strain equations. It sounds complicated, but it is simply a way of saying how much the material (taffy) necks down or gets thinner in the middle when it is stretched (Figure 5.10). Its value is most often between .3 and .4 for plastic materials. Check supplier literature for specific information.

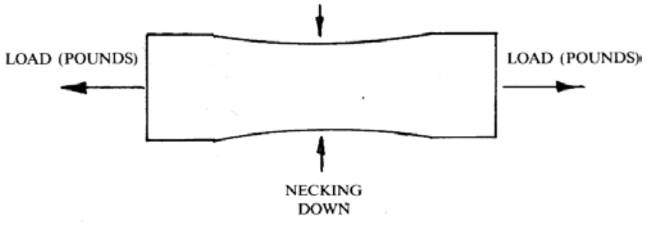

Figure 5.10

Figures 5.11 through 5.15 show the tensile strain curves for different types of materials. Remember to think of pulling on different kinds of taffy; that is, soft and weak, hard and brittle, etc.

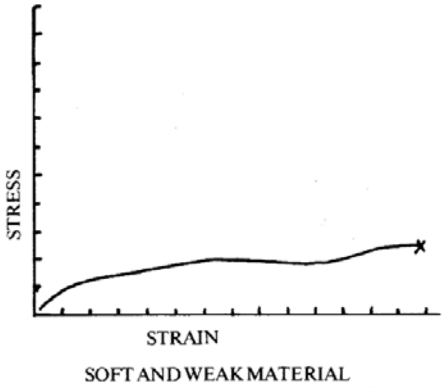

Figure 5.11

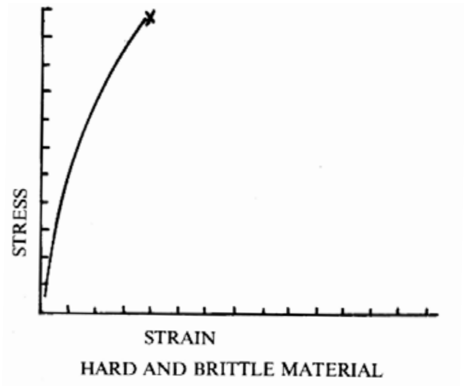

Figure 5.12

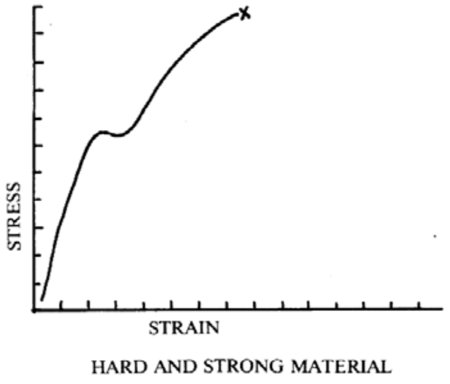

Figure 5.13

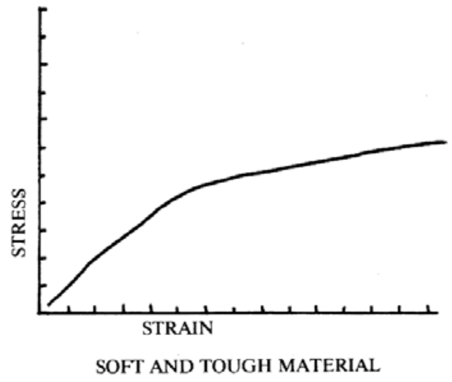

Figure 5.14

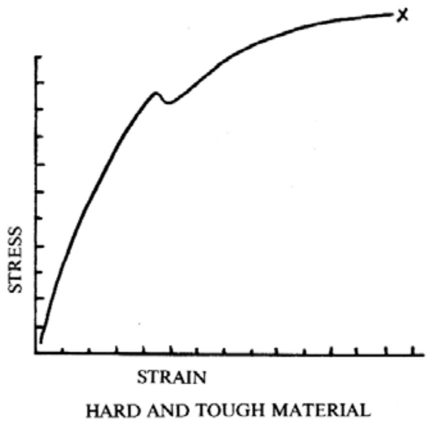

Figure 5.15

Figure 5.16 shows how a plastic material can appear stiffer and stronger if it is pulled apart faster. An example of rate sensitivity is when we cannot pull a string apart, but we can snap it apart.

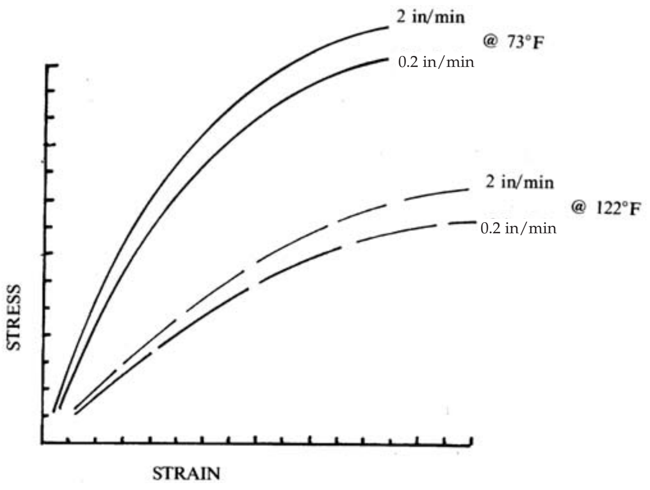

Figure 5.16

Figure 5.16 also shows how the material is softer and weaker at higher temperatures. Plastics are also affected by low temperatures and many become more brittle as the temperature goes down.

