**GE Plastics**
*We bring good things to life.*

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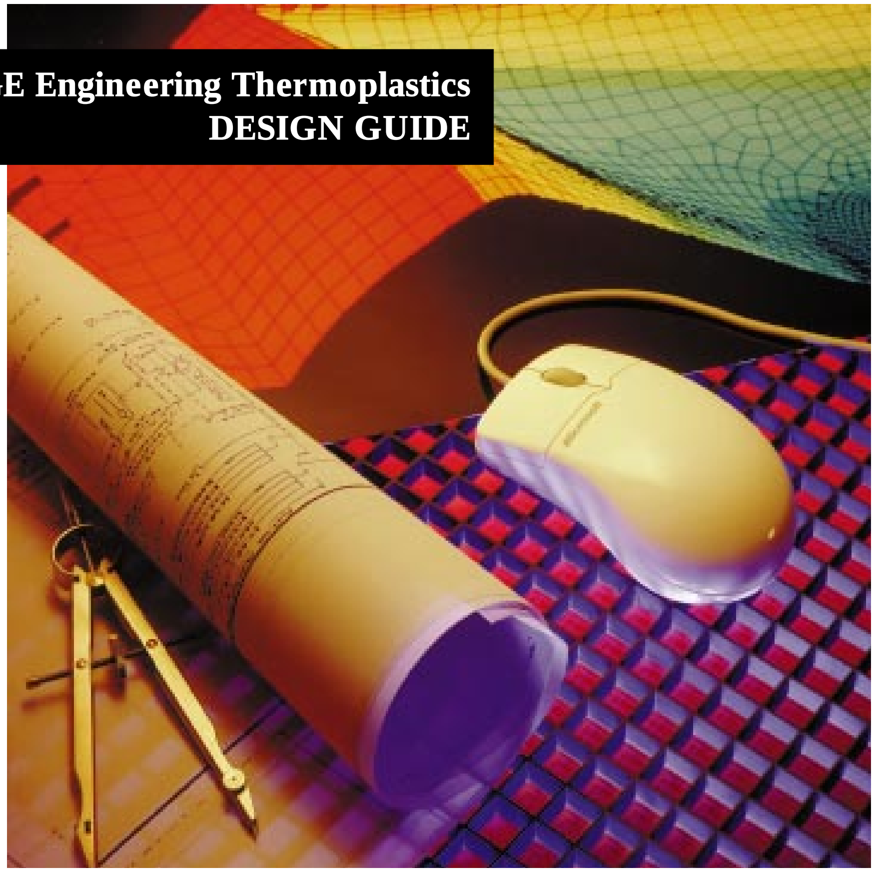
GE Engineering Thermoplastics DESIGN GUIDE

**GE Plastics**

# GE Engineering Thermoplastics
# DESIGN GUIDE



Design
Guide

# Introduction

## About GE

The General Electric Company has its roots in the 'age of invention' when, more that 100 years ago, it was founded by pioneering inventor Thomas Edison.

Closely following its founder's philosophy of innovation and the creative application of technology, GE has grown to become one of the world's largest and most diversified companies in the world.

Today, GE products and services make a positive contribution to virtually every sector of commerce and industry. From jet engines to financial services, from lighting and medical systems to factory automation, power generation, transportation and construction.

### About GE Plastics

Of all GE businesses, one of the fastest growing is GE Plastics. In a short 25 years, GE Plastics has emerged as the leading producer of engineering thermoplastics. Through Application Development Centers around the world, customers can access assistance from GE designers, engineers, tooling, processing and finishing experts, utilizing the most sophisticated equipment and systems available.

Working closely with customers on a "share to gain" basis is at the core of the GE Plastics' business culture. It provides the technologies, ideas and improvements that will get the job done better, more cost-effectively  and within tighter schedules. Having a concentration of molding equipment, testing laboratories and product specialists close to the action enables easy access to unmatched expertise and permits a cross flow of information that leads to important breakthroughs and exciting new product developments.

At the nucleus of this unmatched global technical network are the world-class facilities at GE Plastics' headquarters in Pittsfield, Massachusetts. Realizing that speed is the key to profitability today, these support services are backed-up by production plants in several locations in the U.S., Europe, Australia, Japan and Mexico.

The ultimate value of materials technology is its practical application in the marketplace. That is why GE Plastics offers its engineering thermoplastic resources and technologies to help design engineers and processors develop better products. There are no barriers or boundaries, No limit to the resources that can be brought together for your benefit.

## Engineering Thermoplastics

The advantages of high performance engineering thermoplastics have grown dramatically both from new material developments and through a new generation of design engineers.

Today, designers have learned to "think" in plastics and take full advantage of their inherent benefits, rather than just simply translate metal components into plastic. Some of the unique design benefits offered by GE Plastics discussed in this Design Guide include:

- Consolidation of parts
- Integrated system assembly
- Molded-in assembly features
- Unprecedented strength to weight ratios
- Elimination of painting and other operations
- Outstanding impact resistance
- Excellent chemical resistance

Through re-thinking and re-design, traditional metal assemblies can be produced in dimensionally stable plastics: with 50% fewer parts, engineered for automated assembly and offering a full range of impact, heat, electrical and chemical properties. This Design Guide is one example of how designers can benefit from the knowledge and experience available from GE Plastics.

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GE Plastics

# GE Engineering Thermoplastics
# DESIGN GUIDE

# Product Development

## Product Development

Early in design development, parts are identified as potential plastic applications and applicable manufacturing processes are considered. Designers must decide which should come first: selection of a material or a process for manufacturing a part? Normally, the configuration requirements of the plastic part will direct the design toward a process. In most cases, the process must be determined before a specific resin grade can be selected. During this review, designers also need to consider if the process is capable of meeting the design requirements such as size, shape, detail and tolerances.

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# The Design Development Process

## New Product Development

New products are frequently vital parts of a business strategy. Bringing the right product to the market at the right time and at the right price is an enviable goal. Knowing the process for new product development and executing the steps flawlessly can provide a substantial edge. Manufacturing with engineering thermoplastics continues to enable new product developers to propose innovative solutions.

## The Plastics Development Cycle

While the development process is open to variations, offering a systematic approach can be valuable by highlighting key elements of the process. By-passing steps or ignoring issues raised can increase the risk facing the project. Figure 1-1 presents an overview of the natural progression and groupings at the three phases of the design development process, which includes:

**Design Development Process**

Three "D's"
- Discover
- Develop
- Deliver

**Discover:** Identify an opportunity for a product, consider the market and visualize a competitive edge you feel is obtainable.

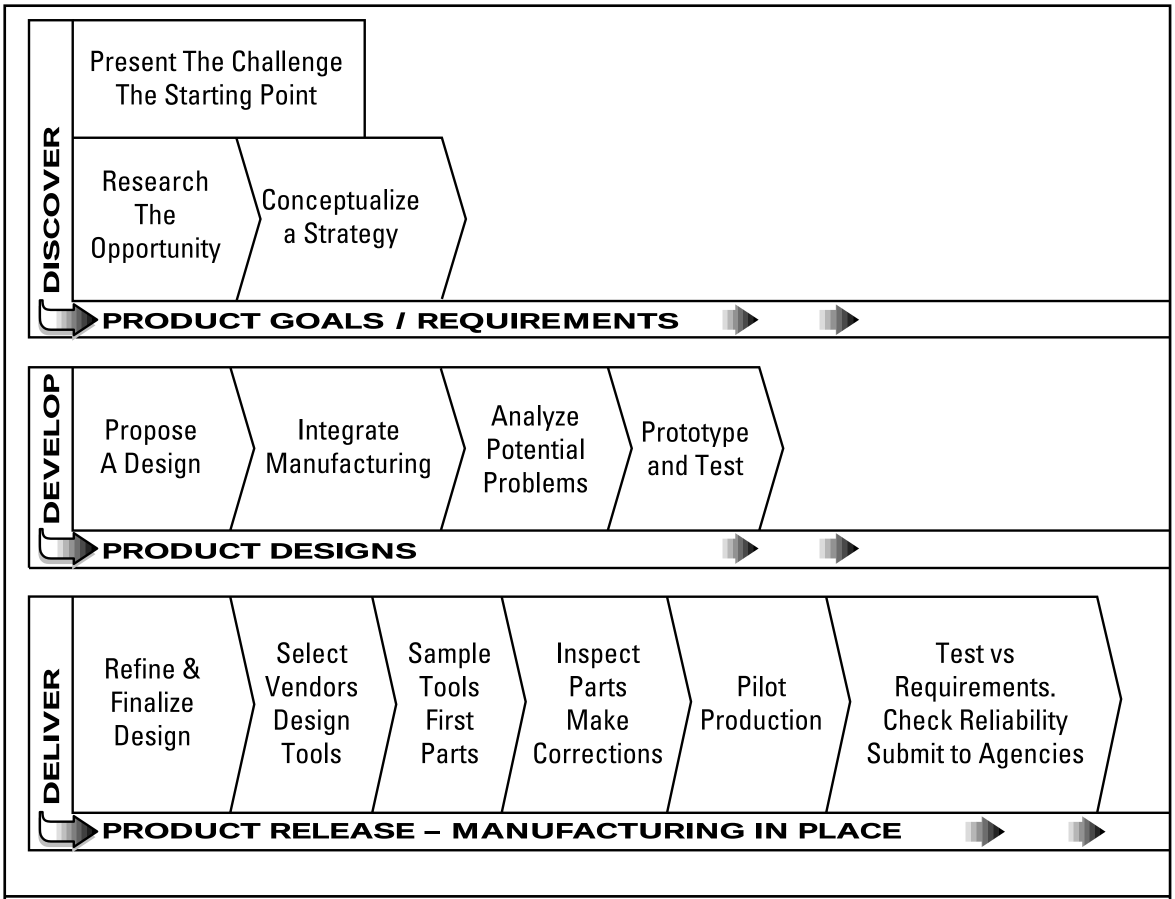
**Develop:** Embracing the conceptual strategy to achieve the stated product goals/requirements, create parts, assemblies and components needed to make the product. Support proposal with engineering analysis or tests.

**Deliver:** With confidence the design will function and can be produced at acceptable cost, the manufacturing capability is ordered, supplies selected, tooling and facilities identified or built. After checking initial parts, pilots are assembled, debugged, and procedures recorded. If all goes well, the product is released for production.

Delivery of the product alone does not ensure success. Distribution, promotion and ability to support customer needs in the use of the product can impact greatly on a commercial endeavor.

# The Design Development Process

**Figure 1-1.** An overview of the process can be seen by looking at the natural progression and grouping the steps into three phases – discover, develop and deliver.



**ACTIONS DURING DESIGN PROCESS**

- Search Literature – *Identify Barriers*
- Test Existing Products – *New Technology*
- Benchmark
- Observe Relationships
- Consider Alternative Solutions
- Set Requirements
- Application Needs (Quality, Function, Deployment)

**ACTIONS TO INITIATE DURING DESIGN PROCESS**

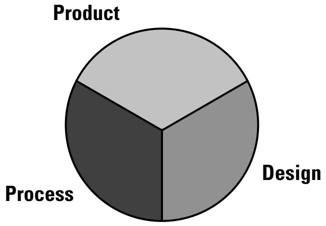
- Design for Assembly – *Consolidate Parts*
- Select Process – *Analyze Structure*
- Select Material – *Process Simulation*
- Estimate Costs – *Prototype & Validate Design*
- FMEA – *Failure Mode*

# Product Development

## Basic Design Guidelines

A successful application of an engineering thermoplastic requires more than identifying a specific product or grade. Of equal importance are following application design guidelines and making sure that the product is properly converted in the molding process. Three areas, product, process and design, are all interrelated and the appropriate guidelines in each area must be used for a successful application.

**Inter-Relationships**



### *Design*

The design of parts using GE Plastics' products is a very specific expertise. Achieving optimal performance in a component made from an engineering thermoplastic requires the use of appropriate design practices. Two principles of design are:

- Minimum Stress – Stress (Load) should be minimized to prevent high localized stresses (stress concentration).
- Uniform Stress – Stress should be distributed uniformly.

To achieve these two design objectives, a designer will strive for uniform and consistent wall thicknesses and gradual transitions when uniformity cannot be maintained. Also, to reduce stress concentration, all sharp inside corners (notches) must have as large a radius as possible.

### *Processing*

GE Plastics' engineering thermoplastic resins are converted into final parts by a melt process. Generally this is the injection molding process where a plastic melt is injected at high pressures into a precision mold. In addition to this being a high pressure process, it is also a high temperature process. GE materials are converted (processed) at temperatures ranging from <400˚F (<205°C) (CYCOLAC® ABS resin) to 800˚F (427°C) (ULTEM® PEI resin). Proper molding practices for GE materials must be employed to prevent excessive product degradation.

# The Design Development Process

A simple visualization of the injection molding process is a two step sequence of three M's and three F's. A product is *melted*, *mixed*, and *moved* in a reciprocating screw extruder and then *flowed* (injected), *formed*, and *frozen* (cooled) in the mold.

As in Design, there are specific practices for each product which, when followed, will result in a properly molded part.

**3 M's**

- Melt
- Mix
- Move

**3 F's**

- Flow
- Form
- Freeze

## *Material Selection Process*

Unfortunately, there is no real sequential process for material selection. The selection of a GE Plastics' resin for an application requires the specifier or designer to consider a great deal of information. This requires the designer to ask the right questions. Some of the information which must be considered to select an appropriate GE material is listed below.

- Identify application requirements
  - mechanical (load, impact, stiffness, etc.)
  - thermal (temperature range, maximum use temperature, etc.)
  - environmental considerations
- Identify the chemical environment
  - define the chemical stress, temperature, contact time and type
- Identify special needs
  - regulatory (UL, FDA., etc.)
  - outdoor or UV exposure
  - light transmission (clear to opaque)
  - fatigue and creep requirements
- Define economics
- Define processing considerations
  - injection molding
  - blow molding
  - extrusion
  - thermoforming
  - foam molding
- Define assembly requirements
  - painting/plating
  - shielding
  - adhesion
- Search history for similar commercial applications

Securing the information listed in the above steps will provide the basis for selecting the appropriate GE Plastics' engineering thermoplatic resin and grade for an application. Other factors specific to the particular application should also be identified and addressed where no history of similar commercial applications is found.

## Application Requirements

Engineering thermoplastics are characterized and defined by their properties. Each specific resin grade has its own property profile that indicates how it can be expected to perform in a given application environment. There are numerous material properties used to describe and compare performance characteristics; however, there are only five key categories or properties measured by plastics' manufacturers.

### *Physical Properties*

- Specific gravity
- Mold shrinkage
- Rheology

### *Mechanical Properties*

- Flexural strength
- Flexural modulus (stiffness – resistance to bending)
- Tensile elongation/ductility
- Impact strength
- Fatigue endurance (resistance to high frequency, cyclic loading)
- Creep resistance (resistance to long-term deformation with a static load)

### *Thermal Properties*

- Deflection Temperature Under Load, DTUL (also Heat Deflection Temperature, HDT)
- Thermal conductivity
- Thermal expansion coefficient
- Relative Thermal Index, RTI (regulatory – continuous use temperature)

### *Regulatory Performance*

- Flammability (Underwriters Laboratories Bulletin 94 vertical burn ratings*)
- High voltage arc tracking (electrical)

---

* This test is not intended to reflect hazards presented by any material under actual fire conditions.

### *Chemical Behavior*

The chemical environment for an application is the most important consideration for a successful use of an engineering thermoplastic. While the term Chemical Resistance is often used, there is no single property that defines an engineering thermoplastic's ability to perform in a given chemical environment.

### *Environmental Considerations*

One of the most important application considerations is the environment in which the product is to be used. This can include the effects of exposure of the proposed application not only to unusual temperatures, but also to weather, UV, excessive moisture, solvents and chemicals.

In this context, understanding the differences between amorphous and semi-crystalline plastics (see page 1-20) leads to an understanding of their differences in expected performance in terms of chemical resistance, mechanical properties, thermal properties and processing characteristics.

With any given resin, little or nothing can be done through part design to offset the effects of chemicals and solvents. There is an almost unlimited number of chemicals and solvents that might be involved in an end-use application, and so to have test data on the effects of all of these in one simple table is obviously impossible. However, as a preliminary screening reference, Chemical Resistance Table 1-1 on page 1-12 summarizes the general resistance of GE Plastics' products to a variety of groups of chemicals. The table is only meant as a guide. Full performance data on chemical resistance to a multitude of chemicals – resulting from actual testing – is available through GE Plastics.

All available data, however, can never replace product use tests under actual application conditions.

### *Chemical Resistance*

Resistance of thermoplastics with various chemicals is dependent on:

- Time (of contact with the chemical)
- Temperature
- Stress (molded-in stress and any external stress to which the application is subjected)
- Concentration of the chemical

Chemical exposure may result in

- Physical degradation – stress cracking, crazing, softening, swelling, discoloration
- Chemical attack – reaction of chemical with polymer and loss of properties of the thermoplastic

*Amorphous* polymers are susceptible to physical degradation. Short-term chemical resistance (days, weeks) should always be checked. The short-term chemical resistance of *semi-crystalline* polymers is generally better.

Long-term chemical resistance (months, years) for both amorphous and semi-crystalline resins should always be checked.

Because of the complicated nature of chemical resistance, many commercially available chemical products have been tested in our laboratories. Chemical resistance data on many of these tests are available from GE Plastics ERIS (Engineering Resin Information System) computerized database, access to which can be gained through your local GE Plastics' representative.

If there is any doubt about the effect of a particular environment on the properties or in-service performance of one of our resins, advice should be obtained. Ask your local GE Plastics' representative for more details. And, as noted above, no GE Plastics' test data can be substituted for customer testing under actual manufacturing and end use conditions.

Table 1-1 on page 1-12 shows chemical resistance in a comparative and descriptive way. Tensile behavior before and after immersion was checked. The ratings should be considered as *purely indicative* of relative differences between materials. Under no circumstances should they be interpreted as representing finished part performance under actual or test conditions.

The chemicals selected represent groups of compounds. Within each group there may be individual compounds which behave differently – especially where end products are subject to high internal stresses due to the processing technology used in their manufacture.

**Table 1-1.** Chemical Resistance.

| | Amorphous Polymers | | | | | Semi-Crystalline Polymers | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Chemicals** | **LEXAN® resin** | **CYCOLOY® resin** | **CYCOLAC® resin** | **NORYL® resin** | **ULTEM® resin** | **XENOY® resin** | **VALOX® resin** | **NORYL® GTX resin** | **SUPEC® resin** |
| **Hydrocarbons** | | | | | | | | | |
| aliphatic | –/• | • | + | •/– | + | • | + | + | ++ |
| aromatic | – | – | – | – | ++ | –/• | + | + | |
| halogenated | | | | | | | | | |
| fully | • | • | – | – | + | – | –/• | + | • |
| partly | – | – | – | – | – | – | – | • | •/+ |
| **Alcohols** | + | n | + | + | + | + | + | + | ++ |
| **Phenols** | – | – | – | – | – | n | – | – | + |
| **Ketones** | – | – | – | – | – | – | •/+ | • | + |
| **Amines** | n | – | –/• | –/• | n | n | n | – | •/+ |
| **Esters** | –/• | – | • | + | •/+ | – | •/+ | + | ++ |
| **Ethers** | – | – | • | • | + | n | + | + | + |
| **Acids** | | | | | | | | | |
| inorganic | –/• | • | + | • | •/+ | •/+ | + | • | •/+ |
| organic | • | • | – | • | •/+ | •/+ | • | • | + |
| oxidizing | – | – | – | • | • | •/+ | – | • | • |
| **Alkalis** | – | • | + | + | – | – | – | + | + |
| **Automotive fluids** | | | | | | | | | |
| Greases (non-reactive organic esters) | n | + | + | •/+ | + | + | ++ | + | ++ |
| Oils (unsaturated aliphatic mixtures) | n | •/– | •/+ | •/+ | + | ++ | ++ | + | ++ |
| Waxes (heavy oils) | n | + | + | •/+ | + | + | ++ | + | ++ |
| Petrol | – | – | – | – | + | ++ | ++ | + | ++ |
| Cooling liquid (glycol) | n | • | • | + | + | ++ | ++ | + | ++ |
| Brake fluid (heavy alcohol) | n | – | – | + | – | ++ | + | + | ++ |
| Detergents, Cleaners | n | •/+ | •/+ | •/+ | + | + | + | ++ | ++ |
| **Water** | | | | | | | | | |
| hot <176˚F (<80˚C) | –/• | •/+ | –/• | ++ | –/• | • | – | – | •/+ |
| **Environmental** | | | | | | | | | |
| **UV** | •/+ | •/+ | •/+ | • | + | •/+ | + | –/• | – |

| | | |
|---|---|---|
| ++ | very good | :found unaffected in its performance with regard to time, temperature and stress<br>– according to agency requirements |
| + | good | :found acceptable in normal exposure<br>– long term exposure may result in minor loss of properties<br>– higher temperatures may result in major loss of properties |
| • | fair | :found marginal<br>– only for short exposures at lower temperatures or when loss of mechanical properties is not critical |
| – | poor | :found unacceptable<br>– will result in failure or severe degradation |
| n | | not tested |

***Ratings as shown are based on controlled tests and are purely indicative. Finished part performance must always be evaluated on the actual part in the end-use environment.***

## Identifying Special Needs

The options available to the designer are immense in both materials and processes. Today, engineering thermoplastics bring performance that can challenge traditional materials like metals, glass or thermosets. The benefits of high productivity and low costs are obtainable in the proper situations.

### *Additives*

Fillers and modifiers are additives used to produce specific changes in the properties and/or characteristics of resins. A large number of common additives are used in the plastics industry, including glass and mineral reinforcements, flame retardants, release agents and UV stabilizers. Many GE Plastics' materials are available with one or more of these additives included, in order to address the specific needs of an application or environment.

### *Aesthetics*

The aesthetics of plastic parts molded with glass fibers can be distinctly different from those molded without them. The normal behavior of glass fibers in most plastics is to move to the surface of the molded part. Thus, aesthetic considerations such as surface finish and gloss can be significantly affected. Texturing is often used to hide surface imperfections and/or obtain a resin-rich surface, by producing protrusions which are too small for the glass fibers to enter during filling (only for long or continuous fibers). Molding discontinuities such as knit lines and wall thickness transitions are also emphasized by glass fibers.

Mineral fillers often reduce the surface gloss appearance of the final part. Texturing can be used to hide this poor appearance. Mineral fillers also emphasize knit lines and wall thickness discontinuities.

### *Coefficient of Thermal Expansion*

The CTE in the direction of flow can be significantly reduced by the addition of glass fillers. Glass fillers are commonly used to lower CTE for parts containing metal inserts; this lessens the thermal fatigue due to hoop stress. Mineral fillers create similar effects.

### *Creep Resistance*

The creep resistance of a material tends to increase with glass loading and fiber length. This effect is primarily the result of the non-viscoelastic behavior of glass and the increased modulus resulting from the glass loading.

The creep resistance of a mineral-filled material also tends to increase with mineral loading – but not significantly – due to the relatively minor increase of modulus when adding mineral fillers.

### *Density*

The density increases with glass loading. This must be accounted for when calculating part weights.

When using mineral fillers, the ratio of filler to resin can be extremely high, causing a significant change in the final weight of the part.

### *Ductility*

The ductility of a material is generally reduced by the addition of glass. The percent strain to failure reduces considerably as glass loading increases. The failure mode of the material generally becomes more brittle in nature, as demonstrated by the significant change that can occur in the stress/strain curve.

Mineral filling can reduce the ductility even more significantly.

### *Electrical Properties*

The addition of mineral fillers often improves the tracking resistance of a thermoplastic.

### *Fatigue Resistance*

The fatigue performance of thermoplastic parts generally improves with glass loading, especially with long or continuous glass fiber. The number of cycles to failure at a specified stress level and the stress required to cause failure in a specific number of cycles both increase with glass loading.

### *Flame Retardants*

A wide variety of flame retardant (FR) packages is currently used in thermoplastics. These additives are used when a plastic part must pass some type of industry or agency standard. Flame retardants are carefully chosen for each material to avoid potential inherent incompatibilities.

Most GE Plastics' products have grades which contain FR packages designed to meet specific flammability requirements.

Generally, the physical properties of these FR resins do not vary significantly from those of the base resin. Flame retardants do have a major effect on flammability and electrical properties, especially the tracking index.

### *Flammability*

Due to the inherent flame resistance of glass, the flame resistance capability of many thermoplastics increases when glass is added. This is especially true when "drip" or "deflection" is a criterion for testing. Mineral fillers create similar effects.

### *Flow*

The addition of glass to thermoplastics generally increases the viscosity of the material and makes it more difficult to process. Glass fibers also increase wear on tools and conversion equipment including screws and barrels. Thin sections and long-flow lengths can be problems for parts made from glass filled (GF) thermoplastics because the glass tends to align itself in the direction of flow, causing anisotropic shrinkage and differences in mechanical properties. Weld lines in GF parts frequently only have the strength of the base resin material, rather than the higher strength of the filled material. These areas are particularly susceptible to impact and fatigue problems.

Similar effects, such as difficulties in filling thin sections and long-flow lengths due to increased material viscosity, are created when using mineral fillers. Mineral fillers, however, tend to decrease the warpage experienced by some highly glass loaded or highly crystalline materials during cooling. Therefore, mineral reinforcement can improve part flatness. The weld lines are lower in strength than the rest of the material. Also, tooling used for mineral reinforced grades often requires increased maintenance and cleaning, since the mineral particles can accumulate, clogging the vents and resulting in reduced surface quality.

### *Glass and Mineral*

Glass fiber reinforcement is the most common method used to increase the stiffness – resulting from increased modulus – and strength of plastics. Glass causes anisotropic effects, such as warpage, and reduces creep, especially at elevated temperatures. It lowers the coefficient of thermal expansion (CTE). Glass can be added in the form of fibers of 'normal length', short fibers, long fibers, glass beads or continuous fibers (or glass mats as used in thermoplastic materials). Glass fibers cause all non-isotropic effects (differences in properties due to orientation).

Mineral fillers are usually added to enhance electrical properties or to reduce warpage in crystalline or glass loaded parts. Minerals are also used to reduce material costs.

**Table 1-2.** Glass and Mineral Fillers Summary.

| | **Glass** | **Mineral** |
|---|---|---|
| **Aesthetics** | decreases | decreases |
| **Creep resistance** | increases | increases slightly |
| **CTE** | decreases | decreases |
| **Density** | increases | increases significantly |
| **Ductility** | decreases | decreases slightly |
| **Electrical properties** | little effect | improves |
| **Fatigue resistance** | increases | — |
| **Flame retardancy** | increases | increases |
| **Flow** | decreases | decreases |
| **Impact resistance** | decreases | decreases |
| **Modulus** | increases | increases slightly |
| **Notch sensitivity** | increases | increases significantly |
| **Shrinkage** | anisotropy | decreases significantly |
| **Strength** | increases | little effect |
| **Temp. resistance** | increases | increases |

### *Impact Resistance*

The impact resistance of an injection molded part generally decreases with increased amounts of glass loading. However, the mode of failure and the amount of energy absorbed will typically be a function of

- the stress levels occurring in the loaded part
- the temperature at impact
- the specific amounts and rates of strain applied to the part

Therefore, although the general statement “glass decreases impact” is valid, the relationship between impact load absorption and material properties is much more complex than it initially appears.

Filling with minerals creates similar effects on impact resistance.

### *Modulus*

The moduli (tensile, flexural, compressive, shear and torsional characteristics) of a material are increased by the addition of glass fillers. The amount of glass loading and the type of glass affects the amount of increase in modulus: the more glass, the higher the modulus. The length of glass reinforcements also influences the modulus increase: longer glass means higher modulus.

The increase of modulus of mineral filled products is relatively small when compared to glass filled products.

### *Notch Sensitivity*

The notch sensitivity of thermoplastics may – depending on brittleness of the matrix – increase with glass loading. This is primarily due to the decrease in ductility and the effects of the discontinuities caused by the glass fibers. This effect can be severe in highly glass loaded materials. The notched Izod test is a relatively good indication of notch sensitivity when used on a comparative basis.

The effect of increasing notch sensitivity through the use of mineral fillers is much more severe than it is for glass loaded materials. The notch sensitivity increase is often identified as the single largest problem with mineral reinforcement.

### *Release Agents*

Release agents are commonly added to thermoplastics to enhance processability, specifically in ejection of the part from the tool. The use of internal release agents does not normally affect the mechanical and thermal properties of a material. GE Plastics offers a variety of "easy release" grades.

### *Shrinkage*

The tendency of glass to align itself in the direction of flow can lead to increased anisotropy of shrinkage, or differences in shrinkage values between flow and cross flow direction. The effect of this anisotropy may cause warpage of parts.

With increased mineral loading, however, the shrinkage of plastics in the cooling portion of the molding cycle usually decreases significantly. Mineral fillers tend to decrease warpage, resulting in much flatter parts.

### *Strength*

The ultimate strength of a material can be significantly increased by glass reinforcement. The quantity, length and orientation of the glass greatly affect the yield and ultimate strengths of plastic parts.

Mineral loading generally does not significantly affect strength.

### *Temperature Resistance*

Glass loading improves stiffness and strength over the typical usable temperature range of the material. This is due to the relative temperature independence of glass properties in comparison to those of thermoplastics. The HDT increases and the RTI rating of the material also improves. The increase in HDT is more significant for semi-crystalline resins than for amorphous ones. Adding minerals creates similar effects.

### *UV stabilizers*

A number of additives have been designed to deal specifically with potential issues arising from exposure to ultraviolet light. Some thermoplastics are inherently UV resistant, while others suffer in varying degrees from UV exposure. The amount and type of property variance which can be caused by UV exposure depends on the specific thermoplastic, the temperature, the stress level, the UV intensity and the specific type of exposure (wavelength).

The most common problems arising from extended exposure of thermoplastics to UV are color shift of colored resins and yellowing of clear or light colored resins. Some thermoplastics can also suffer significant loss in mechanical properties if exposure is severe.

GE Plastics provides UV stabilized versions of many products. As with other chemical additives, care has been taken in selecting the UV stabilizers in order to minimize the chemical, thermal, mechanical and aesthetic issues which might arise from improper selection and concentration. Properties of our UV stabilized resins are typically comparable to those of the base resin.

## Polymer Fundamentals

All engineering thermoplastic grades are created from polymers. Polymers are chemical compounds containing many repeating structural units linked together to form a long, chain-like molecule entangled in a structural mass. The performance capabilities of engineering thermoplastics are defined by the basic chemical composition, the length of the molecular chains (molecular weight), and the structure of the polymer (Figure 1-2). The structure of thermoplastics can be either amorphous or crystalline. An amorphous material is a random entanglement of polymer chains, and a crystalline material contains areas of order (crystals) where the polymer chains are aligned in an ordered pattern. Each structure defines the performance capability of specific engineering thermoplastics. Characteristics of each are described below.

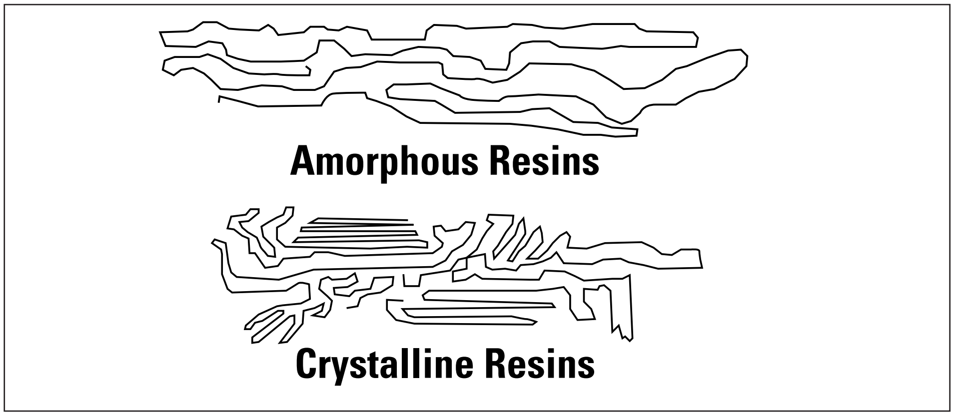


**Figure 1-2.** Alignment of Polymer chains.

**Engineering Resins**

High performance resin normally selected for specific application needs.

**Commodity Resins**

Common performance competing for applications primarily on price.

### *Amorphous Polymers*

- Broad softening point
- Very good mechanical properties (strength, stiffness, impact, etc.)
- Dimensional stability
- Consistent, predictable shrinkage
- Intrinsically transparency possible

### *Crystalline Polymers*

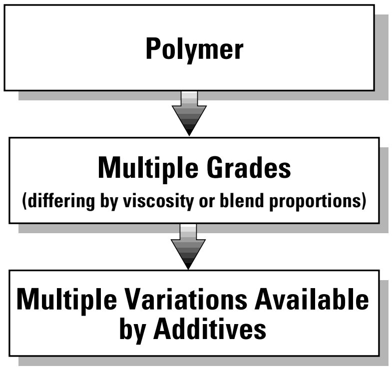
- Sharp melting point
- Resistance to some severe chemical environments
- Anisotropic (differential) shrinkage
- Very good electrical properties
- Higher heat capabilities with reinforcement

### *Amorphous/Crystalline Blends*

- Tailored products to enhance specific, performance capabilities
- Characteristics dependent on blend proportions
- Generally provide a balance of performance

## Product Line Creation

GE Plastics has the broadest product line of any producer of engineering thermoplastics. The product line is comprised of 11 major product families with over 100 specific grades. The creation of this broad product line with multiple grades is easier to understand by visualizing the model shown here. Each product family starts with the base polymer (chemical). The base polymer is produced in multiple variations based on molecular weight (measured by viscosity or, in the case of blended products, by the proportions of the primary blend components.) Many variations of the multiple base polymers are then created by adding modifiers or combinations of modifiers that are required to produce the final grade of engineering thermoplastic. It is important to remember that all GE Plastics' resin products contain additives (modifiers) at some level.



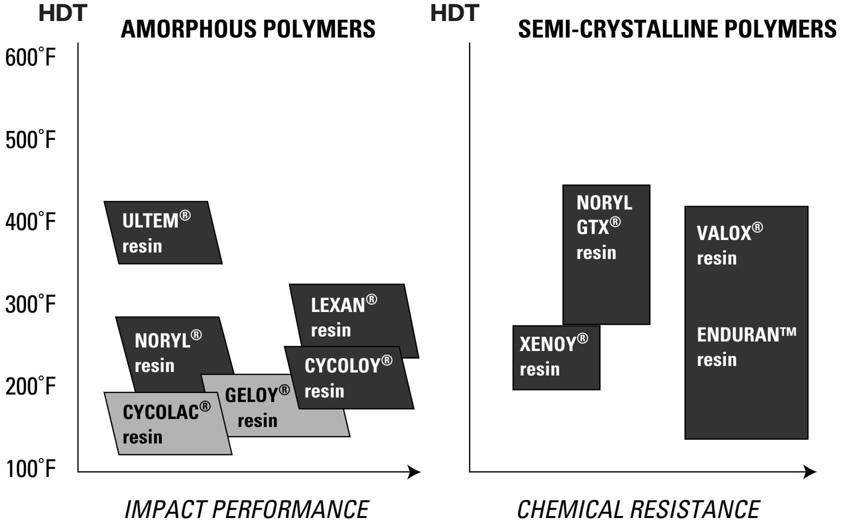
## Product Line Structure

The GE Plastics' engineering thermoplastic product line is comprised of amorphous and crystalline polymers which are structured in a matrix of varying performance capabilities. As noted before, the two major attributes of an engineering thermoplastic are the capability of performing at elevated temperatures and a general balance of other key properties based on the polymer's structure. Thus, GE Plastics' products are defined by thermal performance capabilities with either mechanical or chemical property capability. The first step in identifying a general product for any application is to define its maximum use temperature and which mechanical or chemical properties are critical to successful performance.

The position of key GE Plastics' products in this performance matrix is show in Figure 1-3.

## Product Development

**Figure 1-3.** Performance Matrix.



**GE Plastics offers the industry's broadest product performance portfolio.**

GE Plastics is a leading supplier of a wide range of high performance engineering thermoplastic resins to a broad spectrum of end-use industries. These materials meet specific requirements for heat resistance and mechanical performance, while addressing the growing trend toward greater design integration.

GE Plastics' product line includes resins classified as amorphous, semi-crystalline and unique blends of both, specifically designed to meet diverse performance requirements. Figure 1-3 positions the property profiles of these materials.

## Product Families

The GE Plastics' engineering thermoplastic product portfolio is comprised of product families which cover the range of amorphous and crystalline structures plus amorphous and amorphous/crystalline blends (see page 1-20). Each product family in the portfolio is defined by a registered trademark and a generic chemical name. The GE Plastics product trademarks and their related chemical names are show below.

## Amorphous Resin Families

GE Plastics amorphous resin families include:

- CYCOLAC® ABS resin
- CYCOLOY® PC/ABS blended resin
- GELOY® ASA resin
- LEXAN® PC resin
- NORYL® Modified PPO resin
- ULTEM® PEI resin

**Table 1-3.** Amorphous Resins.

| Product | Chemistry | Outstanding Characteristics |
|---|---|---|
| CYCOLAC ABS resin | Acrylonitrile-Butadiene-Styrene (ABS) | • thermal stability<br>• impact resistance<br>• surface quality<br>• wide range of colors<br>• ease of molding |
| CYCOLOY PC/ABS resin | Polycarbonate (PC)<br>Acrylonitrile-Butadiene-Styrene (ABS) | • low temperature impact resistance<br>• very good indoor UV stability<br>• flame resistance<br>• ease of molding<br>• very good flow |
| GELOY ASA resin | Acrylic-Styrene-Acrylonitrile (ASA) | • weather resistance<br>• heat resistance<br>• impact resistance |
| LEXAN PC resin | Polycarbonate (PC) | • transparency or opaque<br>• high impact<br>• dimensional stability<br>• high temperature performance<br>• flame resistance |
| NORYL Modified PPO resin | Polyphenylene Ether (PPE) + PS | • electrical properties<br>• dimensional stability<br>• hydrolytic stability<br>• high temperature performance<br>• low water absorption<br>• flame resistance<br>• non-halogen |
| ULTEM PEI resin | Polyetherimide (PEI) | • chemical resistance<br>• dimensional stability<br>• high temperature performance<br>• inherent flame retardance<br>• transparent grades available |

### *Semi-Crystalline Resins*

Semi-crystalline resin families available from GE plastics include:

- VALOX® PBT resin
- ENDURAN™ PBT resin
- SUPEC® PPS resin

**Table 1-4.** Semi-Crystalline Resins.

| Product | Chemistry | Outstanding Characteristics |
|---|---|---|
| VALOX<br>PBT resin | Polybutylene<br>Terephalate (PBT) | • very good electric properties<br>• chemical resistance<br>• high temperature performance<br>• flame resistance<br>• fast molding |
| ENDURAN<br>PBT resin | Polybutylene<br>Terephalate (PBT) | • high specific gravity<br>• flame resistant<br>• stain resistant |
| SUPEC<br>PPS resin | Polyphenylene<br>Sulfide (PPS) | • very good chemical resistance<br>• high temperature performance<br>• high rigidity<br>• inherent flame resistance<br>• high flow |

### *Amorphous/Crystalline Resin Blends*

The GE Plastics' product line also includes resin that are blends of other resin families which offer a unique combination of properties. These resins include:

- NORYL GTX® PPE/PA resin
- XENOY® PC/PBT resin

**Table 1-5.** Combination Resins.

| Product | Chemistry | Outstanding Characteristics |
|---|---|---|
| NORYL GTX<br>PPE/PA resin | Polyphenylene<br>Ether (PPE)/<br>Polyamide (PA) | • on-line paintability<br>• low temperature impact<br>• high temperature performance<br>• chemical resistance<br>• low mold shrinkage |
| XENOY<br>PC/PBT resin | Polycarbonate (PC)/<br>Polybutylene<br>Terephalate (PBT) | • very good electric properties<br>• chemical resistance<br>• high temperature performance<br>• fast molding |

As indicated previously, all of the GE Plastics' resin families are identified by product trademarks. Each product line consists of specific grade nomenclature to identify and differentiate products in that line. In many cases, several products in one or more product lines may be suitable for the same application. Specific performance requirements of the application will determine the most suitable grade.

# Product Offerings

## Resin Designations

Following, grouped by product tradename, is a listing of GE Plastics' resin designations with a brief description of the primary property or performance characteristics for each. With some designations, suggested applications are also included.

### *CYCOLAC ABS Resin Materials*

CYCOLAC resins are a family of amorphous thermoplastics that are hard, tough and rigid. They each consist of styrene-acrylonitrile copolymer as a continuous phase, with a dispersed phase of microscopic polybutadiene rubber particles onto which styrene-acrylonitrile copolymer has been grafted. Through variations in composition, molecular weight, and morphology of the rubber phase, these materials exhibit a very wide range of properties.

**Table 1-6.** CYCOLAC ABS Resin Materials.

| Property | Characteristic | Typical Designations |
|---|---|---|
| Medium Impact | A group of products having high strength,high modulus, and high flow. | DFAR, AR, DSK, GPM6300, GPX3700. |
| High Impact | Products having high impact strength, and a very good balance of properties. | T, GSM, GSE, CGA, GPM5600. |
| Super Impact | Characterized by very high impact strength, good ductility at low temperatures, and very good hot strength. | L, LS, LDA, GPM4700, GPX3700. |
| Flame Retardant | Flame retardant grades with good property balance. | KJB, KJU, KJW. |
| Electroplating | Designed for improved performance in plated applications. | EP, ETC. |
| High Heat | Products designed to have higher deflection temperatures under load. | X11,X15,X17,X37, Z48,GHT4400, GHT3510,GHT4320. |

## CYCOLOY PC/ABS Resin Materials

The CYCOLOY resin products are a family of engineering thermoplastic blends of polycarbonate and ABS. This combination provides functional balance of the heat resistance and impact of PC, and the processability, ductility and aesthetics of ABS.

Polycarbonate provides continuous rigid phase, which is impact modified with polybutadiene particles that have undergone grafting with styrene-acrylonitrile copolymer. Varying the molecular weights and ratios of the constituents and the morphology of the rubber phase results in a wide range of properties within the family.

**Table 1-7.** CYCOLOY PC/ABS Resin Materials.

| Property | Characteristics | Typical Designations |
|---|---|---|
| High Flow | High impact, high modulus. UV stable blend. | C1950 |
| Low Temperature | High impact even at low temperatures. | C1110, MC8002 |
| High Heat | Stepped up heat performance with typical attributes of CYCOLOY resin materials. | C1200 |
| Blow Molding | CYCOLOY resin with rheolocti suitable for blow molding process. | MC8100 |
| Electroplating | Provides CYCOLOY resin surface suitable for plating process. | MC1300, EPBM |
| Flame Retardant | Flame retardant grades for meeting UL requirements. | C2800, C2950 |

## GELOY ASA Resin Materials

GELOY resin is based on ASA and blends of ASA with PVC and PC. The resin is commonly used in applications requiring good property retention after prolonged outdoor exposure. Resin grades are available for extrusion, injection, foamed injection and blow molding.

**Table 1-8.** GELOY ASA Resin Materials.

| Property | Characteristic | Typical Description |
|---|---|---|
| Extrudable | Extrusion grades available as a granular powder or pellet form. | GY series |
| Moldable | Injection molding grades. | XP series |

## LEXAN PC Resin Materials

LEXAN resin is renowned for its high impact strength and clarity. It is available with a wide variety of custom formulations designed for specific properties. The most common families are summarized below.

**Table 1-9.** LEXAN PC Resin Materials.

| Property | Characteristic | Typical Designations |
|---|---|---|
| General purpose | Resin grades with tightly controlled viscosity ranges. | 1XX, 2XX series |
| High Flow | Resin grades for hard to fill parts and low molded in stress. | HF series |
| FDA/USP | Specially formulated resins for health care industry to meet FDA and USP class 4 approval. | HP series |
| Flame Retardant | Highly flame retardant grades designed for applications requiring UL 94 *5V/V-0 approval. | 9XX series |
| Thin Wall | Specially designed to meet the specific requirements of the business equipment industry. | SP series |
| Strength/ Toughness | Designed for high strength and toughness with a flexural modulus of 500,000 psi. | 500 grade |
| High strength | Resin grades with glass reinforcement ranging from 20-40%. | 34XX series |
| Wear Resistance | Specially designed resins for increased wear resistance and reduced coefficient of friction. | WR series |
| Optical | Specially designed for optical qualities such as clarity and low birefringence. | OQ series |
| Foam Molding | A variety of LEXAN resin based materials specifically designed for the foam molding process. | FL series |
| High Melt | High melt strength grades of branched resins specifically designed for the blow molding process. | 15X(X) |
| Blow Molding | Specially designed to meet the requirements of the blow molding process. | 15X(X), PK2870 |
| Hi Temp | Polyphthalate carbonate product, specifically designed for increased thermal and hydrolytic stability. | PPC series |

* This test is not intended to reflect hazards presented by any material under actual fire conditions.

## NORYL Modified PPO Resin Materials

A wide variety of standard and specialty grades of NORYL resin is available for specific design requirements. The most common families are listed below.

**Table 1-10.** NORYL Modified PPO Resin Materials.

| Property | Characteristic | Typical Designations |
|---|---|---|
| Unfilled | Standard grades designed for a range of thermal and mechanical properties. | N190X, N225X, 731, N300X. |
| Reinforced | A series of grades containing glass for for stiffness or strength. | GFN2, GFN3,<br>SE1GFN2, SE1GFN3. |
| High Flow | A series of unreinforced and reinforced grades. | (SPNxxx) unreinforced |
| Extrudable | A series of extrudable resin grades offering various thermal properties and enhanced UV stability. | EN series |
| Foamable | A series of foamable resin grades offering a variety of thermal and mechanical properties. | FN series |
| Blow Molding | A series of resin grades with various properties which can be used in the blow molding process. | BN series |
| Automotive | A series of grades developed specifically for the needs of the automotive industry. | PX0722, PX0844, PN235, PX0888, PX1265, PX1390, PX1391. |
| Energy Management | A series of resin grades specifically designed for automotive interiors (heat and impact). | EM series |

## NORYL GTX PPE/PA Resin Materials

NORYL GTX resin is a blend of polyphenylene (PPE) and Polyamide (PA) offering very good heat and chemical resistance. Reinforced grades can meet the performance needs of fluid and material handling systems, while products in furniture and other consumer applications often utilize unreinforced Noryl GTX materials.

**Table 1-11.** NORYL GTX PPE/PA Resin Materials.

| Property | Characteristics | Typical Designations |
|---|---|---|
| Glass Reinforced | Grades with glass reinforcement to improve structural properties at temperature and limit thermal expansion. Blend enhances chemical resistance. | GTX800 series |
| Unreinforced High Temp Grades | Grades offer high temperature capability in a ductile material. With very good chemical resistance. Noryl GTX resins absorb less moisture than straight nylon. | GTX900 series |

## SUPEC Resin Materials

SUPEC resin is a high strength, high performance crystalline polymer based on polyphenylene sulfide technology. SUPEC resin exhibits very good heat resistance, high strength, stiffness, flow and good electrical properties.

**Table 1-12.** SUPEC Resin Materials.

| Property | Characteristics | Typical Designations |
|---|---|---|
| High Strength | High tensile strength, good elongation. Suitable metal replacement material. | G401 |

## ULTEM PEI Resin Materials

ULTEM resin is a high performance amorphous engineering thermoplastic. The basic ULTEM resin families include the following:

**Table 1-13.** ULTEM PEI Resin Materials.

| Property | Characteristics | Typical Designations |
|---|---|---|
| Unreinforced | Resin grades offering very good mechanical, thermal and environmental resistance properties. | 1000 series |
| Glass reinforced | Resin grades offering increased strength and stiffness. (10 to 30% GF) | 2000 series |
| Wear resistant | Resin grades with low coefficients of friction designed for gears, bearings and other sliding surface contact applications. | 4000 series |
| High heat | Resins designed specifically for high heat connector applications requiring thermal dimensional stability. | 6000 series |

## VALOX PBT Resin Materials

VALOX resin is a thermoplastic polyester resin which is semi-crystalline in nature. VALOX resin grades are available with a wide variety of thermal, electrical and mechanical properties. The most common families of VALOX resin are as follows:

**Table 1-14.** VALOX PBT Resin Materials.

| Property | Characteristics | Typical Designations |
|---|---|---|
| Unreinforced | Resin grades with very good thermal and electrical properties, and moderate strength and impact resistance. | 300 series |
| Strength/ Stiffness | A full line of glass reinforced resins (7 to 40%) offering increased strength and stiffness. | 400 series |
| Impact/ Flatness/ Impact Resistance | 30% glass reinforced alloys with improved flatness, aesthetics and impact resistance. | 500 series |
| Thermal/ Electrical | Mineral and mineral/glass reinforced grades with improved thermal and electrical properties. | 700 series |
| Moldability | A series of glass reinforced alloys with improved moldability and aesthetics, as well as lower cost. | 800 series |
| Foamable | A series of foamable grades available with or without reinforcement. | FV series |

## XENOY PC/PBT Resin Materials

XENOY resin is a polymeric blend or alloy of PC and PBT. By combining these two materials in a strategic manner, some of the properties of each are realized. XENOY resin combines some of the impact resistance and toughness of LEXAN resin with some of the chemical resistance and thermal stability of VALOX resin. The basic families of XENOY resin are as follows:

**Table 1-15.** XENOY PC/PBT Resin Materials.

| Property | Characteristics | Typical Designations |
|---|---|---|
| Chemical and Heat Resistance | Good chemical resistance with very good heat resistance and impact strength. | 2000 series |
| Chemical/ Impact | Very good chemical resistance with good impact strength. | 5000 series |
| Chemical/ Impact | Very good chemical resistance and good impact strength and electrical properties, with glass reinforced grades available. | 6000 series |

## Computer-Based Information Resources

GE plastics maintains a number of computer-based sources of information, all of which can assist with the material selection process. Up to the minute technical data is available on-line at www.geplastics.ge.com. This site provides access to over 3,000 pages of technical information.