Figure 5.17 shows the effect of moisture in the atmosphere on the properties of a material like nylon. The dry material is hard and brittle while the wet material is soft and tough. This is like comparing uncooked spaghetti to cooked spaghetti.

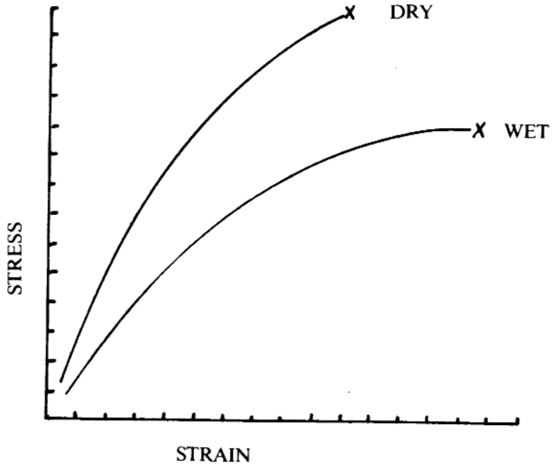

Figure 5.17

TYPICAL TENSILE YIELD STRENGTHS OF SOME MATERIALS (psi)

Low alloy hardening steels; wrought, quenched and tempered	288,000
High strength low alloy steels; wrought, as-rolled	80,000
Aluminum casting alloys	55,000
Aluminum alloys, 1000 series	24,000
Polyphenylene sulfide, 40% glass reinforced	21,000
Acetal, copolymer, 25% glass reinforced	18,500
Nylons, general purpose	12,600
Acetal, homopolymer	10,000
Acrylics	10,000
Acetal, copolymer	8,800
ABS/polycarbonate	8,000
Polypropylene, general-purpose	5,200
Polypropylene, high-impact	4,300

Creep

Visualize large weights being hung on bars of different materials. All materials will experience some initial and immediate deformation or stretching when the load is first applied. As long as the yield point has not been exceeded, a metal sample which acts like a spring will not stretch any more regardless of how long the weight is left on. When the weight is removed, the metal bar will return to its original shape. The length of a plastic bar will continue to slowly increase as long as the load is applied. This is called creep. The amount of creep increases as the load and/or temperature are increased. Some thermoplastics like nylons will creep more when they have softened because of the presence of moisture. The cross-linked or three-dimensional net structure in thermosets resists creep better than thermoplastics. Reinforcements like glass and carbon, which do not creep, greatly reduce the creep of the composite material when mixed with a plastic.

Remember the relationship between stress, strain and modulus:

Modulus = Stress ÷ Strain

The initial strain or change in length with the weight will give a value for the modulus. (This is usually the short term value reported in the property tables for the tensile modulus or flexural modulus.) If the weight (stress) is left on over a period of time, the amount of bending or elongation continues to increase, and the value for the modulus will decrease with time as shown in Figure 5.18. This decreasing modulus that is a function of time (and even temperature) is called the “creep modulus” or “apparent modulus.”

This is the modulus that the designer should be using to more accurately predict the behavior of the plastic materials. The value chosen from the supplier’s literature will be based on the estimated time the load will be applied, the amount of the load, and the temperature conditions present when the load is to be applied.

$$\text{Apparent Modulus} = \frac{\text{Stress}}{\text{Initial Strain + Creep Strain}} = \frac{\text{Stress}}{\text{Total Strain}}$$

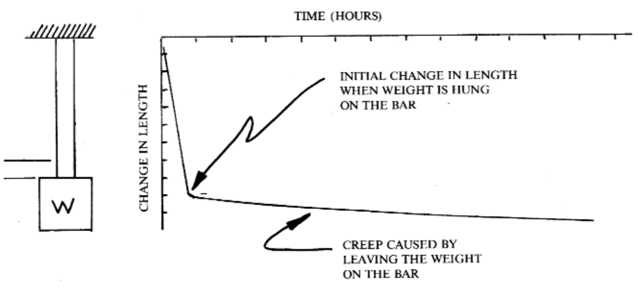

Figure 5.18

CREEP IS AFFECTED BY:

- Load (Stress)
- Temperature
- Length of time the load is applied
- Other environmentals, such as moisture or chemicals

Since the stress is kept constant and the weight or load is not changed or removed, the equation becomes:

Apparent Modulus × Total Strain = Constant (Stress)

Or, in other words, if the strain goes up, then the apparent modulus must come down. Since the strain increases with time and temperature, the apparent modulus decreases with time and temperature.

The data is sometimes presented in supplier literature in terms of stress relaxation. This means that the strain is held constant and the decrease in the load (stress) is measured over time. This is called “stress relaxation.” This information is important for applications, such as gaskets, snap fits, press fits and parts joined with screws or bolts. The equation becomes:

Apparent Modulus ÷ Stress = Constant (Strain)

Or, in other words, as the stress goes down because the material moves, then the apparent modulus also goes down.

Sometimes a supplier will recommend a maximum design stress. This has a similar effect to using the apparent modulus. The recommended design stress for some acrylic injection molded parts is 500 psi, and yet its tensile strength could be reported to be as much as 10,000 psi in the property chart. Designers will often look at the 10,000 psi value and cut it in half to be safe. However, it is not really enough, and could lead to failure of the part (Figures 5.19 and 5.20).

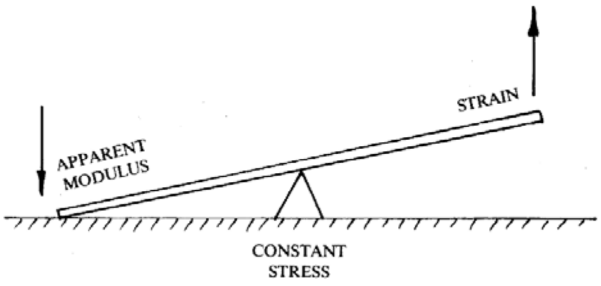

Figure 5.19

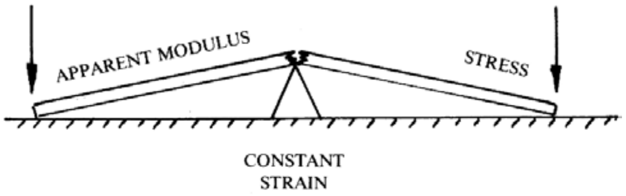

Figure 5.20

Figure 5.21 shows the tensile elongation of a material as a function of time at various stress levels. Think about pulling a piece of taffy to help visualize what is happening. The X indicates that the test bar broke. Notice how the elongation is significantly reduced as the stress level is reduced. A stress level is finally reached where the creep is nearly negligible. These values will be the stress levels recommended as design criteria.

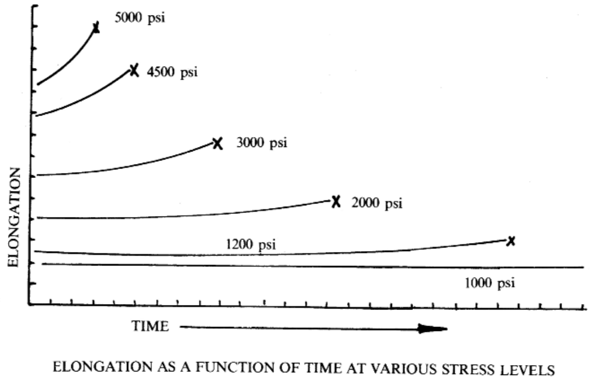

Figure 5.21

Figure 5.22 shows one of the ways the creep data is often presented in literature. The time scale is usually over a very long time, hundreds and more often thousands of hours. Most of the literature will compress the time scale for ease of reading with the use of a logarithmic scale along that axis.

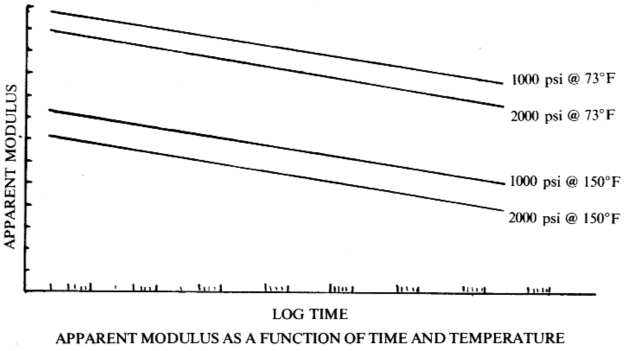

Figure 5.22

Always check the supplier's literature for creep data for a specific material.

Fatigue Strength

Plastics, as well as other materials subjected to cyclic loading, will fail at stress levels well below their tensile or compressive strengths. The combination of tension and compression is the most severe condition. This information will be presented in S-N curves or tables. The S-N stands for stress-number of cycles. A part will survive more cycles if the stress is reduced. The stress can be reduced by reducing the deflection and/or decreasing the thickness of a part.

Some examples of cyclic loading are a motor valve spring or a washing machine agitator. With time, parts under cyclic loading will fail. However, properly designed and tested they will not fail before several million loadings have been completed.

Figure 5.23 shows a typical S-N curve.

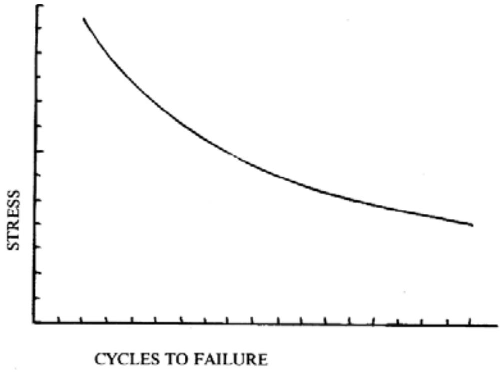

Figure 5.23

Impact Strength

Many plastics demonstrate excellent impact strength. Impact strength is the ability to withstand a suddenly applied load. Toughness is usually used to describe the material's ability to withstand an impact or sudden deformation without breaking. No single test has yet been devised that can predict the impact behavior of a plastic material under the variety of conditions to which a part can be subjected. Many materials display reduced impact strength as the temperature is lowered. Thermosets and reinforced thermoplastics may change less with changes in temperature. Check the supplier literature for any unusual factors that may affect the impact performance of a part.