## Design Assistance

Design assistance starts with the development of innovative concepts demonstrating how and where GE Plastics engineering thermoplastics can optimize performance, functionality, consumer appeal and costs.

Concepts are based on in-depth market knowledge and an understanding of evolving trends, technologies and materials. Simultaneous engineering reviews examine mechanical feasibility.

Selection of the optional molding process is also part of the design process from the very start. GE Plastics is uniquely positioned to identify new opportunities, marshaling the latest technology from the GE Polymer Processing Development Center – the most advanced facility of its kind in the world.

Design For Assembly (DFA) software studies can also contribute to up-front productivity. The savings achieved through component integration are quantified before production begins, including reduced material usage, inventory and labor requirements.

At GE Plastics, advanced design is just one key element in total system strategies for business success. For additional information addressing your specific areas of interest, please call (800) 845-0600.

## Materials Selection Database

*GE Select*™ is a disk-based material selection database designed to simplify the specification of engineering thermoplastics for design engineers. This comprehensive database covers the diverse family of GE polymers and provides properties and engineering data on over 500 commercially available resin grades.

The data is presented in an easy-to-use format designed to help engineers maximize potential, optimize material usage and reduce the chance of costly over-design.

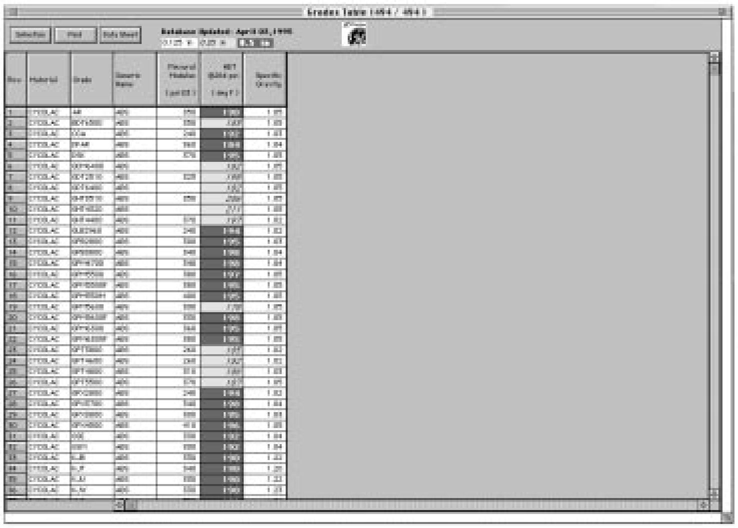


**Figure 1-4.** *GE Select* Database. *The GE Select database grades Table window provides property information for all GE Plastics resin grades commercially available. Product data sheet review is also available for all grades included in the database.*

Once a user has determined some or all of the performance criteria for an application, the program can be accessed. The data base is simple to open, with material and grade names displayed in a window (see Figure 1-4). By using a material selection dialog box, an engineer can conduct a search of product grade property profiles to match specific application requirements. *GE Select* searches the database and displays property information and engineering data for those resin grades that meet the criteria established by the user.

Special functions on the menu bar permit the plotting of engineering data for product/grade comparisons, such as Tensile Stress vs. Strain, as shown in Figure 1-5.

™*GE Select* is a Trademark of General Electric Company.

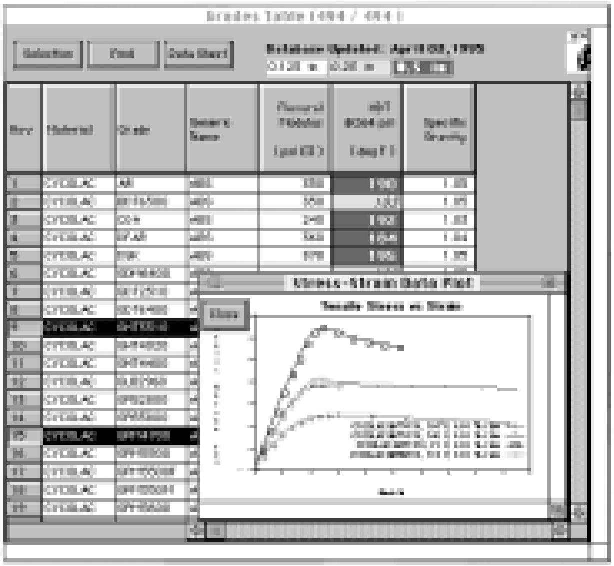


**Figure 1-5.** Materials Selection. *The Materials Selection step of the GE Select database can be repeated, enabling a user to consider one or several resin grades. Special functions on the menu bar permit the plotting of engineering data for product/grade comparisons, such as Tensile Stress vs. Strain.*

The Materials Selection step of the *GE Select* database can be repeated, enabling a user to consider one or several resin grades. The database also allows users to overlay combinations of materials and test parameters – a key feature for design engineers. Engineering data available on *GE Select* include Tensile Creep Data, Tensile Fatigue Data, Dynamic Mechanical Analysis Data and Rheology Data.

With *GE Select*, users can customize query windows, browse through material data sheets and display engineering data. Call (800) 845-0600 to request a copy. *GE Select* can also be downloaded directly from the Internet by accessing GE Plastics' www.ge.com on-line address.

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## Notes

# Processing Considerations

## Plastic Manufacturing Processes

Early in design development, parts are identified as potential plastic applications and applicable manufacturing processes are considered. Normally, the configuration requirements of the plastic part will direct the design toward a process. In most cases, the process must be determined before a specific resin grade can be selected. During this review, designers also need to consider if the process is capable of meeting the design requirements such as size, shape, detail and tolerances.

The plastic manufacturing process selected will typically affect the design of a part. Occasionally, a number of different processes can be considered for the same part with slightly different designs. Under these circumstances, the designer may assess which process offers more inherent value to the overall design and which process results in the most attractive cost scenario. Tooling costs, size of production runs and annual volume will shape the cost comparison and help determine which process will be the most suitable for a specific application.

In determining an appropriate conversion process, there are several key factors to consider including part size, part complexity and wall thickness. Economic considerations such as initial mold and die costs, start-up/set-up charges, production quantity, cycle times, secondary operations (machining, trimming, cutoffs, inserts, bonding) and assembly along with total costs all must be considered. Today, designers are also involved in considering the environmental aspects of design. Yield, scrap and designing for recycling are additional factors of concern. Once a process is selected, the design should reflect the standard practices for the process. Specific details may typically be put off until a material search is complete and a selection made.

It is very common in an application development cycle to pursue two parallel paths, each with a different process and therefore a slightly different design. Once a process and material are determined to meet the application requirements, it is necessary to tailor the design to take advantage of the process features and benefits. When designs for the process and material are modified, it becomes possible to do a detailed cost analysis of the two competing designs and their assemblies.

Table 1-16 shows the relative relationships of several forming processes.

**Design Optimization**

- Combine functions
- Eliminate parts
- Ease of assembly
- Material efficiency
- Eliminate operations

**Table 1-16.** Thermoplastic Process Comparison.

| | INJECTION | EXTRUSION | ESF | EBM |
|---|---|---|---|---|
| Cost Efficient Production Quantity | 10,000 | 50 | 2,500 | 2,000 |
| Tooling Cost 1 = Least Expensive | 5 | 1 | 4 | 3 |
| Part Size 1 = Largest | 4 | 1 | 3 | 2 |

Figure 1-6 shows the relationship for part size and complexity for Solid Injection, Structural Foam, Engineered Blow Molding (EBM), and Extrusion.

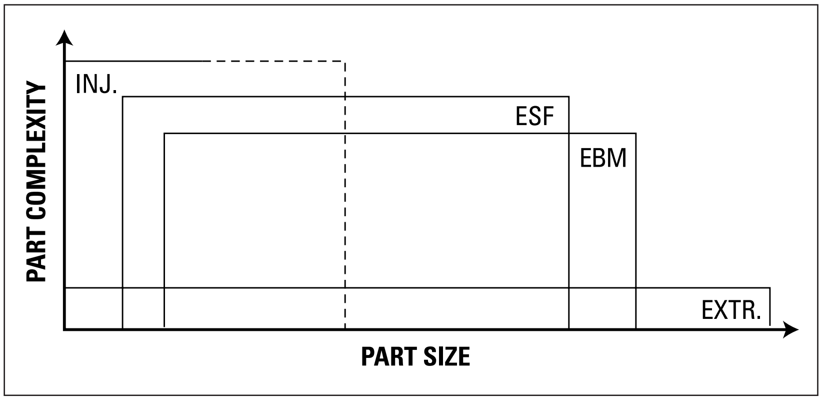


**Figure 1-6.** Part Size vs. Complexity.

## Volume Considerations

The volume should justify the sizable tooling investment and the requirements need to be within the capability of the materials and the process. A sample comparison of competing processes is offered to develop an appreciation of the relative fit and position of each process.

**Table 1-17.** Manufacturing Alternatives, Materials and Processes.

| | | Metals | | | | |
|---|---|---|---|---|---|---|
| **Comparison Grid** | | **Stamped Steel** | **Sand Cast** | **Die Cast Alloy** | **Investment Cast Metal** | **Sintered Powder Metal** |
| **A. Initial Investment Production Tooling** | | | | | | |
| Cost | 1 is high | 2 | 4 | 1 | 3 | 2 |
| Delivery | 1 is long | 1 | 4 | 2 | 4 | 2 |
| **B. Piece Part Cost** | | | | | | |
| Material | 1 is high | 2 | 3 | 3 | 3 | 2 |
| Scrap | 1 is high | 2 | 3 | 3 | 3 | 3 |
| Cycle Time | 1 is long | 4 | 1 | 4 | 2 | 2 |
| Yield | 1 is low | 4 | 2 | 3 | 3 | 3 |
| **Secondary Operations** | | | | | | |
| Machining | 1 is extensive | 3 | 1 | 2 | 2 | 1 |
| Finishing | 1 typ req. | 2 | 2 | 2 | 3 | 3 |
| Maintenance Tooling | 1 freq. req. | 1 | 2 | 2 | 3 | 3 |
| **C. Capability** | | | | | | |
| Size | 1 limited | 4 | 3 | 2 | 1 | 1 |
| Complexity | 1 least | 2 | 2 | 3 | 3 | 2 |
| Precision | 1 least | 3 | 1 | 3 | 2 | 3 |

| | | Thermoset Plastics | | | Thermoplastic |
|---|---|---|---|---|---|
| **Comparison Grid** | | **Compression Molded** | **Transfer Molded** | **Injection Molded** | **Injection Molded** |
| **A. Initial Investment Production Tooling** | | | | | |
| Cost | 1 is high | 2 | 2 | 1 | 1 |
| Delivery | 1 is long | 2 | 2 | 2 | 2 |
| **B. Piece Part Cost** | | | | | |
| Material | 1 is high | 4 | 4 | 4 | 3 |
| Scrap | 1 is high | 3 | 2 | 2 | 4 |
| Cycle Time | 1 is long | 2 | 2 | 3 | 4 |
| Yield | 1 is low | 3 | 3 | 3 | 4 |
| **Secondary Operations** | | | | | |
| Machining | 1 is extensive | 3 | 3 | 3 | 4 |
| Finishing | 1 typ req. | 2 | 3 | 3 | 4 |
| Maintenance Tooling | 1 freq. req. | 3 | 3 | 3 | 4 |
| **C. Capability** | | | | | |
| Size | 1 limited | 2 | 2 | 2 | 3 |
| Complexity | 1 least | 3 | 3 | 3 | 4 |
| Precision | 1 least | 3 | 3 | 3 | 4 |

### *The Plastics Engineering & Troubleshooting System (PETS)*

A unique hardware/software resource that gives users of GE Plastics' resins expert in-house technical support. It captures the accumulated knowledge of experienced development engineers and molders to provide possible solutions to typical molding problems, and is presented in a text/graphics format that is easy to understand and use. Versatile and flexible, PETS has a variety of uses including:

**Education and Training.** Teach or test individuals or groups of new or less-experienced personnel on the latest diagnostic procedures. PETS can output to a variety of projection devices for group viewing.

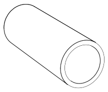
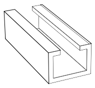
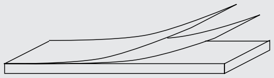
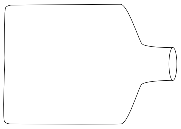
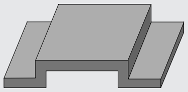
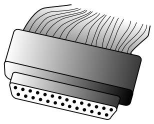
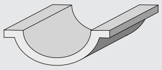
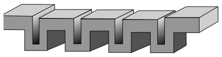
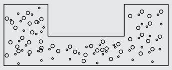
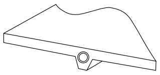
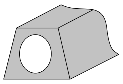
**Troubleshooting.** Assist less experienced personnel in solving problems independently, quickly and cost-effectively.

**Design.** Address a number of considerations in the design and development of plastic parts - structural considerations, plastic behavior, molding considerations for parts and economic considerations.

**Documentation.** Generate printed records combining both text and graphics. These are valuable for use as educational reference or troubleshooting and to assist in mold evaluation, determining parts costs, and justifying mold improvements.

For pricing information and answers to specific questions about PETS, please call 1-800-845-0600.

**Table 1-18.** Plastic Conversion Processes vs. Key Considerations

| PROCESS | CONSTRAINTS |
|---|---|
| **Extrusion**<br><br> | • Limited Geometry. 2 Dimensional Shapes Only.<br>• Constant Cross Section.<br>• Size: Large Parts Possible – Approx. 110 in. (2,795mm) max. Wide with Length to Suit.<br>• Materials: Most Thermoplastics.<br>Amorphous – Better than Crystalline for Shapes.<br>• Aesthetic Surface Possible. |
| **Co-Extrusion**<br> | • Limited Geometry (Like Extrusion) 2 Dimensional Shapes.<br>• Constant Cross Section.<br>• Large Parts<br>Width up to approx. 110 in. (2,795mm) max.<br>Thickness <1.0 in. (25mm)<br>Cut to Length.<br>• Good Tolerance Control on Profiles.<br>• Appearance... Good.<br>• Dissimilar Material Combinations. Protective Weatherable Surfaces Feasible. |
| **Blow Molding**<br> | • Walls Typically Thin.<br>• Large Size Parts Possible.<br>• Double Wall Geometry (Hollow).<br>• Parts Limited to Hollow Shapes.<br>• Wall Thickness Vary as a Function of Draw Ratio.<br>• Good Stiffness to Weight Ratio.<br>• Limited Tolerance Capability.<br>• Surface Finish Acceptable. But Not Class A.<br>(Does Not Compare to Injection Molding.) |
| **Compression Molding**<br> | • Some 3 Dimensional Detail Possible.<br>Standing Detail Difficult.<br>• Large Part Capability.<br>• Difficult to Maintain Flatness.<br>• Non-Aesthetic Surface Appearance.<br>• Can Accept Highly Reinforced Materials.<br>• Low Tolerance Control. |
| **Injection Molding**<br> | • Part Size is Limited – Project Area <2000 $in^2$ Typical.<br>• Very Good Detail and Tolerance Control.<br>• Complex Parts.<br>• Normally Thin Walls.<br>• High Pressure Process.<br>• High Quality Surface Possible for Aesthetic Parts. |
| **Vacuum Forming**<br> | • Low Tolerance Control.<br>• Large Part Capability.<br>• Shape Limited by Draw Ratio.<br>• No Standing Ribs or Other Detail.<br>• Little Surface Replification of Mold. |
| **Pressure Forming**<br> | • Better Tolerance Control Than Vacuum Forming: Still Loose.<br>• Shape Limited by Draw Ratio.<br>• No Standing Features.<br>• Large Part Capability.<br>• Enhanced Surface Replification. |
| **Structural Foam**<br> | • Large Part Capability.<br>• Swirled Surface Appearance (Can be Improved With Counterpressure).<br>• Heavier Wall Thickness (.250 in. [1.6mm] Typical).<br>• Wall Thickness Changes More Acceptable. |
| **Gas Assist**<br><br> | • Part Size Similar to Injection Molding.<br>• Heavy Sections Can be Displaced by Air if Connected to Air Channel.<br>• Very Good Tolerance Control.<br>• Injection Molded Surface Characteristics Typical.<br>• Low Stress Molding. |

# Processing Considerations

| COST FACTORS |
|---|
| • Continuous Process – High Production. Increased Thickness Slows Production Rates and Adds Material Cost.<br>• Moderate Tooling – Extrusion Die/Sizing/Cooling Die.<br>• Significant Start-up Costs<br>• Scrap – Purges/Start-up Cutoffs, Can be Reground and Reused. |
| • Continuous Process – High Production. Increased Thickness Slows Production Rates<br>• Moderate Tooling – Extrusion Die, Sizing and Cooling Die.<br>• Significant Start-up Costs.<br>• Secondary Cutting and Trimming.<br>• Scrap – Regrind Results in New Product if Resin 1 and Resin 2 are Compatible. |
| • Tooling Moderate Costs. Cast Aluminum Molds Feasible.<br>• Suitable for High Production.<br>• Scrap – Trimmed From Parts. Can be Reground and Reused. |
| • Tooling – Expensive, But Less Than Injection Molding Cycle.<br>• Mold Charged by Heated Cut-to-Size Blanks: Labor Intensive.<br>• May Require Trimming of Flash.<br>• Suitable for High Production.<br>• Scrap – Reusable. |
| • Relatively Fast Cycle Times.<br>• Low Scrap – Can be Reused.<br>• Expensive Molds – Machined Steel. |
| • Moderately Slow Cycles Dependent on Thickness.<br>• Trimming Scrap – Can be Reused.<br>• Inexpensive Molds – Wood or Cast Aluminum Acceptable.<br>• Uses Sheet Stock.<br>• Secondary Operations: Trimming, Drilling, Finishing. |
| • Moderately Slow Cycle Time.<br>• Sheet Stock Command Semi-Finished Goods Price.<br>• Trimming.<br>• Moderate Tooling Cost: Cast Aluminum Feasible. |
| • Longer Cycle Time Than Injection Molding (+50%).<br>• Slightly Lower Mold Costs Due to Low Pressure Process.<br>• Finishing Costs For Appearance Parts. |
| • Similar to Injection Molding Tooling, Requires Gas Assist Equipment.<br>• Process Patented. Royalties Need to be Checked.<br>• Cycle Time Comparable to Injection Molding.<br>• Scrap – Reusable. |

# Product Development

## Previous Applications

Before undertaking a detailed material selection process, it is often worthwhile to determine if a similar part has been made before, and if so, from which material it was made. If such an application exists, it may be advisable to conduct further investigation into the specifics of the particular application to see whether newer or more appropriate materials could now be used.

Since it is impossible to list all applications – some grades are used for a multitude of parts in many industries – a relatively limited number has been listed.

This Application Matrix provides an overview of some typical applications in some of the numerous market segments served by GE Plastics.

For further information on a particular grade, please contact your local GE Plastics' representative.

**Table 1-19.** Application Matrix.

| Products | |
|---|---|
| **CYCOLAC<br>ABS Resin** | • ease of molding<br>• surface quality<br>• thermal stability<br>• impact resistance<br>• wide range of colors |
| **CYCOLOY<br>PC/ABS Resin** | • ease of molding<br>• very good flow<br>• low temperature impact<br>• very good indoor UV stability<br>• flame resistance |
| **ENDURAN<br>PBT Resin** | • chemical and stain resistance<br>• dimensional stability<br>• low water absorption<br>• very good processibility<br>• noise attenuation |
| **GELOY<br>ASA Resin** | • excellent weatherability<br>• heat resistance<br>• impact resistance<br>• aesthetics, colorability |
| **LEXAN<br>PC Resin** | • transparency<br>• high impact<br>• dimensional stability<br>• temperature resistance<br>• flame resistance |
| **NORYL<br>Modified PPO Resin** | • electrical properties<br>• dimensional stability<br>• hydrolysis resistance<br>• temperature resistance<br>• low water absorption<br>• flame resistance |
| **NORYL GTX<br>PPE/PA Resin** | • on-line paintability<br>• low temperature impact<br>• temperature resistance<br>• chemical resistance<br>• low mold shrinkage |
| **SUPEC<br>PPS Resin** | • chemical resistance<br>• inherent flame resistance<br>• heat resistance<br>• high strength<br>• very good electrical properties |
| **ULTEM<br>PEI Resin** | • chemical resistance<br>• temperature resistance<br>• dimensional stability<br>• inherent flame resistance |
| **VALOX<br>PBT Resin** | • very good electrical properties<br>• chemical resistance<br>• temperature resistance<br>• flame resistance<br>• fast molding |
| **XENOY<br>PC/PBT Resin** | • high impact resistance<br>• chemical resistance<br>• dimensional stability<br>• UV stability |

# Application Matrix

| Automotive Interior | Automotive Exterior | Automotive Electrical and Mechanical Systems | Transportation/ Aircraft |
|---|---|---|---|
| Instrument clusters and panels; glove box lids; pillar trim; vents, speaker grilles; door liners, pockets; seat covers and knobs; ashtrays; steering column covers; consoles, cladding | Wheel covers; front and radiator grilles; air inlets; mirror housings; door pockets; blow molded spoilers; trim for vents and license plates | Lamp housings; fuse boxes; door handles; seat belt components | Off road vehicles: dashboards, interior trim and cladding, tractor headlamps; trucks and vans: air deflectors, cabin trim, grilles; two-wheelers: body and instrument panels, chain covers. |
| Dashboard components and carriers, center consoles; glove boxes; pillar trim, vents, grilles; air nozzles; parcel shelves | Vents, grilles, trim; mirror housings; wheel covers; spoilers; door handles; bumper filler panels; other exterior body components | Signal lighting reflectors and housings; fuse boxes | Trucks/vans: control consoles, air nozzles; tractor parts |
| | | | |
| Dashboard and door skins | Mirror housings, cowl vent grilles, pillars, front grilles, tail lamp housings | | Trucks, tractors; consoles, trim, hoods |
| Seat belts; boot panels; speaker grilles; dashboard components, instrument panels and clusters, center consoles; heater covers; instrumentation lenses | Bumper fascias: mirror housings; windshield wipers; exterior trim | Lenses and housing for headlamps, rearlamps and signal lighting; electrical motors; ignition system components | Railway signs; traffic lights; seat backs, truck steps |
| Dashboards and components, instrument clusters, center consoles; glove boxes, vents, grilles, ashtrays; panel trim; airducts, air nozzles; steering wheel parts; parcel shelves; roof liners; seats; seat belts, armrests, headrests; handles, winders | Grilles, spoilers; wheel trim hub caps; mirror housings; raingutters; door trim, panels; pillar covers | Connectors, sensors; ignition systems: bobbins, coils, fuse boxes; heater control parts; signal lighting parts; windshield wiper motors | Train seats; dashboard components and instrument clusters for trucks and vans, extruded trim; panels for two-wheelers |
| Dashboard components, center consoles; parcel shelf speaker covers; headrest frames; demister rails; heater covers; air nozzles; vents, grilles; seat-parts; switches | On-line paintable body parts with class A surface finish: fenders, side doors, tailgates, tank flaps, spoilers, trim, wheel trims; bumper fascias; air dams; grilles; car door handles | Forward and signal lighting; fuseboxes, connectors; door handle parts; windshield wiper pumps; ignition systems; air cleaner parts engine covers; fans and fan housings, lamp housings; under-the-hood components | Truck wings and air dams |
| | | Underhood switches and sensors, cooling and fuel system parts | |
| | | Forward lighting reflectors and bezels, connectors, housings, switches, sensors. Transmission components. | Aircraft interiors |
| Dashboard components, connectors instrument clusters; window cranks, door handles; pillar trim | Exterior trim, door handles, tailgate handles; bumper fascia brackets; spoilers; lamp housings, headlamp carriers; windscreen wipers; mirror housings; grille opening retainers | Connectors, plugs, sockets, sensors, switches, electric motors, lamp housings; under-the-hood components: oil and fuel filters, fuel pumps; ignition systems, distributors; alternator boxes; locking systems, door handles; lighting parts | Internal aircraft parts such as seat covers, arm rests, panels and cladding, cockpit equipment, food containers; signal lighting for trucks and vans; railway components |
| Structural components for dashboards and instrument clusters; door liners and cladding; boot panels; roof liners; seat components; sunroof components; door handles | Impact resistant bumpers, front ends, tail gates; wings, air dams, fenders; bumper beams, brackets and supports; tailgate cladding, trim, panels, grilles; sunroof frames and trim; mirror housings; wheel trims; door handles | Door handles; windshield deflectors; steering components; ignition systems; signal lighting parts; battery covers | Impact resistant components. |

**Table 1-19.** (Continued)

| Products | Appliances | Office Automation | Communication Equipment |
|---|---|---|---|
| **CYCOLAC<br>ABS Resin** | Bathroom and kitchen appliances; vacuum cleaners, refrigerator door liners and panels, fans; covers, fronts and panels for washing machines; food preparation: mixers, processors, fruit presses; dental showers; lawn mower housings | Components and housings for business machines: computers, copying machines, printers, paper trays, cassettes, calculators; keyboard caps and housings | Telephones: cordless handsets; cassettes; terminals |
| **CYCOLOY<br>PC/ABS Resin** | Coffee makers, hairdryers, irons, mixers; shower backplates; control panels; computer housings: terminals, towers, desktops, laptops, notebooks, palmtops; printer housings and components; copier parts | Structural components and housings for business machines: computers, printers, copiers, fax machines | Telephones: portable phones, car phones; telephone racks; modems; fax machine components; franking machines; battery chargers |
| **ENDURAN<br>PBT Resin** | Speaker housings; oven handles, iron handles, shaver handles | | |
| **GELOY<br>ASA Resin** | | | Outdoor, telecom |
| **LEXAN<br>PC Resin** | Chainsaw housings; iron handles, heated combs, hairdryers; food mixers and processors; sewing machines; air filters; mini vacuum cleaners; oven doors; components for dishwasher and laundry washing machines | Structural components for business machines: chassis, frames, covers; paper trays, brackets and supports, card cages, copier internals, disk drives, terminals; barcode scanners; smart cards; cassettes, cartridges | Exchange equipment; switchboards; telephone modems and housings; smart cards |
| **NORYL<br>Modified PPO Resin** | Washing machines,  dryers, dishwasher components; vacuum cleaners, hairdryers, mixers, coffee makers | Business machine chassis, frames and housings; components for computers, printers, copiers; keyboard parts | Telephone components |
| **NORYL GTX<br>PPE/PA Resin** | Laundry washer and dryer doors, top loader frames, powder coatable panels; electrical engine frames; diffusors, gears, impellers | | |
| **SUPEC<br>PPS Resin** | | | |
| **ULTEM<br>PEI Resin** | Hot combs, styling brushes, internal hairdryer parts; microwave oven parts; food preparation appliances; iron reservoirs | Disk drive cartridges, cooling fans; copier gears; sleeve bearings | Molded circuit boards, molded interconnect devices; telephone components |
| **VALOX<br>PBT Resin** | Various housings such as chainsaw - grinder - powertool housings; vacuum cleaners, irons, coffeemakers, oven grilles, mixers, deep fat fryers, toasters; handles and knobs; motor components | Components for business machines: fans, fan housings, frames, keys and keyboards; switches, connectors | Components for telephones |
| **XENOY<br>PC/PBT Resin** | Grinder and powertool housings, lawn mower decks, snowblowers, weed trimmers | | Wire and cable; fiber optic tubing |

# Application Matrix

| Audio/ Video | Electrical Engineering | Lighting | Food/ Medical |
|---|---|---|---|
| Satellite dish antennas; radio and TV housings; TV backplates | Enclosures, housings and covers; alarm systems; switches, plugs, connectors | Lamp housings, reflectors | Cosmetic parts: displays, perfume packaging; food packaging: handles, lids; knife handles; medical inhalators, dialyzers |
| TV housing components; DCC cassettes | Enclosures; battery housings, junction boxes; kWh meters; switches, plugs, sockets | Indoor and outdoor lighting parts; kitchen lamps; reflectors; emergency lights | Medical instrument housings |
|  |  |  | Mugs, bowls, cutlery handles, x-ray equipment shields |
|  | Enclosures | Exterior lamp housings |  |
| Optical data storage components: CD's, cartridges; video cameras and recorders; chassis for slide projectors; remote controls; LCD diffusors and reflectors | Motor housings, relay separators, connectors, fuse boxes, switches, plugs, sockets, circuit breakers, transformers | Housings, covers, reflectors and lenses for indoor and outdoor lighting; high intensity discharge lighting, spotlights; traffic lights | Medical instruments; gamma radiation and sterilisable parts; autoclave parts; healthcare parts; baby bottles, milk bottles, chocolate molds, tableware; food packaging containers and lids; cosmetic packaging: perfumes, shampoos |
| Satellite dish antennas; chassis for radio and TV; TV backplates, cabinets, deflection yokes, connectors, bobbins, capacitors; CD racks; video cameras | Amperemeter housings, conduits, connectors, ignition coils, bobbins, yokes, switches, plugs; components for junction boxes; temperature controllers; enclosures; wire coating | Reflectors; warning lamps; profiles | Housings for medical instruments, inhalators; food trays, tableware; potable water applications; hot-water contact parts |
| Guide rails, gears, precision parts | Motor housings; plugs, switches; thermostatic controls; profiles | Indoor lighting parts |  |
|  | Electrical connectors, motor brush holders, bulb sockets |  |  |
| Components for optical disks and video cameras. Fiber optic connectors. | Circuit breakers, connectors, plugs; insulation films; printed circuit boards; switches, controls; transformers; wire and cable coating (Siltem) | Reflectors and housings for indoor and outdoor lighting; dichroic reflectors; spotlights | Potable water applications; microwave oven trays and cookware; bread oven trays; medical and surgical instruments; steam pans; pharmaceutical parts. |
| Fronts for audio equipment; CD loaders | Rotors, connectors, sensors, sockets, plugs, coils; distributor caps, ignition bobbins, terminal blocks, switches, transformers, fuse boxes; housings and enclosures; cable channels, conduits; electric motors | Reflectors and housings for indoor and outdoor lighting; halogen lamps and spotlights; switches | Food conveyor trays; cheese molds; cosmetic products; toothpaste tubes and dispensors; food packaging lidding; tableware; medical instruments, X-ray equipment |
|  | Enclosures and housings; connector boxes | Housings for street lighting |  |

**Table 1-19.** (Continued)

| Products | Packaging | Environmental Engineering | Building and Construction |
|---|---|---|---|
| **CYCOLAC**<br>**ABS Resin** | | Heating, ventilation and air conditioning parts: fanheaters, covers, thermostat valves; plumbing parts: shower heads, tap knobs | Drain, waste and vent pipes; potable water pipes; pipe fittings |
| **CYCOLOY**<br>**PC/ABS Resin** | | Air conditioning components; electrical heaters, radiators | |
| **ENDURAN**<br>**PBT Resin** | | | Countertops, sinks, wall tiles, shower trays, tap and shower head components |
| **GELOY**<br>**ASA Resin** | | | Siding, windows, doors; railings, fencing, decking |
| **LEXAN**<br>**PC Resin** | Multilayer bottles for non-carbonated beverages: milk and fruit juice; water bottles; containers | Kitchen sinks; boilers; pump impellers; air conditioners; electrical heaters; filter housings | Street furniture; telephone and post office boxes; glazing; solar collectors, roofing systems; corrugated and multiwall sheet; profiles |
| **NORYL**<br>**Modified PPO Resin** | Foamed sheet packaging | Water handling parts: pump impellers, water filters and meters; flow regulators, housings, nozzle, pipes and tubing; submersible pumps; reservoirs | Solar collectors; door and window profiles; ceiling profiles; heat exchangers |
| **NORYL GTX**<br>**PPE/PA Resins** | | High pressure pumps, pump impellers; plumbing taps; thermostat valves; kitchen sinks | Furniture parts; window profiles |
| **SUPEC**<br>**PPS Resin** | | | |
| **ULTEM**<br>**PEI Resin** | | Heating, ventilation and air conditioning parts: water pumps; gasmeters; bearing cages; pump housings and impellers; filter bowls | |
| **VALOX**<br>**PBT Resin** | Foils and films; paper coating | Bathroom fixtures and taps; toilet seats, lavatory sinks; parts for heating, ventilation and air conditioning systems; pump housings and impellers | |
| **XENOY**<br>**PC PBT Resin** | | Water supply units | |

# Application Matrix

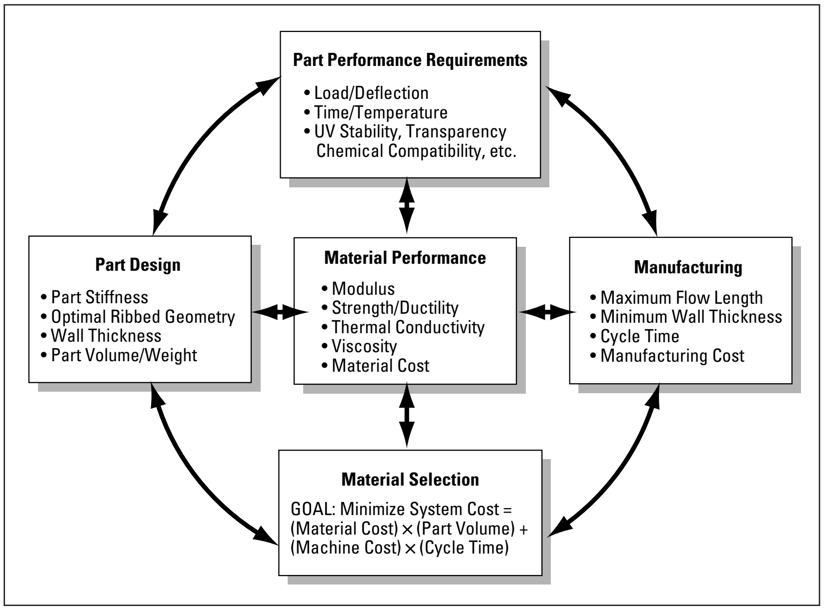
| Materials Handling | Mechanical Engineering | Sports and Leisure/ Safety | Other |
|---|---|---|---|
| Reels | Pipes, fittings | Caravan roofs; small boats; luggage, suitcases; toys; bicycle pumps and chainguards; ski top layers | Pens; clocks, watches; office supplies; tool boxes; chain guards |
|  |  |  | Clocks, watches; photo cameras |
|  |  |  |  |
|  |  | Trailers, spa, pools | Vending machines |
| Containers, boxes, pallets | Metal replacement parts; handles | Eyewear: sun glasses, ski goggles, spectacles, lenses, visors; safety helmets, safety toe caps, protection shields, glazing; hedge trimmers, chainsaws; toys | Clocks, watches; textile bobbins; keyholders; lighters; photo cameras; optical lenses |
| Container boxes | Fans, heaters; air nozzles | Fire extinguisher parts; small boats; garden furniture; luggage; goggles, visors; toys | Clocks, watches; lighters; battery boxes; photo cameras |
|  | Metal replacement parts; air conditioning parts; fans, heaters, gears, sensors; textile bobbins | Tennis rackets; ski-boot bindings | Welding masks; photo cameras; military connectors; gunstocks; grips |
|  |  |  | Down hole drilling components |
|  | Metal replacement parts; sleeve bearings, thrust washers; gears |  | Special connectors; clocks, watches; components for photo cameras |
|  | Motor brackets, chain components, transmission parts, sleeve bearings; textile bobbins; air pressure switches; gas meters; handles; hot air guns, glue guns; loudspeaker baskets | Roller skates; toys; casino chips; playing games | Pens, pencils; paintbrush bristles; clocks, watches |
| Tote bins | Power tools; robotic equipment; casters, rollers, chain links, conduit tubing, sensors; trolley components; industrial seeding parts | Roller, hockey, and ice skates; skiboot bindings; bicycle wheels; safety helmets; luggage |  |

# Material Selection

## Design-Based Material Selection

Design-based material selection involves meeting the part performance requirements with a minimum system cost while considering preliminary part design, material performance and manufacturing constraints (Table 1-20). Some performance requirements such as transparency, FDA approval or flammability rating are either met by the resin or not. Mechanical performance such as a deflection limit for a given load are more complicated requirements.

**Table 1-20.** Design-Based Material Selection Process.



Part design for stiffness involves meeting the deflection limit with optimal rib geometry and part thickness combined with the material stiffness. This part geometry can be used to compute the part volume that when multiplied by the material cost provides the first part of the system cost. The second half of the system cost is the injection molding machine cost multiplied by the cycle time. This total system cost is a rough estimate used to rank materials/designs that meet the part performance requirements. In addition, the manufacturing constraint of flow length for the part thickness must be considered. The entire process is summarized in Table 1-20.

### Plate Example

A simple example is presented to illustrate the design-based material selection process. A 10 × 10 in. (254 × 254 mm) simply supported plate is loaded at room temperature with a uniform pressure of 0.11 psi (760 Pa). The maximum allowable deflection is 0.125 in. (3.2 mm). Through iteration, it is determined that a polycarbonate plate with a thickness of 0.1 in. (2.5 mm) satisfies the requirements (Figure 1-7). From Figure 1-8, the flow length is 12.5 in. (320 mm). Thus, the plate could be filled with a center gate or from the center of an edge. From Figure 1-9, the in-mold cooling time is 10 seconds. The volume of the plate is 10 $\text{in.}^3$ (0.00016$\text{m}^3$).

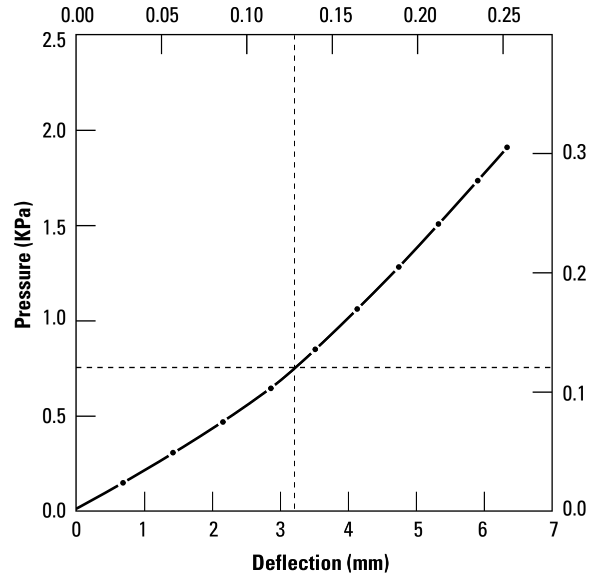


**Figure 1-7.** Nonlinear Pressure-Deflection Response. *10 x 10 in. (254 x 254 mm) Plate with a thickness of 0.1 in. (2.5 mm) and a material with a modulus of 340 ksi (2350 MPa).*

A second design can be produced by designing a rib-stiffened plate. Again, through iteration, a 0.060 in. (1.5 mm) thick plate with 10 ribs in each direction with a rib height of 0.18 in. (4.5 mm) and a rib thickness of 0.060 in. (1.5 mm) would meet the deflection requirement. From Figure 1-8, the flow length is about 7 in. (175 mm). Thus, since a center-gated plate would have a flow length of 7 in. (175 mm), the part would probably fill if the ribs would serve as flow leaders to aid the flow. However, it is generally not recommended to push an injection molding machine to its limits because this will exaggerate inconsistencies

**Figure 1-8.** Flow Length Versus Wall Thickness Predicted by Mold Filling Analysis.

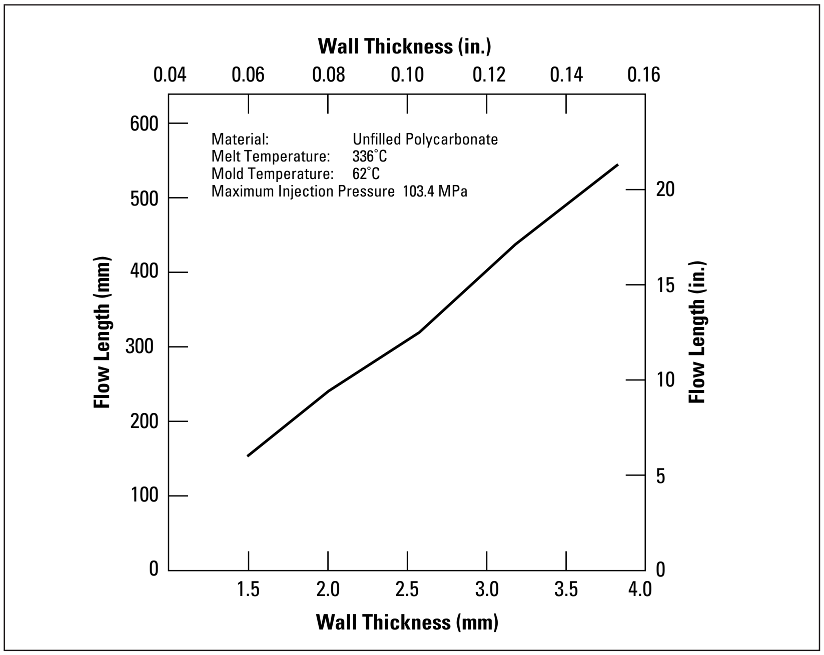
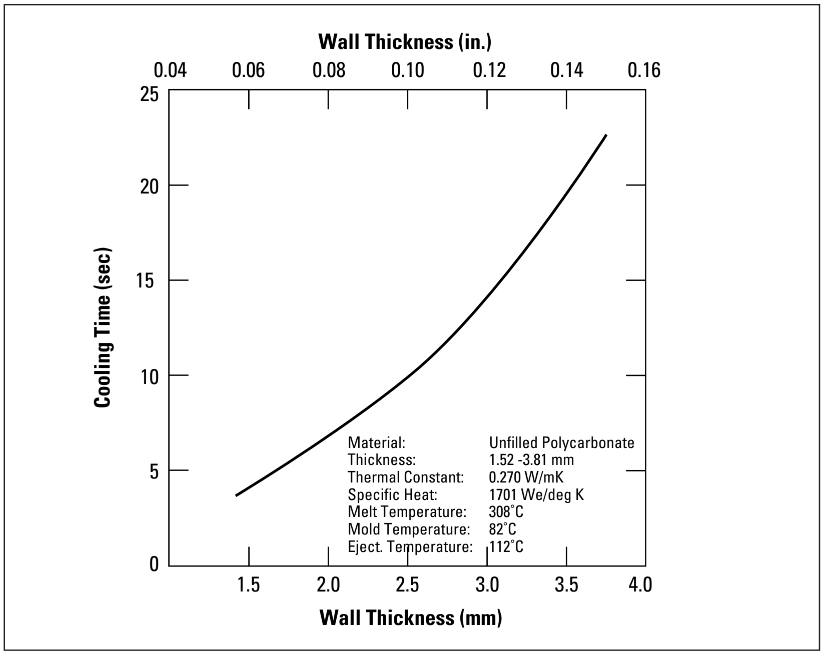


**Figure 1-9.** In-Mold Cooling Time Versus Wall Thickness Predicted from One-Dimensional Transient Mold Cooling Analysis.



in the material and the process. A more thorough three-dimensional process simulation should be performed to determine the viability of this design before it is chosen. From Figure 1-9, the in-mold cooling time is about 4 seconds, a considerable savings (6 seconds/part) in cycle time as compared to the plate with no ribs. In addition, the volume of the ribbed plate is 8 $in^3$ ($0.00013 m^3$), a saving of 20% on material as compared to the plate with no ribs. The system cost of the ribbed plate is computed to be 73% of the plate with no ribs. Since the ribs would produce a constrained, three-dimensional stress state, consideration of impact would be important for high rates of loading and low temperature (Figure 1-10). The fracture map shows a tendency for brittle behavior with polycarbonate resin at low temperature and high loading rates for notched or constrained geometries.

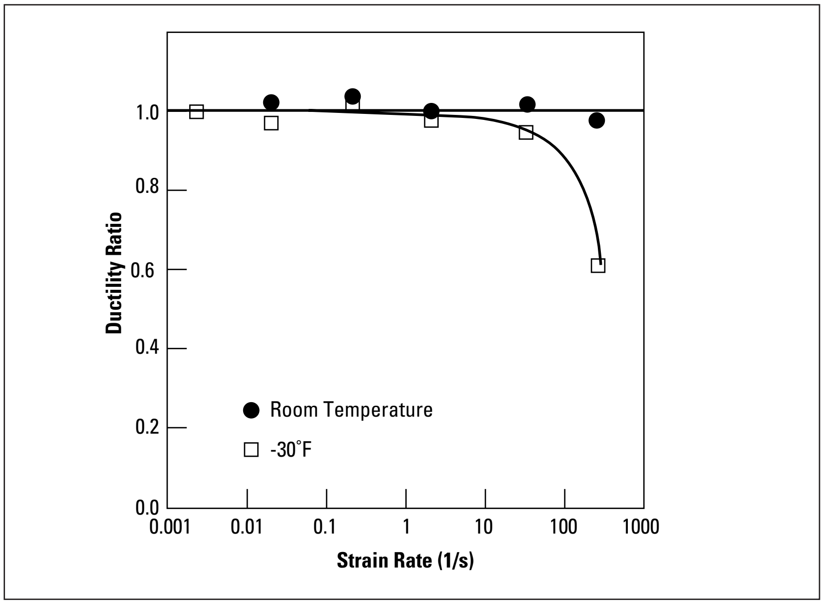
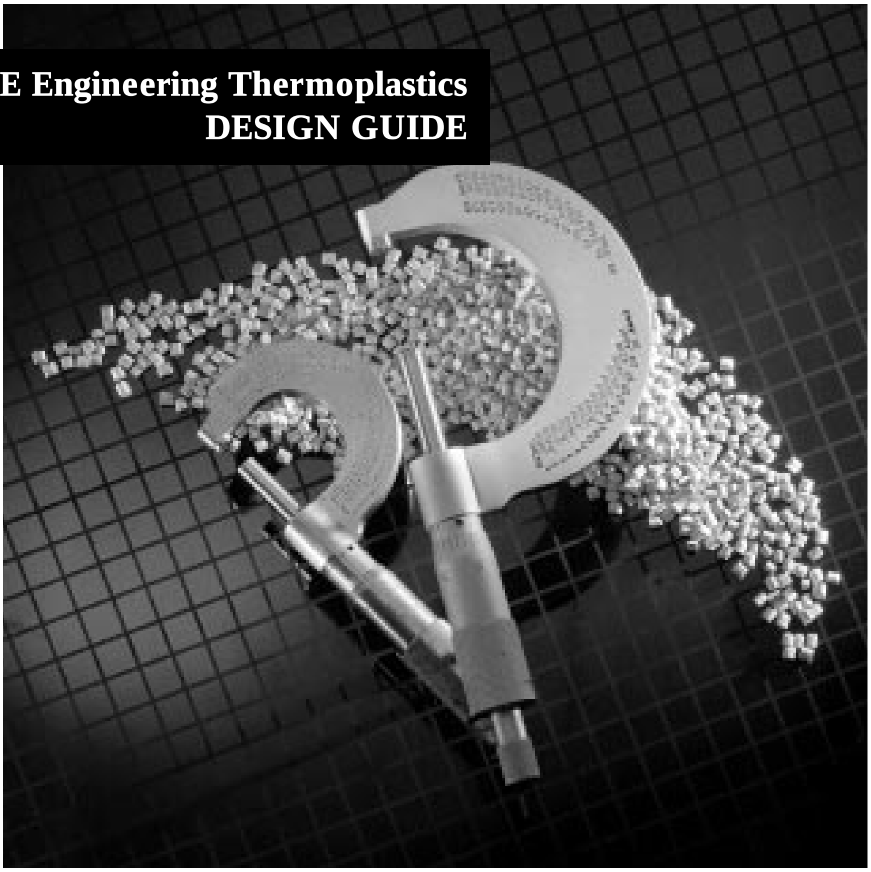


**Figure 1-10.** Fracture Map for Polycarbonate Resin.

If time/temperature performance were added to this example as a requirement, the optimum material may change or the initial design would need to be modified. If the same load were applied to the plate for 1000 hours at a temperature of 175˚F (79˚C), the polycarbonate resin plate would exhibit a deformation as if its material stiffness were about 40% of the room temperature modulus. Simply increasing the thickness of the plate with no ribs to 0.136 in. (3.5 mm) would provide a design that would meet the deflection requirements. The penalty would be a 40% increase in material usage and an additional 8 seconds added to the cycle time. Choosing a material with more temperature resistance or initial stiffness is an option.

**GE Plastics**

GE Engineering Thermoplastics
DESIGN GUIDE



# Thermoplastic Material
# Properties

# Thermoplastic Material Properties

Performance and productivity offered by thermoplastic parts continue to impact today's product designs. The versatility of plastic materials to function as electrical insulators, wear resistant surfaces, carry a variety of loads, survive abuse, or provide aesthetic surfaces and shapes makes multifunctional part designs commonplace. Because of the unique nature of thermoplastic behavior, the properties used to characterize a material's performance must be understood and given proper consideration in the product development process.

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# Physical Properties

## Specific Gravity

The specific gravity is the ratio of the density of a material to the density of water at standard conditions. The value is used in calculating part weight, converting part weight from one material to another, comparing cost of materials per unit volume, or simply determining material costs when quoting parts.

**To calculate material costs from price sheets providing $/lb.**

*Material cost*

(\$/in$^3$ = Price (\$/lb.) x SG x Density of Water

*Material cost*

(\$/in$^3$ = Price (\$/lb.) x SG x .0361 lb./in$^3$

## Moisture Absorption

Thermoplastic materials can absorb significant amounts of moisture from the environment whether it be from the atmosphere or from actual immersion in water (Figure 2-1). The moisture can affect the size of a part as well as mechanical and electrical properties. Absorption of moisture is a reversible process with moisture taken on when the part is dryer than its surrounding environment and losing moisture when the environment is dryer than the part. The rate and capacity for moisture absorption to occur with a material is measured by ASTM 570.

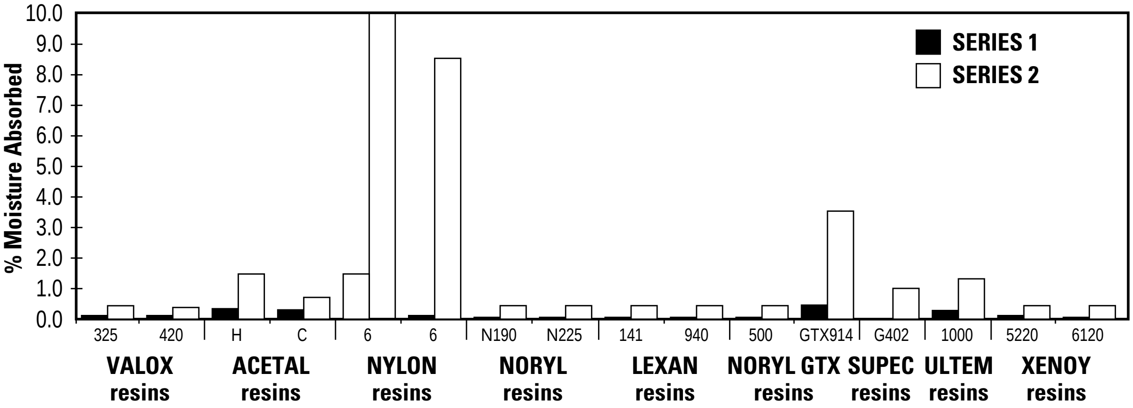


**Figure 2-1.**
Moisture Absorption ASTM 570.

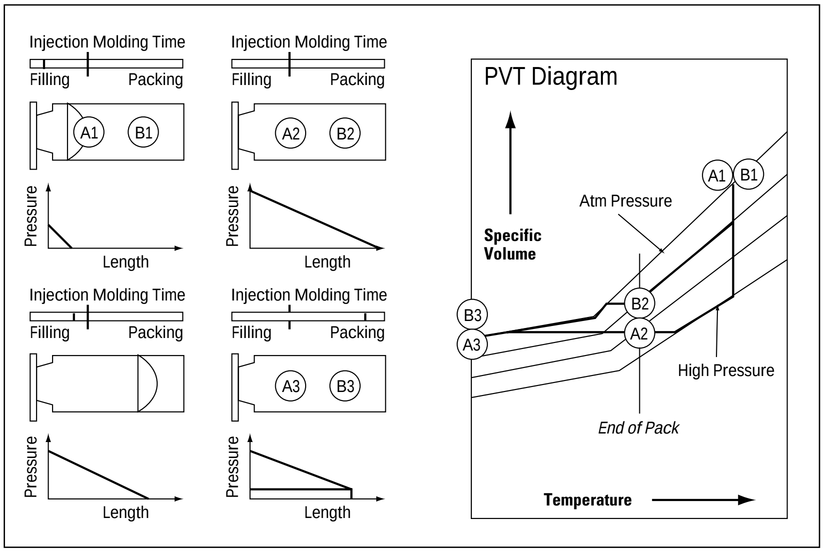
Moisture absorption is also a consideration when processing a material. Moisture in pellets produces volatiles and will degrade the polymer melt during the molding cycle. Plastics are frequently dried prior to molding and some care is taken to keep the material dry before going into a melt phase.

## Mold Shrinkage

A key factor in the development of an injection molded part is the prediction of the part shrinkage. The ability to better predict part shrinkage will save both time and money. Accurately predicting part shrinkage is important in tool design, particularly in applications requiring tight tolerances. Throughout the thermoplastic injection molding community, material shrinkage is currently characterized using the ASTM D955 test method. GE Plastics recognizes that shrinkage information provided by this standard can be inadequate for providing the detailed information required to cut precise mold dimensions. This led to the development of a GE Plastics' procedure for characterizing shrinkage. A description of this characterization method is given in the following sections.

### *Factors That Influence Shrinkage*

In order to more thoroughly understand material shrinkage, we must first understand how various factors influence part shrinkage. Shrinkage is the result of changes in pressures, temperatures and other parameters throughout the filling, packing and cooling phases of the injection cycle. Briefly, the melt starts to cool and shrink as soon as it leaves the nozzle. There is no other heat source applied to it, either electric or mechanical. Packing pressures are then applied to force more material into the cavity until the gate freezes, reducing part shrinkage. Solidified skins surround a molten core which cools at a much slower rate and may cause residual stresses in the part. Following part ejection, the part is allowed to cool and shrink without the mold restraining the part. Although there are a number of factors affecting shrinkage, Figures 2-2 through 2-5 address the most important variables.



**Shrinkage Factors**

- Material
  - *Reinforcements*
  - *Crystalline/ Amorphous*
- Rates
  - *Cooling*
- Temperature
  - *Mold*
  - *Melt*
- Pressures
  - *Packing*
  - *Injection*

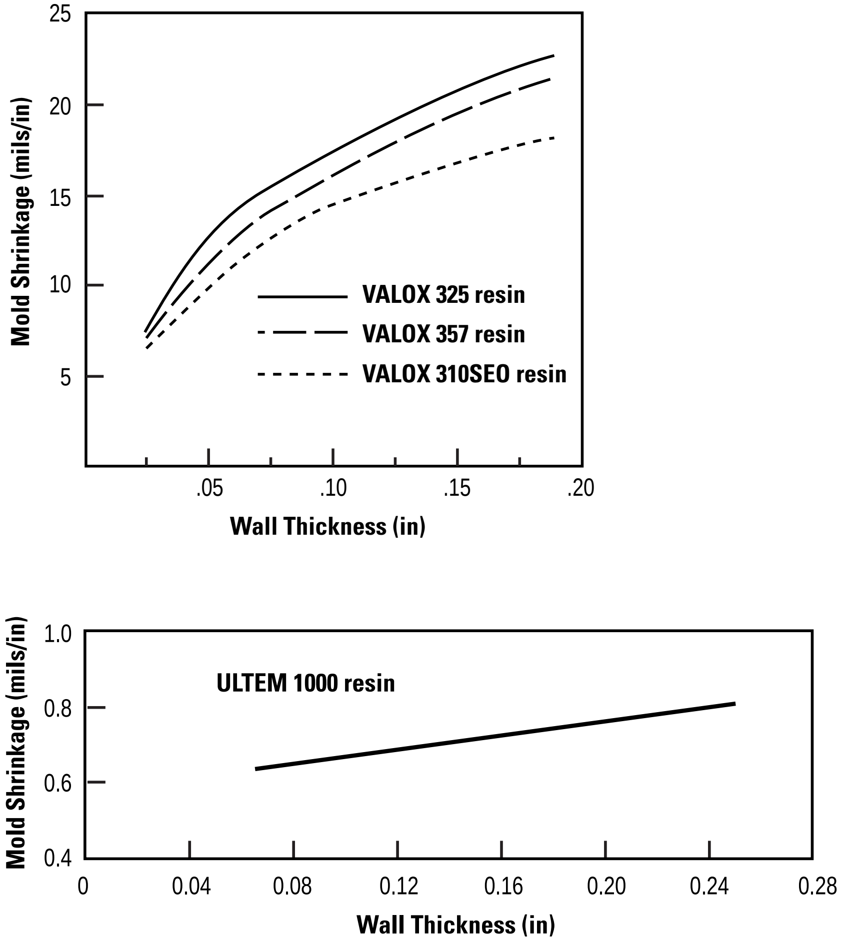
*ASTM D955 may not be suitable for tool shrinkage.*

**Figure 2-2.** A Pressure, Specific Volume, Temperature (PVT) estimate of shrinkage.

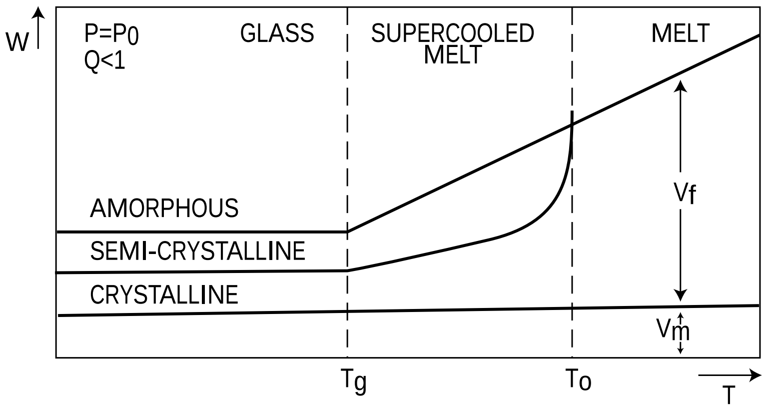
**PVT Estimate of Shrinkage**

$$\frac{\textit{vol. after pack} - \textit{vol. after ejection}}{\textit{vol. after pack}}$$

**Figure 2-3.** Effect of Wall Thickness on Shrinkage.



Shrinkage increases as the wall thickness increases (Figure 2-3). Because the material cools slower in thicker wall sections, greater shrinkage results. Differential shrinkage due to non-uniform wall thickness is a major cause of part warpage in unreinforced thermoplastics.



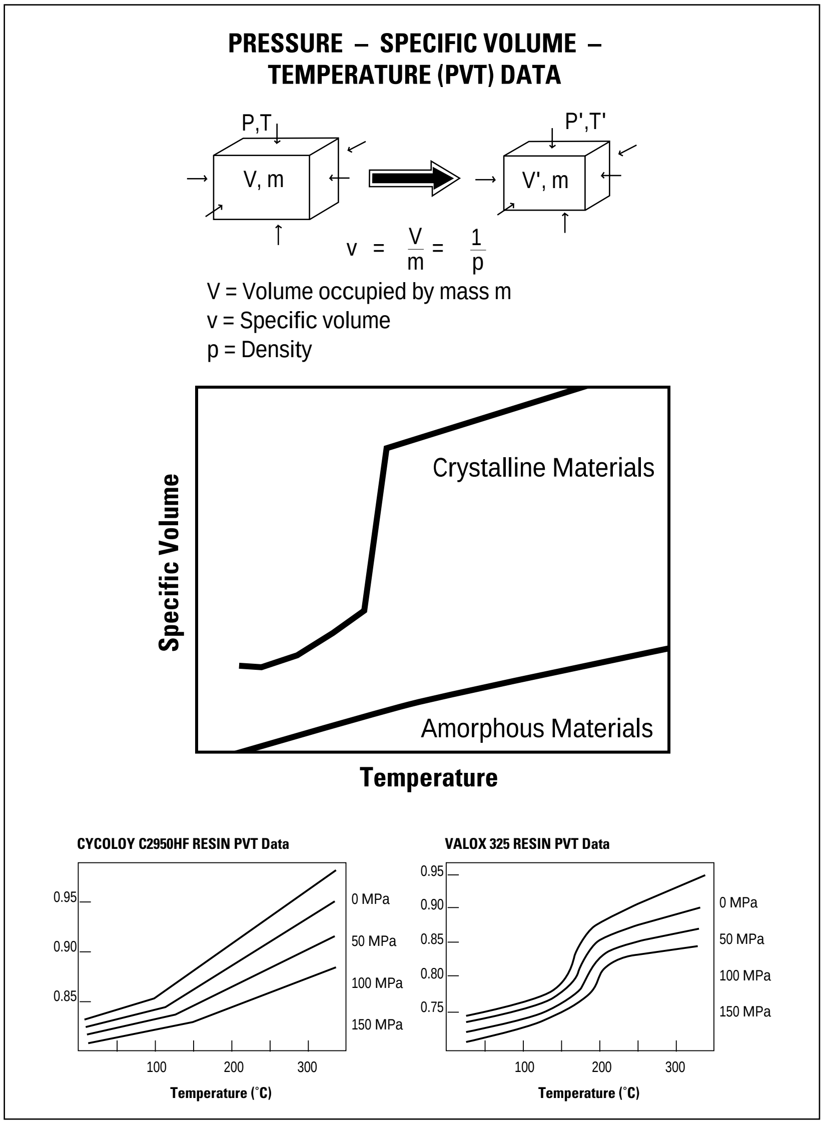


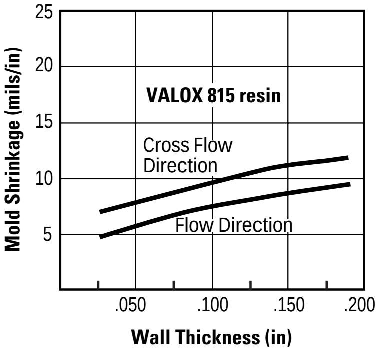
**Figure 2-4.** Specific Volume vs. Temperature.

## *Crystalline/Amorphous Materials*

Crystalline materials tend to have greater shrinkages versus amorphous materials due to the substantial decrease in specific volume as the melt cools to a solid.

Figure 2-4 illustrates this by showing the change in specific volume versus temperature change. Other factors include differences in molecular weights (affecting the melt viscosity), and fillers such as glass fiber and mineral, which reduce shrinkage in the flow direction. CYCOLOY C2950HF resin illustrates the change in specific volume versus temperature change for a typical amorphous material, while VALOX 325 resin illustrates the same characteristic for a crystalline material.

**Figure 2-5.** Mold Shrinkage vs. Wall Thickness.



### *Fiber Reinforcement*

When a thermoplastic is reinforced with glass or other slender fibers, the fibers become aligned in the direction of flow during the fill. When the melt cools, the fibers which are aligned in the direction of flow inhibit shrinkage in the direction of flow but not in the transverse direction, resulting in non-uniform shrinkage (Figure 2-5). Anisotropic shrinkage is a major cause of part warpage in reinforced thermoplastics.

### *Processing Conditions*

The variations of process parameters such as packing pressure, mold and melt temperature and injection speed can have a large effect on the shrinkage of the material. The ability to more accurately control these parameters is now available, but variations from machine to machine make it difficult to characterize the shrinkage of a material.

# Mechanical Properties

## Tensile Stress-Strain

The ability of a part to withstand an expected load is a key design consideration. An engineering analysis to determine the suitability of the design will use relationships which take into account the material's behavior and capability, the geometry of the part design and the application of loads and constraints. The information needed to describe the material response is generally obtained from the stress-strain curve. The test method describing the tensile loading is ASTM D638. To actually analyze a typical problem, a family of curves may be necessary with curves displayed at various temperatures and different strain rates.

### *Tensile Testing*

Typical stress-strain curves for LEXAN 141 resin are shown in Figure 2-6. A number of mechanical-related properties, such as proportional limit, ultimate strength, elongation, tensile modulus and fracture strength are obtained from the stress-strain curve.

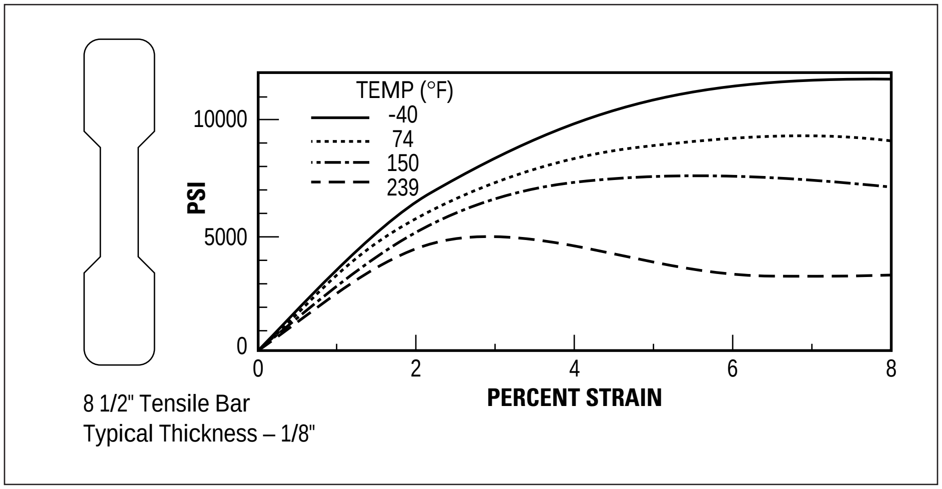


**Figure 2-6.** LEXAN 141 resin Tensile Stress Versus Percent Strain.

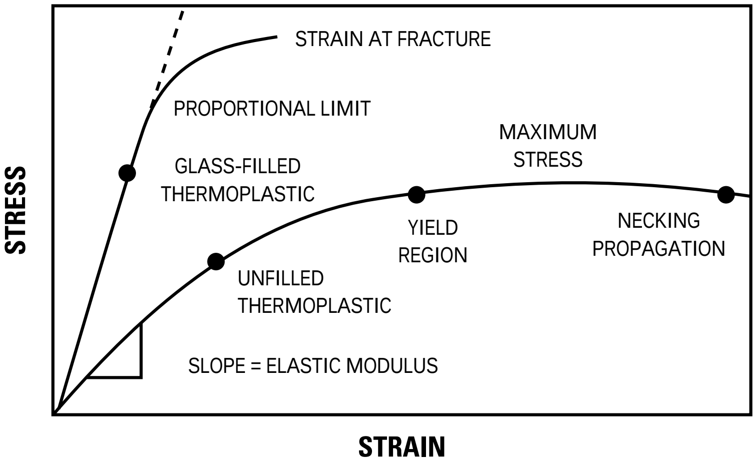


**Figure 2-7.** Tensile Stress vs. Strain.

**Proportional Limit**

The proportional limit of a material is the point at which the linear relationship between stress and strain no longer holds.
.

## Proportional Limit

Although the proportional limit is often thought to be the same thing as the yield point, the two terms are distinctly different. For thermoplastics the two values are not necessarily close. The viscoelastic nature of the material can push the yield point of the material well out into the nonlinear portion of the stress-strain curve (see the yield strength discussion on page 2-12). The stress-strain behavior of a plastic material normally is highly temperature and strain rate dependent. High temperature tests result in earlier nonlinear behavior between stress and strain and a lower proportional limit.

**Elastic Modulus**

The slope of the linear portion of the stress-strain curve.

## Elastic Modulus (Stiffness)

The elastic modulus refers to stiffness. Also known as Young's modulus, it is the slope of the linear portion of the stress-strain curve. Tensile, flexural, shear or compressive testing may be used to generate stress-strain curves and a modulus in the elastic region.

Design engineers tend to prefer the tensile test for design information including the elastic modulus. The elastic modulus of a plastic material depends on temperature and strain rate. The elastic modulus (symbolized by E) is basic for fundamental, linear engineering calculations. It is the constant of proportionality relating stress to strain. (Hooke's Law) There are limitations to the accuracy of these calculations due to a number of considerations including an assumption of small deflections.

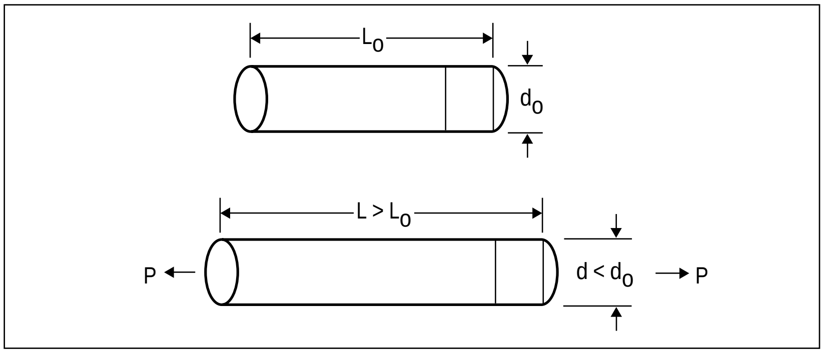


**Figure 2-8.** Poisson's Effect.

## *Poisson's Ratio*

Poisson's ratio is the ratio of lateral strain to longitudinal strain within the proportional limit of a material shown in Figure 2-8.

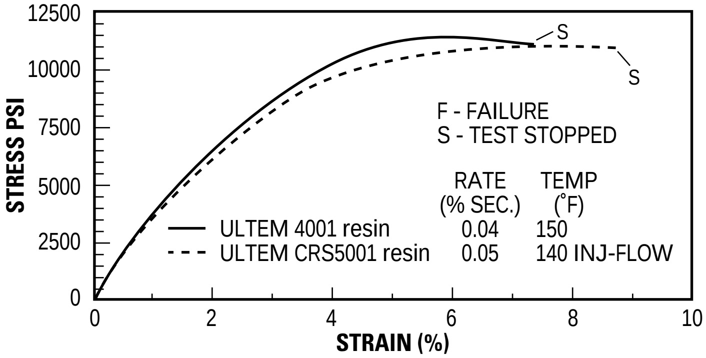
**Table 2-1.** Poisson's Ratio Values.

| MATERIAL | VALUE |
|---|---|
| CYCOLAC resin | .35 |
| CYCOLOY resin | .35 |
| GELOY resin | .40 |
| LEXAN resin | .38 |
| NORYL resin | .38 |
| ULTEM resin | .38 |
| VALOX resin | .40 |
| ALUMINUM | .33 |
| CARBON STEEL | .29 |

### *Yield Strength*

The classical definition of the yield strength of a material is the stress level which will cause a specified small amount of permanent deformation (standard is 0.2% strain) to be observed when unloaded. While this definition also applies to plastics, the yield point of thermoplastics is difficult to determine because of their visco-elastic behavior. The yield point for classical materials such as metals can easily be determined and tested by loading the sample to a point slightly beyond the proportional limit (linear portion of the stress-strain curve) and then unloading it and measuring the permanent set. When plastic materials are tested in a similar manner, what initially appears to be permanent deformation can slowly recover. The amount of recovery depends upon the temperature and rate at which the sample is tested. The yield point of a viscoelastic material is difficult to pick off a stress-strain curve (Figures 2-9 to 2-12). Instead, a hysteresis type test (load, unload, reload, etc. ) is done (with significant time delay) between each cycle. Unfortunately, complete testing is not practical. Thermoplastic yield points are typically estimated or shown as a yield range. The tests are run at several different temperatures and strain rates.

**Figure 2-9.** Tensile Stress vs. Percent Strain.



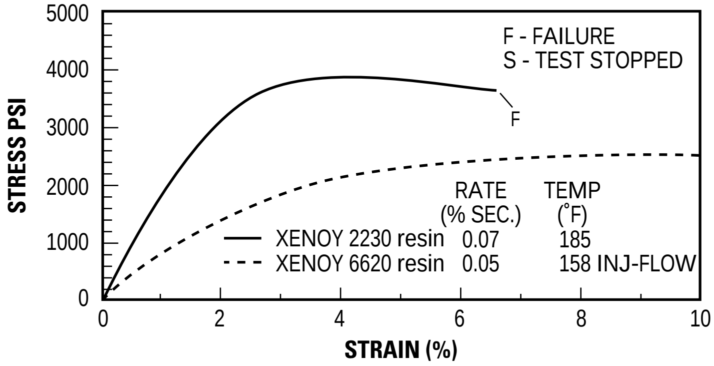


**Figure 2-10.** Tensile Stress vs. Percent Strain for XENOY resins.

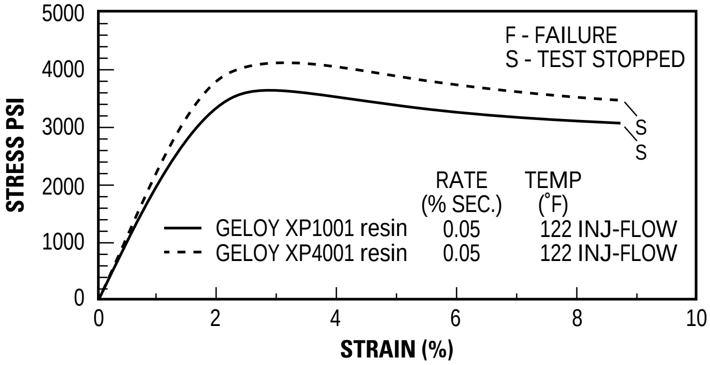


**Figure 2-11.** Tensile Stress vs. Percent Strain for GELOY resins.

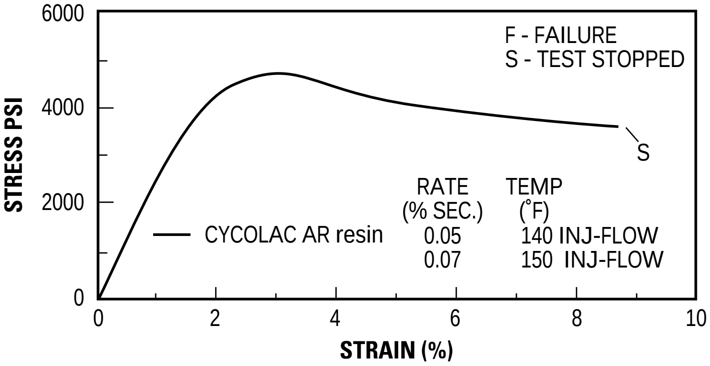


**Figure 2-12.** Tensile Stress vs. Percent Strain for CYCOLAC resin.

### *Ultimate Strength*

The ultimate strength (tensile, flexural, compressive, or shear) of a material is the maximum stress level in a sample prior to failure. The Ultimate Tensile Strength (UTS) of a material is the maximum load per unit area (original undeformed cross-section) the test specimen experiences during the test.

**Common Impact Tests**

- Tensile tests
- Dart impact tests (puncture tests)
- Notched Izod tests
- Compact tension tests

## Impact Tests

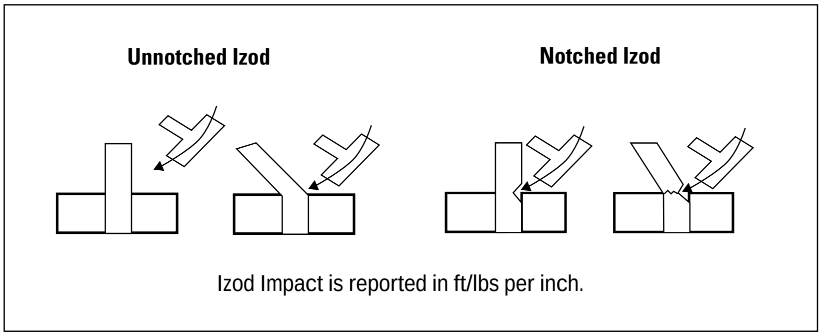
There are a number of impact tests used to provide insight into the impact response of plastics.

Tensile tests and compact tension tests can provide fundamental material data useful for engineering calculations. Dart impact tests and Notched Izod tests (Figure 2-13) do not provide fundamental material properties. They can provide general information on very different regimes of performance for plastics.

### *Izod and Charpy Tests*

Perhaps three of the most commonly used of these tests are the Izod and Charpy notched beam test (Figure 2-13) and the dart penetration test (Figure 2-14). It is important to note that none of these tests result in real, geometry-independent material data which can be used in engineering design. They are useful in applications, for quality control, and initial material comparisons, but even in this latter role different tests will often rank materials in a different order. As a result, proper test choice and interpretation requires that the engineer have a very clear understanding of the test and its relationship to his own particular design requirements.

**Figure 2-13.** Izod Impact Test.



Izod Impact is reported in ft/lbs per inch.

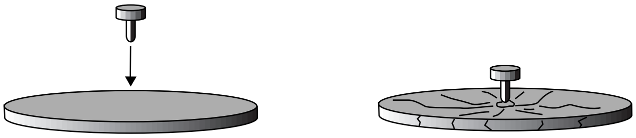
The Izod and Charpy tests are very similar in that they both use notched beam specimens subjected to dynamic bending loads. The notch creates a stress concentration and produces a constrained multiaxial state of tension at a small distance below the notch. These effects tend to make the test severe from the standpoint of early transition to brittle behavior as a function of both rate and temperature. These tests are defined by ASTM standards and the quantity which is generally reported from these tests is the energy required to break the bar divided by the net cross-sectional area at the notch. This energy is referred to as the impact strength and is measured in units of Joules/ meter-squared. It should be emphasized that these units are not those of stress. "Impact strength," as defined by these tests, is not a material property, and cannot be used in design.

The values of impact strength are significantly affected by the parameters defining the specimen geometry like notch tip radius and depth. Even identification of a transition temperature can be significantly affected by geometry such as the width of the beam. Wider beams tend to provide more plane-strain constraint and transition temperatures often appear more distinct and at higher temperatures than those occurring in thinner beams.

**Thick Specimen**

- More plane-strain
- Transition temperature more distinct, higher

Instrumented Impact vs. Gardner Impact Variations
of Falling Dart



Falling Dart tests measure the ability of a material
to resist breaking when struck on a surface

**Figure 2-14.** Typical Falling Dart Tests.

## *Dart Impact Test*

Another impact test which is often reported is the Dart Impact (or puncture) Test. This test is different from the Izod and Charpy Tests in a number of aspects. First, the stress state is two-dimensional in nature since the specimen is a plate rather than a beam. Second, the thin plate-like specimen does not contain any notches or other stress concentrations. Standard test requirements are reported in ASTM Procedure D3029. The quantity most often quoted with respect to this test is the energy required to fail the specimen. Of course, these energies are very different from the energies measured in a notched beam test. They also do not represent any fundamental material property. A transition in the mode of failure during dart tests is often observed as the rate of loading is increased or the temperature is decreased. However, this transition temperature is usually observed at much lower temperatures than the transition seen in the notched beam tests.

**Izod Falling Dart Tests**

- Not appropriate for engineering design
- Possible uses:
  - Quality Control
  - Marketing Comparison

**Failure Mode Transition**

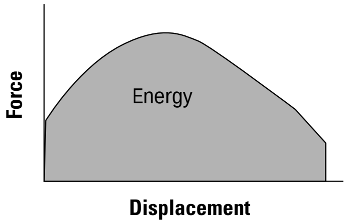
- Rate of Loading
- Temperature
- Transition Temperature (Izod) ≠ Transition Temperature (Dart)

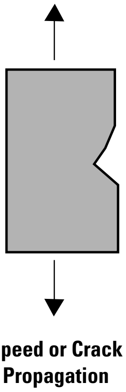
## *Instrumented Impact Test*

In modern, instrumented form of the dart puncture test, the head velocity and force are measured continuously and are output along with a computer calculated energy absorption curve.

For ductile polymers, the energy-to-failure measured in a falling dart test is a complicated function of the yield stress, draw-strain, post-yield modulus, and ultimate failure stress of the material, none of which can be fundamentally tested and measured.

The plane-strain fracture toughness of a material, in contrast to the measurements from the Izod and Charpy tests, is a material property which can be useful in design and pertinent for some impact problems. This property is measured by testing standard cracked specimens such as the compact tension specimen. Although there are standard test methods and specimen geometries defined for measuring the plane-strain fracture toughness of metals as part of ASTM procedure E-399, these standards have yet to be officially adapted for plastics.





## Fatigue Tests

Fatigue tests for plastics try to simulate conditions which lead to fatigue failure and characterize a material's response. Standardized tests exist for both flexural fatigue testing and for tensile fatigue testing. Normally, the tests will be run at a frequency which does not heat the specimen and at a set temperature. The specimen may be loaded with a strain-controlled configuration which could result in reduced stress if elongation or yielding occurs as the test nears completion. Testing under a constant repeated load results in a stress controlled test. The applied load is the same on the first loading cycle as on the last cycle.

**Fatigue Tests**

Simulate conditions which lead to fatigue failure and characterize a plastic material's response

Test results are shown on an SN curve, the stress level plotted against the cycle to failure (Figure 2-15). This curve gives the design engineer some idea of how well the material can withstand a cyclic loading. For a flexural test, normally the specimen is subject to a completely reversed load. The cyclic stress is the amplitude of applied stress. The mean stress is zero. The problem with this approach is the distribution of the stresses across the section is assumed regular and linear. A tensile fatigue stress test avoids this complication by loading the specimens uniformly and simply in tension. The load cycles from some low limit (10% of max. load) to the upper load limit. In this case the stress is tested around a mean stress and the cyclic stress is the difference between the mean stress and the maximum stress (Figure 2-16).

**Tensile Fatigue**

$$\sigma_{mean} = \frac{\sigma_{max.} + \sigma_{min.}}{2}$$

$$\sigma_{cyclic} = \frac{\sigma_{max.} + \sigma_{min.}}{2}$$

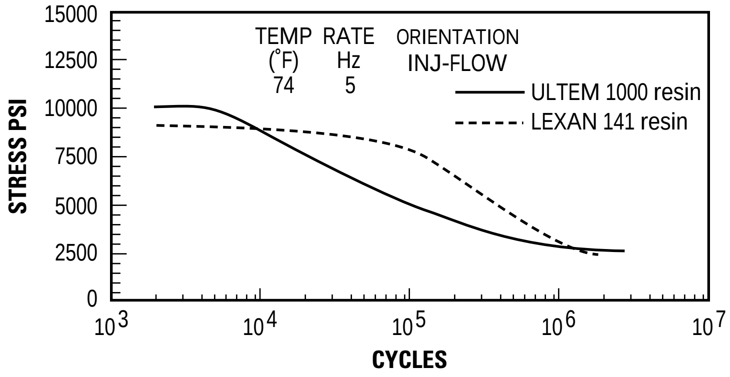
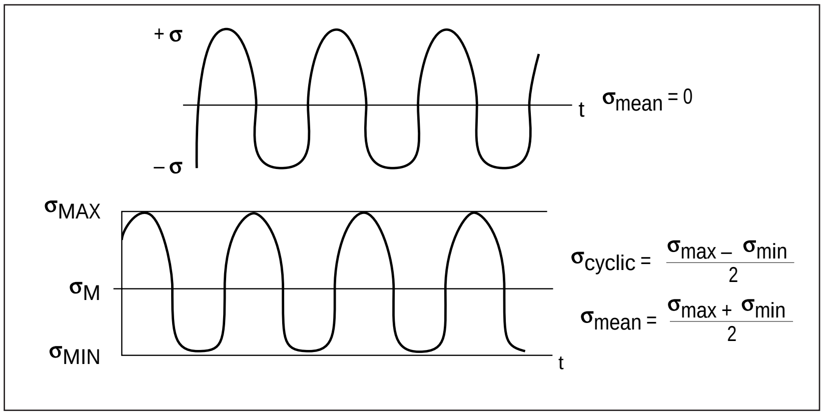


**Figure 2-15.** Fatigue Failure Stress vs. Cycles.

**Figure 2-16.** Mean Stress vs. Cyclic Stress.



### Fatigue Tests

The exact relationship between application conditions and fatigue testing is complex. The behavior of a part will depend on:

- Environmental conditions
- Load frequency
- Maximum load
- Mean load
- Wave form

## Shear Stresses

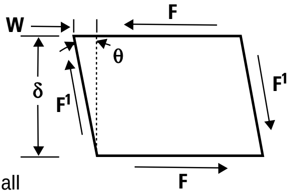
Shear stresses act tangentially to the surface distorting the angle between the faces and not the length of the face. Two pairs of shear stresses must always act together.

Shear stresses will be developed in flexural, compressive, or torsional loading (Figure 2-17). They may be a component of combined loading. When the mode of failure for a structure is yielding, shear stress or Von Misses stress become the criteria for failure.

**Figure 2-17.** Shear Stress and Shear Strain.

Shear stress may be defined as the tangential force divided by the area it acts on.

Shear strain is the angle which results from the application of the tangential force.



Shear strain = $\gamma$ = tan $\theta$ = w/$\delta$, when $\theta$ is small

The ASTM test for shear stress is D732. Values for shear strain are not commonly reported.

The modulus of elasticity in shear is also known as coefficient of rigidity. They are related to the Modulus of Elasticity as follows:

$$G = \frac{E}{2(1+\mu)}$$

Where G = Modulus of Elasticity in shear
E = Modulus of Elasticity
$\mu$ = Poisson's Ratio

## Tensile Creep Testing

Prior to each creep test, tensile stress-strain curves are generated at several temperatures to determine the linear elastic region (Figure 2-18). This information, accurately measured using an extensometer, is used to determine the appropriate stress levels to perform the creep testing for each material.

**Tensile Creep**

The additional strain that occurs over time when a constant load is applied.

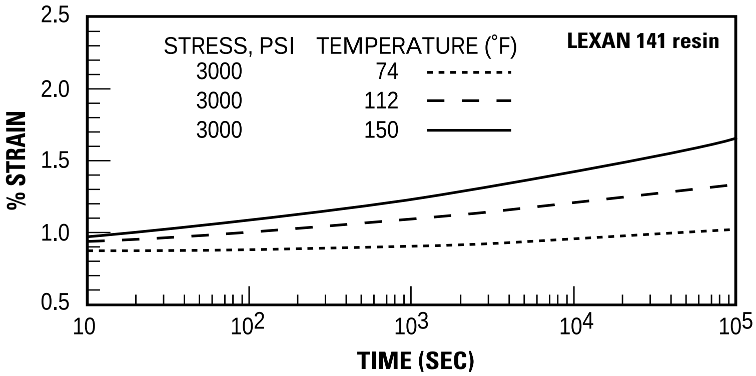


**Figure 2-18.** Creep Time versus Strain Data.

Also, these tests are used to scale the final time-strain data to the correct initial true strain. The creep testing equipment consists of static load creep stations, each having a monitored temperature control system. The extension, which is the increase in length within the gage length, is measured using a Linear Voltage Differential Transducer (LVDT). Displacement is measured directly on the specimen rather than by grip separation.

Following ASTM standards, two tests are performed at each condition for verification purposes.

## Translate Creep Data

CREEP data is used when designing for creep deformation. Since load bearing applications are designed for stiffness and strength, time-strain data is not directly useful. This section describes the steps that were taken to translate the initial short term time-strain data into an isochronous stress-strain curve for any time or temperature.

Several methods for extrapolating time-strain data were evaluated with the objective of obtaining the most accurate fit to the actual data while giving reasonable extrapolation predictions. Based upon simplicity and visual inspection, it was determined that a quadratic function of log time gave the best fit. CREEP data can be used to examine the time-strain data and the adequacy of the fit of the quadratic function. Engineering judgment must be used concerning the appropriate extent of the extrapolation in time. Caution should be exercised when more than an order of magnitude of time extrapolation is used.

Based on fundamental principles for thermally activated processes, use of the Arrhenius relation was chosen to interpolate to different temperatures. Plotting the natural log of the percent strain versus the reciprocal of the absolute temperature, for constant time and stress graph, resulted in a linear interpolation based on the Arrhenius relation (Figures 2-19 through 2-21).

This procedure has yielded a good fit for the amorphous polymers tested. For a semi-crystalline material, such as PBT, this approach needed to be modified when the material was tested

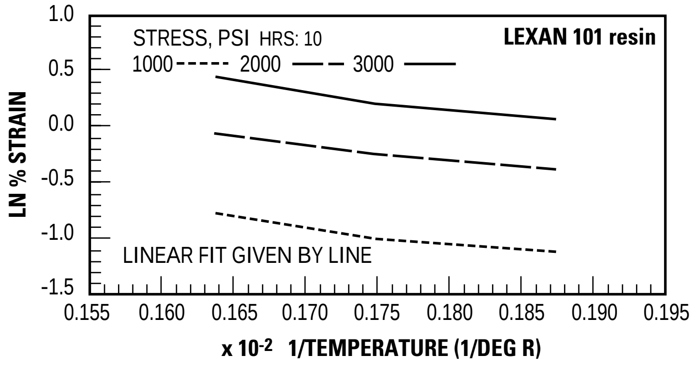


**Figure 2-19.** Arrhenius Temperature Interpolation.

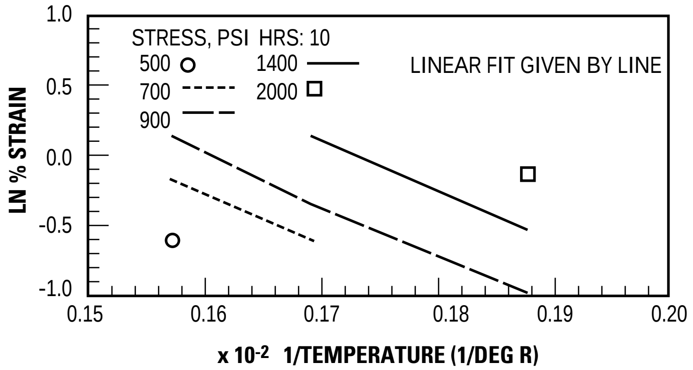


**Figure 2-20.** Arrhenius Temperature Interpolation.

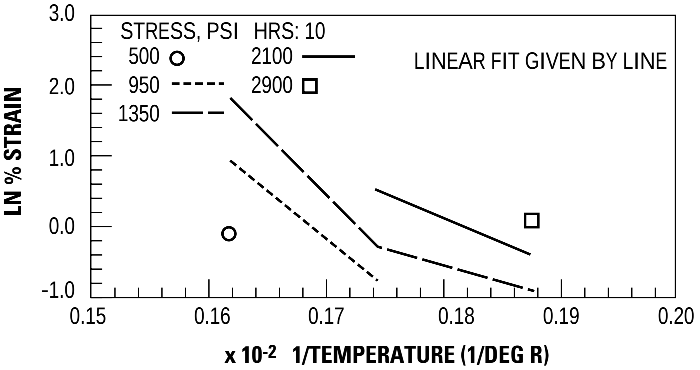


**Figure 2-21.** Arrhenius Temperature Interpolation.

above its glass transition temperature (Tg). The temperature interpolation required, at minimum, two tests above and below Tg. Then, the Arrhenius relation was used above and below Tg with different slopes. Finally, the isochronous stress-strain curve was produced by choosing the appropriate temperature and plotting the stress-strain points taken from the Arrhenius plots at the chosen temperature and time.

## Creep Analysis

For constant stress applications, the isochronous stress-strain curve can be used with traditional hand calculations by choosing the appropriate "effective modulus," considering the range of stresses in the application (Figure 2-22). This requires engineering judgment where higher stressed parts would typically be analyzed with a lower effective modulus.

For parts loaded to a constant strain, stress relaxation will result. Over time, the magnitude of stress will diminish while maintaining the same strain. This can be predicted using an isochronous stress-strain curve showing a number of time periods on the same curve (Figure 2-23). Simply move vertically down (constant strain) from one time curve to the desired time curve. The reduction in stress is the stress relaxation. When the isochronous stress-strain curve is highly nonlinear or the geometry is complex, finite element structural analysis techniques can be used. Then either the complete, nonlinear isochronous stress-strain curve can be used in a nonlinear finite element analysis or a linear effective modulus can be used in a linear analysis (Figure 2-24 through 2-26).

**Figure 2-22.** Isochronous Stress-Strain Curves.

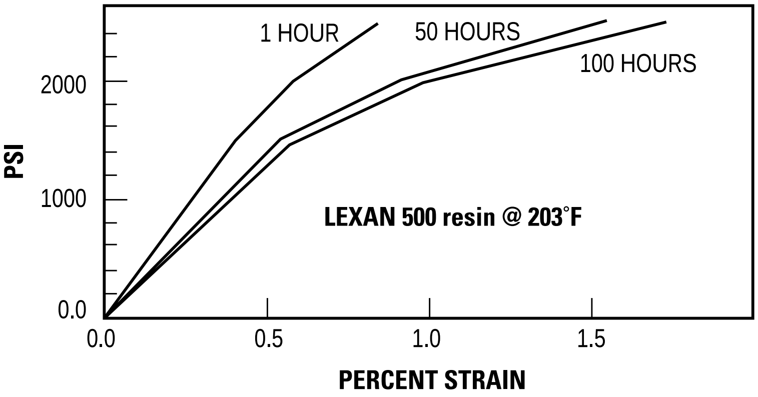
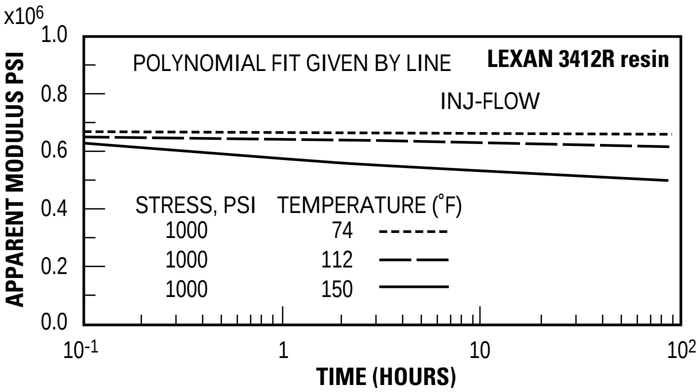


**Figure 2-23.** Apparent Modulus versus Time.



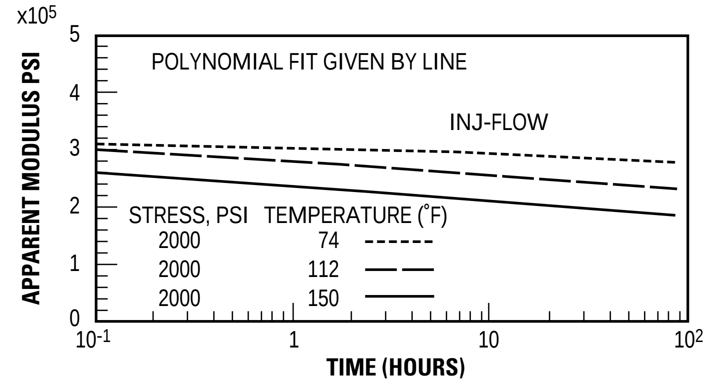


**Figure 2-24.** Apparent Modulus vs. Time for LEXAN 101 resin.

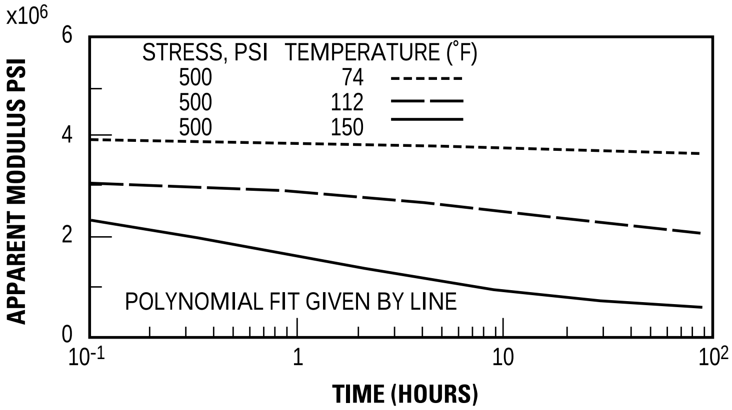


**Figure 2-25.** Apparent Modulus vs. Time for NORYL N190X resin.

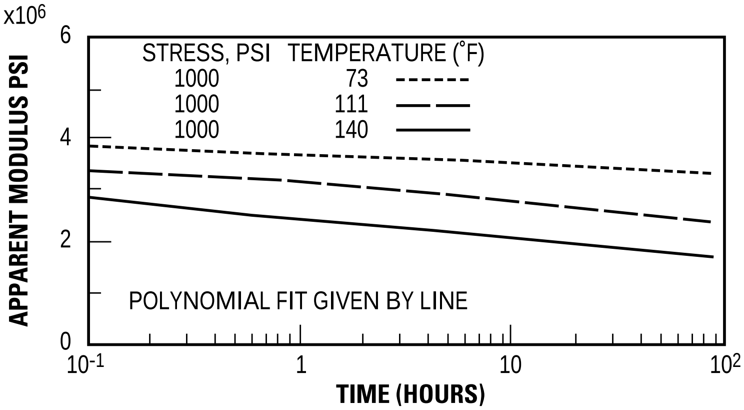


**Figure 2-26.** Apparent Modulus vs. Time for NORYL SE1X resin.

# Environmental Properties

**Plastic materials commonly react with media in either of two ways:**

- **The plastic may plasticize:** Material softens, weight increases, tensile strength decreases.
  - Possible yielding
- **The plastic may craze:** Elongation decreases crystallization.
  - Possible fracture

## Chemical Resistance

Chemical resistance of thermoplastics is dependent on the following criteria: time, temperature, type of contact, molded-in stress and any external stress to which the part is subject in a given application. Chemical exposure ordinarily results in a softening effect, or cracking and crazing of the thermoplastic. As softening occurs, the percent weight increases while tensile strength decreases. As cracking and/or crazing occurs, the percent elongation decreases.

Amorphous polymers tend to be highly viscous and more susceptible to chemical attack than crystalline polymers, which typically are low viscosity and easier-flowing materials. Parts molded of crystalline resins will typically be lower stressed and highly chemical resistant.

The final decision on chemical compatibility is, of course, the end-user’s.

**Table 2-2.**

**The severity of the exposure and the reaction by the plastic is dependent on the following criteria:**

**Time –** is the exposure brief as when the part is wiped or is the contact longer term as a fluid container or an immersed part would be.

**Temperature –** parts exposed at elevated temperature are more likely to be affected as the chemical reaction is accelerated.

**Stress level –** the stress level may be from an applied load or from stresses trapped during the molding process. Stressed parts are more prone to failure.