Some of the impact tests commonly used in supplier literature follow.

Izod Test: designed to measure the effect on toughness when the test specimen is suddenly impacted by a swinging pendulum.

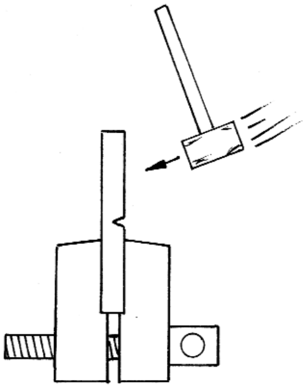

Figure 5.24

Tensile Impact Test: designed to measure the toughness of a small specimen without a notch when subjected to a sudden tensile stress or load.

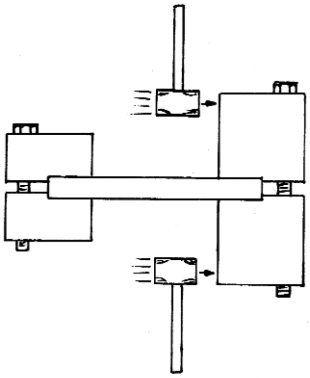

Figure 5.25

Gardner Impact Test: drops a shaped weight and determines the energy required to break the test sample.

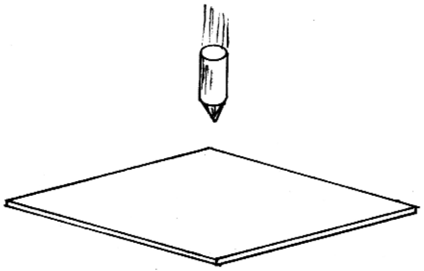

Figure 5.26

Brittleness Temperature Test: determines ability of the material to continue to absorb impacts as the temperature is decreased.

Special tests may need to be devised to more nearly duplicate the actual application. Information provided by these tests will aid in choosing material candidates. However, the designer must still test the actual part under conditions as near as possible to actual use conditions before being confident that the material selection is adequate.

Notch Sensitivity

Some plastic materials have exceptional impact performance and very good load carrying capability. However, the performance of a material can be greatly reduced by having sharp corners on the part. The sharp corners can be part of the design or from machining operations. A sharp corner is a great place for a crack to start. The Izod impact strength of a tough material like polycarbonate is reduced from 20 to 2 as the radius (R) of the notch is reduced from 0.020" R to 0.005" R respectively.

The sharp corners not only reduce the impact resistance of a part, but also allow for a stress concentration to occur and encourage the premature failure of a load carrying part. Minimizing sharp corners may make the machining operation more difficult. However, it may be crucial to the part’s success. Edges of sheet being used in impact applications like glazing must also be finished to be free of sharp notches. This is a concern with acrylics and even tough materials like polycarbonate.

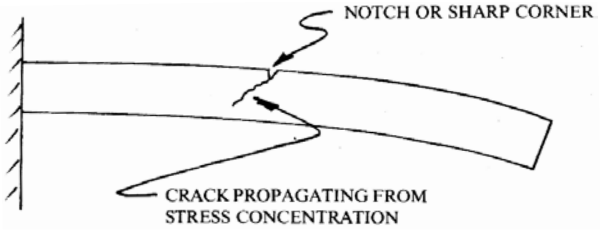

Figure 5.27

Melt Index

Melt index determines the internal flow rate of a plastic through a die at a given temperature and load. In more common terms this test will tell you how fast the plastic will flow when heated. This will affect how the material will process, fill a mold, or flow through a die. Melt index is described in ASTM D1238. A sample of plastic is charged into a heated cylinder within the melt index apparatus. A weighted piston is used to push the plastic through the cylinder and through a die at the end. The temperature at which a sample is tested is predetermined by the standard for each given polymer. After the cylinder is charged and the weighted piston is in place, the piston is blocked and the plastic is heated for six to eight minutes. At that point the block is removed, and the weighted piston forces the molten plastic through the die. A sample is collected for a specific time interval (e.g., one minute) and the extrudate is massed. The melt flow is determined by the following equation:

$$\frac{\text{grams of extrudate}}{\text{time in minutes}} \times 10 = \text{Melt Flow (g/10 min)}$$

Melt flow is affected by the molecular structure of a polymer. The more complex the molecule, the melt flow will tend to be lower. If a plastic has polymer molecules of approximately the same length, the melt flow will tend to be higher. Likewise the plastic that has a mixture of long and short polymer chains will tend to not flow as well and will result in a lower melt index. Melt index is also affected by fillers and reinforcements in a plastic. Crystallinity will affect the melt flow of a material. The range of melt flows can be from 0.5 g/10 min to as much as 25.0 g/10 min.

Specific Gravity

For solids and liquids, specific gravity is the ratio of the density of a material to the density of water at 4°C which is taken as 1.0 (since one cc of water weighs one gram). For example, a solid or liquid with a density of 1.5g/cc has a specific gravity of 1.5/1 or 1.5.

SPECIFIC GRAVITIES OF SOME COMMON PLASTICS
(as measured by ASTM test method D792)

ABS	1.1 to 1.2
Acetal	1.42
Polyethylene (low-density)	0.91 to 0.93
Polyethylene (high-density)	0.94 to 0.965
PVC (rigid)	1.35 to 1.45
PVC (flexible)	1.16 to 1.35
Polymethylmethacrylate	1.17 to 1.20
Polycarbonate	1.20

If the size of a part is known, specific gravity can be used to determine the weight of that part in a variety of materials.

Water Absorption

Water absorption is the degree of penetration of water into the inner structure of another material, such as plastic. A common measure for the degree of absorption is the percent swell, which measures the change in surface area of a material. Plastics such as polyethylene have extremely low water absorption whereas nylon has a relatively high rate of water absorption.

Glass Transition Temperature

Glass transition temperature is the temperature above which an amorphous polymer is soft and rubbery. Below the glass transition temperature an amorphous polymer is hard, brittle and glassy.

Thermal Properties of Plastics

With a change in temperature, plastic materials tend to change size considerably more than other materials, such as steel, ceramics and even aluminum. A designer must consider these differences. In fact, the shipping environment may expose the part to a much greater temperature variation than the part will ever see in use. The measure of how much a part changes size as the temperature changes is called the "thermal coefficient of expansion."

Coefficient of Expansion

The units are usually given in inches per inch per degree Fahrenheit. It is the change in unit length or volume of a part caused by a unit change in the temperature.

TYPICAL COEFFICIENTS OF EXPANSION (IN/IN/F)

Polyethylene	0.000140
Acrylics	0.000060
Acetal, copolymer	0.000047
Polycarbonate	0.000037
Aluminum, 1000 series	0.000013
Polycarbonate, 30% glass reinforced	0.000009
Steels	0.000008
Glass	0.000004

Example: Assuming an acrylic material, how much will a 10" dimension change if the temperature changes 40°F?

The change in length = Original length ×
the coefficient of expansion ×
the change in temperature
= 10 × 0.00006 × 40
= 0.024"

Deflection Temperature Under Load

In addition to changing size, the strength and modulus of elasticity of plastic materials tend to decrease as the ambient temperature increases. The standard test for determining the deflection temperature under load (DTUL) at 66 and 264 psi provides information on the ability of a material to carry a load at higher temperatures. The 66 psi means a light load and the 264 psi means a heavy load on a beam. The temperature of the loaded beam is raised until a certain amount of deflection is observed. The temperature when that deflection is reached is called the DTUL. Plastics usually have a higher DTUL at 66 psi than 264 psi because of the lower load.

Note: The DTUL is sometimes referred to as the heat distortion temperature or HDT.

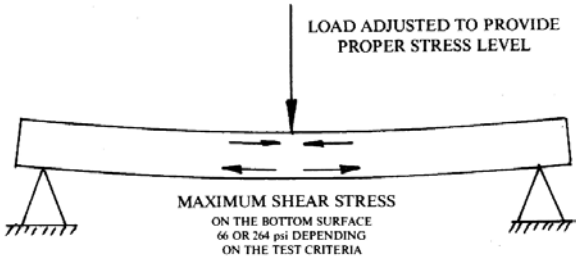

Figure 5.28

TYPICAL DEFLECTION TEMPERATURES, LOADED TO 264 PSI (F)

Silicone materials	850
Nylon, 30% glass reinforced	495
Epoxy, mineral, glass reinforced	400
Acetal, glass reinforced	325
Polycarbonate	295
Nylon, general-purpose	220
Acrylic	180
Propylene, general-purpose	140

Impact strength is also affected by changes in temperature in most plastic materials. The changes in strength can be significant, especially as the temperature is lowered. Check the supplier literature carefully.

Thermal Conductivity

Many plastics are good thermal insulators; that is, heat does not travel through them easily. We experience this every time we pick up a hot pan by its plastic handle. The "conductivity" of plastics is 300 to 2,500 times less than most metals. This property shows why it takes a long time for a casting or other molded parts to cool down in the middle. Internal stress can be set up in a material because of the differences in the cooling rates between the outside of a part and the core.

Electrical Properties of Plastics

Commercial plastics are generally very good electrical insulators and offer freedom of design in electrical products. Electrical properties may also be changed by environmental conditions, such as moisture and/or temperature.

A basic concept to remember is that electrons must be exchanged between molecules for electric current to flow through a material. Plastic molecules hold on to their electrons and do not permit the electrons to flow easily; thus, plastics are insulators.

Plastics containing oxygen and nitrogen molecules are "polar" which means that they will tend to act like little magnets and align themselves in the presence of a voltage or field, the same as the needle in a compass trying to point north. Plastics not containing oxygen and nitrogen molecules such as polyethylene, polypropylene and polystyrene are nonpolar.

The electrical properties of plastics are usually described by the following properties:

Volume Resistivity

Volume resistivity is defined as the ratio between the voltage (direct current or DC), which is like the voltage supplied by a battery, and that portion of current which flows through a specific volume of the specimen. Units are generally ohm per cubic centimeter.

Visualize putting DC electrodes on opposite faces of a one centimeter (.394 inch) cube of a plastic material. When a voltage is applied, some current will flow in time as the molecules align themselves (Figure 5.29).