**Table 2-3**. Chemical Resistance of GE Plastics Engineering Thermoplastic Material.

| Chemicals | Amorphous Polymers | | | | | Semi-Crystalline Polymers | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **LEXAN resin** | **CYCOLOY resin** | **CYCOLAC resin** | **NORYL resin** | **ULTEM resin** | **XENOY resin** | **VALOX resin** | **NORYL GTX resin** | **SUPEC resin** |
| **Hydrocarbons** | | | | | | | | | |
| aliphatic | –/• | • | + | •/– | + | • | + | + | ++ |
| aromatic | – | – | – | – | ++ | –/• | + | + | |
| halogenated | | | | | | | | | |
| fully | • | • | – | – | + | – | –/• | + | • |
| partly | – | – | – | – | – | – | – | • | •/+ |
| **Alcohols** | + | n | + | + | + | + | + | + | ++ |
| **Phenols** | – | – | – | – | – | n | – | – | + |
| **Ketones** | – | – | – | – | – | – | •/+ | • | + |
| **Amines** | n | – | –/• | –/• | n | n | n | – | •/+ |
| **Esters** | –/• | – | • | + | •/+ | – | •/+ | + | ++ |
| **Ethers** | – | – | • | • | + | n | + | + | + |
| **Acids** | | | | | | | | | |
| inorganic | –/• | • | + | • | •/+ | •/+ | + | • | •/+ |
| organic | • | • | – | • | •/+ | •/+ | • | • | + |
| oxidizing | – | – | – | • | • | •/+ | – | • | • |
| **Alkalis** | – | • | + | + | – | – | – | + | + |
| **Automotive fluids** | | | | | | | | | |
| Greases (non-reactive organic esters) | n | + | + | •/+ | + | + | ++ | + | ++ |
| Oils (unsaturated aliphatic mixtures) | n | •/– | •/+ | •/+ | + | ++ | ++ | + | ++ |
| Waxes (heavy oils) | n | + | + | •/+ | + | + | ++ | + | ++ |
| Petrol | – | – | – | – | + | ++ | ++ | + | ++ |
| Cooling liquid (glycol) | n | • | • | + | + | ++ | ++ | + | ++ |
| Brake fluid (heavy alcohol) | n | – | – | + | – | ++ | + | + | ++ |
| Detergents, Cleaners | n | •/+ | •/+ | •/+ | + | + | + | ++ | ++ |
| **Water** | | | | | | | | | |
| hot (< 176°F [80°C]) | –/• | •/+ | –/• | ++ | –/• | • | – | – | •/+ |
| **Environmental** | | | | | | | | | |
| **UV** | •/+ | •/+ | •/+ | • | + | •/+ | + | –/• | – |

| | | |
|---|---|---|
| ++ | very good | :found unaffected in its performance with regard to time, temperature and stress<br>– according to agency requirements |
| + | good | :found acceptable in normal exposure<br>– long term exposure may result in minor loss of properties<br>– higher temperatures may result in major loss of properties |
| • | fair | :found marginal<br>– only for short exposures at lower temperatures or when loss of mechanical properties is not critical |
| – | poor | :found unacceptable<br>– will result in failure or severe degradation |
| n | | not tested |

***Ratings as shown are based on controlled tests and are purely indicative. Finished part performance must always be evaluated on the actual part in the end-use environment.***

## Heat Deflection Temperature (HDT)

*(Sometimes referred to as Heat Distortion Temperature)*

The temperature at which a simply supported beam under a flexural load of 264 psi (1.82 MPa) deflects 10 additional mils from its room temperature position.

## Short Term Considerations

Thermoplastics are viscoelastic materials in nature and thus are affected by strain rate and temperature. As noted in sections dealing with Strength and Stiffness, temperature plays a significant role in the material's response to a load. As the temperature increases, the tensile strength and modulus go down.

One property which addresses the loss of modulus at elevated temperature is the Deflection Temperature Under Load (DTUL) described in ASTM D-648. The test reports the temperature at which a flexed standard bar deflects 0.010 in. (0.25 mm) additionally to the room temperature deflection (Figure 2-27). The amount of additional deflection is not tied to application requirements and occurs in a relatively short period of time. The test is most useful for comparing materials, developing material formulation and possibly for quality control.

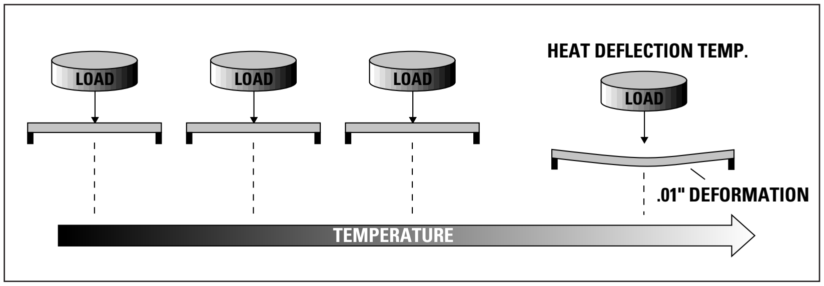


**Figure 2-27.** Heat Deflection Temperature.

## Vicat Softening Temperature

The temperature (Figure 2-28) at which a flat ended needle of 1 sq mm. cross section penetrates a thermoplastic specimen 0.04 in. (1 mm) under a specified load using a constant rate of temperature rise.

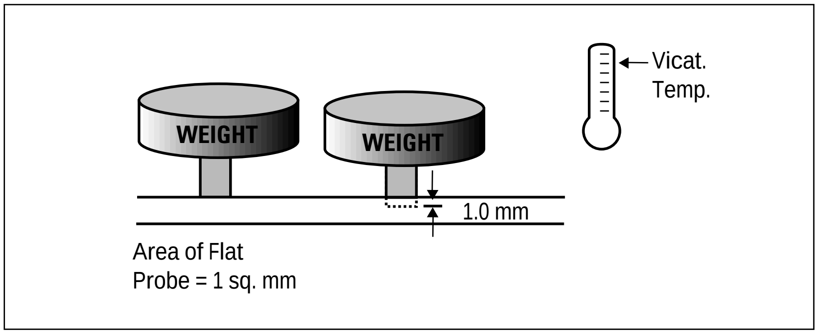


**Figure 2-28.** Vicat Softening Temperature.

## Ball Pressure Temperature

The temperature at which a disc specimen held with a horizontal ring is deflected down 1 in. (2.54 mm) under the weight of a steel ball as the sample is heated at a prescribed rate in water or glycerine bath.

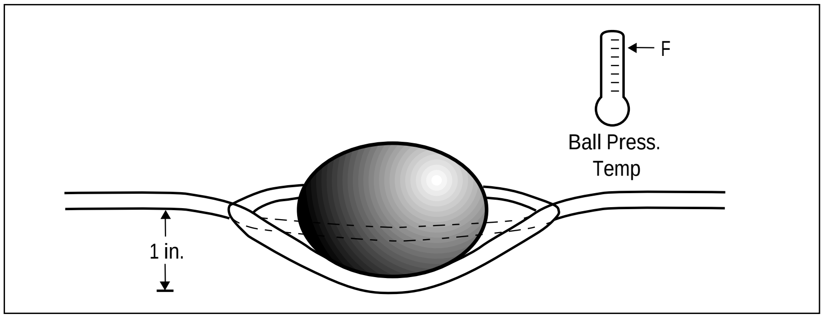


**Figure 2-29.** Ball Pressure Temperature.

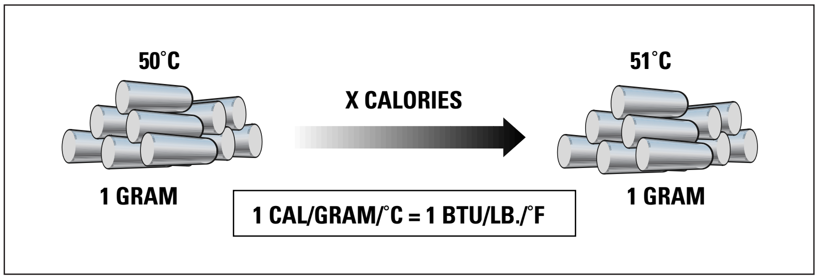
## Coefficient of Thermal Expansion (CTE)

Please refer to the Thermal Expansion Area which is found under the topic Dimensional Properties on page 2-38.

## Specific Heat Capacity

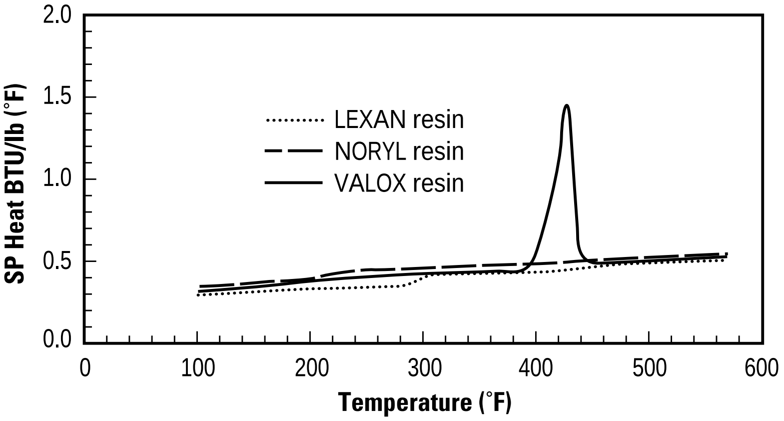
Specific heat capacity is a material characteristic which is defined as the amount of heat required to raise the temperature of one gram of material 34˚F (1˚C). This property is typically reported graphically with Cp described as a function of temperature.

**Figure 2-30.** Specific Heat Capacity. *Specific heat capacity is the energy required to heat one gram of material one degree centigrade.*



These plots can be used to define melting, crystallization, and glass transition temperatures, as well as the amount of heat required to melt a known amount of material. This information is also required to perform a computer-aided mold-filling analysis. Primarily, this information is more useful for processing related analysis than for strictly design engineering tasks.

**Figure 2-31.** Specific Heat vs Temperature.



## Calculating Heat Requirement

The vertical axis represents the specific heat capacity in either cals/gram/˚C or BTUs/lb/˚F. The horizontal axis represents the temperature of the polymer. The area under the trace represents the amount of heat energy being absorbed by the polymer. By calculating the area under the trace from the material's drying temperature to its processing temperature, the total amount of heat energy required for processing can be determined.

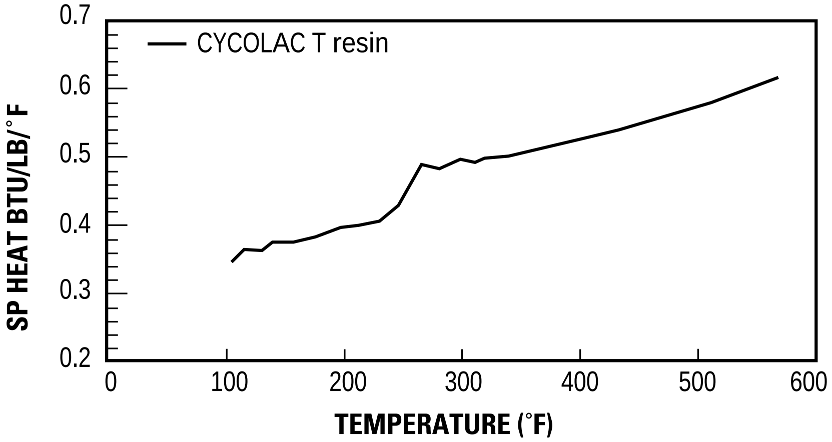


**Figure 2-32.** Calculating the Heat Requirement.

## Relative Thermal Index/Thermal Aging

Thermal Aging in terms of long exposure (months, years) in air and at elevated temperatures will result in a significant loss in properties tending to make the material more brittle. The change is brought on by oxygen and ozone in the atmosphere attacking the plastic molecules. The aging process is irreversible and the effect is cumulative.

# Thermoplastic Material Properties

**UL Relative Thermal Index**

The highest constant temperature at which a material will survive relative to the application requirements.

## UL Relative Thermal Index

The UL Relative Thermal Index is an indication of the thermal stability of a polymer.

Underwriters' Laboratories addresses this phenomenon with the UL Temperature Index. There are three indices as aging affects different properties to a different degree. The index and the associated property are shown below.

| Index | Property |
|---|---|
| Mechanical | Tensile strength |
| Mechanical with impact | Tensile impact |
| Electrical | Dielectric strength |

UL defines the end of service life as the aging time required to produce a 50% drop in the property compared with the initial value. By aging at elevated temperatures, the testing is considerably accelerated. The end of life data points are plotted on an Arrhenius Graph of the reciprocal of the absolute aging temperature versus the time to failure. Extrapolating the curve out to an arbitrary time to failure (normally about 40000 hr.), a temperature index is obtained.

The three different properties age at different rates so an index is obtained on each. Also, the thickness of the test specimen will affect the rate of aging. Normally, thick specimens will age slower than thin ones. The specimen thickness is also noted in the results table.

The temperature indices are used by UL as a guideline when they compare hot spots on devices and appliances they regulate. The indices are not automatically applied to many devices as much history and experience is considered in the engineer's judgment.

## Thermal Conductivity

When a temperature gradient exists in a body, energy is transferred from the high temperature region to the low temperature region. The rate at which this transfer takes place is proportional to the temperature gradient, the surface area normal to the direction of flow, and a material specific proportionality constant. This constant is referred to as the thermal conductivity of the material. Table 2-4 below lists the thermal conductivity of several materials.

**Table 2-4.** Thermal Conductivity of Various Materials.

| Material | Thermal Conductivity k BTU-in/hr-ft²-°F) |
|---|---|
| ULTEM 1000 resin | |
| 120°F (49°C) | 1.440 |
| 300°F (149°C) | 1.680 |
| ULTEM 2300 resin | |
| 120°F (49°C) | 1.800 |
| 300°F (149°C) | 2.004 |
| Copper | 2780.000 |
| Aluminum | 1560.000 |
| Brass | 730.000 |
| Steel | 320.000 |
| Titanium | 110.000 |
| Concrete | 13.000 |
| Glass | 7.000 |
| Water | |
| 32°F (0°C) | 4.116 |
| 140°F (60°C) | 4.524 |
| Nylon | 1.80 |
| LEXAN Polycarbonate resin | 1.32-1.56 |
| CYCOLAC GSM resin | 1.224 |
| CYCOLAC L resin | 1.224 |
| Polystyrene | 1.08 |
| Rubber (soft) | 0.96 |
| Polypropylene | 0.84-1.32 |
| Polystyrene, expanded (“Styrofoam”) | 0.252 |
| Air | |
| 32°F (0°C) | 0.168 |
| 200°F (93°C) | 0.217 |
| Steam | |
| 200°F (93°C) | 0.1583-1 |

As the table shows, thermoplastics should be considered insulators, relative to most common metals. This means that a part made from a thermoplastic resin will either resist a temperature increase for a much longer period of time or require much longer to dissipate heat than a part made from metal.

## UV Exposure

Ultraviolet radiation should be considered an element of the environment which may affect the long term performance and/or appearance of a plastic part. When evaluating an application involving ultraviolet exposure, key considerations are:

- the source, type and intensity of the ultraviolet radiation.
- the expected exposure time during the life of the product.
- the acceptable retention level of properties likely to be affected.

Ultraviolet radiation sufficient to be a factor can be encountered in either indoor or outdoor environments. The severity of the exposure which may affect the rate of change of properties or appearances is dependent on a couple of factors.

**Table 2-5.** Sources of UV Exposure.

| | **Source** | **Intensity** |
|---|---|---|
| Outdoor<br>reflected sunlight | Direct sunlight | – Geographical location<br>– Time of year<br>– Incident angle<br>– Water spray |
| Indoor | Sunlight through window<br>Fluorescent lights | <br>– Distance from the light |
| Industry tests:<br>Outdoor test stands | | – can be located anywhere<br>– Arizona exposure standard<br>– Arizona exposure with water spray & tracking used to accelerate test<br>– Florida test a standard |

Design options to protect plastic parts and extend product life:

- Use UV stabilized plastic grades*. Some grades are offered with a UV stabilization additive compounded into the product. These will tend to slow the loss of properties.
- Some pigments will slow the loss of properties. Black typically provides the most UV protection of a range of colors.
- A co-extruded skin which exhibits very good UV resistance can provide a stable system. Outdoor building and construction applications use this technology.
- Paint can provide a protective layer to UV radiation. While this does require a secondary operation, matching colors, as in the case of automotive exteriors, or color variation, as in the use of roofing tiles, are possible through painting.

**Samples are Tested for:**

- Color shift
- Gloss loss
- Impact retention
- Tensile strength retention

## Hydrolytic Stability

Exposure to hot water (140˚F [60˚C] and above) for prolonged time periods may hydrolyze a polymer resulting in a loss of properties. Typically, the first properties affected are the elongation and impact strength. As exposure continues, the polymer will embrittle and eventually the tensile strength will begin to drop.

The damage to the plastic is irreversible which makes the exposure times cumulative. This affect should be considered when evaluating applications which have intermittent or cyclic exposures.

## Hot, Moist Environments

Hydrolytic stability may also be extended to hot moist environments. Normally, atmospheric levels of moisture under ambient temperatures have little affect on engineering plastics. However, in the presence of a heat source and a high level of humidity, hydrolytic stability should be considered and acceptable levels of performance specified.

* UV stabilizers enhance the retention of mechanical properties of certain resins under UV exposure conditions. Actual results may vary depending on application; therefore, actual end-use testing is recommended.

## Notes

# Electrical Properties

## Plastics as Electrical Insulators

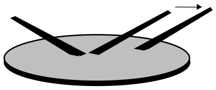
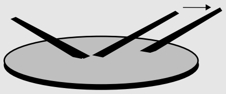
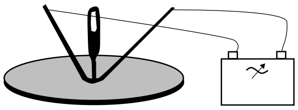
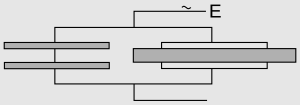
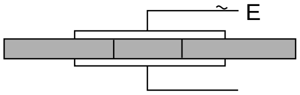
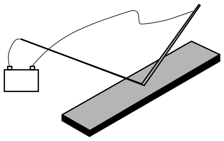
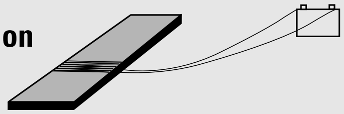
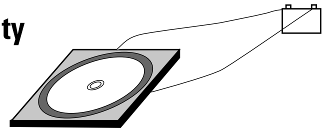
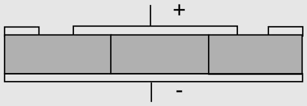
Engineering plastics are frequently specified for a wide variety of applications requiring electrical insulation. While each of the applications has its own set of requirements, hazards regarding electrical shock and fire must be considered. Safety concerns are addressed by regulatory agencies through safety standards which test the design performance and check suitability of the material selected. In trying to understand the behavior of the different materials as electrical insulators and their resistance to ignition, engineers need to understand what electrical properties are and what their significance is. Table 2-6 below compares the electrical properties of various resin grades. Table 2-7 on pages 2-36 and 2-37 provides information on various test methods utilized for thermoplastic resins.

**Table 2-6.** Electrical Property Comparison of GE Engineering Thermoplastics.

| | | Electrical Properties | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | D257 | D149 | D150 | | D150 | | D495 | |
| GE Resin | | | | Dielect. Con. | | Dis. Factor | | | |
| Product | Grade | Vol. Resist. (ohm/cm) | Dielect. Str. (volts/mil) | 50 Hz | 1 MHz | 50 Hz | 1 MHz | Arc (Sec.) | CTI (Volts) |
| **VALOX resin** | 325 | 4.0x10$^{16}$ | 590-400 | 3.00 | 3.10 | 0.002 | 0.02 | 184 | 600 |
| | 357 | 2.2x2x10$^{16}$ | 600-380 | 3.20 | 3.10 | 0.003 | 0.02 | 71 | 275 |
| | 420 | 3.2x10$^{16}$ | 630-475 | 3.80 | 3.70 | 0.002 | 0.02 | 146 | 600 |
| | 420SE0 | 3.4 | 610-490 | 3.80 | 3.70 | 0.002 | 0.02 | 28 | 185 |
| | 553 | 4.3 | 650-480 | 3.60 | 3.60 | 0.002 | 0.02 | 94 | 145 |
| | 780 | 0.35 | 650-460 | 3.80 | 3.80 | 0.007 | 0.02 | 126 | 230 |
| **LEXAN resin** | 141 | >10$^{16}$ | 380 | 3.17 | 2.96 | 0.0009 | 0.01 | 10<br>120 | — |
| | 940 | >10$^{16}$ | 425 | 3.01 | 2.96 | 0.0009 | 0.01 | 10 | — |
| | HF1110 | 10$^{15}$ | 384 | 3.00 | 2.90 | 0.0009 | 0.01 | 114<br>120 | — |
| | 500 | 10$^{16}$ | 450<br>570 | 3.10 | 3.05 | 0.0008 | 0.0075 | 5-10 | — |
| **ULTEM resin** | 1000 | 6.7x10$^{17}$ | 831 | — | 3.15 | 0.0013 | 0.0025 | 126 | — |
| | 2300 | 3.0x10$^{16}$ | 770 | — | 3.7* | .0015* | 0.0053 | 85 | — |
| | 6000 | 1.0x10$^{17}$ | 750 | — | 3.0* | .001* | — | 127 | — |
| **NORYL resin** | 731 | >10$^{15}$ | 550 | 2.65 | 2.60 | 0.0004 | 0.0009 | — | — |
| | GFN3 | >10$^{15}$ | 550 | 2.93 | 2.90 | 0.0009 | 0.0015 | — | — |
| **CYCOLAC resin** | GSM | 4.0x10$^{15}$ | — | — | — | — | — | — | — |
| | KJB | 1.0x10$^{14}$ | — | — | — | — | — | — | — |
| | KJT | 1.0x10$^{14}$ | — | — | — | — | — | — | — |
| | KJU | 1.0x10$^{14}$ | — | — | — | — | — | — | — |
| **CYCOLOY resin** | C2800 | 1.0x10$^{17}$ | — | — | — | — | — | — | — |
| | C2950 | 1.0x10$^{17}$ | — | — | — | — | — | — | — |
| | C2950HF | 2.0x10$^{17}$ | — | — | 2.7 | — | 0.0071 | — | — |
| **GELOY resin** | XP1001 | 1.0x10$^{14}$ | — | — | — | — | — | — | — |
| | XP2003 | 7.0x10$^{14}$ | — | — | — | — | — | — | — |

# Thermoplastic Material Properties

**Table 2-7.** Test Methods Utilized for GE Thermoplastic Resins.

| PROPERTY | TEST METHODS | DEFINITION |
|---|---|---|
| **Arc Resistance (sec.)**  | ASTM D495<br>(as done at UL) | Arc resistance is the elapsed time in which the surface of a material will resist the formation of a continuous conducting path when subjected to a high voltage, low-current arc under carefully controlled laboratory conditions (tungsten electrodes). |
| **Arc Tracking Rate (in/min)**  | UL 746A Polymeric Materials-Short Term Evaluations (in./min) | The rate at which an arc can carbonize the surface of the material and produce a conductive path. |
| **Comparative Track Index (volts)**  | ASTM D3638 | The voltage which when exposed to 50 drops of an aqueous contaminant will produce tracking on the surface of the tested material between two standard electrodes. |
| **Dielectric Constant (no units)**  | ASTM D150 | The ratio of the capacitance of electrodes with the insulating material as a dielectric to the capacitance of the same system with the dielectric replaced by vacuum or dry air. |
| **Dielectric Strength (volts/mil)**  | ASTM D149 | Dielectric strength is the maximum voltage obtained between two specified electrodes prior to breakdown of the insulating material being evaluated. Property is reported in volts per unit thickness. |
| **Dissipation Factor (no units)** | ASTM D150 | The tangent of the loss angle for an insulating material. |
| **High Current Arc Ignition (arcs)**  | UL 746A | The number of arcs required to ignite a material under specified conditions. Test establishes an absolute numerical index for comparing materials. |
| **Hot Wire Ignition (sec)**  | UL 746A Ref.<br>ASTM D3874 | The time required for an insulator to ignite when wrapped with a wire of specified resistance and connected to a specified voltage. |
| **Surface Resistivity (ohm/sq)**  | ASTM D257 | The resistance measured between two electrodes that are on the specimen surface. The ratio of the applied direct voltage on the electrode to the current measured. |
| **Volume Resistivity (ohm/cm)**  | ASTM D257 | The ratio of the direct voltage applied across electrodes in contact with or imbedded in an insulating specimen to that portion of the current between them. |

| SIGNIFICANCE |
|---|
| The test is intended to differentiate in a primary fashion the resistance of similar materials to form a conductive path as a result of a particular arc playing over the surface. The arc is controlled using AC high voltage low current. A different power source may affect the relative performance of materials tested. The environment is clean and dry, representative of a laboratory. Results are normally used to screen similar materials. Information is for comparison and not for design. In addition, ASTM does not suggest test for use in material specification. |
| The test specifies an alternating current high voltage low current arc typical of a high voltage power supply. The conditions are controlled laboratory conditions…no dust, contaminants or moisture. The results may be used to establish an absolute numerical index. Useful primarily for comparative purposes. May be referred to in UL safety standards. |
| The test determines the resistance of the material to electrical tracking at relatively low voltages, under 600 V AC, in the presence of an aqueous contaminant. The contaminant, 1% ammonia chloride, is specified because of its rapid and reproducible results. The conditions are not intended to duplicate service environments and limit the value of the test to material comparisons. The results are not useful for direct comparison of expected service performance or application designs. |
| Insulating materials are generally used in two ways, to insulate and support electrical conductors or components from each other and ground or as a dielectric for a capacitor. In the first instance it is desirable to have a capacitance as small as possible. For use in a capacitor, a high dielectric constant is desirable. An increase in dielectric constant will typically result in greater loss when insulating a current and consequently generate more heat. Generally, the dielectric constant is an indicator of the polarity to the insulating material. The higher the polarity, the greater the dielectric constant. |
| Test measures an insulator's ability to maintain electrical resistance in the presence of an electrical field at commercial power frequencies. Test may be used in partial evaluation of materials for specific applications. Conditions which affect the test results include: *specimen thickness… thinner specimens give higher dielectric strengths * temperature… higher temperatures reduce dielectric strength * time… more rapid rate of voltage increase results in higher dielectric strengths * frequency… little effect with frequencies in commercial power ranges * moisture… depends on propensity of specimen to absorb moisture. Generally, moisture will reduce dielectric strength. |
| When an alternating power source is applied to an ideal dielectric material, current will flow so that it is 90˚F (32°C) out of phase with the voltage. Real insulators result in the current leading the voltage by something less than 90˚F (32°C). The dissipation factor is the tangent of this small loss angle. Another interpretation is the ratio of the current dissipated as heat to the current transmitted. Lower values correspond to ideal dielectric materials. Conditions which adversely affect dissipation factors are temperature increases, frequency increases, humidity increases and voltage increases. |
| The test differentiates among insulating materials with regard to resistance to ignite from an electrical arc. Arcs are provided from a 240 volt 60 hertz AC power supply with a short circuit current of approximately 32.5 amperes. The test is devised to simulate the possible ignition of the insulating material if it were in the close proximity of an arc developed under normal or abnormal circumstances. Actual value is the average of three tests. Results may be referenced in the UL safety standards. |
| The test is intended to simulate conditions in which electrical components or conductors in intimate contact with an insulator heat up under normal or abnormal service. The results provide a relative index of the resistance of various insulators to ignition. Results may be referred to in UL safety standards. |
| Insulating materials are used to isolate components of an electrical system from each other and from ground, as well as provide mechanical support for components. For this purpose, it is generally desirable to have a higher value. One occasion where a low surface resistivity may be desirable is to avoid static buildup of an electrical charge such as might happen with copier parts moving paper. |
| Insulating materials are used to isolate components of an electrical system from each other and from ground, as well as provide mechanical support for components. For this purpose, it is generally desirable to have a higher value. Resistivity may be used as an indication of moisture content. Volume resistance is dependent on temperature and humidity. Values may be useful in designing an insulator but the environment must be considered. |

# Dimensional Properties

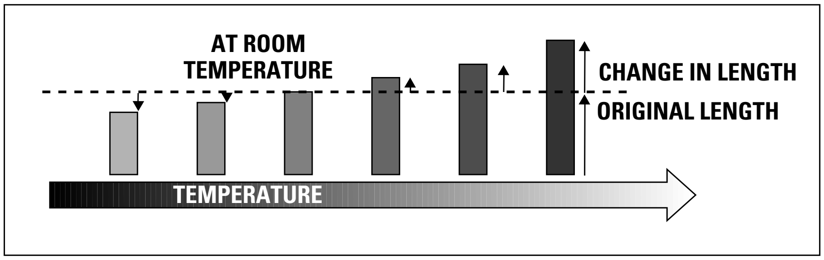
## Dimensional Effects – Reversible

Thermal expansion occurs in all materials as they are heated (Figure 2-33). This change in dimension is considered reversible because if the temperature of the part is allowed to cool back to its original temperature, the size of the part will return to its original size.

## Coefficient of Thermal Expansion (CTE)

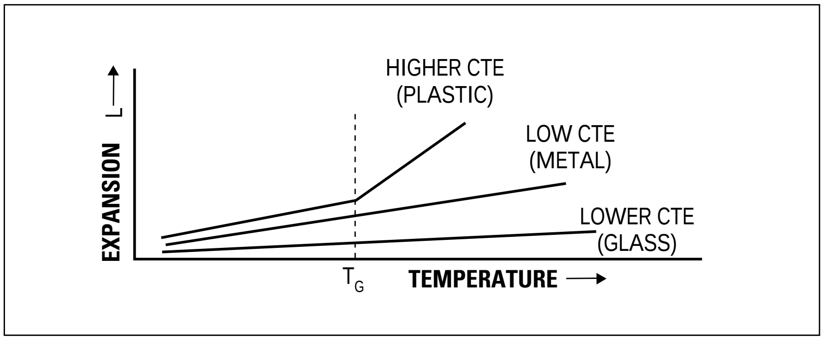
Typically, each material expands and contracts differently depending on its coefficient of thermal expansion. The differences in coefficients of thermal expansion can be quite significant when comparing very different materials such as thermoplastics and metals.

**Figure 2-33**. Coefficient of Thermal Expansion (CTE). *The coefficient of thermal expansion is a measurement of a material's expansion upon heating and contraction upon cooling.*



These differences pose design problems for an engineer if dissimilar materials are secured to each other and a temperature excursion is anticipated in the life of the product. One example of this would be a molded-in insert for a plastic part. The injected plastic will solidify around the cool insert and then contract according to its coefficient of thermal expansion (Figure 2-34) around the insert until room temperature is reached. Since the metal contracts less, a tensile stress is developed in the plastic material surrounding the insert. This can be expressed as shown in Figure 2-35.

**Figure 2-34.** CTE Comparison. *The slope of the curve = Coefficient of Thermal Expansion.*



$$\sigma = E\,(\alpha_p - \alpha_s)\,\Delta T$$

**where** $E$ = **Modulus of plastic at 73°F (23°C)**
$\alpha_p$ = **Coefficient of thermal expansion of plastic**
$\alpha_s$ = **Coefficient of thermal expansion of insert**
$\Delta T$ = **Change in temperature**

**Table 2-8.** Relative magnitudes of coefficients of thermal expansion for different materials. *Typically, plastic materials have much higher thermal expansion than metal or glass.*

| Material | CTE (10**-5 in/in/°F) |
|---|---|
| Aluminum | 2.3 |
| Brass | 1.9 |
| Steel | 0.65 |
| LEXAN resin | 3.75 |
| 20% Glass Reinforced LEXAN resin | 1.49 |
| NORYL resin | 3.3 |
| 20% Glass Reinforced NORYL resin | 2.0 |
| VALOX resin | 4.0 |
| 15% Glass Reinforced VALOX resin | 2.5 |

For plastic materials, especially reinforced materials, the coefficient of thermal expansion is directional. The thermal expansion is less in the direction of flow than across the direction of flow. In some unreinforced plastic materials, the thermal expansion is directional only to a lesser degree and the direction of flow expansion may be slightly larger than the cross direction of flow. Thickness may also influence the coefficient of thermal expansion as the degree of orientation of the section is affected.

The coefficient of thermal expansion is not always constant for a thermoplastic. Typically, at the glass transition temperature, the thermal expansion will increase and remain fairly constant until the melting point is approached.

## Post Mold Shrinkage

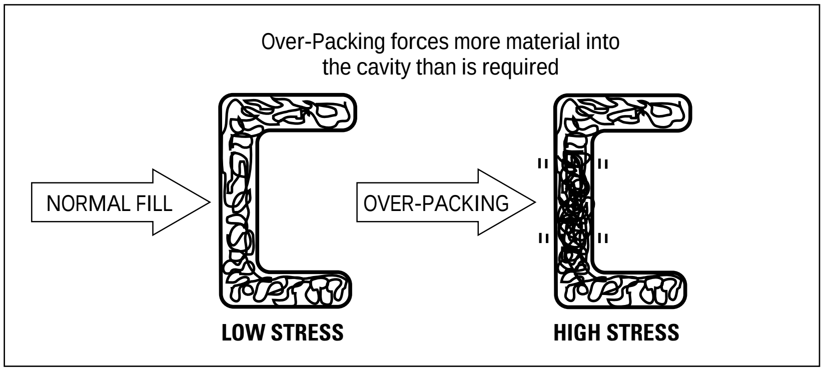
Molded plastic parts may change irreversibly in dimensions when subjected to elevated temperatures. The changes may be the result of stress relaxation in the part or could be the result of post mold shrinkage. Part design, tooling, processing and material selection will all bear on these tendencies.

### Stress Relaxation

Part dimensions are subject to change as a result of exposure to a thermal soak which allows the molded in stresses to relax. Occasionally, the relaxation of stresses will result in warped parts. Injection molded parts may develop internal stresses from a number of causes. Uneven cooling of the part will occur when parts are designed with uneven wall thicknesses or the mold has inadequate cooling. This results in uneven shrink rates and warped parts.

Uneven packing of the part can also develop significant stresses which change dimension at elevated temperatures (Figure 2-35). With anisotropic materials and glass reinforced grades, the shrink is a function of the way the material fills the cavity. The differential shrinkage can result in molded in stress which relieves itself as warp when exposed to high temperatures.

**Figure 2-35.** Over-Packing. *The polymer molecules are frozen into this compressed state upon cooling causing molded-in stress.*



A second type of irreversible dimensional change which thermal exposure may produce is post mold shrinkage. Post mold shrinkage is more prominent in semi-crystalline parts and the magnitude is dependent on the initial molding conditions. Essentially, a semi-crystalline material, VALOX PBT resin or nylon resin, is made up of two phases: crystals, with tightly, well arranged molecular chains, and amorphous regions, with random intermingling of polymer chains.

If the melt is quenched rapidly as when molded in cold molds, some of the molecules that normally form crystals are trapped in the solid matrix (Figure 2-36). With the onset of heat raising the temperature above the glass transition temperature, the amorphous region becomes mobile and additional crystals are formed. Since the crystals are more dense than the amorphous region, a volumetric reduction results in additional shrinkage. The additional shrinkage must be taken into account early in the design process and be accommodated in the tooling fabrication.

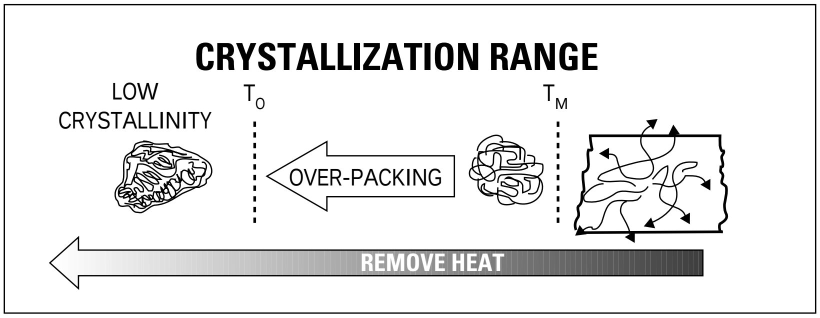


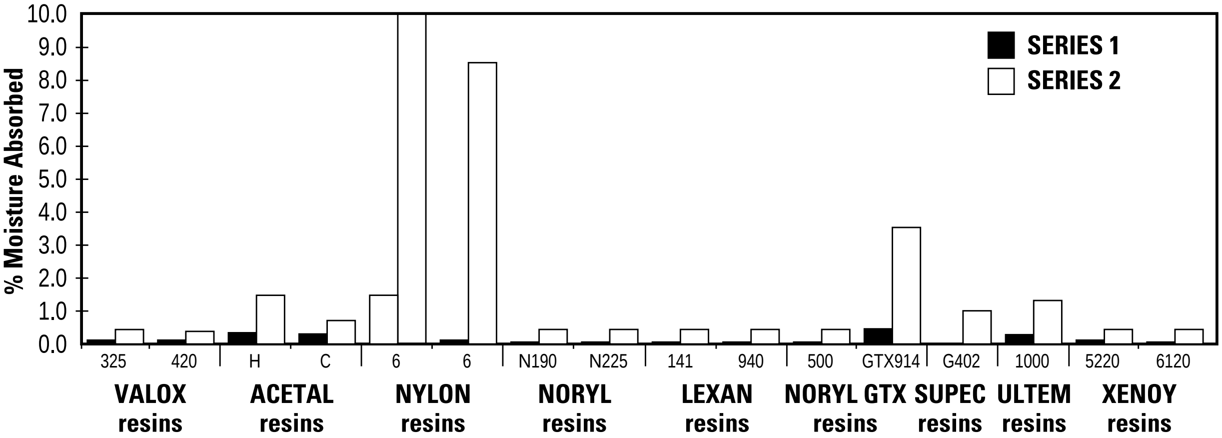
**Figure 2-36.** Cold Mold Lower Crystallinity. *A cold mold freezes the polymer quickly not giving it a chance to fully crystallize (quenching). A volumetric reduction results in additional shrinkage.*

## Moisture Absorption

Thermoplastic materials tend to interact with the environment. Water or water vapor can be absorbed in the polymer matrix which will swell the molded part. The most notable example of this phenomenon is nylon (Figure 2-37). Nylon is normally designed with an allowance for 2.5% moisture absorption. This translates to about 7.5 mils/in. dimensional increase at equilibrium. Over extended periods of time, the moisture level will vary, also affecting dimensions.

**Rule of Thumb:** Delta L = (% moisture x 3 mils/in.) length.

**Figure 2-37.**
Moisture Absorption ASTM 570.



# Optical Properties

## Refractive Index/Light Transmission

Two optical properties for transparent plastics are:

- refractive index commonly thought of as the speed of light in a material.
- light transmission i.e., the loss of light due to internal reflection.

The ratio of the refractive indices at an interface determines the angle of refraction according to Snell's Law (Figure 2-38). A typical refractive index for LEXAN resin is 1.586.

$$\frac{n_1}{\text{sine } \alpha_1} = \frac{n_2}{\text{sine } \alpha_2} = \frac{n_3}{\text{sine } \alpha_3}$$

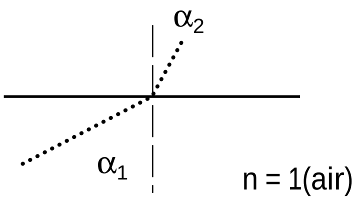


**Figure 2-38.** Snells Law. *Snells Law relates the sines of the Refractive Angles at an interface. This relationship would be used to design a lens.*

See also Optical Design, pages 6-24 to 6-31.

## Notes

# Lubricity Properties

## Lubricity

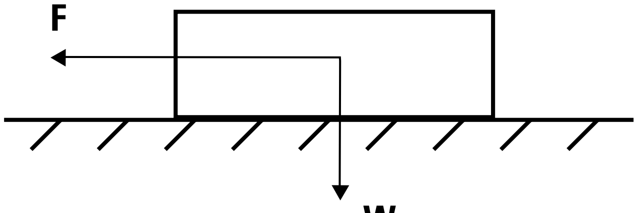
The surface properties of engineering thermoplastics may qualify them for applications involving relative motion, rubbing contact or transmission of forces. Typical applications include gears, bearings, guides, linkages, supports or cams. By designing within the capability of the materials, rubbing surfaces can be integrated into the design, giving reliable, low maintenance performance.

The key considerations when selecting a material requiring lubricity are the frictional behavior and the wear behavior. Friction deals mostly with efforts and losses (efficiency) while wear is the removal of material affecting dimensions and/or location. Both properties are indicators of a material's lubricity.

## Friction

Friction is the resistance encountered when two solid surfaces slide over each other (Figure 2-39). The coefficient of friction is the ratio of the force required to slide an object across a horizontal surface to the weight of the object.  The values for coefficient of friction vary significantly with thermoplastic materials depending on the test methods used and the environment. Because plastics are considered "soft" materials and because of their viscoelastic nature, considerations of time, temperature and load bear on the results.

**Figure 2-39.** Friction. *Friction is the resistance encountered when two solid surfaces slide over each other.*



$$F = \mu W$$

$\mu_s$ = Static Coefficient of Friction

$\mu_d$ = Dynamic or Sliding Coefficient of Friction

COEFFICIENT OF FRICTION

**Table 2-9.** Coefficient of Friction for GE Engineering Thermoplastic Materials.

| | | | Static | Kinetic |
|---|---|---|---|---|
| LEXAN resin | | | | |
| | 141 | steel | .33 | .39 |
| | | self | | |
| | WR1210 | steel | .14 | .18 |
| | | self | | |
| | WR2210 | steel | .17 | .21 |
| | | self | | |
| NORYL resin | | | | |
| | SPN422L | steel | .16 | .21 |
| | | self | | |
| | 731 | steel | | .33 |
| | | self | | .27 |
| | SE1X | steel | | .17 |
| | | self | | .27 |
| | SE100X | steel | | .24 |
| | | self | | .43 |
| | GFN2 | steel | | .22 |
| | | self | | .35 |
| | SE1GFN2 | steel | | .24 |
| | | self | | .29 |
| | GFN3 | steel | | .28 |
| | | self | | .43 |
| | SE1GFN3 | steel | | .32 |
| | | self | | .45 |
| ULTEM resin | | | | |
| | 1000 | steel | .38 | .40 |
| | | self | | |
| | 2300 | steel | .31 | .42 |
| | | self | | |
| VALOX resin | | | | |
| | 310SE0 | steel | | .24 |
| | | self | | .22 |
| | 325 | steel | .17 | .19 |
| | | self | .14 | .15 |
| | 357 | steel | | .28 |
| | | self | | .20 |
| | 420 | steel | .19 | .21 |
| | | self | .15 | .18 |
| | 420SE0 | steel | | .22 |
| | | self | | .18 |
| | 815 | steel | | .34 |
| | | self | | .27 |
| | 830 | steel | | .30 |
| | | self | | .23 |
| | 855 | steel | | .26 |
| | | self | | .24 |
| | 865 | steel | | .22 |
| | | self | | .20 |
| | DR48 | steel | | .36 |
| | | self | | .30 |
| | DR51 | steel | | .24 |
| | | self | | .22 |

## Thrust Washer Test

The thrust washer test is used to provide data for friction and wear properties. The test consists of an upper rotating sample that has a washer-like wear surface. The surface area of this rotating sample is 0.3927 in.$^2$, having an O.D. of 1.125 in. (29 mm) and an I.D. of 0.875 in. (23 mm). The upper specimen spins on a larger stationary lower specimen. The lower specimen has an O.D. of 1.245 in. (32 mm) and an I.D. of 0.625 in. (9 mm). Wear is measured from the upper rotating specimen, since its full surface is in contact with the lower specimen at all times. The upper specimen is the plastic being tested and its original wear surface is the as-molded skin. The lower stationary specimen is either C1018 steel, case hardened to RL30 having a 16 RMS finish or the same grade of plastic used in the upper specimen, with a milled machine finish.

Test data for friction is obtained by monitoring the torque transmitted through the test surface at a set thrust.

**Figure 2-40.** Coefficient of Friction vs. Pressure.

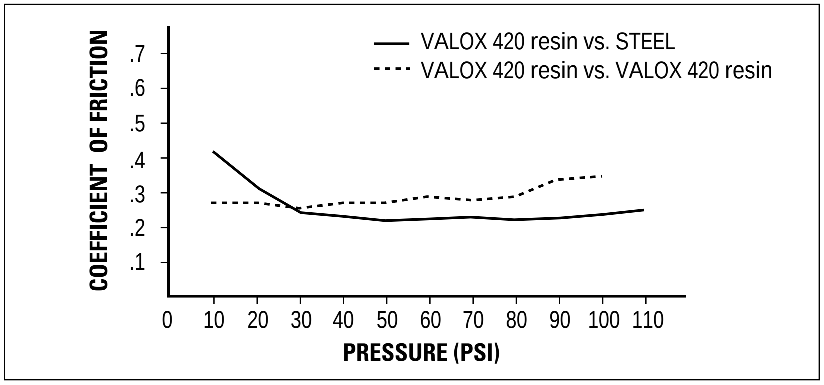
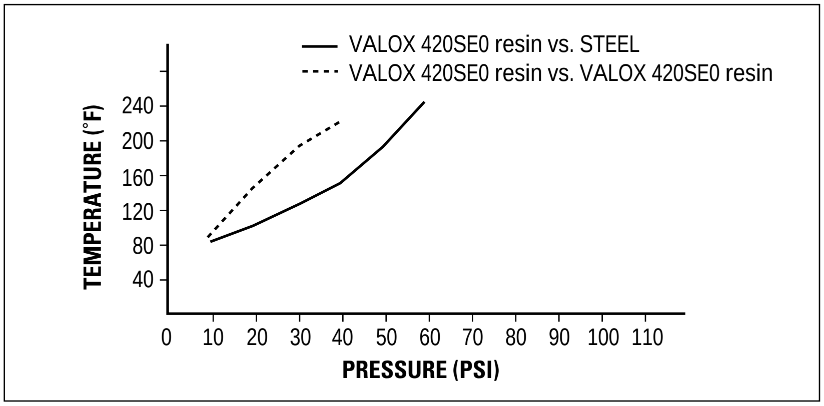


**Figure 2-41.** Temperature vs. Pressure.



## Friction Variances

### *Friction Variances as a Function of Temperature*

As the temperature of the contact surfaces increases, the compressive modulus and shear strength both decrease. Since modulus is proportional to the ratio of shear strength to yield pressure, some change will be expected but will vary from polymer to polymer (see Figures 2-42 and 2-43). Typically, a plastic on plastic combination will result in a temperature rise as the low thermal conductivity is slow to dissipate the heat.

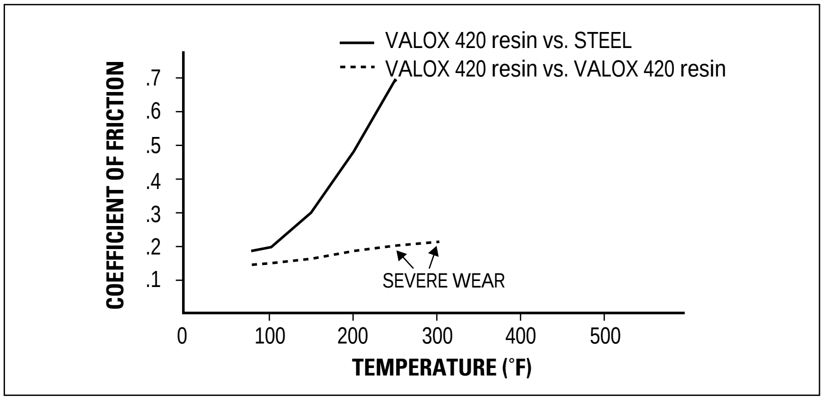


**Figure 2-42.** Coefficient of Friction vs. Temperature.

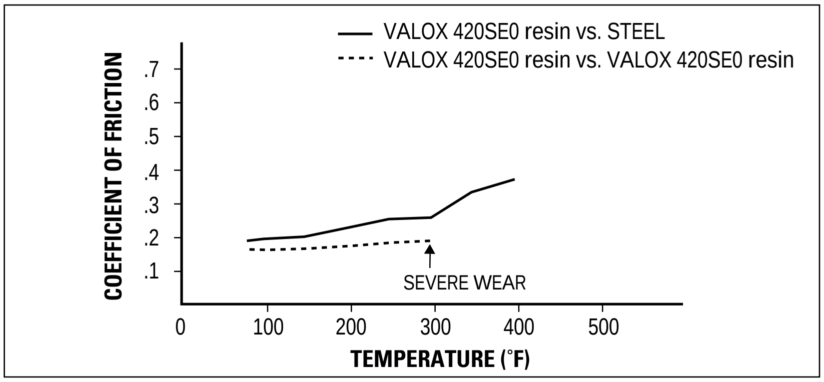


**Figure 2-43.** Coefficient of Friction vs. Temperature.

### *Friction Variances as a Function of:*

**Load –** Changes in pressure can increase friction at the high and low extremes. The temperature of the specimen is affected by changes in pressure which may in turn affect friction.

**Sliding Velocity –** Viscoelastic properties tend to increase friction at very low speeds and decrease friction at higher speeds. Over time, high sliding velocities will increase the temperature of the surface and affect friction.

**Wear in** – The time the specimen is loaded and at rest before the test can affect the static friction. It has been reported that the coefficient of friction may increase 40% by increasing the rest time from 0.1 minute to 16.6 minutes.

**Glass reinforcement –** Glass reinforcement slightly increases the coefficient of friction versus an unreinforced grade. This appears true for crystalline and amorphous materials.