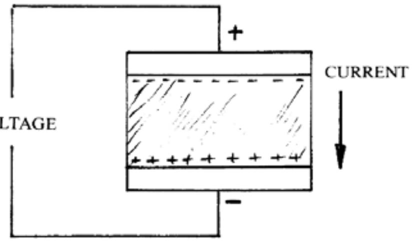

Figure 5.29

Ohm's Law tells us that the voltage (volts) divided by the current (amps) is equal to a resistance (ohms) or V/I = R. When the voltage applied to the cube is divided by the current, the resistance for 1 cm of the plastic is determined, or ohm per cm.

Generally, plastics are naturally good insulators and have very high resistance. The volume resistivity can change with temperature and the presence of moisture or humidity.

Surface Resistivity

The surface resistivity is the ratio between the direct current (DC) and current along the surface per unit width. Units are generally ohms.

Again referring to Ohm's Law, the surface resistivity is a measure of how much the surface of the material resists the flow of current.

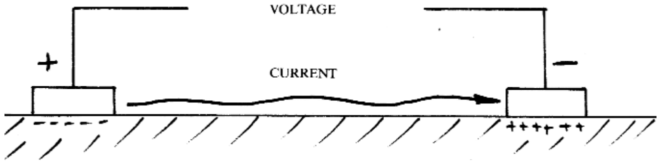

Figure 5.30

Dielectric Constant

The dielectric constant is the ratio of the capacitance (AC voltage) of electrodes with the insulating material between them to the capacitance of the same electrodes with a vacuum or dry air in between. The dielectric constant is a measure of how good a material works to separate the plates in a capacitor. Remember that the molecules are like little magnets and are trying to realign themselves every time the voltage (current) changes direction. Some materials do it better than others.

The dielectric constant for a vacuum has a value of 1. Dry air is very nearly 1. All other materials have "dielectric constants" that are greater than 1. The "dielectric constant" for a plastic material can vary with the presence of moisture, temperature, and the frequency of the alternating current (and voltage) across the plates. The units for frequency are usually "hertz" (Hz) which means cycles per second. Three kilohertz is the same as 3,000 Hz and 3 megahertz is the same as 3,000,000 Hz.

Dielectric Strength

Dielectric strength is the voltage difference (DC) between two electrodes at which electrical breakdown occurs and is measured as volts per mil of thickness. This is an indication of how effective an "insulator" the material is.

Note: One mil is another way of saying .001 of an inch, so a piece of plastic film 5 mils thick is .005 inch thick.

The test is similar to that used for "volume resistivity" except the voltage is increased until there is an arc across the plates. This means that the voltage was strong enough to break down the material and allow a large current to flow through it. Again, this property can be affected by the presence of moisture and temperature. Frequency may also affect this property when the material is subjected to an alternating current.

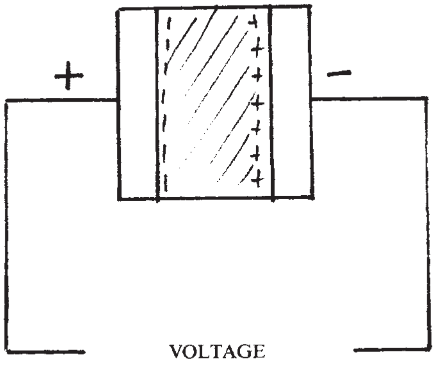

Figure 5.31

Dissipation Factor

The dissipation factor (AC) is the tangent of the loss angle of the insulating material. It can also be described as the ratio of the true in-phase power to the reactive power, measured with voltage and current 90 degrees out of phase.

This is an indication of the energy lost within the material trying to realign the molecules every time the current (voltage) changes direction in alternating current. The property varies with moisture, temperature and frequency.

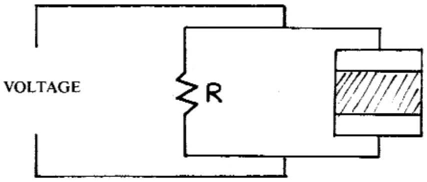

Figure 5.32

Arc Resistance

The arc resistance is the elapsed time in which the surface of the material will resist the formation of a continuous conductive path when subjected to a high-voltage (DC), low-current arc under rigidly controlled conditions.

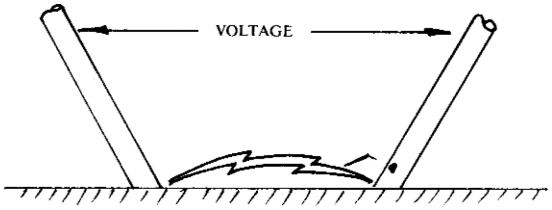

Figure 5.33

Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI)

There is also considerable effort being expended by material suppliers to try and improve the conductivity of plastics for applications requiring electromagnetic interference (EMI) and radio frequency interference (RMI) shielding. This becomes more and more critical as circuitry is getting smaller and denser. The improvement in conductivity is currently achieved by adding carbon fibers, metal fiber, and/or metal flakes as a filler in the material, or coating the plastic part with conductive paint.

EMI and RFI are electromagnetic energy that can be emitted by an electronic product and affect the operation of other electronic equipment near it. Conversely, energy from the other products could interfere with the operation of a given product. Federal Communications Commission (FCC) regulations control the amount of energy that can be emitted by a product.