**Flame retardance –** In crystalline materials, flame retardance tends to increase friction. In amorphous materials, flame retardance tends to increase the coefficient of friction; however, there are exceptions to this generalization.

**Lubrication –** Lubrication is a common way to lower friction. Some care is needed in the selection of a lubricant as it should be compatible with the plastic resin. In addition, the lubricant should have a surface tension less than the critical surface tension of wetting, so that the lubricant spreads out over the surface. Studies show that boundary lubrication of plastics is similar to the lubrication of metals. Of note is that lubrication is more effective on plastic-metal interfaces than plastic-plastic interfaces.

Internal lubricants are effective in reducing friction as evidenced in grades of LEXAN and ULTEM resins, amorphous materials, not normally associated with lubricious properties.

## Wear

In rubbing and sliding applications, wear is a property most associated with the product's life. Normally, failure is brought on by excessive wear of a component causing dimensional change, loss of alignment or change of location. To assess the performance of a plastic material in a wear application, the engineer needs to compare the pressure and the velocity of the rubbing surfaces with the pressure – velocity (PV) limit of the material. If the PV of the application is within the PV limit of the material, this wear rate can be used to predict the design life of the product. Often these calculations are only rough approximations as a number of factors will affect the results. Testing under expected abuse conditions is the best way to prove a design.

### *Wear Testing*

The thrust washer test as described for friction tests is also used to characterize wear. The test equipment is described in ASTM D3702. Key properties determined by this test are PV limit and K wear factor.

### *PV Limit*

The PV limit of a material is the product of the limiting bearing pressure psi (Kg/em(2)) and limiting velocity fpm (M/min) of the sliding surfaces. The limit describes a critical, easily recognizable change in the bearing performance of the material and may manifest itself in one or more forms: melting, cold-flow, unstable friction or a radical change in the wear rate vs. PV curve. The test method calls for a specified velocity to be maintained and the pressure increased periodically. The friction is monitored by the torque and should stabilize within the PV limit. If stability does not occur, this signifies that the condition exceeds the PV limit.

### *K-Wear Factor*

The wear rate is the change in the normal dimension of the specimen over a specified time at a specified PV.

$$\textbf{K-factor} = \frac{\textbf{in./hr}}{\textbf{psi x ft/min}} = \frac{\textbf{in.(3)-min}}{\textbf{lb-ft-hr}}$$

On the thrust washer test, the specimen is mounted, run in, initial dimensions taken, tested at predetermined PV for a set time period and dimensionally checked. The change in dimension is divided by the test time and that rate is normalized by the PV.

**Table 2-10.** Wear Rate Table of Values.

| PV = 2000 psi ft/min | K factor x $10^{10}$ in/hr (psi x ft/min) |
|---|---|
| LEXAN 141 resin | 13000 |
| LEXAN WR2210 resin | 60 |
| NORYL SPN422L resin | 95 |
| VALOX 325M resin | 210 |
| ULTEM 4000 resin | 62 |
| VALOX 357 resin | 240 |
| VALOX 420 resin | 65 |

# Rheological Properties

## Rheology

Rheology may be considered the characterization of the way a plastic material flows in its melt phase. This characterization is particularly significant to the processability of the material and related disciplines such as part design and tool design. Rheological information is necessary to characterize a material for computer-aided mold filling analysis used to model the filling phase of the injection molding process.

The flow of a material will directly or indirectly influence the part design, tool design or processing conditions.

**Table 2-11.** Injection Molding Processing Considerations.

| Process Considerations | |
|---|---|
| Part design | wall thickness, flow length, draft angle |
| Tooling | number of gates, runner size, gate size |
| Processing | melt temperature, injection pressure, clamp requirements, processing window, melt temperature, weld line strength |

**Table 2-12.** Extrusion, Blow Molding, Thermoforming Processing Considerations.

| Process Considerations | |
|---|---|
| Melt strength | the ability to hold a shape when unsupported while still soft or molten. Forming temperature range…if too narrow forming is unmanageable. |
| Quality Control Testing | Under low shear rate conditions, the melt flow of a polymer will reflect the molecular weight of the polymer chains. The length of the polymer chains can be diminished by abusive processing resulting in lower properties and part performance. |

## Rheological Terms

Terms which have specific meaning in Rheological discussions are:

### *Shear Rate (1/sec.)*

A measure of the rate of deformation of a polymer melt. Calculated from the flow rate and the geometry through which the polymer flows.

**Example:** In injection molding, decreasing the gate size at a given injection speed will increase the shear rate.

### *Shear Stress (psi or pascals)*

A measure of the pressure required to sustain a constant flow rate through a given geometry.

**Example:** In extrusion, increasing the die length will require an increase in shear stress to maintain a constant flow.

### *Viscosity (poise, centipoise, pascal x sec.)*

The measure of a polymer's resistance to flow in the melt phase.

Viscosity = Shear stress/Shear rate

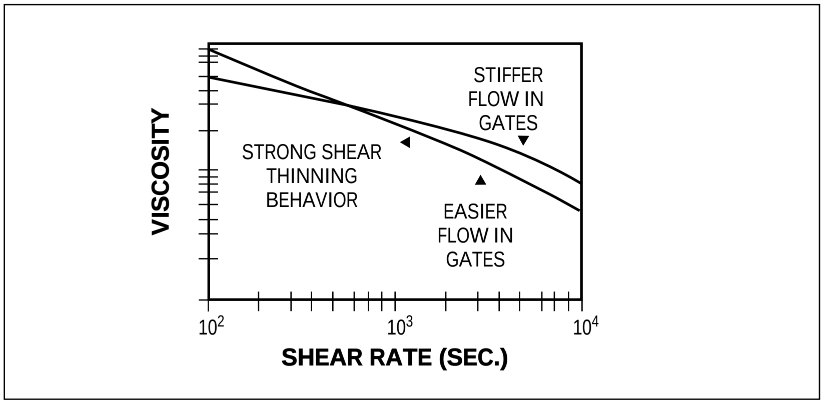


**Figure 2-44.** Shear Thinning (Constant Temperature).

### *Shear Thinning Behavior*

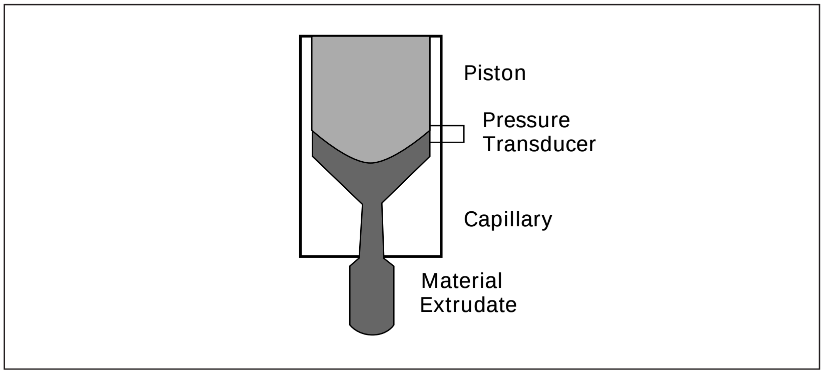
A decrease in viscosity with increasing shear rates due to molecular alignment during flow. (Not to be confused with shear sensitivity – a drop in molecular weight due to degradation.)

## Shear Rate Rheology

### *Tests for High Shear Rate Rheology*

High Shear Rheology testing is performed in a capillary rheometer which measures viscosity of the resin under high shear rate conditions (>100 Sec(-1)). The material is kept at a constant temperature in the barrel as it is pushed by a piston through a capillary die at various rates of shear. The test is performed over a range of temperatures and shear rates which correspond to processing conditions. Viscosity is then calculated.

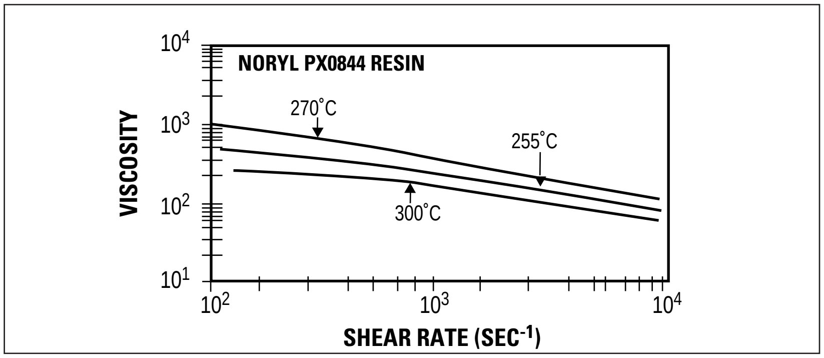
**Figure 2-45.** Capillary Rheometer.



### *High Shear Rate Rheology Curves*

The graph below shows a typical curve obtained from a capillary rheometer displaying viscosity over a range of shear rates. Each curve represents the material's behavior at a specific temperature. This information can be compared to determine the relative flow of materials or could be used to build a material file for CAE mold filling analysis.

**Figure 2-46.** Melt Rheology.



## *Tests for Low Shear Rate Rheology*

One method of testing Low Shear Rate Rheology is a Dynamic Mechanical Analyzer (Figure 2-47) equipped with parallel plate fixtures mounted between an actuator and a transducer.

The sample is located between the plates. The actuator supplies an oscillating force to the sample at a frequency and the transducer records the sample response.

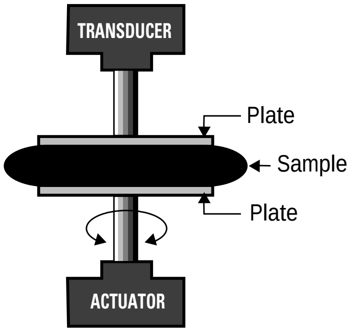


**Figure 2-47.** Dynamic Mechanical Analyzer.

## *Low Shear Rate Rheology Curve*

Below is a typical Parallel Plate Rheometry trace defining G' (Elastic Modulus), G" (Viscous Modulus) and (Viscosity) as a function of Frequency (Shear Rate) for NORYL HS2000 resin.

**Higher G' < Higher Melt Elasticity**

**Higher Melt Elasticity < Higher Die Swell**

G" — Measures the viscous component of flow.

**Higher G" < Lower Melt Elasticity**

**Lower Melt Elasticity < Less Die Swell**

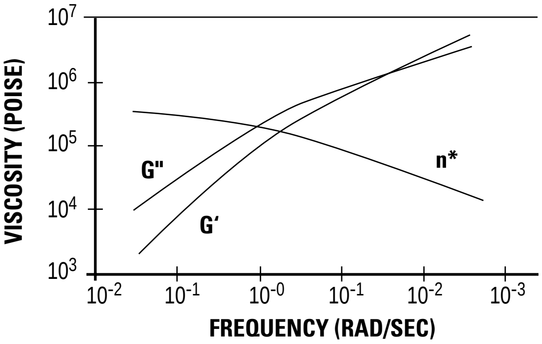


**Figure 2-48.** Parallel Plate Rheometry for NORYL HS2000 resin.

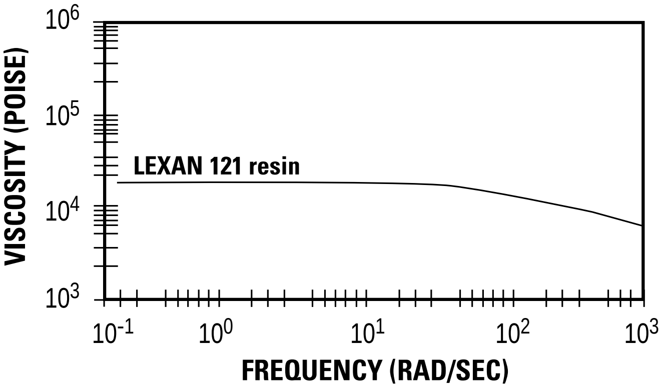
## Melt Rheology

Figure 2-49 traces Viscosity vs. Frequency for these LEXAN resins with different behavior:

**LEXAN 121 resin:**

Low Molecular Weight ➜ Low Viscosity

**Figure 2-49.** Melt Rheology.

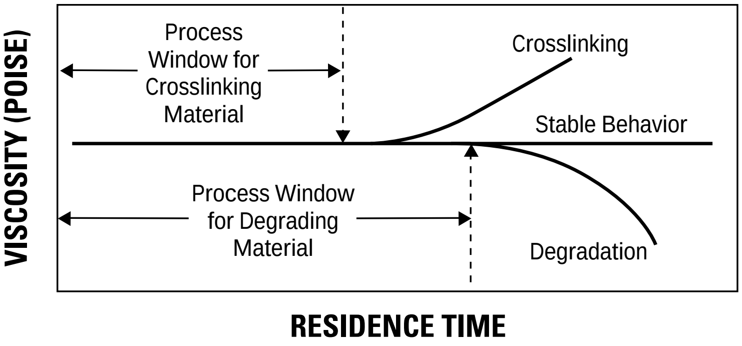


## Thermal Stability

By measuring how viscosity changes with time, the Thermal Stability (constant temperature and shear rate) of a resin can be determined. A significant drop in viscosity indicates resin degradation.

If viscosity increases, the resin may be crosslinking, resulting in a build in molecular weight.

**Figure 2-50.** Residence Time Evaluation.



## Melt Flow Rate (MFR)

Melt flow rates are widely used in the plastics industry to check material consistency. The test (per ASTM D1238) is run on an apparatus as shown in Figure 2-51. A heated barrel is loaded with polymer and time is allowed for melting and equilibration. A weight (constant Shear Stress) is then placed on the piston and molten polymer is extruded through a fixed size orifice (constant Shear Rate). The extrudate is weighed after one minute and the MFR is calculated as the number of grams of polymer which would be extruded in 10 minutes.

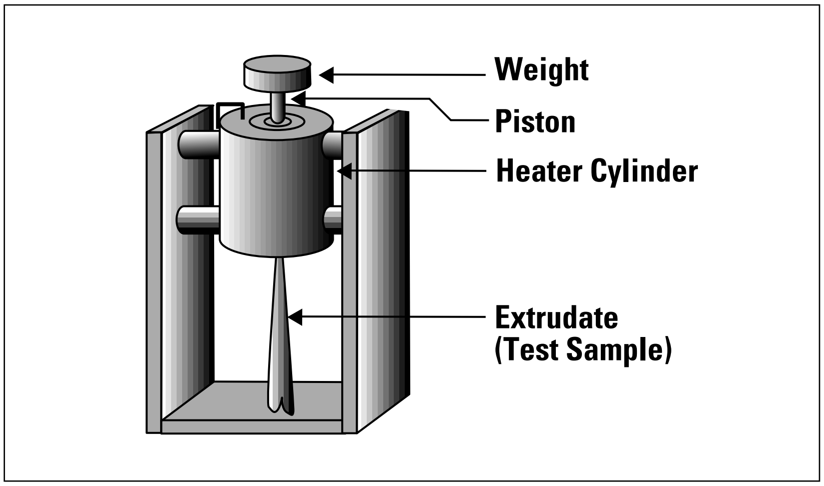


**Figure 2-51.** Melt Flow Test.
*To identify the Melt Flow Rate Test, three variables must be specified:*
- *Temperature*
- *Weight*
- *Capillary dimensions*

*ASTM D1238 prescribes various "conditions" which define these variables.*

Low Viscosity resin extrudes more freely in the MFI test and results in a high value of MFI.

**MFR AND VISCOSITY ARE INVERSELY RELATED**

**Low Viscosity** = High MFR **High Viscosity** = Low MFR

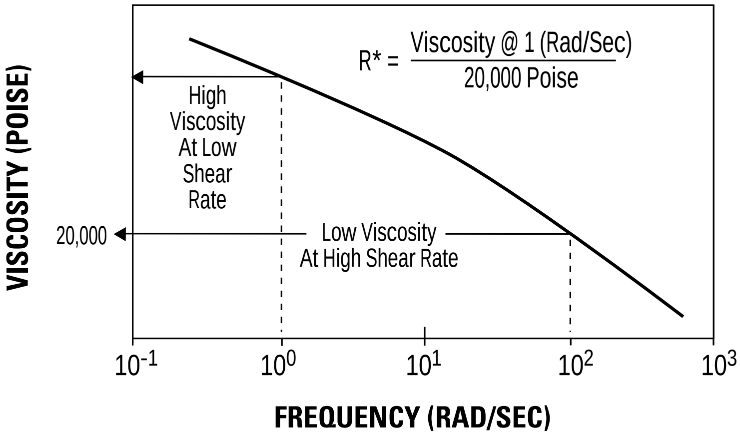
Changes in viscosity due to material degradation may be detected by changes in MFR. This type of test is standardly used in failure analysis of molded parts.

Kasha Index (KI) and Melt Viscosity (MV) are both variations of this same test method.

## R* Index - A Rating for Blowmolding Processability

Low Shear Rate Rheology is used for calculating both the process temperature and the melt strength of blowmoldable resins. Process temperature is identified as the temperature which gives a Viscosity of 20,000 poise at 100 rad/sec. R* is then calculated by a ratio of viscosities at 1 and 100 rad/sec. (at the defined process temperature). High R* (Shear Thinning Behavior) means that the resin flows easily during extrusion and also has sufficiently high melt strength to support the parison when the shear is removed.

**Figure 2-52.** Calculating R* Index



# Agency Considerations

## Agency and Regulatory Considerations

Many applications are submitted to industry-supported or government-controlled organizations which test and examine products to see if they comply with recognized standard practices to provide for public safety. These agencies include Underwriters Laboratories, CSA, IEC, NSF and FDA. At UL, products are evaluated for electrical shock, flammability and mechanical hazards under typical operating conditions and foreseeable abuse conditions.

For products involving plastic components, UL considers the performance of the materials selected with the requirements of the applications as determined by actual testing. Materials are submitted by resin manufacturers for characterization by UL. The tests include a standard flammability classification, a number of electrical tests to determine the stability of electrical insulation properties, and the resistance of the material to ignition from electrical sources. Long term tests on the stability of mechanical and electrical properties in heat aging are conducted with the results compiled in a UL file for a particular polymer. Performance results for materials can be compared to application requirements as determined by standard tests run on a product to determine suitability for a material.

For plastic materials, common UL tests are:

**Table 2-13.** Common UL Tests.

| | |
|---|---|
| **UL 746A** | **Polymeric Materials –**<br>Short-term Property Evaluations |
| **UL 746B** | **Polymeric Materials –**<br>Long-term Property Evaluations |
| **UL 746C** | **Polymeric Materials –**<br>Use in Electrical Equipment Evaluations |
| **UL 94*** | **Test for Flammability of Plastic Materials** |

* This test is not intended to reflect hazards presented by any material under actual fire conditions.

## UL 94* Test Procedure

Most electrical applications which are intended for home or industrial use must meet some type of flammability specification. The intent of these specifications is to reduce the potential for fires resulting from sparks, arcing or overheating of electrical components. A common flame rating specification is Underwriters Laboratories Test Number 94 (UL 94).

UL 94 rates materials for flammability using specified test results for classification. The classifications are given with a minimum thickness. These ratings are referred to in actual device evaluations and may be required in the UL listing process (Figure 2-53).

Although UL 94 is the most common, there are a variety of other flammability tests which may be required for a specific application, including the Steiner Tunnel Test, the Canadian Standards Association Flame Test, and the UL smoke generation testing.

## Specimen and Procedures

For the horizontal burning test, the specimen is horizontally tilted at 45 degrees and the lower edge is exposed to the prescribed location and size of flame. At the end of 30 seconds, or prior to it if the flame has reached 1 in. (25 mm), the Bunsen burner is removed.

If the specimen continues to burn, the time to reach the 4 in. (102 mm) mark from the 1 in. (25 mm) mark on the specimen is recorded and the rate of burning is calculated.

For the vertical burning test, the specimen is clamped at one end and the opposite end is exposed to the prescribed location and size of flame for 10 seconds. The test flame is withdrawn and the duration of flaming is observed. When specimen flaming ceases, the burner flame is immediately placed under the specimen. After 10 seconds, the flame is again withdrawn and flaming and glowing are noted.

* This test is not intended to reflect hazards presented by any material under actual fire conditions.

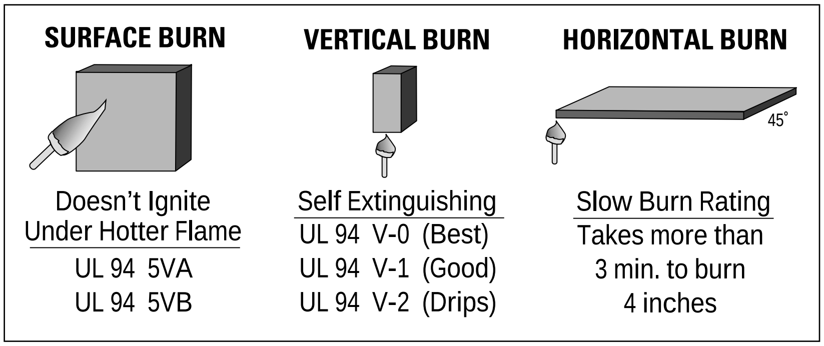


**Figure 2-53.** UL 94 Flammability Tests. *Underwriters Laboratories reports the following flammability ratings per UL Bulletin 94.*

**Table 2-14.** UL Flammability Ratings.

| UL Rating | Flame Spread | Flame Extinguishing Limits | Flaming Drips |
|---|---|---|---|
| HB t > .120<br>< .500<br>t < .120 | 1.5 in. (38 mm)/min.<br>3.0 in. (76 mm)/min. | < 3.0 in. (76 mm) spread | |
| V-0 | Flame or glow cannot reach clamp | < 10 sec. for any flame application<br>< 50 sec. total for 10 flame application<br>Glow out < 30 sec. | 0 Drops |
| V-1 | Flame or glow cannot reach clamp | < 30 sec. for any flame application<br>< 250 sec. total for 10 flame application<br>Glow out < 60 sec. | 0 Drops |
| V-2 | Flame or glow cannot reach clamp | < 30 sec. for any flame application<br>< 250 sec. total for 10 flame application<br>Glow out < 60 sec. | OK |
| 5VA | | < 60 sec. for 5 flame application<br>Glow out (no hole in specimen) | 0 Drops |
| 5VB | | < 60 sec. for 5 flame application<br>Glow out (hole in specimen) | 0 Drops |

## Steiner Tunnel Flame Test

The tunnel test (ANSI/ASTM E-84, NFPA 255, UL723) is intended to measure surface burning characteristics (flame spread, fuel contributed and smoke developed) of various types of building materials. This test is used extensively by regulatory bodies for materials used in the construction of buildings and is required for all vertical furniture non-movable panels > 10 ft$^2$. Wire management and lighting systems require V-0/5V rating.

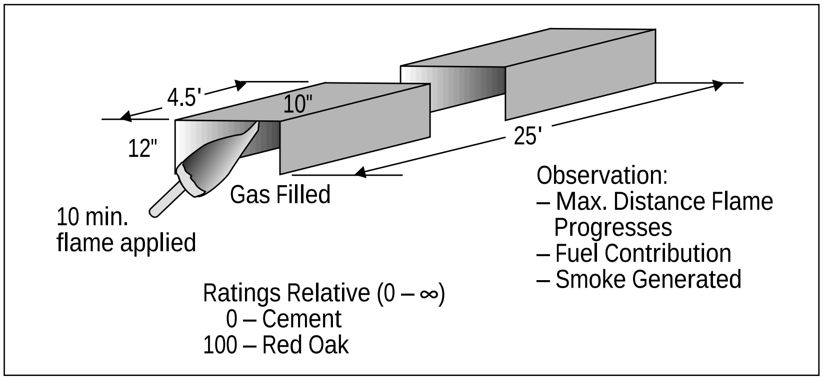


**Figure 2-54.** Steiner Tunnel Flame Test.

The tunnel test utilizes a horizontal chamber 10 in. (254 mm) wide, 12 in. (305 mm) high, and 25 ft. long (Figure 2-54). The test specimen is mounted on the ceiling of the chamber and is exposed for 10 minutes to a gas diffusion flame over its first 4-1/2 ft. Observations are made of the maximum distance to which flames progress along the sample surface, fuel contribution by the specimen and the amount of smoke produced. Relative ratings for interior finish materials from 0 to infinity are assigned by comparison, 0 being that of cement and 100 being that of red oak. The NFPA in Code 101 section 6-5.3 designates the following classification: flame spread 0-25, smoke developed 0-450, Class A; flame spread 26-75, smoke developed 0-450, Class B; and flame spread 76-200, smoke developed 0-450, Class C. Any material with a flame spread over 200 is unacceptable for interior finish use. The Smoke Development Index must be less than 200 to be UL listed for interior finish use.

# Barrier Properties

Barrier properties may become key requirements in packaging or container applications where changes in gas, vapor or liquid content over time may affect the contents or pressure levels. These considerations deserve attention especially when considering replacing metal or glass containers with plastics.

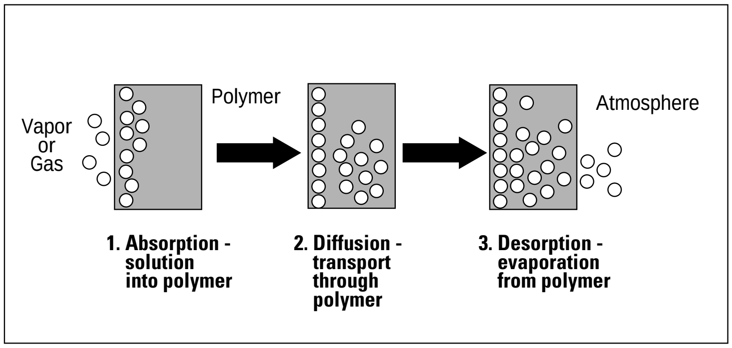


**Figure 2-55.** Mechanism of Permeability.

## Terms Related to Barrier Properties

**Permeation –** The rate at which a gas or organic vapor passes directly through a material.

**Permeation Coefficient –** The measure of permeation rate.

**Steady State Permeation –** The constant rate at which a vapor or gas passes through a material.

## Properties Relating to Permeability

**Crystallinity –** Very tightly bound chains which gases or liquids cannot penetrate; higher crystallinity implies lower permeability.

**Orientation –** In crystalline polymers, orientation will reduce permeability.

**Moisture Sensitivity –** Some polymers are plasticized by water, and their permeability is increased (i.e. nylon).

**Temperature –** Permeability will increase about 5% per °C rise in temperature.

## Conversion Factors for Units of Permeability Coefficients

**Table 2-15.** Conversion Factors for Units of Permeability Coefficients.

$$P = \frac{1.0\ (\text{cm}^3)(\text{mil})}{(24\ \text{hrs})(100\ \text{in}^2)(\text{ATM})}$$

$$= 6.00 \times 10^{-13}\ \frac{(\text{cm}^3)(\text{cm})}{(\text{sec})(\text{cm}^2)(\text{cmHg})}$$

$$= 4.56 \times 10^{-11}\ \frac{(\text{cm}^3)(\text{cm})}{(\text{sec})(\text{cm}^2)(\text{ATM})}$$

$$= 3.94 \times 10^{-1}\ \frac{(\text{cm}^3)(\text{mm})}{(24\ \text{hrs})(\text{m}^2)(\text{ATM})}$$

$$= 3.89 \times 10^{-3}\ \frac{(\text{cm}^3)(\text{mm})}{(24\ \text{hrs})(\text{m–})(\text{hpa})}$$

$$= 3.89 \times 10^{-12}\ \frac{(\text{m}^3)(\text{mm})}{(24\ \text{hrs})(\text{m}^2)(\text{kpa})}$$

$$= 2.68 \times 10^{-17}\ \frac{M(\text{g})(\text{cm})}{(\text{sec})(\text{cm}^2)(\text{cmHg})}$$

Where M is the molecular weight of the permeating gas or vapor.

$$\text{WVTR} = \frac{(1.0)(\text{g})(\text{mil})}{(24\ \text{hrs})(100\ \text{in}^2)} = 1.02 \times 10^{-6} \left(\frac{1}{M \times P}\right) \frac{(\text{cm}^3)(\text{cm})}{(\text{sec})(\text{cm}^2)}$$

Where M is the molecular weight of the permeating vapor and P is the partial pressure gradient across the film.

WVTR: For Water Vapor at. $100^\circ\text{F} = 1.15 \times 10^{-6}\ \frac{(\text{cm}^3)(\text{cm})}{(\text{sec})(\text{cm}^2)(\text{cmHg})} = \frac{(1.0)(\text{g})(\text{mil})}{(24\ \text{hrs})(100\ \text{in}^2)}$

## How to Use Permeation Data

Example: A situation concerns the permeability of VALOX resin to water. A cylindrical part has a surface area of 22 in. (559 mm) and a wall thickness of 80 mils (0.080" [2.03 mm]). It will be filled with 150 grams of water. *How much water will the application lose in two years at 100˚F (37.8˚C)?*

**SOLUTION:**

**Water vapor permeation rate of:**

VALOX resin $1.3\text{g} \times \text{mils}/100\ \text{in}^2 \times 24\ \text{hrs}$

$$1.3\text{g} \times \text{mils}/100\ \text{in}^2 \times 24\ \text{hrs}\ \frac{(22\ \text{in}^2 \times 730\ \text{days})}{80\ \text{mils}}$$

= 2.6g of water would be lost in 2 years

**EXAMPLE with different material:**

Polypropylene $0.3\text{g} \times \text{mils}/100\ \text{in}^2 \times 24\ \text{hrs}$

$$0.3\text{g} \times \text{mils}/100\ \text{in}^2 \times 24\ \text{hrs}\ \frac{(22\ \text{in}^2 \times 730\ \text{days})}{80\ \text{mils}}$$

= 0.6g of water would be lost in 2 years

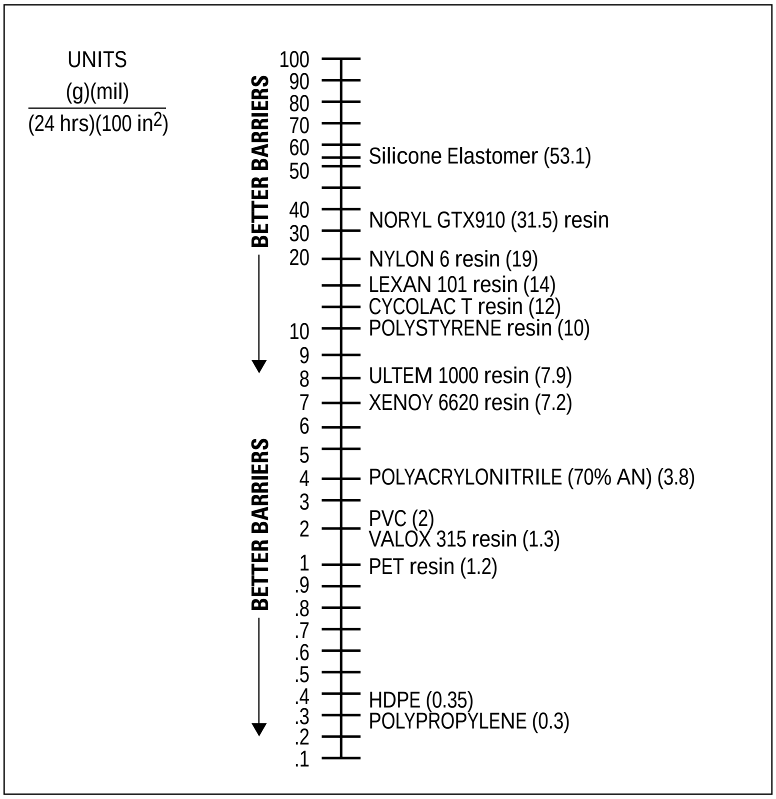


**Figure 2-56.** Water Permeability at 37.8˚C + 98% RH.

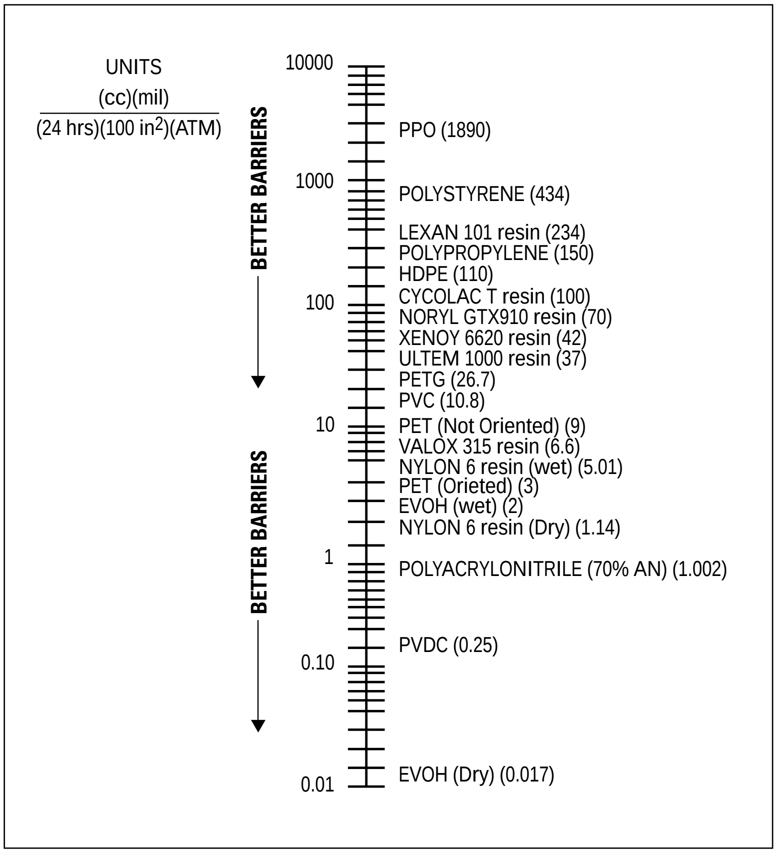
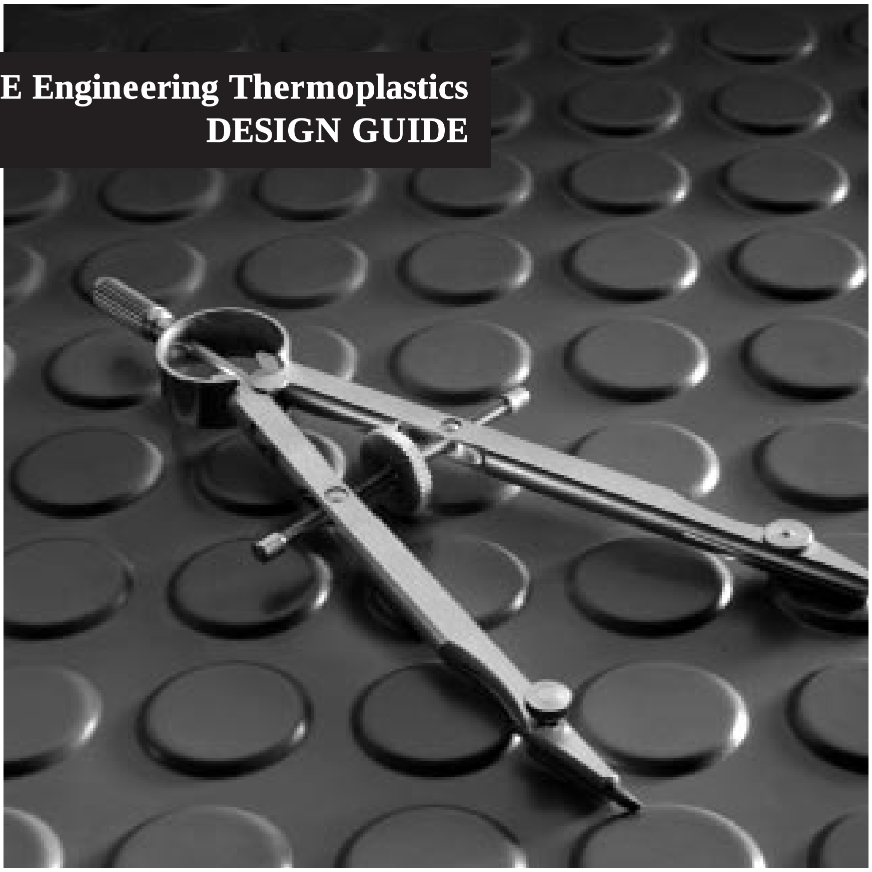


**Figure 2-57.** Oxygen Permeability at 25˚C.

GE Plastics

# GE Engineering Thermoplastics
# DESIGN GUIDE



# Product Design

- *Design for Manufacture*
- *Relative Motion Situations*

# Product Design

Product design accounts for a small amount of development costs but affects a majority of the product costs. Gains in productivity are available to the designer who intelligently uses thermoplastic components and designs them for manufacture and assembly. Also, situations involving plastic parts subject to relative motion including hinges, gears, bearings or guides should be considered. Executing well-conceived product design enhances the probability of success.

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# Design For Manufacturing & Assembly

In today's manufacturing cycle, achieving increased productivity gains requires new and different approaches than those used in the past. These approaches can no longer be simple one-for-one material replacements; rather, consideration should be given to the use of engineering thermoplastics for both the consolidation of parts into more functional applications and the assembly of these parts during manufacture. By considering manufacturing and assembly steps in the initial design equation, manufacturers have the opportunity to engineer both the part and the production process at the same time.

**Productivity Gains**

Multifunctional parts reduce number of parts, and ease assembly and handling.

This approach allows design engineers to maximize the use of engineering thermoplastics. More functional designs can mean fewer parts. Attachment methods such as snap-fits, integrated slides, screw threads and bosses can be incorporated with extremely close tolerances. Through this kind of parts consolidation, inventory and assembly time are reduced, as is the entire product development cycle. Within the manufacturing process there is also the opportunity for greater automation and reduced energy consumption during the manufacturing process.

The ten basic rules of design on the following pages can assist designers in obtaining positive results when utilizing engineering thermoplastics.

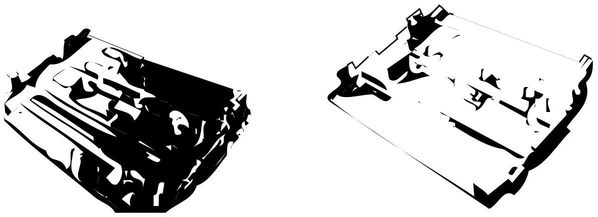
## 10 Basic Rules

### Rule 1 – Minimize the number of parts

Having fewer parts is beneficial to the manufacturer from a number of standpoints. It reduces overhead by eliminating documentation, (drawings, material specifications, purchase orders, inspection reports, routing and inventory), speeds assembly and improves quality.

To determine the theoretical minimum number of parts required in an assembly, the need for each part should be challenged. A part can be identified as a candidate for elimination if all three questions are found to be negative.

- Does the part move relative to the mating part?
- Does the function require a different material?
- Is the part required for disassembly or service?



| Typical parts to be eliminated: | To be replaced with: | |
|---|---|---|
| – Fasteners | Snap fits<br>Press fits<br>Interlocks | ultrasonic<br>thermal stake |
| – Spacers | Bosses | |
| – Labels | Embossed lettering | |

**Figure 4-1.** Parts consolidation.

**Rule 2 – Minimize Assembly Surfaces**

Multiple assembly surfaces typically add time and motion to the assembly sequence. In addition to the time required to rotate a partially assembled product, parts which are not fully secured can dislodge requiring rework or worse, a quality problem.

If automating, multiple assembly surfaces can increase fixture costs and equipment costs. If plastic parts are involved, the multiple assembly surfaces will likely complicate the mold with side pulls or lifters.

**Rule 3 – Design for Z-Axis Assembly**

The simplest and most preferred assembly motion is a straight down (Z-axis) stroke. This design utilizes gravity to assist the assembly. It also tends to result in the most automatable assemblies.

Alignment features such as depressions, locating pins, slots, or ribs can guide mating parts together and facilitate assembly.

**Figure 4-2.** Nut & Bolt vs. Stud & Nut.

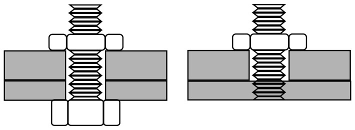


**Figure 4-3.** Part Mating.

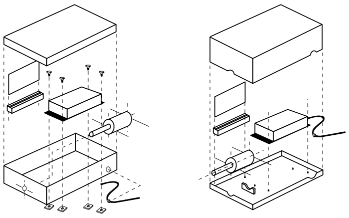
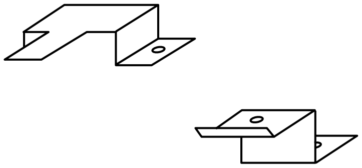


**Figure 4-4.** Nut & Bolt vs. Stud & Nut.



### Rule 4 – Improve Assembly Access

Provide a “clear view” for assembly operations. This is important for manual assembly and, in most cases, essential for automatic assembly. Avoid parts or assembly sequences that require tactile sensing for installation. Such “blind” assembly exposes the manufacturing process to significant quality risks.

### Rule 5 – Maximize Part Compliance

Part mating is a major challenge to automatic assembly. Part misalignment and tolerance stack-up is the form in assembly where different processes such as stamping, injection molding, casting, and machining — all from different vendors — are to be mated. Compliance, the ability of one part to move so that it can mate with another, must be designed into both the product and the production process. Product design compliance techniques include generous chamfers on both mating parts, adequate guidance surfaces and specifications requiring part consistency. One simple example of design for compliance is the use of oblong holes rather than round holes for post mating or screw assembly. This allows for slight misalignments due to tolerance issues. Part tolerance specification should be reasonable as they can drastically increase per part cost.

### Rule 6 – Maximize Part Symmetry

The more symmetrical a part, the easier it is to handle and orient, both manually and automatically. Symmetry also reduces assembly quality risks. The need for symmetry increases significantly with high rate automation. If symmetry is impossible, existing asymmetry should be “identified” on the outer surfaces of the part in order to provide easy recognition of parts for feeding devices or to avoid component mislocation.

### Rule 7 – Optimize Part Handling

Avoid flexible parts, such as wiring for parts that require two-handed manipulation, whenever possible. Flexible parts are difficult to automate economically. If possible, retain part positioning from the point of manufacture to the point of assembly. For example, retain position of plastic parts by automatically unloading parts to palletized trays. Avoid part designs that nest, tangle, stick together, are slippery or require careful handling.

For robotic or automatic handling, provide symmetrical vertical surfaces to simplify gripper design. Simple surfaces or towers can often be molded in to allow for neat and orderly stacking of parts without sticking.

**Rule 8 – Avoid Separate Fasteners Wherever Possible**
Fasteners are a major barrier to efficient assembly. They are difficult to feed, can cause jamming due to poor quality, and normally require monitoring for presence and fastening torque. In manual assembly, the cost of driving a screw can be six to ten times the cost of the fastener. The best design approach is to incorporate the fastening function into a major component. In plastic design, threaded fasteners are particularly poor due to the high levels of hoop stress they can generate and the notch effects they can induce. See the Product Assembly (Section 5) for molded-in fastening techniques.

**Rule 9 – Provide Parts with Integral "Self-Locking" Features**
Design parts to "nest" so that no further repositioning is required. Provide projections, indentations or other surface features that maintain the orientation and position of the parts already in place. Self-locking features are especially important for automation if the difficult task of handling and orienting parts can be uncoupled from the easier task of securing parts in the assembly sequence.

**Rule 10 – Drive Toward Modular Design**
Modular design simplifies final assembly because there are fewer parts to assemble. Automation system downtime is reduced, since experience has shown that total system performance is directly related to the number of parts being assembled. Try to limit subassemblies, including the final assembly, to no more than 15 components. Modules lend themselves to easier quality inspection prior to their insertion into the final assembly.

***Reference***
*The ten "rules" listed above are taken from "Product Design for Manufacturing and Assembly" by Bart Huthwaite. The actual rules appearing in that source have been modified to apply specifically to thermoplastics.*

# Bearings and Guides

There are a number of advantages which thermoplastic materials have over conventional materials for light load, low velocity bearing applications. These bearings can often be molded into other plastic parts at very little additional cost, so that no inventory, assembly or alignment is required. The key issues which should be addressed in bearing design are covered in this section.

## Wear

The wear rate of a plastic bearing depends on a number of variables, including bearing pressure, sliding velocity, and surface roughness.

- Bearing part pressure is the load (force) divided by the supporting area.
- Sliding velocity is the rate at which the surface of the part is sliding past the surface of the support. For a shaft, the speed can be calculated simply by multiplying the circum ference of the shaft times the shaft speed expressed in RPM or revolutions per second.

The coefficient of friction will be a function of the types of material used for the shaft and the bearing, the temperature, the surface finish of the molded parts and the effects of any lubricants which are used. In general, unreinforced crystalline polymers have lower sliding coefficients of friction than most conventional materials and amorphous plastics. GE Plastics offers a few special grades of LEXAN, VALOX and ULTEM resins which use special additives to reduce the coefficients of friction.

## Heat Dissipation

Although plastic is rarely used for high load ($P > 500$ psi) or high speed (100 fpm) bearings, heat generated from frictional resistance must be dissipated to prevent thermal acceleration of wear, chemical attack, or loss of physical properties. In general, much care is required to design bearings of this type. This dissipation of heat is largely a function of the coefficient of thermal conductivity. Since plastic materials are considered thermal insulators, bearing combinations of plastic on plastic under long duty cycles may well pose a heat problem.

## Dimensional Tolerance/Stability

The performance of a plastic bearing is very much a function of dimensional control over component sizes. If a bearing or shaft is out of location, the bearing will often not function correctly and wear may greatly accelerate. If the bearing or shaft is out of spec with respect to size, two basic conditions can occur. In the case of an undersized shaft or an oversized bearing, excessive clearance may result and a reduced support area would increase pressure. An oversized shaft or an undersized bearing can cause excessive friction or binding. Occasionally parts start out sized correctly, but change size due to interaction with the environment. Moisture absorption can affect the size of some polymers (nylon) while large temperature excursions can make thermal expansion and CTE important.

## Surface Finish/Molding

Bearing surfaces should be polished in the mold to provide a smooth finish. Some materials are better suited for smooth bearing surfaces than others. In general, an unfilled material can yield a better bearing surface than a glass-filled material. GE Plastics produces a few lubricious grades of LEXAN, VALOX and ULTEM resins which have special additives included to improve wear performance.

## Weld Line Severity/Location

The circular nature of bearings makes them naturally prone to the formation of weld lines as the plastic flows around both sides of the bearing during fill. Areas containing weld lines can be significantly lower in strength than areas not containing them. The strength of the weld line will largely depend on the properties of the material and the molding conditions (which control the temperatures of the melt fronts as they combine). As a general rule, a conservative estimate of weld line strength is between 50 to 100% of the strength of the base resin (unreinforced). As discussed above, the actual strength will depend upon material properties, part geometry and molding conditions.

Weld lines can also cause irregularities in the bearing surface and can be more prone to wear. For this reason and the strength issue discussed previously, weld lines should be located in less critical areas if at all possible.

## Strength

The strength of a bearing can be measured by comparing stresses calculated from simple formulas to the yield properties of the material. However, there are two reasons why this typically is not a significant issue for engineering thermoplastics:

- Bearings made of engineering thermoplastics will deflect when exposed to significant loadings. This can cause interference or bottoming out of the rotating members long bearing yield.
- The wear characteristics of high load bearings are generally too severe for thermoplastic materials.

**Internally Lubricated**

ULTEM 4000 resin
ULTEM 4001 resin

## Stiffness

The stiffness of a thermoplastic bearing can be determined through the use of computer-aided engineering (finite element analysis) much more accurately than through the use of hand calculations. Thermoplastic bearings require sufficient stiffness to prevent deflection, which may affect alignment and fit of mating parts. Thermoplastic bearings work best for low load, low speed bearings. GE Plastics does offer grades of ULTEM resin which are specially designed for load bearing, sliding contact applications. These grades of ULTEM resin exhibit significantly more potential for medium speed and load bearings, but chemical compatibility must be considered.

**Table 4-1.** ULTEM resin. *Coefficient of friction.*

| | | | Static | Kinetic |
|---|---|---|---|---|
| **ULTEM resin** | 1000 | steel | .38 | .40 |
| | | self | | |
| | 2300 | steel | .31 | .42 |
| | | self | | |
| | 7801 | steel | .30 | .44 |
| | | self | | |

# Hinges

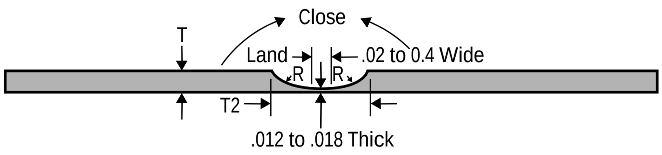
Many different types of hinges can be used when designing parts in engineering thermoplastics. Hinges can be molded-in or assembled as a secondary operation. There are design issues which must be addressed for each type of hinge. There are also specific material considerations and properties which are important to proper function of the hinge.

## Types of Hinges

Many different types of plastic hinge designs can be molded into thermoplastic parts. This can result in a significant reduction in total cost by eliminating a number of additional parts and operations, and by reducing potential quality problems regarding alignment of hinge components. A few of the potential molded-in hinge designs are as follows:

### *Living Hinge/Assembly Hinge*

Both parts being hinged together are molded in one piece, connected by a thin band of material. This band of material must flex so that the two halves come together without breaking. Both the living hinge and the assembly hinge induce high strain in the material. The living hinge is intended to withstand frequent flexing throughout the life of the part whereas the assembly hinge is intended to flex only on initial assembly of the part. Glass or mineral reinforced materials are not recommended for this type of hinge use. Elastomeric materials and unreinforced VALOX resins, because of their relatively high values of strain to fracture, may be suitable. However, even unreinforced resins used in, assembly hinges, may not be suitable for a load bearing hinge or a hinges which will be opened and closed frequently. Living hinges are often used in crystalline materials with higher strain to fracture such as nylon, polyethylene and polypropylene.