Examples of EMI and RFI interference are: when you hear other noise and/or stations on your car radio; when a CB broadcast is heard on your FM receiver; when you see “snow” on your television set when an appliance is run; warnings in restaurants that a microwave is being used.

The screen or perforated metal seen in your microwave door is an example of EMI/RFI shielding. Coaxial cable for your television antenna is a wire surrounded by a woven metal shield that is to be grounded. The shield absorbs energy coming in from outside sources and keeps the signal in the wire pure while preventing that signal from escaping and interfering with some other electronic product.

Another serious potential problem is the static charge that can be picked up walking across a room and can zap an electronic product. The charge can often be harmlessly dissipated by correctly grounding the equipment. The application of an anti-static may also be used to provide a temporary solution.

Optical/Colorability Properties of Plastics

Many plastic materials are transparent and used in optical applications. Some of these materials are acrylics, styrene, PVC, polycarbonate, ABS and epoxy. The properties measured and presented in the material suppliers’ literature are concerned with items, such as the percent of haze (cloudiness) in a material, the transmittance capability (how much light gets through the material), yellowness index (appearance), and the index of refraction (how much light is bent as it goes into and out of the material).

Transparent colored materials transmit that portion of the visible spectrum that allows the eye to see the desired color. Most plastic materials are not transparent and the color of the base material may limit the selection of colors available.

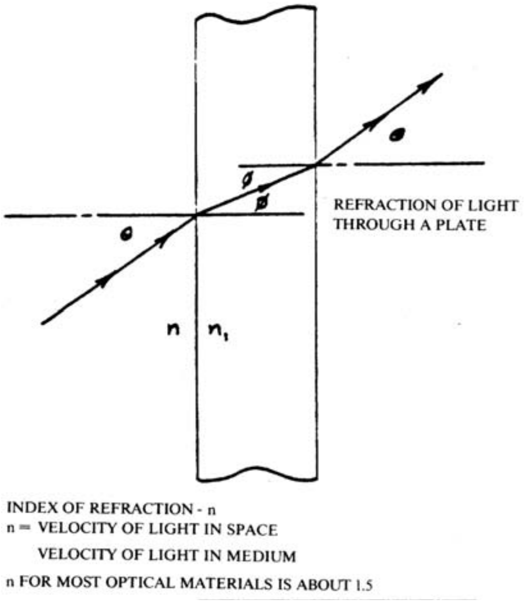

Figure 5.34

Enhancing the Properties of Plastics

As previously discussed, the properties of the various plastics vary from one another, and the polymers can be modified to alter the properties within a family of plastics. Another way that the properties of a given plastic are changed is the addition of items, called additives, such as colorants, fillers and/or reinforcements.

Additives (Improve Specific Properties)

Additives are selected to be compatible with the material and the process conditions for shaping the material. The improvement of a specific property of a material by the addition of an additive is usually at the expense of some other property. The chemist attempts to keep all of the other material properties as high as possible while achieving the desired improvement in the specific property, such as improved resistance to burning. Some of the additives that are used in plastics are antioxidants to improve high temperature stability, antistatic agents, biocides, flame retardants, impact modifiers, friction reducers, foaming agents, fungicides and ultraviolet stabilizers.

Reinforcements (Improve Strength)

Some additives enhance the strength of a material. Examples of reinforcing materials are carbon, glass, mica and aramids. They may be in the form of short fibers, continuous filaments, mats, spheres or flakes. These reinforcements usually increase the material's strength at the expense of impact resistance, with the exception of fiber reinforcements, which usually increase impact resistance. The use of reinforcements in plastics permits them to be used at higher temperatures and loads with greater dimensional stability. The freedom of design, high strength and light weight of composite materials are permitting significant advances in technology in the automotive, aerospace and aviation fields. Reinforcements tend to make stock shapes, such as rods, tubes and slabs more difficult to machine because of increased tool wear.

Colorants (Change Appearance)

Another group of additives are colorants that provide the desired color to the material. The colorants may be dyes, or organic or inorganic pigments. The colorant chosen must be compatible with the base plastic, shaping process, and the proposed usages for the finished material. For example, a colorant must also withstand high temperatures and be weatherable if the material is to be extruded and then used outdoors. The type of colorant also affects optical properties of transparent materials, such as acrylics, polycarbonate and styrene. A colorant can be added such that a clear material is transparent, translucent or opaque.

Effects of the Environment on Plastics

All plastics are subject to failure if environmental effects are not taken into account. The environmental conditions that are particularly damaging to plastics include exposure to: ultra-violet light, moisture, chemicals (liquid or vapor), oxidation and temperature.

There are two considerations to help diminish environmental conditions that attack polymers. One is by choosing a plastic that is inherently good for the application, and the other is by introducing additives that can assist in combating environmental conditions.

For example, if there is an application with a high temperature range, one of the first materials that comes to mind is Teflon®. It is common knowledge that Teflon® is excellent in high temperature applications. It would be difficult to increase the temperature range (melting point) of a plastic by using additives.