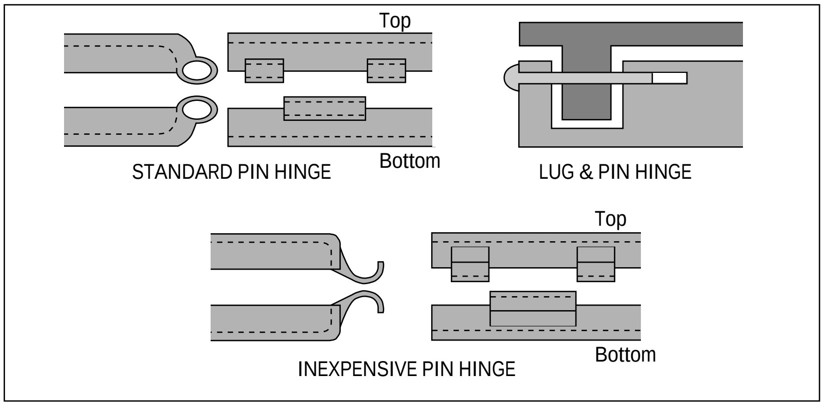
- T = Nominal Wall Thickness
- T2 = T × 2 + Land Width
- R = T, Smooth, Blended & Polished

**Figure 4-5.** Living Hinge.

### Pin and Tube Hinges

There are a variety of pin and tube hinges which can be molded into plastic parts. Alternating flanges with semicircular section geometries can be used in place of a tube so that slides and cams in the tool will not be needed. Pins are often molded with flat sections which are beyond the normal range of rotation so that the pin can be inserted from the side. It is also possible to mold alternating semicircular flanges into both parts and then insert a separate metal or plastic pin through the center. Pin and tube hinges can be designed so that the tube slides down over the pin and is locked in place when the hinge is closed but can be lifted off when the hinge is all the way open. This is often desired when cover removal is necessary for service of the internals.

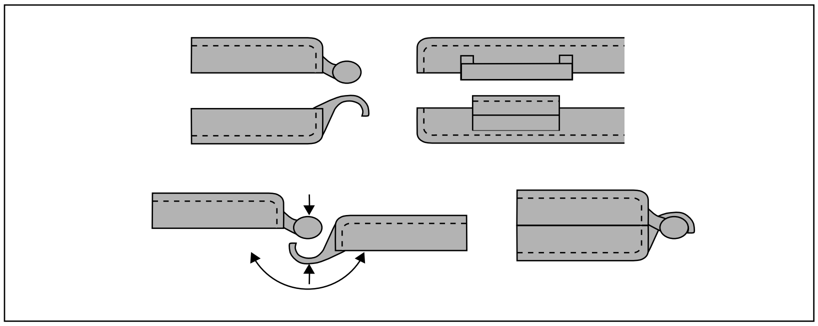
**Figure 4-6.** Pin and Tube Hinges.



### Snap-Together Hinge

These types of hinges can be molded so that they snap together during assembly. Sometimes, they consist of a pin which is supported at both ends molded into one part and a "C" shaped receptacle or semicircular opposing flanges with interference so that the sides are deflected by the pin as it is inserted.

**Figure 4-7.** Snap-together hinge.



Snap-together hinges can consist of two opposing spherical nubs that snap into a barrel with spherical receptacles on either side.

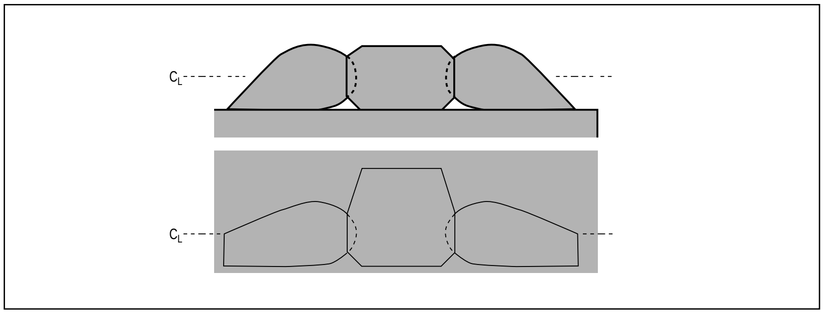


**Figure 4-8.** Snap-together hinge.

## Insert Molded Hinges

Hinge assembly plates or pins can often be molded into the part by placing the components in the tool prior to injection of the plastic. There are a variety of design and material issues associated with this method and there are cost issues associated with obtaining these hinge inserts. However, secondary operations are usually not required. The hinge can be significantly stronger and more wear resistant than a hinge which is molded out of the plastic material.

## Secondary Assembled

### *Rathbun Hinges*

A Rathbun hinge consists of two snap fit areas on each part,with a metal spring clip shaped into each.  This type of hinge is most appropriate for areas where less than 90˚ of hinge travel is desired. It does require the metal clip, but the snap fits are easily molded into the parts and the assembly process is quite simple.

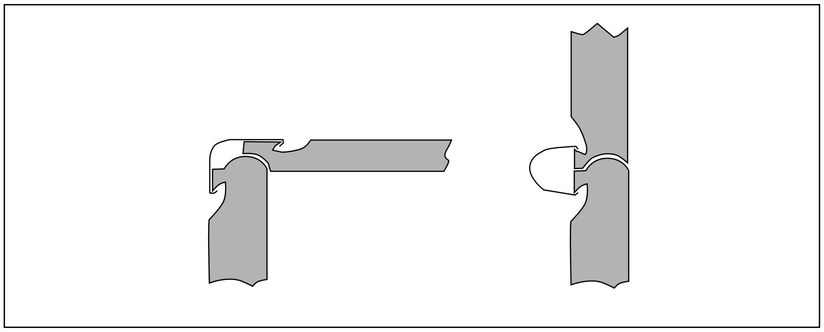


**Figure 4-9.** Rathbun hinge.

### *Assembled Hinges*

Hinges can be attached by secondary operations in order to provide for simple molding of the parts, increased wear resistance and load bearing capacity of the hinge in thinner areas of the part, and improved dimensional control in tight tolerance applications. Assembled hinges require additional parts and secondary operations, but can be put in places where hinges cannot normally be located. Often, location and attachment features, such as heat and ultrasonic stakes, ultrasonic energy directors, adhesive retention grooves, guide ribs, and bosses for threaded fasteners, can be molded into the parts quite simply. These features can significantly facilitate the location and attachment of secondary operations.

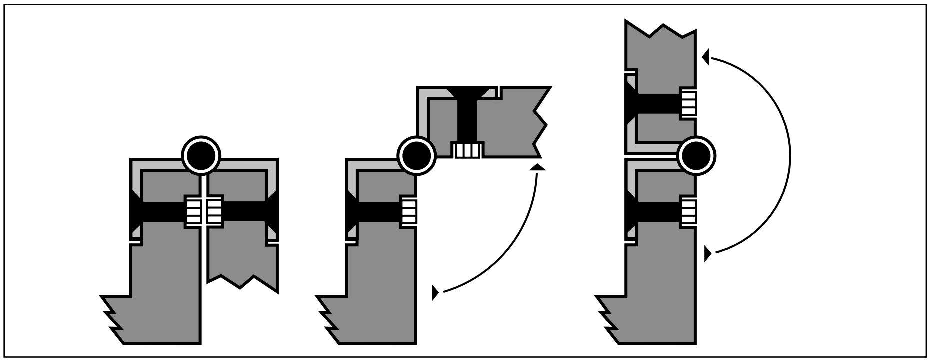


**Figure 4-10.** Assembled hinges.

# Design Issues

## Weld Lines

Weld lines form when flow fronts come together during the filling stage of molding. Depending on processing conditions, weld line strength can vary significantly. Awareness of weld line location is advisable and avoidance in critical areas is suggested. If part is not designed properly, weak weld lines can result in premature part failure.

## Parting Lines

Parting lines are the lines on the part where the tool halves come together. Often the parting line will be noticeable as a bump on the surface of the part which is caused by the material that seeped into the joint. If this bump occurs on a hinge component which is in sliding contact, (such as the side of a molded pin from a pin hinge), it can lead to either increased friction and resistance or “play” in the hinge system. Parting lines should be strategically located. The tool shutoff in that area should be identified as an important issue to the tool maker.

## Moldability

The thickness and length of the hinge, in comparison to the rest of the part, must be reviewed to determine if the hinge is likely to fill. Material flow characteristics and gating must be taken into account. Molded-in hinges often involve thin flanges or pins which can be difficult to fill. This can be especially true with a glass filled material or in a situation where the material must flow a significant distance from the gate prior to entering the hinge. Molding considerations often force hinge designers to modify hinge geometry or to incorporate flow leaders to assure filling of the hinge area.

## Coefficient of Friction

In most situations, the resistance to motion is not critical as long as it is reasonably low. However, in some cases designers want to control this factor. The resistance to motion will primarily be a function of contact area, contact pressure and the coefficient of friction between the adjacent material surfaces. The contact area can be easily controlled by changing the dimensions of the hinge pin. The contact pressure is a function of the dimensional interferences between the pin and clasps or tube. This pressure can change over long periods of time due to stress relaxation if the stress levels exceed the limits of the material at the given temperature (see page 2-22). The contact pressure can also change significantly with changes in temperature. If different materials are used, this effect can be quite severe due to the differences in coefficients of thermal expansion. This can be true even for parts made from the same material if geometric effects or glass alignment are important factors. The coefficient of friction is a function of the materials used and the finishes of the contact surfaces. For this reason, the tool is often highly polished in the contact areas. The coefficient of friction can also change during the life of a product due to wear. Also, semi-crystalline materials tend to have lower coefficients of friction than amorphous materials when rubbing against metals or a different crystalline material.

## Lubricants

Lubricants are often used to reduce coefficients of friction in hinges which require frequent motion. Some lubricants are chemically incompatible with some engineering thermoplastics. Conduct tests before using on any thermoplastic.

## Thermal Effects

Temperature can affect the hinge components in a variety of ways. Mechanical properties such as yield stress are highly temperature dependent. The strength and stiffness of the hinge components can change if a significant change in temperature occurs. Also, differential expansion or contraction can cause problems with dimensional interference, causing high levels of stress and/or increased frictional resistance to hinge motion. Temperature also influences chemical compatibility.

## Coefficient of Thermal Expansion

The coefficient of thermal expansion (CTE) of the material is important to the performance of the hinge for a number of reasons. Differential expansion or contraction of the materials in the hinge can cause a dimensional interference which results in higher stress levels and increased resistance. With molded-in inserts, different rates of expansion for the two materials can lead to high levels of internal stress. The overall part dimensions will also change with temperature, which may result in misalignment preventing proper closure of the mating parts.

## Molded-In Stress

The level of molded-in stress in the part will affect the dimensional stability, chemical resistance and physical properties of the part. The level of molded-in stress is a function of the pressures and temperatures in the molding cycle, the tool temperature, the material viscosity and the part geometry. High levels of molded-in stress in the hinge area can hinder the performance significantly.

## Stress Relaxation

Stress relaxation is an important material characteristic for determining the long term performance of a hinge, with regard to resistance to motion. The stress relaxation characteristics of a material can be significantly affected by additives such as glass and minerals. These additives tend to reduce the level of stress relaxation and improve the creep resistance of the material.

## Yield Strain

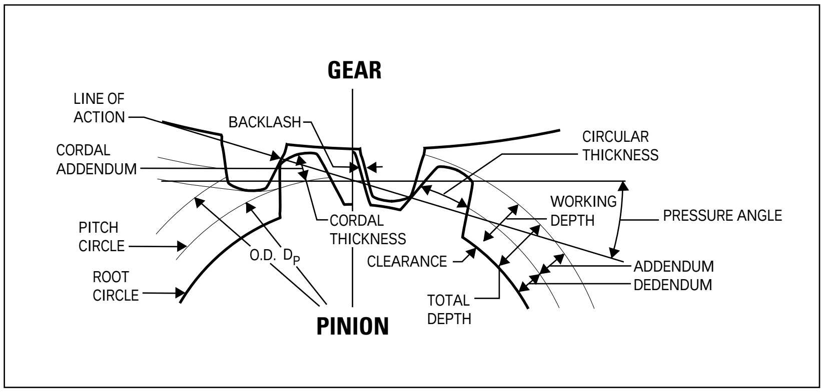
The percent strain to yield of a material is an important characteristic to consider when designing snap-together hinges. Often a snap-together hinge is taken well beyond the normal operating strains during the assembly operation. It is critical to the function of the hinge that this strain be recoverable. The percent strain to yield (permanent deformation) is dependent upon the temperature and rate of deflection.  Due to the viscoelastic nature of thermoplastic materials, it is often possible to take a material beyond the proportional limit and still have complete recovery.

Momentary loading above the proportional limit is encountered in snap fit design also. A check of the material characterization for snap fits may prove helpful.

# Gears

Plastics are very good materials for low speed, light load gears for reasons of economy, performance, production efficiency and weight. Engineering thermoplastics are particularly well-suited for gears because of their combination of thermal, mechanical, electrical, environmental resistance and flame retardant properties. Gear loads are transmitted during the gear motion by mating teeth which mesh with each other. This action tends to bend the teeth and subject them to a certain sliding motion. Thus, the wear characteristics and lubricity of the gear material are very important. All gear types (spur, worm, bevel, helical, and annular – internal and external) experience some combination of these rolling and sliding forces. In general, wear is critical on the tooth profile and dimensional stability is critical for overall gear performance. Due to the wide variety of gears which can be molded out of plastics and the number of equations relevant to each, only a general discussion of gear design issues is presented here. For detailed information regarding gear design, consult a gear design book or a plastic gear specialist.

**Figure 4-11.** Gear-Tooth Nomenclature.



## Gear Terminology

**Active Profile:** That part of a gear tooth profile which actually contacts the profile of its mating tooth along the line of action.

**Addendum:** The height of a gear tooth outside the pitch circle; the radial distance from the pitch circle to the outside diameter of the addendum circle, numerically equal to the reciprocal of the diametral pitch.

**Addendum Circle:** The circle at the top of the teeth on a gear.

**AGMA Number:** A number indicating the relative quality of a gear as specified by the American Gear Manufacturers Association, a higher number indicating higher quality.

**Angle of Action:** The angle through which one tooth travels from the time it first makes contact with its mating tooth on the line of action until contact ceases. This is divided into the angle of approach and the angle of recess.

**Angle of Approach:** The angle through which a tooth moves from the time of first contact with its mating tooth until contact is made at the pitch point.

**Angle of Recess:** The angle through which a tooth moves from the time of contact at the pitch point until the contact with its mating tooth ceases.

**Backlash:** The amount by which a tooth-space exceeds the thickness of the meshing tooth, provided to compensate for thermal expansion; the difference between tooth thickness and tooth-space as measured on the pitch circle.

**Base Circle:** The circle from which an imaginary line would be unwound to develop the involute curve.

**Base Diameter:** The diameter of the base circle.

**Base Pitch:** The normal pitch of an involute gear; the distance between two successive parallel involutes which form the profiles of two adjacent teeth, equal to the circumference of the base circle divided by the number of teeth on the gear.

**Center Distance:** The distance between the centers, or axes, of a pair of mating gears.

**Circular Pitch:** The length of an arc of the pitch circle that corresponds to one tooth interval, equal to the circumference of the pitch circle divided by the number of teeth on the gear.

**Circular Tooth Thickness:** The thickness of a single tooth measured along the pitch circle; for an unmodified tooth, equal to one-half the circular pitch.

**Clearance:** A small space provided so that the top of a meshing tooth will not touch the bottom land of the other gear as it passes the line of centers.

**Dedendum:** The depth of a tooth-space below the pitch circle; the radial distance from the pitch circle to the root circle, equal to the addendum plus the tooth clearance.

**Diametral Pitch:** The ratio of the number of teeth to the pitch diameter of a gear, representative of the number of teeth per inch of pitch diameter.

**Face:** The surface of a gear tooth lying between the pitch circle and the addendum circle.

**Fillet Radius:** The radius of curvature of the corner where a tooth joins the root circle. This corner is radiused with extra material in order to reduce the buildup of stress concentrations.

**Flank:** The surface of a gear tooth lying between the pitch circle and the root circle.

**Gear:** The larger of a pair of gears.

**Gear Rack:** A spur or helical gear with an infinite gear radius, wherein the pitch surface is a plane which has translational motion while rolling with the pitch cylinder of its mate.

**Gear Ratio:** The ratio of the number of teeth in the gear to the number of teeth in the pinion.

**Interference:** A term relating to conditions which permit contact between mating teeth away from the line of action so as to interfere with the transmission of uniform motion.

**Involute:** A system of gearing; the principal profile of a gear tooth; a curve generated on a circle, the normals of which are all tangent to that circle.

**Line of Action:** The line along which correct contact between mating teeth is made, resulting in transmission of uniform motion from one gear to another.

**Module:** The ratio of the pitch diameter to number of teeth of a gear; the reciprocal of diametral pitch, representing the pitch diameter per tooth of a gear.

**Pinion:** The smaller of a pair of gears.

**Pitch Circle:** A circle that represents a smooth disc which would transmit the desired relative motion by friction.

**Pitch Diameter:** The diameter of the pitch circles of mating gears.

**Pressure Angle:** The angle between the line of action and a line perpendicular to the common center line of two mating gears or the angle cutting the tooth face at the pitch point and the tooth face itself. The most common pressure angles are 14.5, 20 and 25°, of which 20° is by far the most commonly used.

**Root Circle:** The circle at the bottom of the tooth-spaces in a gear.

**Whole Depth:** The total depth of the tooth-space in a gear measured radially between the addendum circle and the root circle.

**Working Depth:** The depth that the teeth of one gear extend into the spaces of its mating gear, equal to the sum of the addenda of mating gears; also equal to the whole depth minus the clearance.

## Types of Gears

While the primary purpose of a gear is to transmit a load through uniform motion, the nature of that load and the magnitude of the forces involved can vary greatly from application to application. In an application such as an instrument to monitor pressure, a gear may never have to rotate more than one revolution and would experience forces which are negligible. However, if the application is of critical importance, say for constant monitoring of pressure in a chemical reactor, then very smooth, highly reliable performance is essential to accuracy.

### *Spur Gears*

Spur gears are the most common types of gear and are the ones typically thought of when the word “gear” comes to mind. They transmit motion from gear to gear tangentially in the plane of the gear. A pair of spur gears may have different diameters to permit either an increase or a reduction in rpm or torque, but in order to transmit uniform motion, the two gears must have the same diametral pitch as well as the same pressure angle. When these conditions are met, the horsepower transmitted across a pair of spur gears is constant. Spur gears are relatively simple to manufacture and their design is both uncomplicated and well-documented. They can be used at virtually any speed as long as the noise at high speed is acceptable.

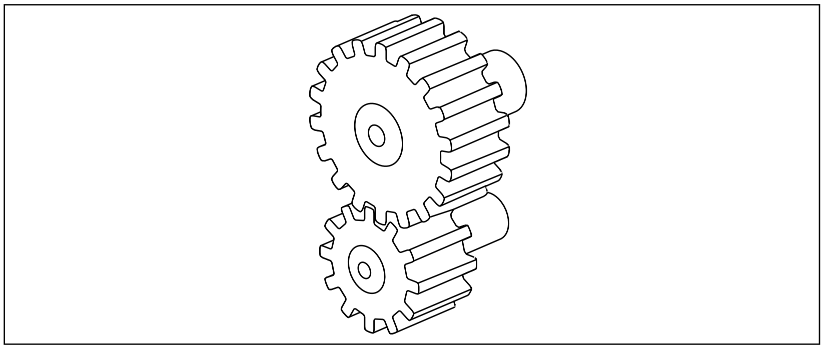
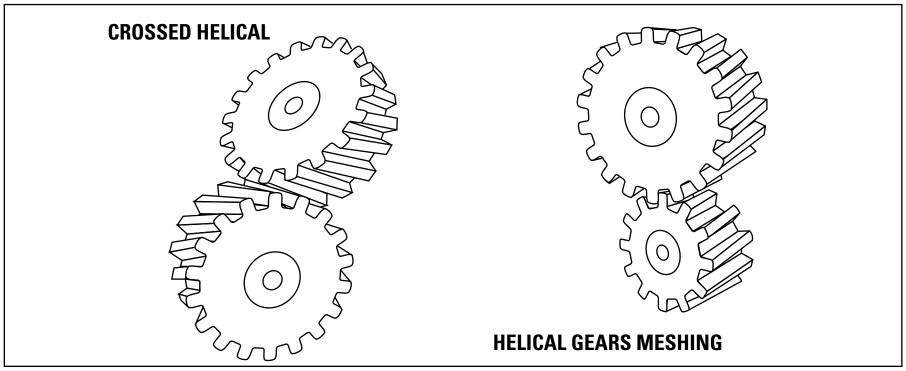


**Figure 4-12.** Spur Gear.

### Helical Gears

Helical gears have teeth which are formed on a spiral that winds around the axis of the shaft running through the gear (as opposed to spur gear teeth which are formed parallel to this axis). They are high-efficiency gears (~98 to 99%) which are typically used when high speeds and high horsepower are involved. The gear helix may be either left- or right-handed and can have various helix angles. These angles cause the pair of gears to exert end-thrust on the bearings that carry the shafts on which the gears are mounted. End-thrust increases with the helix angle, so these angles are generally confined within the range of 13 to 23˚. Provisions should be made to compensate for thrust in the bearings. The design equations for helical gears are similar to those for spur gears, with a modification to account for the helix angle. Helical gears are considered superior to spur gears due to a helical overlap (more than one tooth in contact) that can be 2.0 or greater. This overlap is what gives helical gears a maximum of smooth and quiet operation. Axial thrust in a helical gear can be eliminated by a modification known as the herringbone or double helical configuration. This variation combines a left-hand and a right-hand helix with the result that the two thrusts cancel each other out.

**Figure 4-13.** Helical Gears.



### Annular or Internal Gears

Annular, or internal, gears can have either spur or helical configurations. The pitch diameter of the external gear should not be larger than two-thirds that of the internal gear for maximum efficiency. These gear combinations offer a reduction in center distance and are most useful where space in an assembly is limited. In addition, the internal gear serves as a protective cover over its mate.

## *Bevel Gears*

Bevel gears are typically used for right angle drives and for providing high efficiency in operation. They may also be used to transmit power between shafts at any angle. Bevel gears can be made with either straight or spiral teeth which taper in both thickness and height to almost zero at the axis of the gear. In a straight bevel gear, the teeth intersect at the axis.

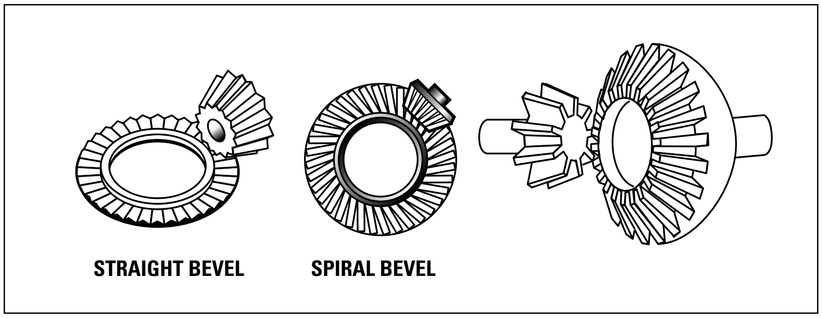


**Figure 4-14.** Bevel Gears.

## *Worm Gears*

Worm gears are used for right angle drives and can provide very high gear ratios, but they operate with much more sliding action than other gear types and have comparatively lower efficiency (~90%) as a result. Wear is a greater concern with worm gears, particularly with single enveloped worms when there is only line contact between the gear pair. In VALOX resin applications, PV values should be calculated and the worm gear design should be modified to accommodate the wear factor. Double enveloped or waisted worms will provide the greatest contact area.

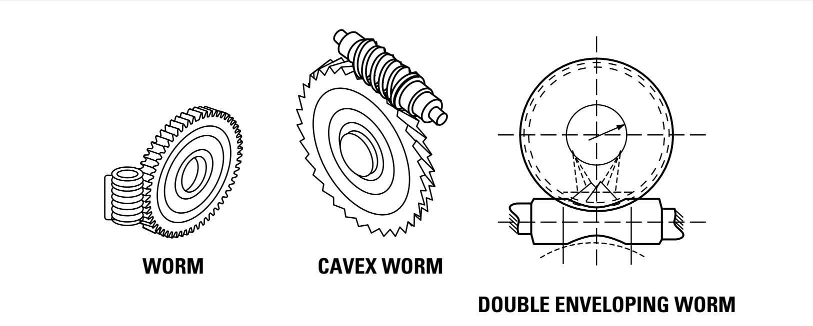


**Figure 4-15.** Worm Gears.

### *Gear Tooth Forms*

In order to transmit uniform motion across mating gears, tooth profiles must be of conjugate form and long enough to provide continuous action. Both the cycloidal and involute gear systems meet these requirements, with the latter being the most common.

## Gear Action and Force

**Driving Force Has Two Components:**

- A Tangential Force F(t)
- A Radial Force F(r)

When one gear tooth drives another, the driving force F(n) acts along the line of action. This driving force has two components:

- A tangential force F(t), and
- A radial force F(r)

The tangential component represents the work function transmitting the load from the driving shaft to the shaft being driven. The radial component represents the work expended in an attempt to separate the shafts, i.e., work dissipated in the form of heat generated in the bearings.

Many factors determine the operating pressure of a pair of gears, but in applications calling for maximum gear efficiency, the oper ating pressure angle should be kept as low as other considerations will permit. Each tooth may be considered to be a cantilever beam supported at one end. Contact with its mating tooth exerts both bending and shearing forces, causing the requirement that the gear material have sufficient stiffness, flexural strength and shear strength to withstand the load.

During gear travel, the mating teeth both roll on and slide over each other, causing a combination of compressive stress and stress due to friction on the tooth surface at point of contact. First, there is an initial compressive loading caused by contact. The rolling action of the two surfaces pushes this compressive stress just ahead of the contact point. At the same time, sliding occurs causing frictional forces to develop a region of tensile stress just behind the point of contact. The areas in which these two stresses interact are the stress centers.

In some gear designs, rolling forces will predominate; in others, sliding forces may be more critical, but all will have a combination of both no matter how well-designed or expertly manufactured. When the contact point on the tooth and the pitch point coincide, the sliding forces on each tooth face change direction and nullify each other; only rolling forces will apply. However, this does not mean that the pitch point is less susceptible to surface failure. In fact, it is at the pitch point that serious failure is most likely to occur.

While the pitch point does not experience compound stresses, it does bear high unit loading. This is because at both start and end of tooth contact, the previous pair of teeth should still be bearing some of the load, if the gears have been properly designed. At mid-contact, however, one tooth pair is usually bearing the entire load at or slightly above the pitch line. This high unit loading can cause fatigue, severe heat build-up and/or surface deterioration that may lead to failure.

Contributing to this stress is the factor of non-uniform wear above and below the pitch line. Because the sliding forces are not at work in this area, the pitch point tends to wear less than the rest of the tooth face. If wear is particularly severe on the balance of the tooth surface, the region of the pitch line can become elevated. This concentrates and increases the loading pressure of contact which, in turn, causes proportionally higher fatigue and heat build-up in the area.

Analyzing for stress in any gear design must take all the effects of gear action into account in order to ensure optimum gear performance.

## Gear Stress

**Gear Stress**

Backlash can effectively allow for dimensional change in gears. Radii at root improves shock load compatibility.

**Fatigue Endurance Limit**

$$\text{Mean Stress} = \frac{\text{Max. Stress}}{2}$$

**Flexural Strength**

Not appropriate.

For gear designs in engineering thermoplastics, as with any plastic, it is advisable to calculate the increase in gear size at the highest use temperature and provide sufficient backlash to prevent binding. Since the mechanical properties of VALOX resin are temperature dependent, the load-bearing capacity of molded gears decreases with increasing temperature.

Gears are also very susceptible to stress build-up at the roots of the teeth due to shock loading. Because plastics are notch-sensitive, extending a full radius to the tooth root is suggested.

Since the teeth of plastic gears are basically stressed in a flexural manner, the endurance limit of the material should be used when designing, to allow for cyclic reduction of mechanical stress.

Gear tooth shape, however, does not conform to the idealized configuration of the three-point bending test used to determine flexural strength by ASTM D790. For this reason, it is often preferred to use the tensile strength of the material in order to provide a greater margin of safety.

## Tangential Load on a Gear Tooth

Generally, load limits or design requirements can be calculated from the Lewis equation:

$$Wb = \frac{S*f*Y}{p}$$

where: S = design stress for a given life expectancy (psi)
p = diametral pitch (1/in) f = face width, teeth (in)
Y = Lewis tooth-form factor (Table IV, B.40)
Wb = tangential load on tooth

The conditions of gear service should be taken into account in load calculations by dividing the design working stress by a service factor, Cs. Values for various service factors are given below.

**Table 4-2.** Type of Service.

**TYPE OF SERVICE**

| | Regular 8-10 hrs/day | Constant 24 hrs/day | Intermittent 3 hrs/day | Occasional 1/2 hr/day |
|---|---|---|---|---|
| **TYPE OF LOAD** | | | | |
| Steady Load | 1.00 | 1.25 | 0.80 | 0.50 |
| Light Load | 1.25 | 1.50 | 1.00 | 0.80 |
| Medium Shock | 1.50 | 1.75 | 1.25 | 1.00 |
| Heavy Shock | 1.75 | 2.00 | 1.50 | 1.25 |

## Gear Torque

Torque is transferred by a gear through the tangential forces acting on the gear teeth. Assuming that only one tooth of each gear in contact at or near the pitch point is carrying the entire load, a simple method of calculating the tangential force on a gear tooth is given by:

$$Wb = \frac{2 \times T}{Dp}$$

where: Wb = tangential force on tooth (see tangential load)
T = gear torque
Dp = pitch diameter

Rearranging:

$$T = \frac{S \times Dp \times f \times Y}{2 \times p}$$

where: T = gear torque (in-lb)
S = allowable bending stress (see tangential load)
Dp = pitch diameter (in)
f = face width, tooth (in)
Y = Lewis tooth-form factor (see tangential load)
p = diametral pitch (1/in)

In international units:

$$Hp = \frac{S \times Dp \times f \times Y \times n}{126{,}000 \times p}$$

where: Hp = Horsepower transmitted
n = gear speed (rpm)

Many gears are subjected to a “stall torque” which is significantly higher than the actual operating torque. In these cases, it is advisable to use the yield stress of the material at operating temperature of the bending stress calculations.

## Factors Affecting Tooth Loading

To calculate tooth loading accurately, several factors must be known, including:

- the gear ratio
- center distance limits
- gear or pinion speed
- gear or pinion horsepower or torque
- type and duration of loading
- operating temperature
- service life requirement
- type of lubrication (if any)

The gear ratio is determined by the desired rate of motion between the driving (or input) gear and the driven (or output) gear. Center distance is usually set by the space allocated to the gear pair.

The speed of either the driving gear or the driven gear must be known, as well as either the horsepower to be transmitted or the torque of one of the gear pair.

The expected service life should be stated along with the operating conditions (loading, temperature and lubrication) for meaningful predictions to apply.

In addition, pressure angle and diametral pitch are critical factors, since they determine the size and shape of a gear tooth and, consequently, determine the load-sharing ability and strength of the tooth.

The most common pressure angles are 14.5, 20 and 25°, with the 20° pressure angle being used most often. The 20° pressure angle has a higher load-bearing ability than the 14.5°, and it allows using fewer pinion teeth to be used before undercutting becomes a concern.

A 25° pressure angle has an even higher load carrying capacity than the 20° angle and may have better wear characteristics than lower angles. However, it is also more sensitive to center distance variation and as a result it is usually not as smooth or quiet in operation.

Lubrication (or the lack thereof) has an effect on gears in that lubricated gears tend to fail in flexure while unlubricated gears tend to fail through surface wear. Unlubricated gears must be designed for contact stress.

## Helical Gear Design

A helical gear is essentially a spur gear with teeth slanting across its face in a cylindrical spiral, or helix, to the axis. Helical gears are preferred over spur gears in many applications due to their smoother and quieter operation.

The involute tooth profile is normally used for helical gears as small variances in center distance will not affect tooth action. However, helical gears require perfect tooth profiles and exactly equal helix angles for proper performance. These requirements can be difficult to fulfill, particularly when mating gears are of dissimilar materials.

## Bevel Gear Design

Bevel gears are widely used in applications involving power transmission between intersecting shafts where the angle between shafts is equal to the sum of the pitch angles of the mating gears.

On a straight bevel gear, the teeth are formed with all elements on planes which intersect at the axis of the gear. Bevel gear teeth are tapered in both thickness and height, with the outer portion (the heel) longer than the inner part (or toe). The tooth profile in a normal section is approximately that of an involute spur gear.

The pressure angles most commonly used for bevel gears are 14.5 and 20°. Dimensions will vary with the shaft angle and are not given here. Bevel gears exert both axial thrust and radial loads on the shaft support bearings, which must be accounted for. Also, if bevel gears have too few teeth, undercutting can be a problem.

## Worm Gear Design

**Plastic Limitations in Worm Gear Sets**

- High pressure
- Surface temperature build-up
- Excessive wear

Worm gears are the least common application area for plastic due to a number of limiting factors in worm design. Worm gear sets are composed of a small driving gear which resembles a screw (the worm) mated with a larger take-off gear called the wheel, the teeth of which are curved to conform to the diameter of the worm.

Because a throated contact line cannot be molded into plastic gears as readily as in machined metal worms, a simple helical configuration is usually given to the wheel. As a result, the gear load is transmitted across very small contact points between the teeth of the helical wheel and the threads of the worm. This leads to high pressures, surface temperature build-up and excessive wear.

**Torque Capacity**

Helical gears determine torque capacity.

Since the teeth of the helical wheel are weaker than the threads of the worm gear, maximum output torque is limited by the torque capacity of the helical gear. Thus, the load-bearing capacity of plastic worm gear sets is lower than that of other gear types.

Due to the dissimilar configuration of the toothed wheel and the screw-like worm, extremely high sliding forces are present during operation. These can increase the strength of the material and promote a higher wear rate. Worm gears generally have very small diameters since they are typically cut or molded as part of a drive shaft. The nature of most applications is such that the shaft is not well-supported at both ends. Overloading and/or stalling torques can cause the shaft to bend axially with a resultant interference in the meshing gears.

Also, because of the small diameter of the worm gear, the tooth size of the wheel is limited. Since the load is concentrated on only a small area of the tooth, there is uneven stress distribution across its width.

Initial lubrication should always be provided and continuous lubrication is suggested wherever possible. Other heat-dissipation methods, should be considered, particularly when external heat can be carried into the gear, as from a motor.

For worm gear calculations, the most liberal safety factors should be applied to allow for stress concentrations due to limited point contact.

## Backlash

Also known as “circumferential play” or “tangential clearance,” backlash is generally defined as the distance by which tooth-space exceeds tooth thickness, as measured on the pitch circle. The purpose of backlash is to prevent gears from binding or seizing-up by making simultaneous contact on both sides of meshing teeth.

Backlash is necessary for several reasons and is influenced by various factors, among them:

- operating temperatures
- thermal expansion
- mounting tolerances
- tooth shape and position
- center distance tolerances
- tooth size and accuracy
- post-mold dimensional changes
- other components of the assembly
- runout of shaft bearings
- gear load, speed and running conditions

All of these are interdependent to some degree, but the most critical factor is temperature.

Gears operating under moderate loads and at moderate speeds at room temperature will be less affected by small variations in backlash. At high load, high speed or high temperatures, gears should have both greater tooth accuracy and additional backlash to compensate for the effect of thermal expansion. As a starting point, here are suggested backlash values for VALOX resin gears operating at room temperature:

| Diametral Pitch | Pitch Backlash in (mm) |
|---|---|
| 16 | 0.004 – 0.006 (0.102 – 0.152) |
| 20 | 0.003 – 0.005 (0.077 – 0.127) |
| 32 | 0.002 – 0.004 (0.051 – 0.102) |

This is only a starting point, since the operating temperature is dependent upon other factors such as gear load, running speed and tooth size. Gears operating at room temperature at high permissible loads and speeds can experience a rise in tooth temperature of 100°F (38°C).

Clearly, any method of heat management at the tooth surfaces will decrease the likelihood of gears binding due to insufficient backlash. One method is through continual lubrication. Another is to pair the plastic gear with a metal mate having a higher heat dissipation factor.

Backlash may be increased by extending the center distance of mating gears. This provides an advantage of more clearance between the outside diameter of one gear and the base diameter of the other, allowing for expansion at high temperatures without radial interference. However, increasing center distance causes the teeth to mesh outside the pitch circle, which can result in greater wear.

It must also be noted that the specified center distance can be affected by other factors. If, for example, other components of the assembly are molded of plastic, their dimensions may change over time due to thermal expansion or post-mold shrinkage from high temperatures. Gear type can also influence center distance, as with bearing runout due to the axial thrust of helical gears.

Therefore, providing backlash by means of increased center distance is a method which should be approached with the utmost caution.

In all cases, backlash and center distance measurements and adjustments should be made under actual operating conditions over time using molded prototypes in order to accurately predict gear performance.

## Fillet Radius

Plastic gears are most susceptible to stress concentrations at the teeth roots. These stresses are built up by shock loading and should be accounted for in design.

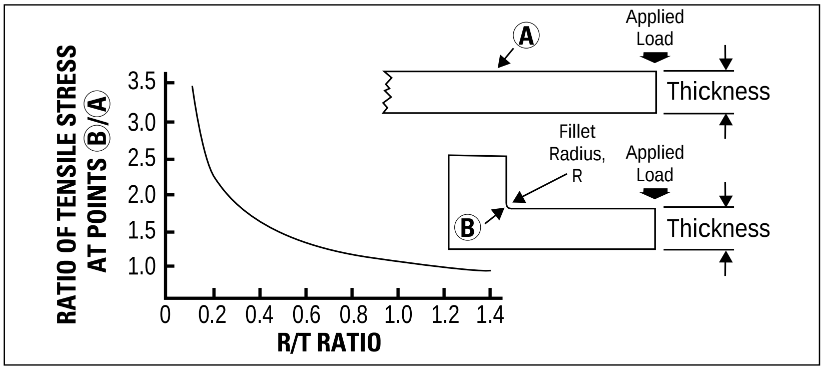


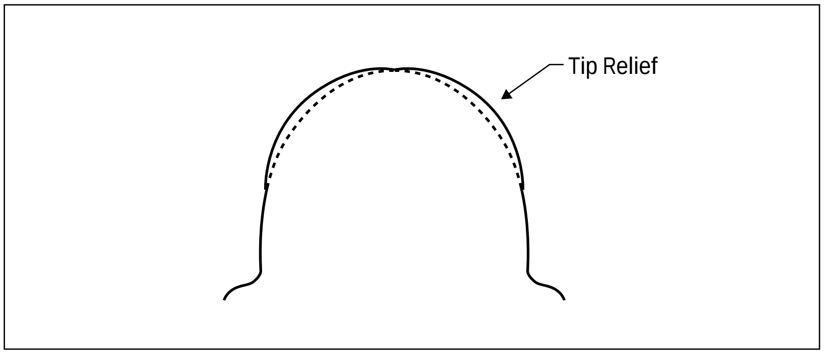
**Figure 4-16.** Stress-Concentration Factor.

A suitable design is a full fillet radius which extends from the root of one tooth to the root of its adjacent tooth. As with threads, the larger the radius, the lower the stress concentration.

## Tip Relief

Because plastic gears are prone to deflection, the teeth may require tip modification to prevent interference which could cause excessive noise or wear.

**Figure 4-17.** Tip Relief.



This modification, called tip relief, is commonly accomplished by trimming or shaving the tooth faces from a point about halfway up the addendum to the top. The amount of material removed depends upon the accuracy of the gear (i.e. more relief is typically required for lower AGMA quality numbers) but this should not appreciably affect the overall strength of the tooth.

## Noise

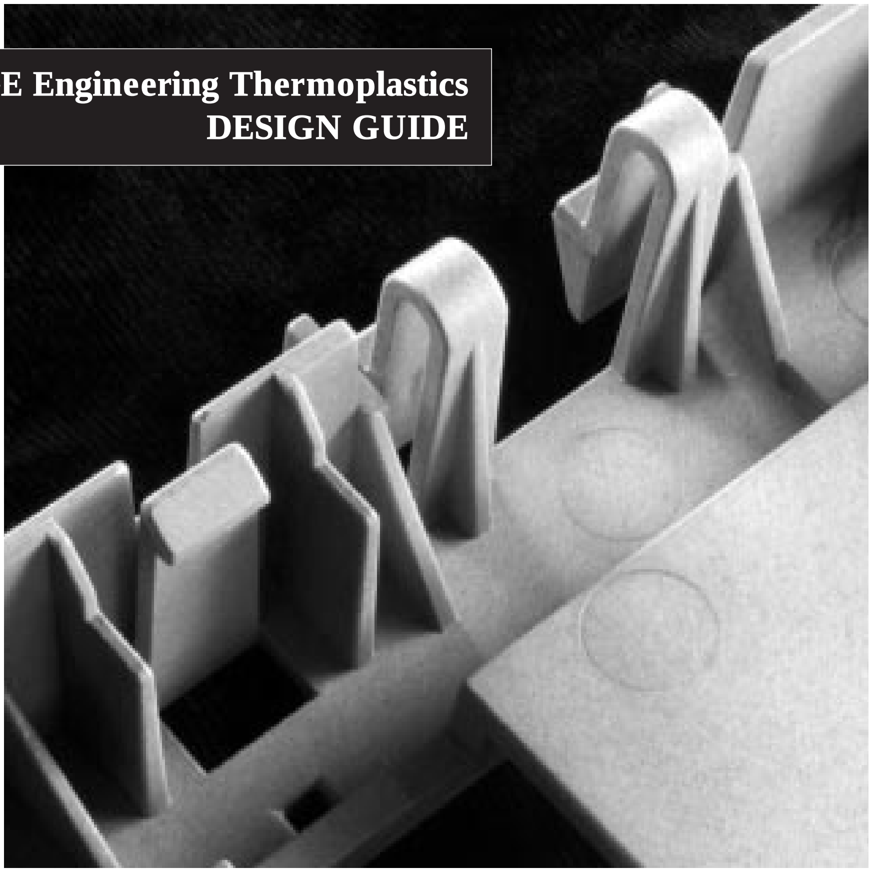
Plastic gears are generally less noisy than metal gears due to their resiliency, lower coefficient of friction and ability to dampen vibration. However, noise can occur in a plastic gear system and, if it becomes a problem, may be handled by one of the following:

- tip relief
- increasing gear accuracy (higher AGMA number)
- increasing contact ratio

## Notes

**GE Plastics**

GE Engineering Thermoplastics
DESIGN GUIDE



# Product Assembly

- *Assembly Options*
- *Coatings/Shielding*
- *Aesthetic/Decorative*
- *Painting*

# Product Assembly

Parts made from thermoplastic materials lend themselves to a number of ways of assembly and finishing. Many assembly techniques can use the inherent nature of the material to eliminate parts. Finishing may serve decorative or functional requirements of an application. A variety of techniques are offered. The best suited technique for a particular design is dependent on performance, cost and number of units to be produced. In most cases, design considerations should be examined early in the development cycle.

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# Assembly Options

## Press Fits

The strength of a press fit is dependent on mechanical interface, thus it is possible to assemble parts made of dissimilar materials, whether they are dissimilar plastics, or metal and plastic parts. With no physical bond at the interface, the designer should not expect a hermetic seal.

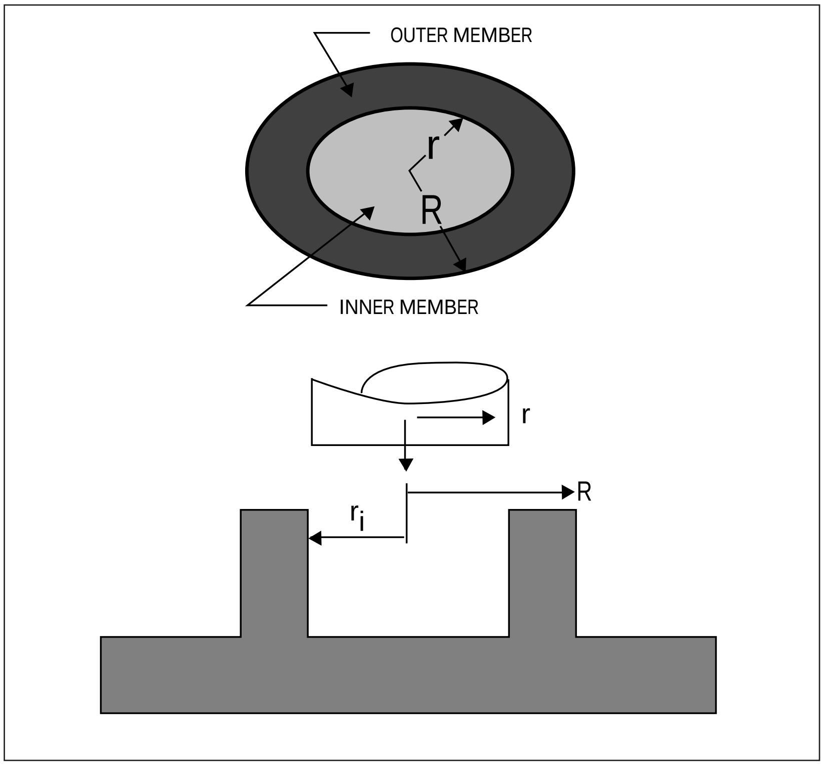
*Press fits provide a fast, clean and economical method of component assembly.*

Press fits involve a significant level of stress applied continuously. This condition makes environmental elements and long term performance key items of concern. Chemical compatibility of materials under stress must be assessed. Temperature changes will affect the joint strength as modulus change; interference may change with dissimilar materials with significantly dissimilar coefficients of thermal expansion and the rate of creep will change. Despite the complex interactions, press fits are frequently used to retain contacts or hold conductors in electrical bases.

### *Stress Level Calculations*

For a cylindrical interference press fit the contact pressure is needed in order to calculate the stress levels.

**Figure 5-1.** Press Fit Dimensions.



In the case of a press or shrink fit, $r - r_i$ is the radial interference; twice this sum is the diametrical interference, Δ, or

If shaft and hub are similar material, the allowable interference, Δa, is

$$\Delta a = \frac{2r\sigma a}{Ep} \quad \frac{K+1}{K}$$

If shaft is metal and hub is plastic

$$\Delta a = \frac{2r\sigma a}{Ep} \quad \frac{K+\nu p}{K}$$

$\sigma a$ = Allowable design stress for plastic
$E_P$ = Modulus of plastic
$V_P$ = Poisson's ratio of plastic

**Diametrical Interference = Δ**

$$\Delta = \frac{2rP}{K}\left[\frac{K+\nu_h}{E_h} + \frac{(1-\nu_s)}{E_s}\right]$$

$P$ = Contact pressure
$E_h$ = Hub modulus
$E_s$ = Shaft modulus
$\nu_h$ = Poisson's ratio for hub material
$\nu_s$ = Poisson's ratio for shaft material

$$K = \frac{1+\left(\frac{r}{R}\right)^2}{1-\left(\frac{r}{R}\right)^2}$$

Keeping with prudent design practices, a reasonable factor of safety must be used when designing a press fit. Dimensional tolerance required for parts used in press fits can be critical and should be accounted for by doing a worst case calculation for the maximum material conditions (maximum tolerance limit O.D. of inner part, minimum tolerance limit I.D. of outer part). Initial stress level should be interpreted using accurate stress-strain curves. Long term material response should also consider creep curves for viscoelastic considerations.

**Tolerances**

Check tolerance stacks for acceptable interference.

**Long-Term Considerations**

- Creep rupture
- Chemical attack
- Stress relaxation

## Temperature Effects/Thermal Expansion

If dissimilar materials are used in a press fit assembly, the different coefficients of thermal expansion will cause the parts to contract or expand at different rates as the temperature changes. This can cause a dramatic increase in the stress levels in the part and can also lead to thermally driven fatigue of the material, if the temperature change is severe and repeated. The severity of this condition often depends upon the disparity between the coefficients to thermal expansion of the two materials (e.g. steel - 0.65; x10(-5) in/in/°F; unfilled NORYL resin - 3.3 x10(-5) in/in/°F). Thus, glass or mineral filled materials are often more appropriate than unreinforced materials for press fits with metal components. A sample thermal expansion calculation for various materials can illustrate this point:

Change in Diametrical Interference

$I = (CTE1 - CTE2) \times (b) \times (T2 - T1)$
CTE1 = Coefficient of Thermal Expansion Material 1
CTE2 = Coefficient of Thermal Expansion Material 2
b = O.D. of Inner Member (Original Contact Surface)
T2 = New Temperature
T1 = Old Temperature

Example:

CTE 1 (Unfilled Noryl resin) = $3.3 \times 10^{-5}$ in/in/°F
CTE 2 (Steel) = $0.65 \times 10^{-5}$ in/in/°F
Temperature 1 = 73°F (23°C)
Temperature 2 = 140°F (60°C)
Initial O.D. of Inner Part = 3.0 in (76.2 mm)
Initial Interference = 0.010 in (0.254 mm)

$I = (3.3 \times 10^{-5} - 0.65 \times 10^{-5}) \times (3.0) \times (140 - 73) = 0.0053$ in (0.1346 mm)

Thus, with change in temperature, the effective diametrical interference will be decreased 50% with NORYL resin hub and steel inserts.