However, there are many additives that can greatly reduce the effects of the environment. Plastics used outside have additives to help protect against exposure to ultra-violet light and oxidation. And, although it is not as common, there are also additives to assist in decreasing the amount of moisture absorbed into a polymer. One of the most common additives to assist in blocking ultra-violet light degradation is carbon black. Generally speaking, materials that are black in color are UV protected.

When left unprotected and exposed to environmental conditions, materials change both in appearance and in their molecular structure. These changes generally manifest themselves in the form of a slight increase in density and a marked decrease in tensile strength values.

There are many options available to manufacturers in counteracting environmental concerns. For that reason, there are also differences in the opinions on what is the most effective. If you have any questions about environmental effects or ways of controlling, please consult your supplier.

Wear Characteristics of Plastics

Wear characteristics of a material are very difficult to define. It can mean being resistant to scratching when the part is cleaned. It might mean being resistant to abrasion when the wind blows sand against it. It might mean the deterioration caused by running another part against it. It might mean being able to maintain its appearance after considerable handling.

A material like glass may be very resistant to scratching yet can be readily abraded by sand blasting, as evidenced by the pits in a windshield. Conversely, another material like acrylic is easily scratched when wiped and yet is much more resistant than glass to abrasion from sand blasting. It is usually best to devise a test that will duplicate actual use conditions to accurately determine a material's suitability for an application.

Many plastics are specifically formulated for running against surfaces. The base polymer may exhibit self-lubricating properties. Additives such as PTFE, TFE, silicone oil, molybdenumdisulfide, and carbon are used to improve the wear life of some materials.

Material Selection

The selection of a material for an application is a very difficult task. Usually one is only able to narrow the selection down to two or three candidates and the final selection is then determined by testing. Sometimes the selection is determined by the best material immediately available so the schedule can be met or the least expensive material used. This does not always lead to a successful application or a satisfied customer.

As a plastic materials professional, one must be alert to those applications that are not correct for plastics. Sometimes a designer or customer becomes enamored with using a plastic without understanding the properties of plastics and if a plastic material is even suitable for the application. In other instances, a designer or customer chooses a material or grade which might be available for one process (e.g., injection molding), but not for the process necessary to manufacture the part, especially in smaller quantities (e.g., extrusion followed by a machining process). One must also be careful of a design that has worked in aluminum or steel and is to be converted to plastic. A metal part may not work in plastic. This is where it is important to understand what the customer expects the part to do. A material supplier may have to be consulted before the customer can be given a suggestion.

The first and most important step in selecting a material from the broad spectrum of materials (steel, aluminum, brass, polycarbonate, acrylic, nylon, etc.) is to carefully define the requirements of the application. The second step is to determine the key property without which the material will fail in the planned application. The third step is to determine, evaluate and weigh the other important properties the application needs. The fourth step is to try and match those requirements to the properties of the available materials.

Many of the materials have similar properties and the different companies compete for the same markets. This is what makes material selection difficult and accurate definition of the application's requirements important. Several materials may be acceptable for an application and cost and/or availability will often be the deciding factor. The more subtle differences, such as slight differences in chemical resistances, better dimensional stability, processability, lower smoke generation, or slightly more heat resistance become the deciding factors in critical applications. It is suggested that suppliers' literature be read for additional and more specific information.

It may be necessary to ask some or all of the following questions to define the application. The more completely the application is defined, the better the chance of selecting the best material for the job.

What load will the part have to carry?

Will the design carry high loads? What will the highest load be? What is the maximum stress in the part? What kind of stress is it (tensile, flexural, etc.)? How long will the load be applied? What is the projected life of the part or design?

Note: Thermosets often perform well under high continuous loads. Reinforced thermoplastics, such as a thermoplastic polyester, may also perform satisfactorily.

Will the part have to withstand impact?

Will the part be subjected to impact? Which impact test/data most closely duplicates the projected application?

Note: Laminated plastics, such as glass-reinforced epoxy, melamine or phenolic, generally have good impact strength. Polycarbonate, PVC, acrylic and UHMW-PE also exhibit excellent impact resistance.

Will the part see cyclic loading (fatigue)?

Will the part be subjected to a variable load? Is the load alternating compressive/tensile? What will the stress levels be? What is the thickness of the part being flexed? How much will the part be deflected?

Note: Materials like acetal and nylon are generally good candidates for cyclic loading.

What temperatures will the part see and for how long?

What is the maximum temperature the material will see in use? What is the minimum temperature the material will see in use? How long will the material be at these temperatures? Will the material have to withstand impact at the low temperatures?

Note: The temperature extremes could occur during shipping.

Will the material be exposed to chemicals or moisture?

Will the material be exposed to normal relative humidity? Will the material be submerged in water? If so, at what temperature? Will the material be exposed to steam? Will the material be painted? Will the material be submerged or wiped with solvents or other chemicals? If so, which ones? Will the material be exposed to chemical or solvent vapors? If so, which ones? Will the material be exposed to other materials that can outgas or leach detrimental materials, such as plasticizers?

Note: Crystalline and thermoset materials generally exhibit good chemical resistance.

Will the material be used in an electrical design?

To what voltages will the part be exposed? Alternating (AC) or direct (DC) current? If AC, what frequencies? Where will the voltage be applied (e.g., opposite side of the material, on one surface of the material)?