### *Modulus Change*

The temperature environment to which the part is exposed will affect the moduli of various materials differently. In general, the moduli of thermoplastic materials are more temperature dependent than those of many other materials, such as metals. The strength of a press fit will change significantly at elevated temperatures.

The appropriate modulus at temperature can be substituted in the interference equations to calculate the joint pressure and stress.

### Long-Term (Time) Effects

In applications where the long-term holding power of an assembly is of prime importance, reliability will depend on the creep behavior of the materials used. For example, because of its outstanding creep resistance, VALOX resin offers excellent perfor mance in press-fit operations. Figure 5-2 gives the recommended maximum diameter interference for VALOX resins and metal at ambient conditions.

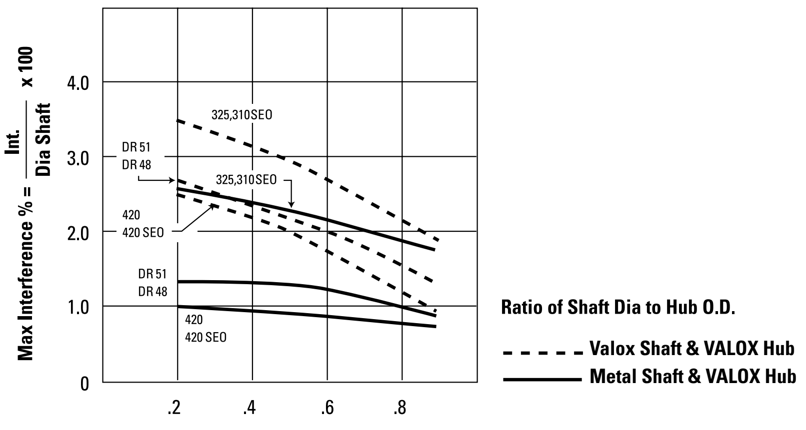


**Figure 5-2.** Press Fit Insert.

The Lame's equations for thick-walled cylinders can be used to determine a general expression assembly interference.

$$\Delta D = \frac{S_d D_s}{L}\left(\frac{L + \nu_h}{E_h} + \frac{1 - \nu_s}{E_s}\right)$$

and

$$L = \frac{1 + (D_s/D_h)^2}{1 - (D_s/D_h)^2}$$

Where:

$\Delta D$ = Diametrical interference (in)
$S_d$ = Design Stress (psi)
$D_h$ = O.D. of hub (in)
$D_s$ = O.D. of shaft (in)
$E_h$ = Tensile modulus of hub (psi)
$E_s$ = Modulus of elasticity of shaft
$\nu_h$ = Poisson's Ratio of hub
$\nu_s$ = Poisson's Ratio of shaft
$L$ = Geometry factor
$\iota$ = Engagement length

The holding and assembly force may be approximated by multiplying the joint pressure, joint area and coefficient of friction of the materials together.

$$F = PAf = \frac{S_d}{L} (\pi D_s l)\, f$$

Where:
F = Assembly molding force
P = Joint pressure
A = Area of joint
$D_s$ = Shaft diameter
l = Length of press fit
f = Coefficient of friction
$S_d$ = Design stress

At elevated temperatures, the strength of the assembly will be altered due to changes in effective interface caused by thermal expansion and the modulus of elasticity. To calculate the loss of interface due to thermal expansion when a VALOX resin hub is assembled to a metal shaft:

$$D - D_o = (\alpha_h - \alpha_s)\, D_o \Delta T$$

Where:

$D_o$ = Original diameter
D = Original diameter at temperature
$\Delta_h$ = Coefficient of thermal expansion of hub
$\Delta_s$ = Coefficient of thermal expansion of shaft
ET= Changes in temperature

The use temperature modulus can be substituted into the proper interference calculation to determine the reduced design stress.

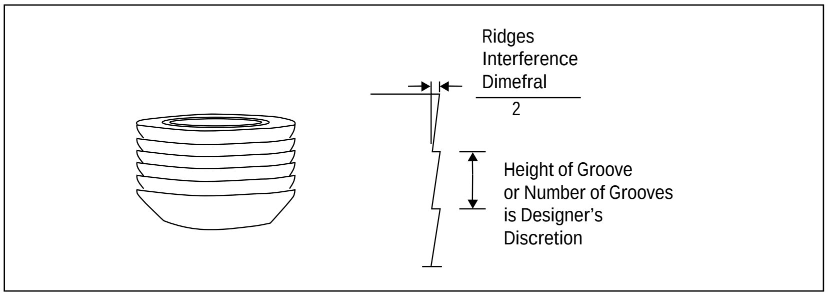


**Figure 5-3.** Press Fit Insert.

When subjected to a long-term load, thermoplastic materials exhibit creep or stress relaxation. This is a viscoelastic response to the continuous load induced by the interference fit. Time and temperature will affect the quality of the joint. For controlled conditions, creep curves can be used to predict the performance of the press fit.

The retention of strength in a press fit can be enhanced by adding detail to the part (see Figure 5-3). When the material creeps, it flows into the relieved area and increases the grip.

### *Pull Out Strength*

The pull out strength of a press fit is a function of the interference pressure and the coefficient of friction between the two materials and the area of the joint. This relationship is shown below:

$F = P \times A \times f$
$F$ = Pull Out Force
$P$ = Pressure of Interference (see stress level calculation)
$A$ = Joint Area (for a cylinder - $\pi \times b \times L$ where b is the O.D. of the inner part and L is the engagement length)
$f$ = Coefficient of Friction between the two materials

The results from this calculation should be considered as a rough estimate only because the coefficient of friction can vary significantly, depending on molding conditions, surface texture and other variables.

## Inserts

Inserts should be considered when an application requires repeated assembly and disassembly, or the available engagement length is not sufficient. There are several different varieties of inserts to choose from, each having its own advantages and disadvantages, and many of these styles can be used for more than one application. For instance, an insert that is specified for use as an ultrasonic insert might work just as well in a thermal application.

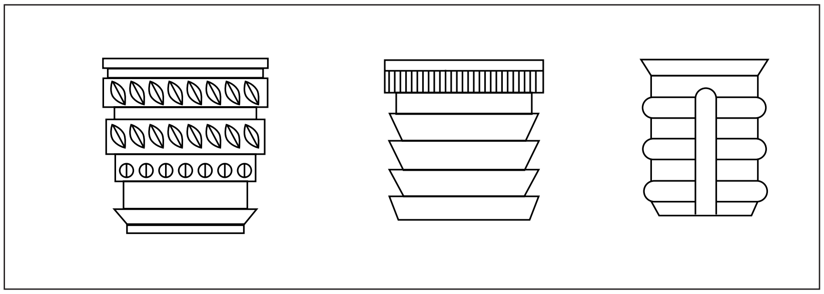


**Figure 5-4.** Insert Designs. *Inserts should be considered when an application requires repeated assembly and disassembly.*

### *Insert Designs*

The aspects of an insert's exterior profile are designed to provide certain properties:

**Knurls –** Provide a general holding enhancement. They provide minimal pullout and strip out values.

**Apposed Herringbone –** Provide excellent strip out values and minimal pullout and jackout enhancement.

**Undercuts –** Provide excellent jackout and pull out values. Provide little strip out enhancement.

### *Installation Methods*

The most common type of insertion used is ultrasonics. This assembly technique utilizes high frequency vibrations to fasten the insert into the base material. An insert is first positioned over a cored hole that is slightly smaller in diameter than the insert itself. The ultrasonic horn is placed in contact with the insert, transferring high frequency mechanical energy to the insert, causing frictional heating at the insert/plastic interface. This heat produces a thin layer of melt which flows into the flutes and knurls of the insert. When the power source is

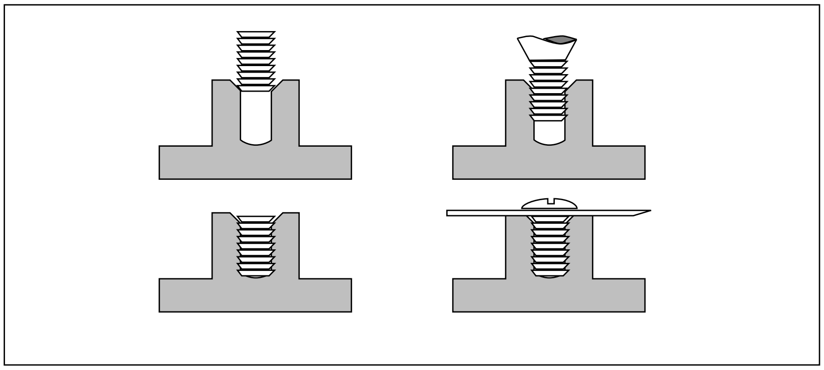


**Figure 5-5.** Insert Installation.

removed, the melt quickly solidifies around the insert, locking it in place. The advantages of ultrasonic insertion are rapid insertion rates, low residual stresses and good material flow around the insert. Material flow is especially important, as better material flow produces better bond strength.

A less expensive alternative to ultrasonics is thermal insertion. Similar to ultrasonics, a metal insert is located over a cored hole that is slightly smaller in diameter than the insert. A heat source is then applied to the insert and, as the heat increases, a thin layer of melt is formed. As the insert is pressed into the hole, this melt flows into the undercuts and profiles of the insert to provide a strong bond. When the heat source is removed, the insert cools and the melt solidifies, locking the insert into place. The advantages of thermal insertion are low equipment costs, low residual stresses and good material flow around the insert. The disadvantage of this method is the slow insertion time it provides. The extra time demand is produced by a need to heat up and cool down the inserts at each insertion site.

### *Other Insertion Methods*

Molding-in has always been a popular technique for the application of inserts. This procedure consists of placing the inserts on core pins in the mold and forming the part around them. This is a fairly successful technique and is used often.

Molded-in inserts, however, have many drawbacks. The cycle time of each part produced is increased by the need to stop between each cycle and position inserts in the mold cavity.

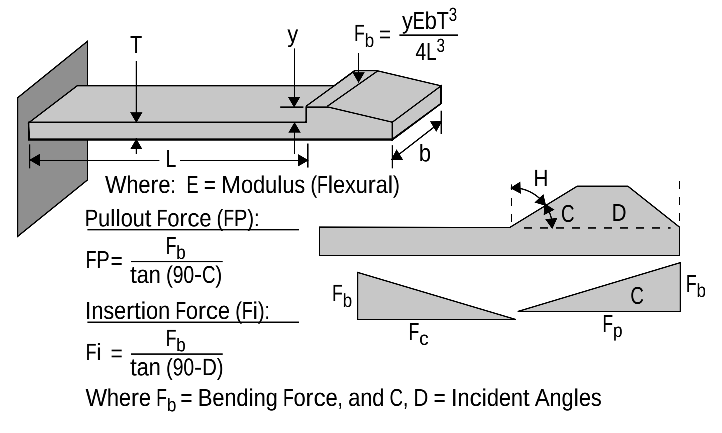
If the inserts are not positioned correctly, expensive mold damage can result. More importantly, due to the vast difference in coefficients of thermal expansion between metals and plastics, areas of high molded-in stress are created around the inserts. These inherent stresses must be accounted for with thicker boss and wall sections around any inserts. If they are not, part failure will often occur.

The last two varieties of inserts are the press fit and expansion types. These are the fastest and easiest methods of insertion, but they are also by far the weakest. Press fit inserts are just that. A barbed insert is forced into a hole that has a slightly smaller diameter than the insert itself. The friction produced by the pressure on the walls of the hole keeps the insert in place. Expansion inserts are placed in a hole that is slightly larger than the insert's major diameter. When the screw that the insert is to hold is driven into place, it expands the insert's flanges against the walls. The friction produced by this pressure locks the insert in place. In softer plastics, a limited amount of stress relaxation will occur and increase the pullout strength of the insert.

Both of these insert types are inexpensive and quick. Unfortunately, they also tend to induce a great deal of hoop stress during assembly which, as stated before, is an undesirable effect. Since there is little or no material flow around the insert, the holding strength supplied by these inserts is severely limited.

## Snap Fits

The snap fit is an effective method of assembling plastic parts. Snap fits use the inherent flexibility of the plastic materials and the molded-in functional capability of injection molding to eliminate fasteners and secure parts in assembly. They can be used to locate and mount components, attach adjacent parts or assemble complete units.



$F_b = \frac{yEbT^3}{4L^3}$

Where: E = Modulus (Flexural)

Pullout Force (FP):

$FP = \frac{F_b}{\tan(90-C)}$

Insertion Force (Fi):

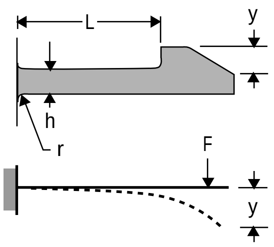
$Fi = \frac{F_b}{\tan(90-D)}$

Where $F_b$ = Bending Force, and C, D = Incident Angles

**Figure 5-6.** Snap Fit Assembly Forces.

*Snap fits use the inherent flexibility of the plastic materials and the molded-in functional capability of injection molding to eliminate fasteners.*

Snap fits can be designed for either permanent (one-time) assembly or multiple insertion and removal. The design of snap fits may appear to be a simple task, using linear beam equations. However, the large stress and strain levels associated with the assembly step often lead to nonlinear stress-strain effects. Also, snap fit designs can be geometrically complex when the base radius, angle of orientation, taper, and thickness gradient are varied. Often, these factors cannot be accounted for in a simple beam equation.



The equations for stress and deflection should be used to determine assembly force and required stiffness. For a cantilever beam with constant cross section:

(Stress) $\sigma = \frac{FLc}{I}$

(Deflection) $\gamma = \frac{FL^3}{3EI}$

When designing the actual snap fit member, the strain formula should be used:

(Strain) $\varepsilon = \frac{3\gamma c}{L^2}$

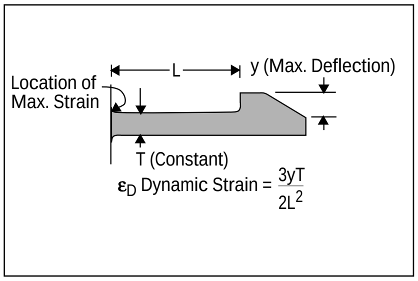
$\sigma$ = Maximum Stress
$\gamma$ = Maximum deflection of a constant section beam
$\varepsilon$ = Maximum fiber strain
F = Load causing deflection
L = Length of beam from tangent of fillet to point of load

E = Modulus or apparent modulus
I = Moment of inertia of cross section
c = Distance from neutral axis to extreme fiber (c = h/2 for rectangular section)

**Figure 5-7.** Snap Fit Design.

### Analysis Techniques

Snap fits are strain controlled analysis situations. For a given deflection, strain varies approximately linearly with the deflection. Strain at the intersection of a constant width and thickness beam at its support may be calculated using the equations shown in Figures 5-8 and 5-9.



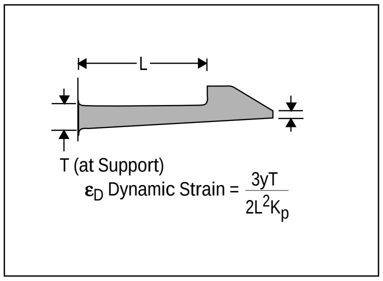


**Figure 5-8.** Dynamic Strain – Straight Beam.-left

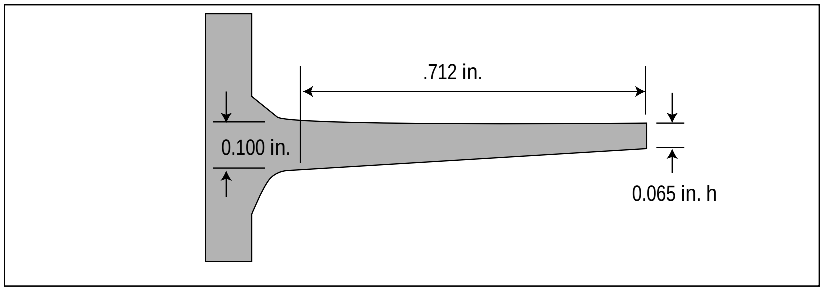
**Figure 5-9.** Dynamic Strain – Tapered Beam (A) -right

The normal reaction force is also an important piece of information to consider because of its influence on snap-in and snap-out force (the force necessary to engage or disengage the snap fit). The nonlinear stress-strain behavior of the material will also significantly affect the normal reaction force. For one-time assembly applications, it is often desired that the normal reaction force be very high to prevent potential disengagement.

### Calculation of Tapered Beam for Snap Fits

VALOX DR51 resin is to be used for a tapered beam in a related snap fit design. When the deflection is .125 in. (3.2mm), what is the strain induced to the beam?

**Figure 5-10.** Dynamic Strain – Straight Beam.



Using the equation for strain of a tapered beam:

$$\varepsilon_t = \frac{3y_th_s}{2K_sL^2} \ (\times 100\%)$$

$K_s$ can be obtained from the plot in Figure 5-12 (page 5-17).

$$R = \frac{h_o}{h_s} = \frac{.065\text{ in.}}{.100\text{ in.}} = 0.65$$

Therefore: $K_s = 1.37$

$$\varepsilon_t = \frac{3(.125\text{ in})\,(.100\text{ in})}{2(1.37)\,(.712\text{ in})^2}$$

$$\varepsilon_t = 2.70\%$$

This strain level is too high for VALOX DR51 resin in a cyclic condition. It should be reduced to 2%. To reduce the levels of strain, the degree of taper must be increased.

First determine what $K_s$ factor will reduce the strain to 2%.

$$\varepsilon_t = \frac{.0370}{K_s} = 0.02$$

Therefore: $K_s = 1.849$

From Figure 5-12 (See page 5-17) the corresponding R value is .42,

Knowing $R = \frac{h_o}{h_s}$

$$h_o = h_s R = (0.1\text{ in})\,(0.42)$$

$$h_s = 0.42\text{ in}$$

## Strain Recovery

It is important to consider recovery after loading to ensure that the snap fit will function properly by returning to engage. Since this is mainly a problem for unreinforced resins, a laboratory test technique was developed to provide the necessary material data.

**A Snap Fit Will Be Considered Satisfactory If:**

- After 3 flexes, the beam does not take a set of 10% of the deflection.
- Does not fracture.

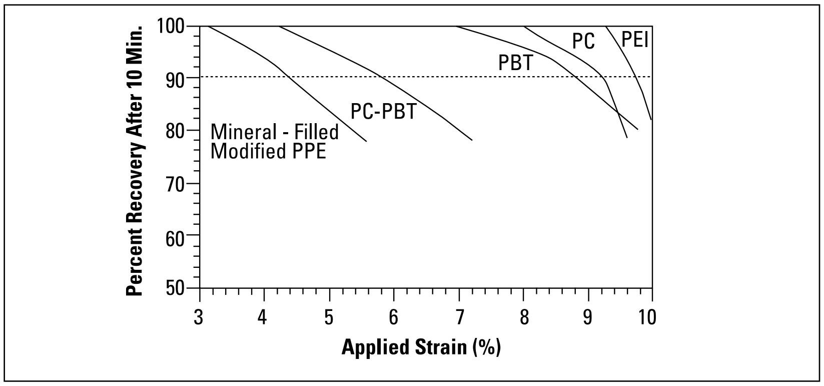


**Figure 5-11.** Recovery as a Function of Applied Strain.

Tensile specimens were loaded to various strain levels at a rate of 10%/second and then rapidly unloaded, while the strain recovery was monitored. Since the rate of recovery was very slow after 10 minutes due to viscoelasticity, the percent recovery (residual strain/applied strain) after 10 minutes was plotted as a function of applied strain. A design rule of 90% recovery is shown in the strain recovery plot, establishing the strain limits for snap fit applications in these materials.

### Tapered Beams

Applications which make use of tapered beams require the use of a separate set of beam equations. The maximum deflection of a tapered beam of constant width (b):

$$\text{Ymax} = \frac{-6F}{Eb}\left[\frac{LR}{h_o(1-R)}\right]^3 (2\ln R + 3 + R^2 - 4R)$$

Where:
Ymax = maximum deflection
F = normal force at end of beam
E = flexural modulus
b = width of beam (constant)
L = length of beam
R = ratio of height of tip to height of support
$h_o$ = height of tip
ln = natural log

Note: Equation is discontinuous when R=1 or R=0

Where $R = h_o/h_s$ (see Figure 5-12), maximum bending stress:

$$\sigma = \frac{6FL}{bh_s^2}$$

and the maximum strain:

$$\varepsilon_t = \frac{3y_t h_s}{2K_s L^2} \ (\times 100\%)$$

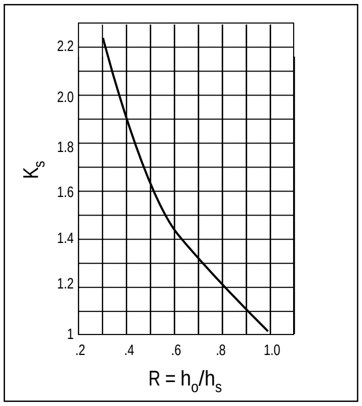
$b$ = beam width
$h_o$ = height of tapered beam at the tip
$h_s$ = height of tapered beam at the support
$K_s = y_t/y_o$ ($K_s$ can also be obtained from Figure 5-12)
$y_t$ = deflection of tapered beam
$y_o$ = deflection of constant beam with same thickness at support

The previous analysis considers the theoretical perpendicular force required to deflect the beam a specified distance, but in actual application, force is applied at the end of the beam via a lead in the angle. This angle causes the beam bending force to be a function of the tangent of the lead angle, i.e., F insertion = F bending tan $\phi$.

Because of this fact, the force required to push the snap in place will always be of a different magnitude than the force required to produce the calculated beam deflection, unless the lead angle is 45°, when the forces will be equal. In designing a snap fit cantilever beam, therefore, the force needed to produce the desired deflection does not have to equal the assembly force.

Snap fits can also be designed to allow pull-off, as shown in Figure 5-13. In place of a 90° buttress, an angled lead can be designed, which will function in the exact manner as the push-on lead angle.

The height of the lead ramp should never exceed the calculated deflection. When the ramp height exceeds deflection, maximum allowable strain will be exceeded.



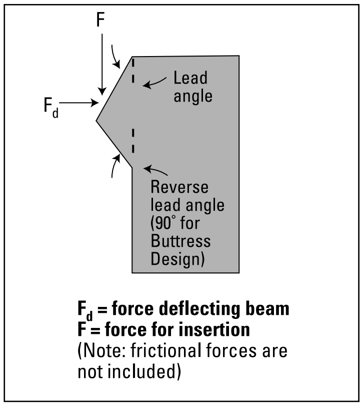


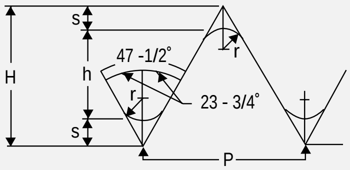
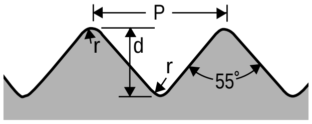
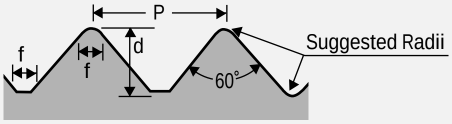
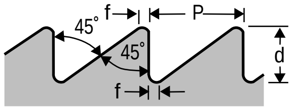
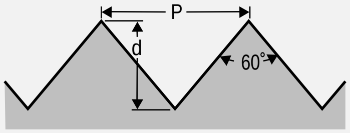
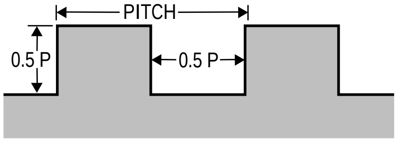
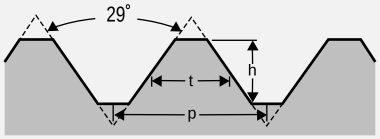
**Figure 5-12.** Proportionally Constant – Tapered Beam (Height at the support = height of constant beam).-left

**Figure 5-13.** Designing for Pull-Off.-right

## Molded-In Threads

Threads can often be molded into injection molded parts for use in assembly or part function. There are a number of different types of threads which are commonly used and there are many specialty threads for specific applications. The type of thread selected will make a large difference in the performance of the part.

**Table 5-1.** Types of Threads

| | | | |
|---|---|---|---|
| BRITISH ASSOCIATION STANDARD | If:<br>P = Pitch of thread<br>H = Depth of v-thread<br>h = Depth of B.A. thread<br>r = Radius at root & crest of thread<br>s = Root and crest truncation. | Then:<br>H = 1.13634 × P<br>h = 0.60000 × P<br>r = 0.18083 × P<br>s = 0.26017 × P |  |
| WHITWORTH THREAD | Pitch = P<br>Depth = d<br>Radius = r<br>Number of Threads Per Inch = n | P = 1 inch /n<br>d = 0.640327 × P<br>r = 0.137329 × P |  |
| AMERICAN NATIONAL OR UNIFIED THREAD | Pitch = P<br>Depth = d<br>Flat = f<br>Number of Threads Per Inch = n<br>Plastic Applications f = Full Radii | P = 1 inch /n<br>d = 0.61343 × P<br>f = 0.125 × P |  |
| BUTTRESS THREAD | Pitch = P<br>Depth = d<br>Flat = f<br>Plastic Applications f = Full Radii | P = 2 × Screw Diameter/15<br>d = .75 × P<br>f = 0.125 × P |  |
| V THREAD | Pitch = P<br>Depth = d<br>Number of Threads per Inch = n | P = 1 inch/n<br>d = 0.866 × P |  |
| SQUARE THREAD | | |  |
| ACME THREAD | Pitch = P<br>Height = h<br>Thickness = t<br>Number of Threads per Inch = n | P = 1 inch/n<br>h = 0.5 × P<br>t = 0.5 × P |  |

## Plastic Threads

The following general rules should be followed in most cases for thermoplastic thread design:

1. Maximize root radius (internal and external threads)
2. Avoid tapered (pipe) threads
3. Select an appropriate thread type

This screw thread is recommended by the British Standards Institute for all screws smaller than 0.25 in (6.35 mm) diameter. This thread design is well-suited for plastic applications due to its specified root radius of 0.18083 P.

Although this thread is being phased out in industry by the unified thread, it is an excellent thread design for plastic applications. This is true because of the generous radius at the root of each thread which reduces the stress concentration effects. The root radius is specified as 0.1373 P.

The unified thread is currently the most common thread design for general use.

The buttress thread is somewhat unique in that the threads are not symmetric about a cross-sectional center line. Buttress threads have advantages in load bearing applications where the load is in one direction only (along the axis of the screw). Because the load bearing face is nearly perpendicular to the axis of the screw, the loads are transferred almost entirely along the axis rather than in the radial direction. The American National Buttress Thread has a standard root radius of 0.0357 P to 0.0714 P. The largest possible root radius is suggested for plastic applications.

Although it is the easiest to tool, the V-thread is one of the worst thread designs for plastic applications. The sharp notch at the root of the thread often results in extreme stress concentrations which can cause catastrophic part failure. The stress concentration factors associated with this thread type are often between 3.0 and 5.0. Thus, three to five times the average stress values (resulting from simple calculations) are often seen by the part.

A square thread is often used for power transmission applications, such as the power screw which drives a lathe, vice or jack. This is done because the square thread is very efficient at transferring force and power. The square thread type is not commonly used for plastics due to the stress concentrations induced into the threads at the base, which can cause the threads to strip or shear off.

The acme thread has a flat root and crest and is generally used for power transmitting applications. This thread type is not well-suited for plastic applications due to the stress concentration effects of the sharp corners.

## Fasteners

Mechanical fasteners are a popular means of joining thermoplastic parts. When surface appearance is not of great importance or when disassembly may be required, mechanical fasteners are an excellent assembly option. Mechanical fasteners provide a strong, inexpensive joint in a relatively short time.

*When surface appearance is not important, or when disassembly is required, mechanical fasteners are an excellent option.*

The least expensive and most common family of mechanical fasteners for plastics are self-tapping screws, which can be classified as either thread cutting or thread forming. Self-tapping screws create their own threads as they are driven. This aspect helps to decrease production times and costs by eliminating the need for molded-in threads or tapped holes. Self-tapping screws are available in a wide variety of sizes and configurations, each having properties suited to specific applications.

### *Definitions*

When screws are discussed, several basic terms are used. The following are brief descriptions of these terms.

**Thread Angle –** The angle included between the sides of the thread measured in the axial plane.

**Crest –** The top surface of the thread.

**Root –** The base surface of the thread.

**Pitch –** The distance measured from crest to crest parallel to the axis.

**Pitch Diameter –** A diameter measured at the point on the thread where the width of the thread and the groove are equal.

**Minor Diameter –** The smallest diameter of a straight thread screw.

**Major Diameter –** The greatest diameter of a straight thread screw.

**Flank –** The load bearing surface of a screw thread located between the root and crest.

There are six attributes that determine the performance of screw/part assemblies. Drive, strip, seating and prevailing torques are measured in foot-pounds and pullout force is measured in pounds.

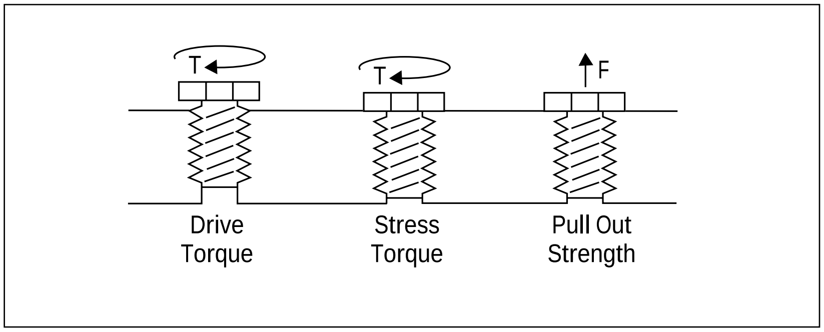


**Figure 5-14.** Fastener Testing.

**Drive Torque** – The torque necessary to drive a screw into an unthreaded pilot hole. Lower values of drive torque are desirable as they produce lower assembly costs and help increase the strip/drive differential.

**Strip Torque** – The torque that causes the threads in the plastic to fail in shear. High values of strip torque are desirable as a safeguard against over-torquing.

**Strip / Drive Differential** – The difference between the strip torque and the drive torque for a given screw. High strip/drive differentials are desired to allow for some margin of error in the settings of torque wrenches used in production.

**Prevailing Torque** – The torque required to remove a screw from the threaded receptacle after the clamp force is released. High values of prevailing torque are desirable as they are an indication of resistance to vibrational loosening.

**Pullout Force** – The axial force that must be applied to tear the screw out of the mating material. High pullout forces indicate a strong bond.

**Seating Torque** – The amount of torque necessary to produce a desired clamping force. Suggested seating torques are usually the drive torque plus 50 to 80% of the strip/drive differential.

## *Thread Forming/Thread Cutting*

When inserted, a thread forming screw can induce high residual stresses. In softer, more ductile plastics, this is acceptable, as these stresses will eventually subside due to stress relaxation.

**Thread Forming**

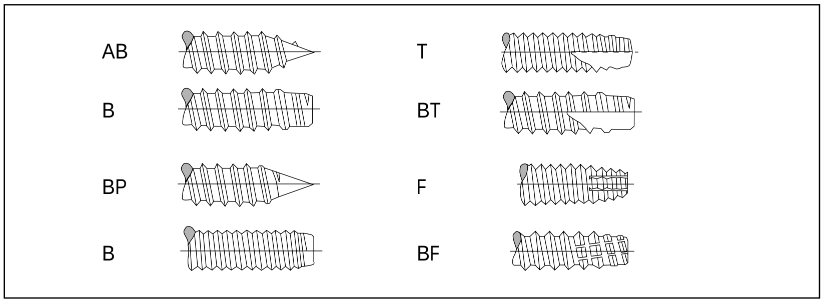
- Consider thread cutting for injection molded parts.
- OK for structural foam parts.

Unfortunately, in the stiffer engineering plastics where stress relaxation is minimal, they tend to remain. These residual stresses can be an additive with other loads and may lead to reduced chemical compatibility in some cases. These factors may lead to eventual failure of the part. For this reason, thread forming screws are not generally suggested for use with solid injection molded GE resins. They are, however, suggested for use with foam molded parts, since the thread forming action is much less damaging to the foamed core.

Thread cutting screws are not suggested for applications requiring repeated assembly and disassembly, for if care is not used, subsequent reinsertion may result in the formation of a second set of threads. As mentioned previously, this cross threading action will severely decrease the strip torque and pullout strength of the assembly. If disassembly is required, a thread forming screw with the same pitch diameter and threading should be used for reassembly.

There are two basic classifications of self-tapping screws: thread forming screws (TF) and thread cutting (TC) screws.

**Figure 5-15.** ANSI Standards.



Thread forming screws (i.e., types AB, B, BP, C) form threads by radial displacement of the material in which they are inserted. Screws of this type are usually suggested for applications that may require more than one or two assemblies and disassemblies. The shape of the thread forming flights allows the screw to locate its previously tapped threads when reinserted, and prevents the formation of a second set of threads or cross threading.

Thread cutting screws (i.e., Types BT, T, BF, F) produce mating threads by cutting out or removal of the material in which they are inserted. A notch at the tip of the screw acts as both a cutting surface and a storage space for the chips cut during insertion. This type of screw tends to have lower drive and strip torques, but does not produce the potentially high residual stresses associated with thread forming screws.

Beyond the two main screw categories are the speciality screw designs. As thermoplastics became more accepted and demand for fastening of these unique materials grew, technology developed which addressed the thread spacing, sharper flank angles and non-traditional shank shapes. These designs increased holding power, while inducing much lower hoop stresses.

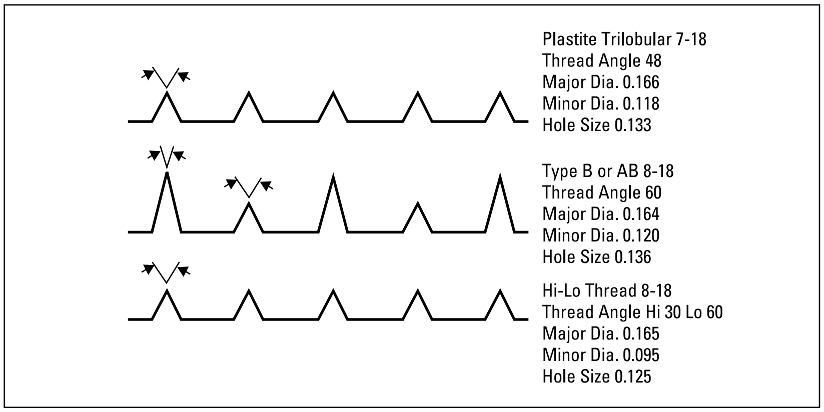
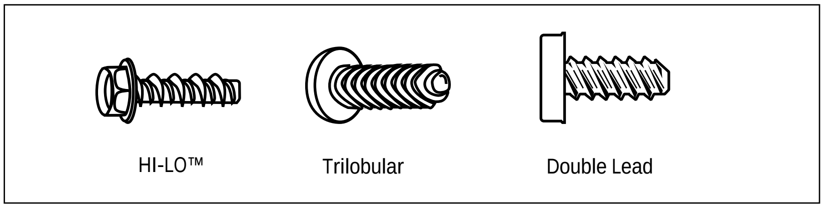


**Figure 5-16.** Screw Thread Profiles.

### *Specialty Screws*

The HI-LO™ screw by Elco Industries possesses a double-threaded lead. One thread flight has a deep cutting 30° angle flank, the other, a smaller 60° angle flank. The combination of the two allows for a lower driving torque, while still producing high pullout strength and moderate strip torque. HI-LO screws come in both thread cutting and thread forming varieties.

**Figure 5-17.** Specialty Screws.

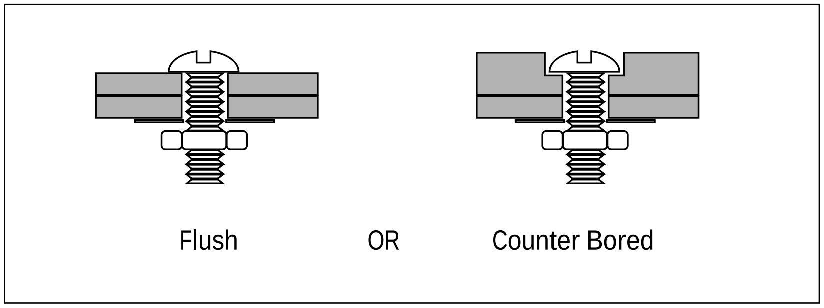


Another speciality item is the Plastite™ screw, also known by its shape as a tri-lobular screw. The Plastite screw, patented by Continental Screw Co., comes in a variety of styles, including single and double leads and a variety of flank angles. The most common configuration has a single set of 45˚ threads on a slightly triangular shank. Initially, the prevailing torque of this screw is not much greater than most, but after stress relaxation has occurred, the out-of-round shank effectively locks the screw in place increasing its resistance to loosening. Plastite screws come as thread formers only, since the thread cutting action would negate the advantages of the design.

Double lead screws have also become popular in the plastics industry. The steeper helix angle of the two thread flights permits higher strip torque and pullout strength.

When metal screws are being used to assemble plastic parts, pan head or truss head screws on flat surfaces or in counter-bored holes are suggested.

**Figure 5-18.** Pan Head or Truss Head Screws.



Clamped fastener design develops compressive stress in the plastic parts around the fastener. Over time and particularly if elevated temperatures are encountered, stress relaxation should be expected. Locking fasteners might be considered to keep screws from flow backing off. Washers will also help distribute the load.

Flat head screws are not suggested, due to a wedge effect (see pipe thread design). Hoop stress can be quite high when a flat-head screw is driven into plastic. This makes the part more prone to chemical, mechanical or impact driven failure.

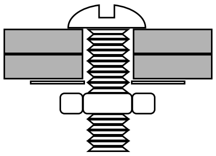
| | Screw Size | Hole Diameter in (mm) |
|---|---|---|
|  | #2 | .096 (2.44) |
| | #4 | .122 (3.10) |
| | #6 | .148 (3.76) |
| | #8 | .174 (4.20) |
| | #10 | .200 (5.09) |
| | #12 | .226 (5.74) |
| | 1/4 | .260 (6.60) |
| | 5/16 | .323 (8.20) |
| | 3/8 | .385 (9.80) |

**Figure 5-19.** Machine Screw Clearance. *When a metal nut or fastener is used, adequate clearance for the plastic part should be considered.*

### *Rivets*

Rivets are a popular and simple method of assembly. However, care should be taken to avoid the high stress concentrations inherent in most riveting techniques. Large diameter heads and reinforcing washers are suggested to distribute stresses, and all sharp corners should be broken or radiussed. The holes should provide a 0.010 in (0.254 mm) clearance on the rivet shank to ease assembly and compensate for tolerances and coefficient of thermal expansion. Aluminum rivets are preferred over steel, since the aluminum will more readily deform under high stress. Using a shouldered rivet will also keep control stresses by limiting the compressive forces that can be applied to the plastic part.

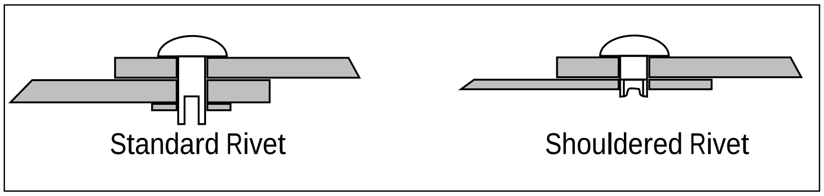
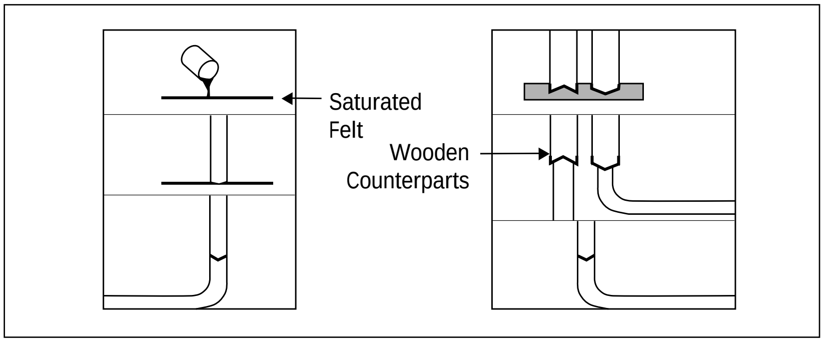


**Figure 5-20.** Rivets.

## Solvent Bonding

Solvent bonding is a common technique used for joining parts molded of amorphous thermoplastic resins. When parts are bonded in this manner, the solvent dissolves the surface of the two mating parts and allows the material to flow together. After the solvent evaporates, what is left is a pure material-to-material bond.

**Figure 5-21.** Solvent Bonding.



When solvent bonding, the parts should be dampened with solvent and then assembled using moderate pressures to hold them together. This wetting process can be accomplished by wetting a piece of felt or a mating preform made of wood with solvent and lightly pressing the parts to be bonded against them. Parts can be safely set aside to dry after 40 to 60 seconds of hold time, but full bond strength will not be achieved for 24 to 48 hours. In some cases it may be desirable to heat the assembly in an oven to drive off excess solvent.

It is very important in this technique to have well-matched parts. Often, attempts are made to remedy improperly mating parts with excessive amounts of solvent or pressure. These “remedies” will only result in a sloppy or overly stressed joint. Locator pins and/or tongue and groove assemblies can help to provide good part matching as well as easy part location after the application of solvent. Both of these profiles should be shallow to avoid entrapment of excessive amounts of solvent. If part mating continues to be a problem, slurries made of solvents and up to 25% base resin may be used.

Solvent bonding provides many advantages, but with it also comes disadvantages.

**Advantages**

- Distributes stress over entire bond area
- Provides aesthetically pleasing bond
- Can provide bond where bosses are not possible
- Can provide hermetic seal

**Disadvantages**

- Parts cannot be disassembled
- Sufficient area must be available for proper joint design
- Vapors released may be hazardous
- Only practical with amorphous materials
- Tight molding tolerances are needed to produce properly mating parts

Adequate ventilation should always be provided to avoid possible health hazards posed by the use of solvents. OSHA, EPA and local regulations should always be researched and obeyed. Always avoid direct contact with the solvents.

### *Effective Solvents*

For many amorphous resins produced by GE Plastics, there is a solvent or a number of solvents that can be used for bonding. Some of the solvents and the materials they are appropriate for are listed here. NORYL resin can be solvent bonded to substrates other than itself. Solvents and solvent ratios for welding NORYL resins are listed.

| Resin Grade | Effective Solvent(s) |
|---|---|
| CYCOLAC ABS resin | • Acetone<br>• Methylene Chloride<br>• MEK |
| NORYL resin to NORYL resin | • Trichloroethylene<br>• Trichloroethylene/ Methylene Chloride 1:1<br>• Trichloroethylene/ Monochlorobenzene 4:1<br>• Trichloroethylene/ Dichloroethylene 1:1 |
| NORYL resin to ABS resin | • Trichloroethylene/MEK 4:1 |
| NORYL resin to PVC resin | • Xylene/MEK 1:1 |

## Adhesive Bonding

Adhesive bonding is one of the most convenient methods of assembling a plastic part to either a similar or dissimilar (including non-plastic) material. Adhesives distribute stresses over the entire bond area, and can provide a hermetic seal if needed. Flexible adhesives allow some movement between mating parts, and thus can compensate for differences between the materials, such as coefficient of thermal expansion. Adhesives are relatively inexpensive, and often require little or no special equipment for application.

**Why Adhesive ?**

- Ease of Application
- Dissimilar Materials
- Uniform Stress
- Sealing
- Elasticity
- Low Cost
- Reduce Hardware
- Insulation
- Ease of Repair
- Aesthetics

### *Adhesive Families*

There are five major families of adhesives, each with a somewhat unique set of characteristics. When choosing an adhesive for a specific application, these characteristics can provide an initial direction for the search. For example, if the end use environment will exceed 100˚C, an epoxy or an anaerobic adhesive would be worth considering. Or, if set time and cure time are critical during assembly, a cyanoacrylate or anaerobic adhesive might be appropriate.

**Table 5-2.** Adhesive Families.

| | IMPACT RESISTANCE | MOISTURE RESISTANCE | NO. OF COMPONENTS | TEMP. LIMITS (C) | R.T. CURE |
|---|---|---|---|---|---|
| **EPOXY** | G | E | 1 OR 2 | 200+ | 5 MIN. + |
| **URETHANE** | VG | F | 2 | 100 | 5 MIN. + |
| **ANAEROBIC** | G | G | 1 | 200 | 10 SEC. |
| **CYANOACRYLATE** | F | F | 1 | 80 | 10 SEC. |
| **ACRYLIC** | G | G | 2 | 100 | 2 MIN. + |

**Adhesive Concerns**

- Chemical Resistance
- Bond Strength
- Temperature Stability
- Handling
- Toxicity
- Low Cost
- Compatibility
- Surface Preparation

### *Adhesive Concerns*

Other adhesive properties to be considered in the choice of an adhesive include resistance to the end use chemical environment, bond strength in the specific joint design and long-term temperature stability. In the assembly facility, shelf life, handling requirements and potential toxicity issues must also be considered. Chemical compatibility with the substrate(s) and any need for surface preparation should be evaluated before a final choice is made.

## Adhesion Testing

To evaluate the strength and adhesion of an adhesive in a specific application, the type of loading at the joint should be recreated as closely as possible. Basic adhesive tests on standard samples can recreate loading situations that a joint might see in end use. These include tensile shear (or lap shear), cleavage, butt joints (tensile) and peel.

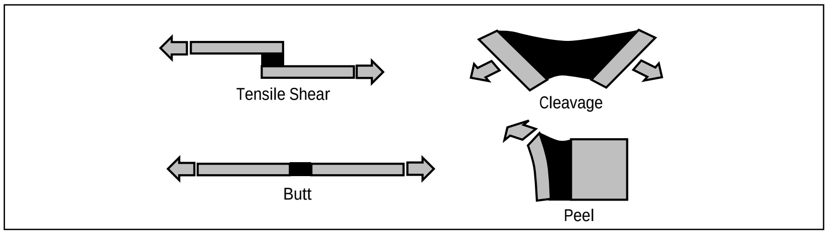


**Figure 5-22.** Basic Adhesive Tests.

Peeling or brittle failure of the substrate may indicate that chemical attack by the adhesive is affecting the strength of the plastic, and additional testing might be warranted.

## Adhesive Evaluations

Typical screening of an adhesive with a particular substrate would consist of two tests: a compatibility evaluation and a strength/adhesion test. The compatibility screening for adhesives evaluates visual or tensile property degradation after the suggested cure cycle at 0.5% induced strain. The strength/adhesion test records tensile lap shear strength and mode of failure.

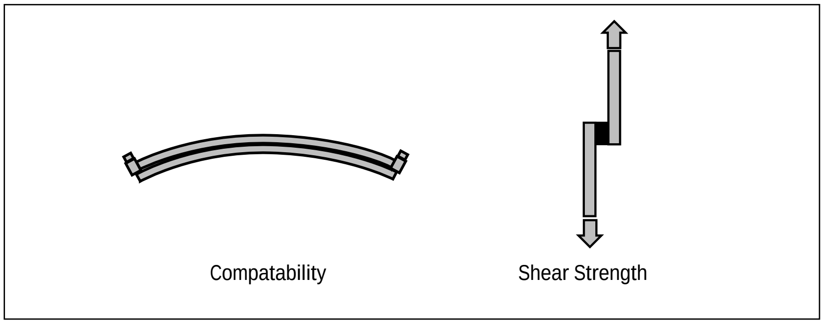


**Figure 5-23.** Adhesive Evaluations.

## Adhesive Selection

When selecting an adhesive system for bonding a thermoplastic resin to itself or to a dissimilar material, one should first consider the factors common to all adhesive bonding applications. The expected end use environment is probably the most important of these considerations.

*continued on page 5-32*

**Table 5-3.** Resin Families.

| Resin Family | Forms | Shear Strength |
|---|---|---|
| **Epoxies**<br>Epoxies are known for their versatility. Their bond strength, electrical conductivity and temperature resistance can be modified to fit almost any specific application needs. Epoxies are made in either one-or two-part formulations. The two-part systems consist of a resin and a hardener which must be mixed together in strict proportions for maximum bond strength. They can be cured at room or elevated temperatures. One-part epoxies require no mixing; however, they must be cured by heat, usually around 300˚F (148°C) for one hour or more. Heat cured epoxies tend to exhibit greater strength than their mixed counterparts. However, two-component systems are more widely used because they may be stored for long periods of time and will not activate until mixed. Unlike other adhesives, epoxies are not solvent based, but cure as the result of a chemical reaction. | liquid<br>paste | 5000 to 10,000 psi |
| **Urethanes**<br>This adhesive family, also called polyurethanes, can provide strong bonds on a variety of substrates. Urethanes are primarily found in applications that require high strength as well as flexibility. Urethanes are available in both one- and two-part systems. One-part formulations require heat curing while two-part systems may be room temperature cured. | liquid<br>paste<br>solvent-based | up to 8,000 psi |
| **Acrylics**<br>The acrylics used today are second generation or modified acrylic systems.<br>These “improved” acrylics provide many of the same attributes as the epoxies and urethanes; in addition, they also offer the advantage of rarely needing primers.<br>These are a one-or two-part system consisting of a catalyst primer and the adhesive. Usually, the two-part systems do not need mixing or weighing, which simplifies their application immensely. Acrylics boast rapid cure at room temperature with a setting time of approximately 60 to 90 seconds and full cure within 30 minutes or less. The application of heat may be used to reduce cure times. | liquid<br>paste | up to 6000 psi |
| **Anaerobics**<br>Anaerobics are a one-part thermosetting adhesive family whose curing mechanism is triggered by the absence of oxygen. This eliminates the problem of premature curing.<br>Curing occurs at room temperature and the addition of heat or ultraviolet radiation will increase the speed of the curing process. The cure cycle may be as short as 15 seconds set time and 2-24 hours for full cure. Anaerobics also exhibit the useful property of being easily cleaned from unbonded surfaces after the bondline has set up.<br>Anaerobics are excellent for critical sealing and bonding applications where strength is not needed. Their use is also expanding into the sealing of welds and soldered joints. | liquid | up to 5000 psi |
| **Cyanoacrylates**<br>Cyanoacrylates are single-part, fast curing “convenience adhesives”. With a normal setting time of 2 or 3 seconds, and a full cure time of 24 hours at room temperature, these systems are popular in tacking and quick contact assembly operations.<br>Curing is initiated by the presence of surface moisture, even in limited quantities such as humidity in the air. These adhesives are highly application specific in their use. | liquid | up to 5000 psi |

| Operating Temperature | Advantages | Disadvantages |
|---|---|---|
| -70 to 450°F<br>-21 to 232°C | • good adhesion<br>• high tensile and shear strength<br>• creep resistance<br>• good rigidity<br>• high heat tolerance<br>• easy to cure | • poor peel strength<br>• brittle<br>• low impact strength<br>• high cost |
| -300 to 300°F<br>-149 to 149°C | • toughness<br>• flexibility<br>• impact strength<br>• abrasion resistance<br>• high peel strength | • volatile<br>• excessive creep<br>• poor strength at high temperature<br>• chemical sensitive<br>• lacks long-term durability<br>• usually needs primers<br>• moisture sensitive in uncured state |
| 240 to 350°F<br>116 to 177°C | • bonds to dirty surfaces<br>• high strength<br>• superior toughness<br>• fast curing | • strong odor<br>• problems with flammability<br>• minimal gap filling |
| 65 to 400°F<br>18 to 204°C | • good solvent resistance<br>• bond flexibility<br>• high peel strength<br>• good impact strength | • sensitive to surface cleanliness<br>• poor gap filling properties |
| 65 to 180°F<br>18 to 82°C | • high tensile strength<br>• no shelf life limitations | • brittle<br>• not usually suggested for dissimilar materials<br>• poor gap filling<br>• not suggested for constant water exposure<br>• limited impact and peel strength |

Among the environmental concerns are expected temperature ranges, chemical and UV exposure and possible UL electrical requirements.

Other important considerations are the anticipated bond loading and strength requirements of the final application. In most cases, more than one type of adhesive could fulfill the necessary requirements. Each system exhibits characteristic properties that fit particular application needs. There are five common families of adhesives used for bonding GE resins as shown in Table 5-3 on pages 5-30 and 5-31.

### *UV Curable Adhesives*

In the mid 1960's, UV curing technology was first used as a curing agent for inks in the packaging industry. Since that time, the technology has advanced and spread into other applications. In addition to inks, adhesives, potting compounds, encapsulates and sealants are now available with UV curing systems. In fact, UV curables are one of the fastest growing families of adhesives in use today.

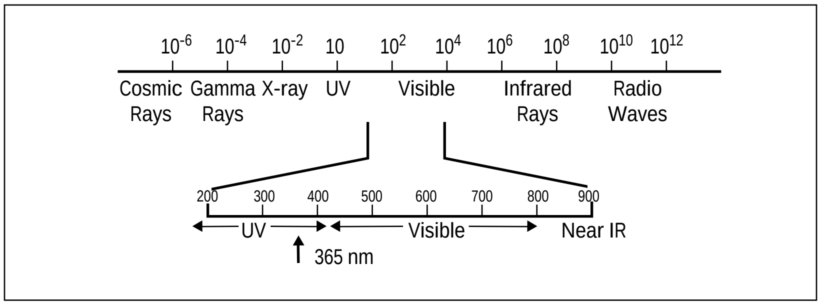


**Figure 5-24.** The Electromagnetic Spectrum.

*The main drawback of UV adhesives is cost. UV curing equipment as well as the adhesives themselves are relatively expensive. Therefore, careful consideration must be given to whether these adhesives can be economically feasible in a given application.*

UV (Ultra Violet) curing uses light energy to initiate polymerization. The bulk of industrial UV is provided by low pressure mercury vapor lamps.

In the early stage of development, UV curables could be used only with transparent substrates or other applications that would allow the entire bondline to see the UV. Since that time, technology has overcome this problem. Today, most UV curable adhesives include a secondary cure mechanism. Anaerobic, oxygen and moisture cures are often used to cure those areas not directly exposed to light.

A trigger cure is another alternative for bonding opaque substrates. This method consists of applying the adhesive to one half of an assembly and exposing it to UV light. The parts to be bonded are then fixtured together trapping the preactivated adhesive between them. The initiated cure then continues to completion and forms a secure bond. This method is slower than the typical UV cure cycle and may provide bondstrengths somewhat lower than direct light curing.

UV adhesives offer many advantages. They are 100% reactive liquids which avoids the hazardous solvents found in other systems. This aspect also improves dimensional stability in these adhesives, for there is no loss of volume due to solvent evaporation. UV curing is also extremely fast, typically 3 to 10 seconds. This allows much faster production times as well as eliminating time and space consuming fixturing. Cyanoacrylates can provide similar production times, but cannot compete with the physical properties of the UVs.

## *UV Curable Adhesive Suppliers*

At the present time, (as of this publication) GE Plastics has no data available concerning the performance of UV curable adhesives with our resins. Adhesive suppliers have conducted some testing with GE resins and may be able to provide some information. There is a study in process at GE to screen UV curable adhesives with the various resins.

**Ashland Chemical Inc.**
Specialty Polymer & Adhesives
(Aerogrip and Plyogrip)
Columbus, OH
800-322-6580

**BF Goodrich**
Adhesive Systems Division
Akron, OH 44318
216-374-2900

**Bostik**
Middleton, MA
800-726-7845/508-777-0100

**Grace Specialty Polymers**
(formerly Emerson & Cummings)
(Owned by WR Grace)
800-832-4929

**Hartel Enterprises**
Pacoima, CA
818-767-0861

**Hernon Manufacturing**
Sanford, FL
800-527-0004/407-322-4000

**HB Fuller Company**
Vadnais Heights, MN
800-468-6358/612-481-3300

**IPS**
Gardena, CA
800-421-2677/310-366-3300

**Loctite Corporation**
Newington, CT
800-562-8483

**Masterbond**
Hackensack, NJ
201-343-8983

**Morton International**
Chicago, IL
312-807-2000

**National Starch and Chemical**
Brightwater, NJ
800-606-5280/908-685-5000

**Permabond**
Englewood, NJ
800-653-6523/201-567-9494

**Synthetic Surfaces**
Scotch Plains, NJ
908-233-6803

**Uniroyal**
Adhesives Department
Mishawaka, IN
800-336-1973

## *Compatible Adhesives*

A wide variety of adhesive systems have been evaluated for use with various GE Plastics resins. As a starting point for choosing an adhesive for a specific application, 24 adhesives are listed here, indicating the resin families with which they are compatible. This is not an all-inclusive list of adhesives that can be used, but provides a variety of adhesive types and manufacturers for consideration. The following suggestions as well as additional information is available from your local GE Plastics representative.

**Table 5-4.** Compatible Adhesives

| Adhesive/Type | Manufacturer | Maximum Operating Temp. | Set Time/ Cure | Bonds to |
|---|---|---|---|---|
| EPON 828 V-40<br>Epoxy - 2-Part | Miller Stephenson<br>Danbury, CT (203) 743-4447 | 150 ˚F | 60 Minutes/<br>7 Days / RT | VALOX, XENOY, ULTEM resins<br>Glass, Metal, Rubber, Concrete, Wood, Ceramics |
| LA2337-8<br>Epoxy - 1-Part | Emerson & Cuming<br>Woburn, MA (617) 935-4850 | 100 ˚C | 1 Minute/<br>30 Min./100 ˚C<br>5 Min. / 150 ˚C | VALOX, XENOY, ULTEM resins |
| Scotch-Weld 1838L<br>Epoxy - 2-Part | 3M Company<br>St Paul, MN (612) 733-1110<br>(215) 638-6300 | 350 ˚F | 8-10 Hours/<br>24 Hours / RT | LEXAN, VALOX, NORYL, PREVEX, XENOY, ULTEM, GELOY resins, Wood, Metal, Ceramic, Fabric |
| Scotch-Weld 2214<br>Epoxy - 1-Part | 3M Company<br>St Paul, MN (612) 733-1110<br>(215) 638-6300 | 350 ˚F | 8-10 Hours/<br>40 Min. / 250 ˚F<br>5 Min. / 350 ˚F | VALOX, NORYL, PREVEX, XENOY, NORYL GTX resins,<br>Wood, Metal, Ceramic, Fabric |
| Scotch-Weld 2216 4-7<br>Epoxy - 2-Part<br>(215) 638-6300 | 3M Company<br>St Paul, MN (612) 733-1110 | 350 ˚F | 8-10 Hours/<br>7 Days /40 ˚ F<br>30 Min. / 200 ˚F | LEXAN, VALOX, NORYL, PREVEX, XENOY, ULTEM, GELOY, CYCOLAC, CYCOLOY, NORYL GTX resins<br>Wood, Metal, Ceramic, Fabric |
| Uniset A401-37<br>Epoxy - 1-Part | Emerson & Cuming<br>Woburn, MA (617) 935-4850 | 150 ˚F | 20 Min./<br>20 Min. / 250 ˚F<br>10 Min. / 350 ˚F | VALOX, XENOY, ULTEM resins<br>Metal, Glass, Ceramic |
| Scotch-Weld 2216 4-7<br>Epoxy - 2-Part<br>(215) 638-6300 | 3M Company<br>St Paul, MN (612) 733-1110 | 350 ˚F | 8-10 Hours/<br>7 Days /40 ˚ F<br>30 Min. / 200 ˚F | LEXAN, VALOX, NORYL, PREVEX, XENOY, ULTEM, GELOY, CYCOLAC, CYCOLOY, NORYL GTX resins<br>Wood, Metal, Ceramic, Fabric |
| 80 J<br>Epoxy - 2-Part | Synthetic Surfaces<br>Scotch Pines, NJ(201) 233-6803 | 300 ˚F | 8 Hours/<br>7 - 10 Days / RT | ULTEM, GELOY resins<br>Metal, Wood, Ceramic |
| Arathane 5540/41<br>Urethane - 2-Part | CIBA-GEIGY<br>Madison Heights, MI<br>(313) 585-7200 | 150 ˚F | 3-15 Min./<br>60 Min. / 200 ˚ F | VALOX, NORYL, PREVEX, XENOY, ULTEM, GELOY, NORYL GTX resins<br>Thermosets, Primed Metals, Masonry |
| Betamate 73553/<br>72034 Primer<br>Urethane - 1-Part | Essex Chemical<br>Troy, MI (313) 524-1999 | 300 ˚F | 1 Hour<br>7 Days / RT | VALOX, NORYL, PREVEX, XENOY, ULTEM resins, Metal, Glass, Ceramic |
| Scotch-Weld 3532<br>Urethane - 2-Part<br>(215) 638-6300 | 3M Company<br>St Paul, MN (612) 733-1110 | 350 ˚F | 8-10 Hours/<br>24 Hours / RT | LEXAN, VALOX, NORYL, PREVEX, XENOY, GELOY, CYCOLAC, CYCOLOY, NORYL GTX resins, Wood, Metal, Rubber |
| Tyrite 7500 A/C<br>Urethane - 2-Part | Lord Corp<br>Erie, PA (814) 868-3611 | 350 ˚F | 2 Hours<br>24 Hours / RT<br>15 Min. /200 ˚F | LEXAN, VALOX, NORYL, PREVEX, XENOY, ULTEM, GELOY, CYCOLAC, CYCOLOY resins |

## Adhesive Joint Design

Adhesive bonding is a complex phenomenon involving chemical reaction, electrical attraction at the molecular level and various mechanical factors. The adhesive introduced at the interface of two parts must be compatible chemically, electrically and mechanically with BOTH substrates AND with the end-use environment. In addition, the adhesive medium should have a similar coefficient of thermal expansion to the substrates, or, if they are dissimilar, it must be flexible.

Joint design is critical to the optimum performance of a bond. Factors to be considered in choosing a joint design include:

- Joint orientation will define the type of loading applied to the bond - shear, peel, tensile, etc.
- Optimize the area of the bond to match the adhesive strength and the expected loadings.
- Aesthetics in the bond area may restrict the choice of joint design.
- Moldability and mold design can be compromised by some joint designs.
- Ability to maintain tolerances on the mating parts is critical to some joint designs, such as the tongue and groove.
- Part design and mold design must anticipate the tolerances required at the joint interface.
- Gap filling ability of the adhesive must be considered in the dimensions of the joint.
- Set time for the adhesive and the need for handling of the parts after assembly may make some joints more advantageous.

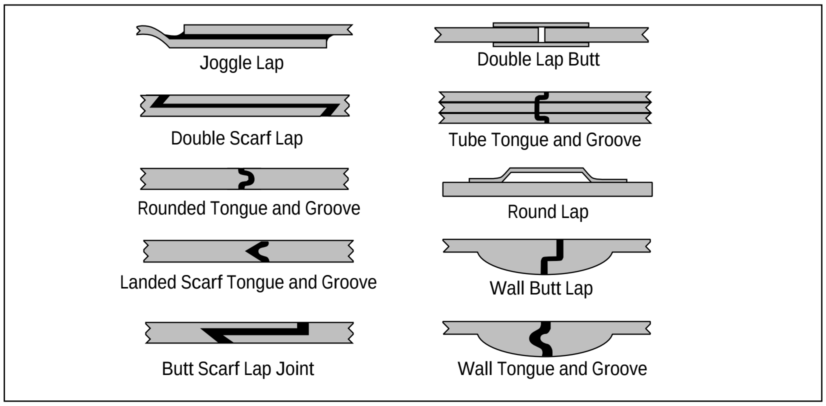


**Figure 5-25.** Joint Design – Optimized Area.

**Surface Preparation**

- Degreasing & Cleaning
- Abrasion
- Flame Treatment
- Corona Discharge
- Plasma Treatment
- Chemical Etch

## Adhesive Surface Preparation

For optimal bonding results, the surface of the substrate must be clean and dry. Surface preparation includes any method; mechanical, chemical, or electrical in nature, used to remove contaminants which might interfere with the bonding process. The amount and type of surface preparation needed depends on the adhesive used, the bond strength required, the end-use environment and economic practicalities. For the most effective adhesion, bonding should take place as soon as possible after surface preparation has been completed.

**DEGREASING AND CLEANING**. This is the most common method of surface preparation and is usually used prior to any type of adhesive bonding. The surface of the materials to be bonded should be clean and relatively free of contaminants. Among the methods used for cleaning are vapor degreasing, immersion baths, solvent spraying or wiping, and acid etching. Care should be taken in ensuring that the chemicals used for cleaning are compatible with the materials being cleaned as well as EPA and OSHA approved.

**ABRASION**. This method of surface preparation includes sandblasting, sandpaper and “Scotch-Brite™”. An increase of up to 15% in adhesion strength after abrasion can be achieved for some materials. Notch sensitive materials require careful application of this method. It should also be noted that some type of solvent cleaning is usually needed both before and after abrasion in order to remove any surface contamination.

**FLAME TREATMENT**. The area of the substrate surface to be bonded is exposed to the oxidizing area (i.e. blue, not yellow) of a flame. This is done with a controlled flame, usually natural gas, until the surface is shiny. Care must be taken to avoid overheating or melting of the substrate. This method is commonly used for olefinic materials.

**CORONA DISCHARGE**. The material to be bonded is placed between two electrodes where the bombardment of electrons and ions causes the surface to be oxidized. Corona equipment was mainly developed for use on films, but new developments allow for more complex parts to be treated. This is helpful in improving the bonding of adhesives as well as printing inks and paints.

**PLASMA TREATMENT**. This is a variation on the Corona Treatment. The substrate is placed in a vacuum chamber that is filled with an inert gas. A high electrical tension is applied to the gas and the substrate surface is bombarded with electrons causing a similar surface oxidation.

**CHEMICAL ETCH**. This is a wet process in which the part to be bonded is dipped into an acid solution. The etching solution forms either highly oxidized or complex inorganic surface layers. Chemical etching requires careful control.

### *Adhesive Application Methods and Curing*

How an adhesive is applied is as important to successful bonding as the type of adhesive applied. Methods of application fall into one of three categories: manual, semi-automatic and automatic processes. Manual methods, although slow, offer the combined advantages of simplicity and low equipment cost. Automated applications, on the other hand, provide greater speed and the potential for improved consistency, but usually require expensive machinery. Semi-automatic techniques represent a compromise between the speed and expense of automatic equipment and the comparative slowness and economy of manual equipment. Occasionally, there are also unique applications when conventional methods are not adequate and a special technique must be devised to apply the adhesive system.

**Adhesive Application**

- Manual
- Semi-Automatic
- Automatic

There are some common criteria to be followed for the application of adhesives:

- The assembly should be kept clean of dust and contaminants. Control of humidity and temperature in the lay up room is dependent on the demands of the adhesive.
- Separation of the adhesives may occur during storage. Care should be taken to thoroughly mix the adhesive before use. In the case of two-component systems, proportional blending affects the bond strength and should receive appropriate attention.
- For either automated or manual application, bond line thickness may affect the strength of the bond. Generally, maximum strength and rigidity will be achieved using as thin an adhesive layer as possible without starving the joint. Thin bond lines require greater forces to deform, are less apt to creep and have a lower probability of containing air bubbles. In addition, thin films have a greater resistance to cracking.
- As much as possible, curing should take place under temperature and timing control. The selection of cure time, rate of heat rise and cool down rate are dependent on the adhesive formulation, type of joint and expected service condition of the bond.
- Uniform pressure should be maintained over the entire joint area during the curing cycle. Some pressure is required to prevent movement of the assembled parts, so as to obtain a uniform bond layer, as well as to overcome the internal pressures created by outgassing of the adhesive.

## Plastic Fusion

### *Ultrasonic Welding*

**Advantages**

- Fast, Clean and Reliable
- Avoids Solvents, Adhesives and Long Cure Time
- Strong Bonds
- Economical

Ultrasonic welding is one of the most common methods of assembling two thermoplastic parts. Ultrasonics provide strong, reliable bonds at very fast cycle times. An ultrasonic unit can cost as much as $20,000, and each application requires a customized horn and fixturing which will add additional expense. A single ultrasonic welder can be used to join parts up to approximately 8 in (203 mm) in diameter, but several welders can be combined or "ganged together" to weld larger parts.

An ultrasonic welding system (Figure 5-26) generally consists of two major components. One is the power supply which converts 60 cycle electric power to high frequency (generally 20,000 cycle) electrical energy. This unit may also contain process controls for the welder.

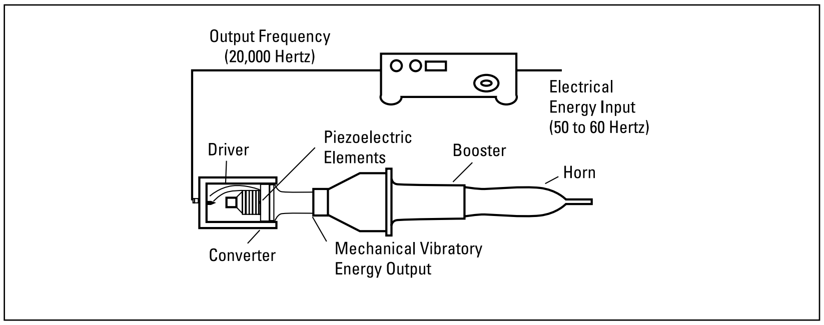


**Figure 5-26.** Components.

The second unit houses the elements which convert the electrical energy to mechanical motion and apply it to the part in the proper form. The converter contains the driver and the piezoelectric elements which provide this vibrating mechanical energy. A booster unit is connected to the converter and is used to increase, decrease or just couple the vibrational amplitude from the converter to the horn. Boosters are commonly available which supply from 0.5 to 2.5 times the converter output amplitude. The mechanical motion is then transmitted via a horn to the part. The horn is designed specifically for the parts to be assembled – delivering the proper amplitude directly to the joint area.

Only one of the mating plastic parts comes in contact with the horn. The part transmits the ultrasonic energy to the bonding area, resulting in a rapid, consistent weld. Both mating halves remain cool, except at the weld interface, where the energy is quickly converted into heat and plastic melt. Optimum energy transmission and control is obtained when the horn is close to the bond. “Near field” welding describes the condition where the horn is within 0.25 in (6.35 mm) of the weld. “Far field” welding, with distances in excess of 0.25 in (6.35 mm), can be much less effective.

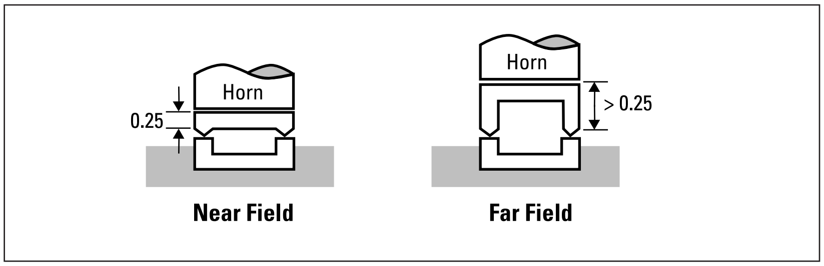


**Figure 5-27.** Ultrasonic Welding.

### Ultrasonic Welding Key Elements

The key elements for successful ultrasonic welding include joint design, part design, horn configuration and fixturing. The factors that will most influence these elements are:

- resin grade
- surface cleanliness
- uniform wall sections
- single bond plane
- simplicity of shape
- near field or far field
- welder power level
- weld time
- hold time
- clamping pressure

**Key Elements**

- Joint Design
- Part Design
- Horn Configuration
- Fixturing

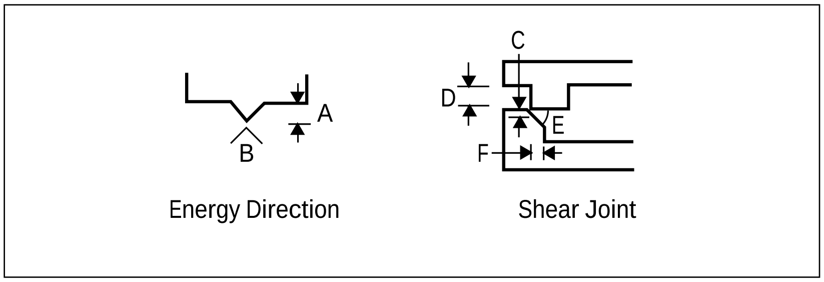


**Figure 5-28.** Ultrasonic Joint Design.

*Typical Ultrasonic Design Dimensions*

| | | | |
|---|---|---|---|
| ENERGY DIRECTION | | | |
| Height A | = .025 in (0.64 mm) (Amorphous) | .020 in (0.51 mm) (Crystalline) | |
| Angle B | = 75 to 90°F (24 to 32°C) | | |
| SHEAR JOINT | | | |
| Lead-in C | = .020 in (0.51 mm) | | |
| Depth D | = .050 in (1.27 mm) | | |
| Angle E | = 30 to 45°F (-1 to 7°C) | | |
| Interference per side F | = .008-.012 in (0.203-0.305 mm) | .012-.016 in (0.305-0.406 mm) | .016-.020 in (0.406-0.51 mm) |
| for part width | =< .750 in (19.05 mm) | .750-1.50 in (19.05-38.1 mm) | > 1.5 in (38.1 mm) |
| and width tolerance | = +/- .001 in (0.025 mm) | +/- .002 in (0.051 mm) | +/- .003 in (0.077 mm) |

## Vibration Welding

Vibration welding is the simple process of rubbing two similar plastic parts together under pressure until sufficient frictional heat develops to produce a melt. Once melting has been initiated at the interface, motion stops and pressure is maintained until the weld solidifies. Alignment can usually be maintained within a few thousandths of an inch. The frequency of vibration and displacement are low. Typical ranges are:

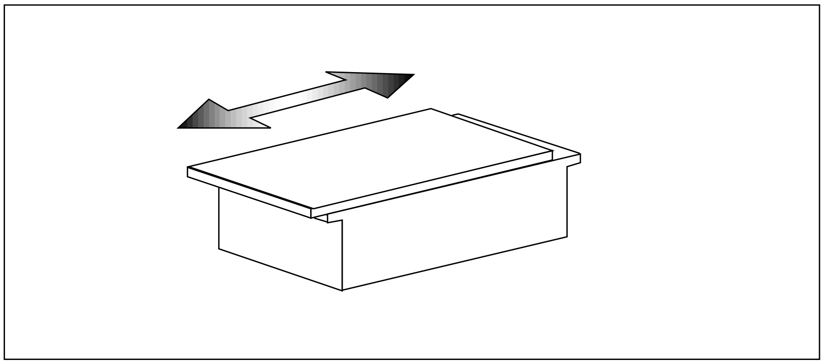


**Figure 5-29.** Vibration Welding.

Frequency – 120 Hz; Linear Displacement –
0.080 to 0.140 in (2.032 to 3.557 mm)

Frequency — 240 Hz; Linear Displacement –
0.030 to 0.060 in (0.762 to 1.524 mm)

### *Vibration Welding System*

Vibration welding equipment consists of a linear motion generating system, a vibrating element and a clamping mechanism. Vibration may be initiated by activating electromagnets while a set of flat springs control the relative position of the parts. Alternatively, the entire system may be controlled by hydraulics. Parts to be vibration welded are limited in width to about 24 in (610 mm) and depths of 12 in (305 mm) on conventional equipment. However, with side-to-side ganging in the direction of motion, this length may be adjustable.

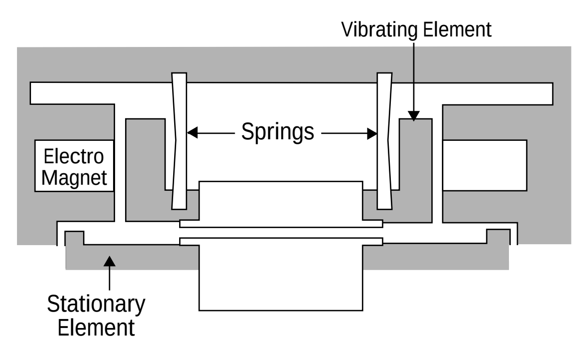


**Figure 5-30.** Vibration Welding System.

### *Vibration Welding Joint Design*

Mating part surfaces must be parallel; complex or irregular part surfaces usually cannot be welded by the vibration process. The basic joint design is a butt profile, and if flash is not acceptable, consideration must be given to a flash trap design which takes the direction of vibration into account.

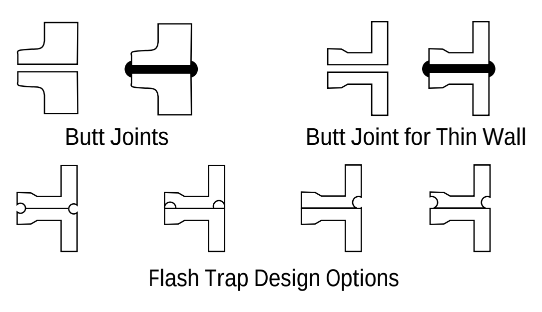


**Figure 5-31.** Vibration Welding Joint Design.

### *Vibration Welding Advantages*

**Advantages**

- Large Parts
- Hermetic Seals
- Surface Tolerant
- Internal Wall

**Disadvantages**

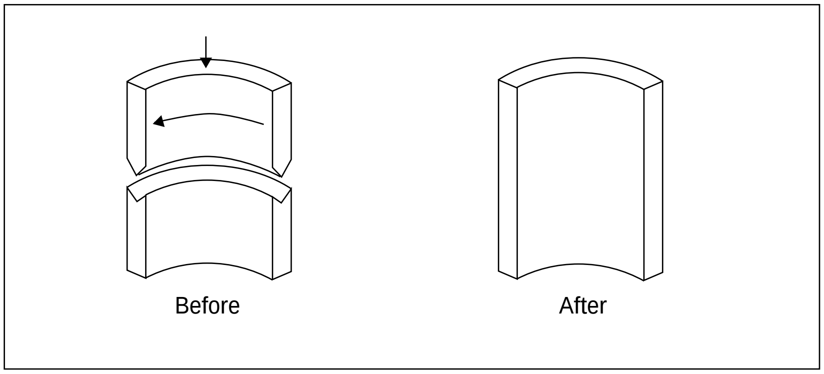
- Single Plane
- Economics

Vibration welding has a number of advantages over other welding methods. Standard equipment handles up to 24 by 12 in (610 by 305 mm) parts, properly designed joints can provide hermetic seals and internal walls can be welded at the same time as the external walls. Also, the reciprocating motion pushes surface contaminants, such as mold releases, coatings, and even paint, out of the weld area. The major disadvantage of this process is that the weld is generally limited to a single plane. Also, equipment cost is somewhat greater than other welding techniques.

## *Spin Welding*

Spin or frictional welding is a relatively simple method of joining thermoplastic parts. The process consists of rotating, at high speeds, one part against a fixed part under pressure. The frictional heat created at the interface will create a layer of melt on each part to be bonded. When the rotational motion is stopped, the pressure on the parts is maintained until the joint has solidified.

**Figure 5-32.** Spin Weld.



### *Typical Spin Welding System*

A typical spin welding unit consists of four (4) main parts: a motor, a drive head, a flywheel and a holding fixture. Usually an electric motor, with sufficient power to overcome the frictional forces involved in this welding technique and to provide the necessary linear speed at the weld area, is used as a drive mechanism. The drive head is the most sophisticated part of the spin welding unit. It consists of a spring loaded pressure plate, a clutch assembly and drive lugs. The spring is adjusted to provide the right amount of pressure on the part and allow the drive lugs, usually rubber knobs, to be engaged. At this point, the clutch mechanism is released and the flywheel engaged. The holding fixture keeps the lower half of the part to be assembled stationary while the top is rotated against it by the drive head. After the prescribed weld time, the clutch and flywheel are disengaged and the pressure is maintained for the suggested hold time.

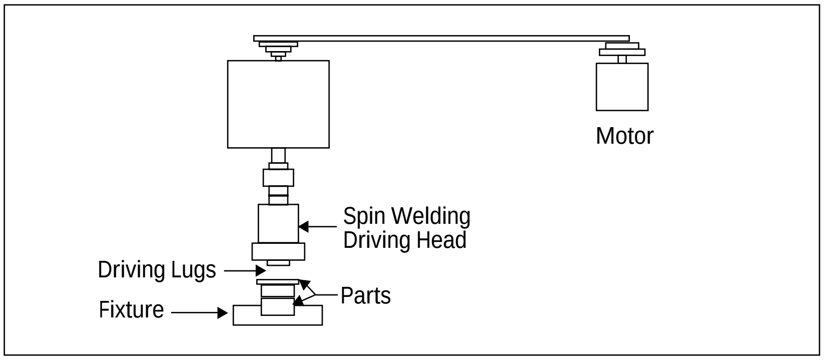


**Figure 5-33.** Typical Spin Welding System.

**Advantages**

- Tight seal
- Diameters up to 24 in (610 mm)
- Reasonable cost for equipment
- Short weld times (1 to 3 sec)

**Disadvantages**

- One part must be round
- Difficult profile orientation
- Fillers act as contaminants

### *Spin Welding Joint Designs*

The most important aspect of a spin weld joint is the design of the joint itself. It is necessary to provide adequate bond area while keeping the linear speed differential over the weld area to a minimum. For this reason, the tongue and groove, scarf and shear joints are usually suggested. The butt joint can also be used, but tends to provide weaker bonds. If surface appearance is of any importance, flash traps should be designed into the weld area.

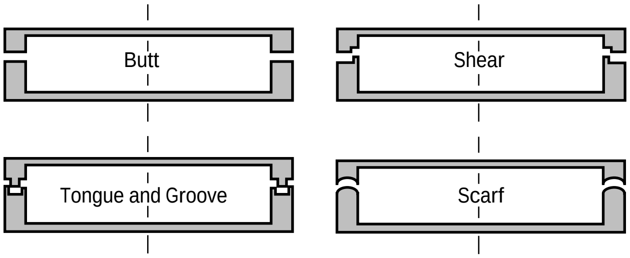
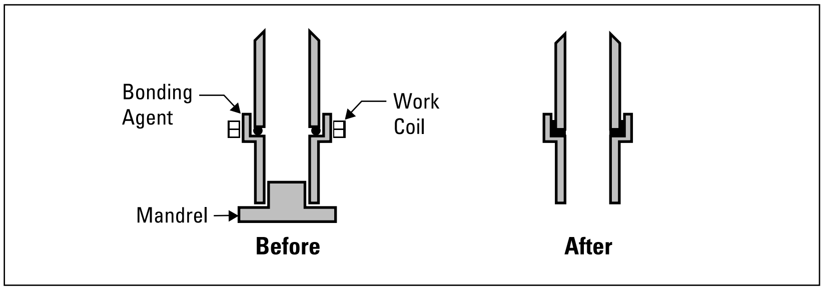


**Figure 5-34.** Spin Welding Joint Designs.

## Electromagnetic Welding

Electromagnetic welding is one of the high-technology welding techniques in use today. This process utilizes high frequency electromagnetic fields to produce heat and melt at the interface of two thermoplastic parts. The process is fast, efficient and very versatile. It consists of exposing a magnetically active gasket material to an oscillating magnetic field. This gasket material is produced by incorporating minute ferromagnetic particles in a thermoplastic matrix which is the same as the materials to be joined.

**Figure 5-35.** Induction Bonding.



**Advantages**

- Large Parts
- Complex Joints
- Reversible
- Variety of Materials
- 3 to 12 Seconds

**Disadvantages**

- Gasket Cost
- No Metal Part
- High Equipment Costs

When exposed to a magnetic field, these particles become excited and produce enough heat to cause the gasket material to flow. Heat generated in the gasket material is conducted to the abutting surfaces causing them to fuse to the gasket. The whole process occurs in 3 to 10 seconds and is dependent upon the weld area and the base resins to be welded. The two working parts of the induction welder are the induction generator and the work coil. The generator consists of a high voltage transformer and a rectifier that supplies power to the work coil. The work coil is a copper tube connected to a cooling water supply. It is the work coil which actually produces the magnetic field. Generators and work coils come in a variety of shapes and sizes. Combinations of the two are tuned to each application.

The advantages of induction bonding are numerous. There are few size limits, and weld lines up to fifteen feet in length are possible. Complex joint configurations are possible due to the lack of need for external energy transfer. This technique also allows welded parts to be disassembled – the gasket is simply reactivated.

Drawbacks and limitations to electromagnetic welding need to be noted. The need for a third component for the weld, the gasket, adds cost to the process – particularly in the case of custom molded gasket shapes. Parts containing metal inserts pose a problem since the inserts may also react to the magnetic field. The cost of the supporting equipment can become significant as different applications usually require custom work coils.

### *Electromagnetic Joint Design*

Joint designs for electromagnetic welding are slightly different than for the other welding procedures. The presence of the molten gasket material makes it necessary to design the weld area to contain this melt. As outlined above, these variations of typical joint designs do just that.

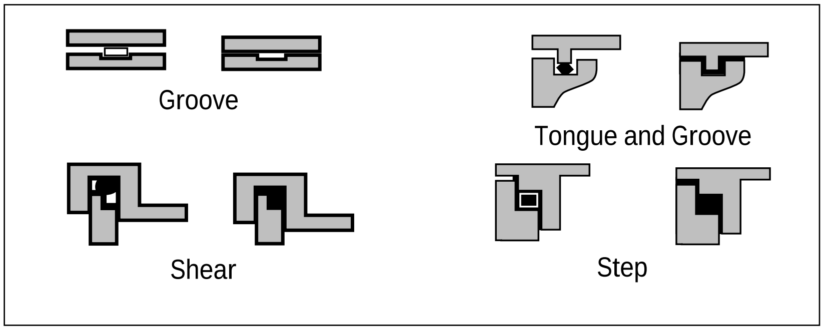


**Figure 5-36.** Joint Design.

**Induction Bonding Advantages**

- Large Parts
- Complex Joints
- Reversible
- Variety of Materials
- 3 to 12 Seconds

**Disadvantages**

- Gasket Cost
- No Metal Part
- High Equipment Costs

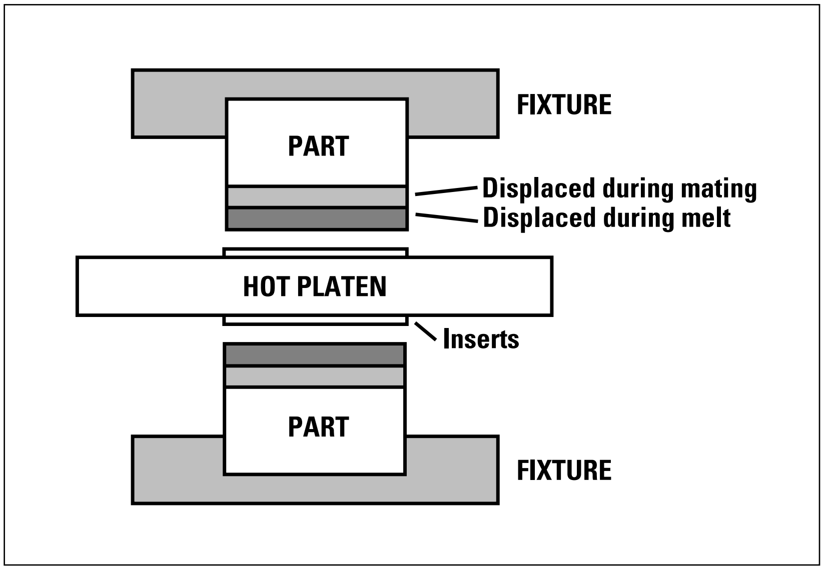
### *Induction Weldability*

The presence of the gasket material makes it possible to weld substrates that might not weld using other techniques. Below is a list of some acceptable material combinations.

### *Hot Platen or Hot Plate Welding*

Hot Platen or Hot Plate welding consists of heating two parts to be joined with a heated insert. The heated platen, at the correct temperature, is placed at the interface of the parts to be joined. The parts are then brought into contact, or in some cases very close to, the hot surface. Stops on the insert and the fixtures which hold the parts determine the depth of the initial melt. The hold time determines the depth of the secondary softening. This initial contact produces a good mating surface as both are made level by the insert. At this point the insert is removed and the parts are pressed together. The stops on the fixtures now determine the amount of material displaced during mating. The entire cycle is usually completed in 15 to 20 seconds.

**Figure 5-37.** Hot Platen Welding.



### Hot Platen Welding Joint Design

Joint design is important in hot plate welding for mainly cosmetic reasons. The material displaced during the joining process will form a bead at the weld area. It may be necessary to design the joint to hide such a bead, or the bead can be removed after the welding process is completed. Because of the method of heat application, the flat platens, only butt joint and variations on butt joints are usually used.

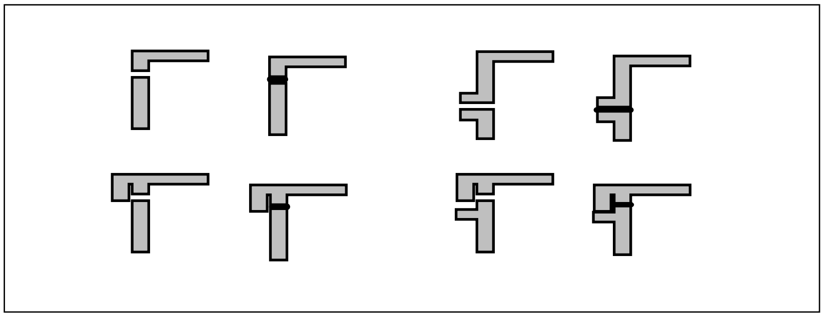


**Figure 5-38.** Hot Platen Welding Joint Design.

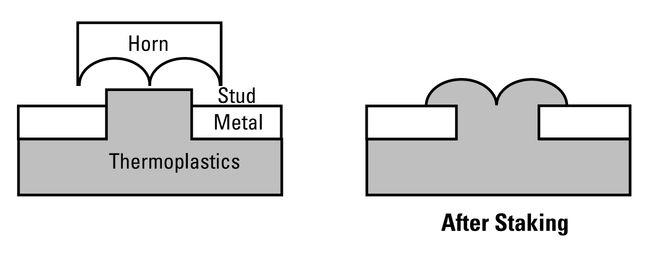
| **Advantages** | **Disadvantages** |
|---|---|
| • Irregular shapes | • Long cycle times |
| • Bond strength | • Plastic can sticks to inserts |
| • Dissimilar materials possible | • Equipment cleaning |
| • Reliable seal quality | • Material degradation possible |
| | • High temperature requirements |

## Staking

Staking is the process of deforming a plastic stud or boss to capture another part. This can be accomplished using either heat or ultrasonic energy and pressure. Both processes are performed with a contoured tool that transfers heat or energy to the plastic "stake," producing a melt phase and exerting pressure to reform the plastic. Tight assemblies require that pressure be maintained until the plastic resolidifies into the new holding contour.

Selection of the optimum staking technique for a given application will be based on considerations such as resin grade, assembly time, tool wear and equipment costs. In general, ultrasonics are often chosen over heat staking because the contact tip of the tool stays relatively cool during the process and forms a clean head with minimal sticking and stringing. For both thermal and ultrasonic staking, a slow tool approach is necessary to develop even melting and prevent cold forming with its associated stress.

**Figure 5-39.** Staking Procedure.



### *Staking Profiles*

There are a number of staking profiles available to provide a variety of appearances and strength. The standard profile produces a headform having twice the diameter of the original stud. Other profiles, which provide appearance enhancements, generally provide less holding strength than the standard profile. The staking horn tip should be contoured to contain the molten plastic and assure a tight assembly. Also, with glass or mineral reinforced materials, hardened steel or carbide tips are suggested to minimize surface erosion and extend tool life.

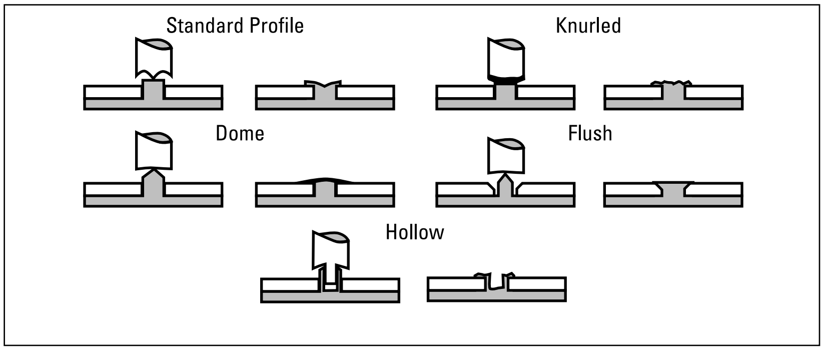


**Figure 5-40.** Staking Profiles.

# Coatings/Shielding

**Hardcoated Applications**

- Safety eyewear
- Face shields
- Headlight lenses
- Aircraft canopies
- Building glazing
- Optical lenses
- Visors
- Mass transit windows
- Automotive glazing
- Instrument panel covers

## Hardcoating

Hardcoating a part molded from LEXAN resin can provide a surface that is more resilient to scratches, chemical attack and yellowing caused by exposure to ultraviolet light. On opaque grades, applying a hardcoat can also give the part a wet-glossy or deep finish, enhancing the part's appearance.

There are several different types of hardcoats, the most widely used being silicone and acrylic hardcoats. The most common procedure is to use a primer, followed by a topcoat. The primer coat is used to promote adhesion of the coating to the part.

### *Thorough Cleaning*

To help ensure optimum performance from a hardcoat, parts should undergo a thorough cleaning to remove any contamination such as mold release or skin oils. If a mold release is not used, and care is taken not to touch parts with bare hands, an air wash may be the only cleaning treatment needed. For a more thorough cleaning, a compatible cleaner for LEXAN polycarbonate resin such as isopropyl alcohol or Freon TF can be used. Automated systems, ultrasonic baths or power washes can handle many more parts and maintain quality control. Cleanliness is critical to the production of good parts.

### *Dip, Spray, Flow*

The primers/topcoats are applied from solution by dip, spray or flow coating. Dip coating is performed by dipping the part in a tank filled with the coating material. Film thickness is controlled by the rate at which the part is removed from the tank. Spray coating is the process of spraying the part with the coating material via a spray gun, as in a painting application. Flow coating involves applying the coating to one end of the part and allowing it to flow across the entire surface. This technique is useful when only one side of a part is to be coated.

Applying the hardcoat most likely will require the use of a climate controlled clean room. Dust contamination will result in poor adhesion of the hardcoat to the surface of the part, as well as giving a flawed appearance. "Blushing" will result if the climate deviates from the hardcoat manufacturer's suggested conditions.

### *Air Dry/Oven Cure*

Curing the hardcoats will generally require that they air dry in the climate controlled clean room until tack-free. The time required to reach this tack-free state can depend upon the application technique and the specific coat used. After this air drying period, the parts are typically cured in an oven for 60 minutes. The temperature and humidity of the oven is very important: generally manufacturers' suggestions will be to cure at 130°F (54°C) and less than 50% humidity. Specific cure conditions should be obtained from the coating manufacturer. Consult manufacturers' material safety data sheets for information on the hazards of using and storing specific hardcoatings.

## Hardcoat Suppliers

An alternative to in-house application of a hard coat is to acquire the services of a custom coater. The vast majority of coating is done through the services of custom coaters. A custom coater may offer a variety of application techniques and a variety of hardcoats, and custom coaters save the trouble and expense of installing and maintaining a hard coat facility.

### Custom Hardcoaters

**Air-Lock**
108 Gulf Street
Milford, CT 06460
203-878-4691

**Exxene**
P.O. Box 8997
Corpus Christi, TX 78468
513-991-8391

**Glass Alternatives**
65 Fochtman Industrial Drive
Petoskey, MI 49770
616-347-1135

**Laird Plastics**
10110 Foster Avenue
Brooklyn, NY 11236-2194
718-257-4444

**Lexamar**
100 Lexamar Drive
Boine City, MI 49712
616-582-3163

**Fostatek Optics**
320 Hamilton Street
Leominster, MA 01453
978-534-6511

**Mascotech Coatings Inc.**
4662 Puttygut Road
China Township, MI 48054
810-329-2274

**MXL**
1764 Roherstown Road
Lancaster, PA
717-569-8711

**Panelgraphics**
10 Henderson Drive
West Cadwell, NJ 07006
201-227-1500

**SDC Coatings**
1911 Wright Circle
Anaheim, CA 92806
714-939-8300

**Texstar Inc.**
802 Avenue J East
Grand Prairie, TX 75033-4036
972-647-1366

**TSP Incorporated**
2009 Glenn Parkway
Batavia, OH 45103-1676
513-732-8900

**W&M Manufacturing**
100 North Morton Street
Portland, IN 47371
219-726-9800

### Hard Coating Suppliers

**GE Silicone**
**Product Division**
260 Hudson River Road
Waterford, NY 12188
800-255-8886
518-233-3330
(Silicone Hardcoats)

**Sherwin Williams Company**
**Chemical Coating Division**
11541 S. Champlain Ave.
Chicago, IL 60628
312-821-3460
(UV Curable Hardcoat)

**Morton International**
**Bee Chemical Division**
2701 East 170th Street
Lansing, IL 60438
708-474-7000
(Acrylic Hardcoat)

**Techneglass**
Building 52
25875 State Road 25
Perrysburg, OH 43551
419-247-7046
(Silicone Hardcoats)

**R&D Coatings, Inc.**
P.O. Box 325
Wexford, PA 15090
412-935-6830
(UV Curable Hardcoat)

**PPG Industries, Inc.**
Allison Park, PA
412-434-3346
(UV Curable Hardcoat)

**Qure Tech**
135 Folly Mill Road
Seabrook, NH 03874
603-474-5753
(UV Curable Hardcoat)

### Conformal Coating Suppliers

**GE Silicone**
**Product Division**
260 Hudson River Road
Waterford, NY 12188
800-255-8886
518-233-3330
(Thermal Cure)

**Loctite**
1001 Trout Brook Crossing
Rocky Hill, CT 06067
800-LOCTITE
860-0-571-5100
(UV Curable)

**Humiseal**
Woodside, NY 11377
718-932-0800
(Thermal Cure)

**Specialty Coatings**
Amherst, NH
603-883-3339
(Vacuum Deposition)

### UV Protection Coatings Suppliers

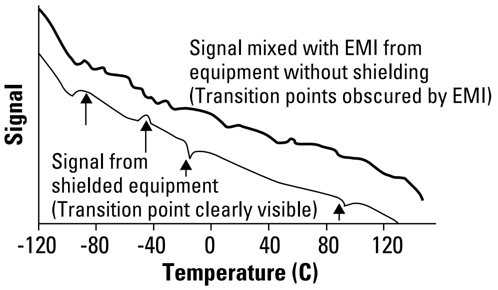
**Spraylat Company**
716 South Columbus Avenue
Mt. Vernon, NY 10550
914-699-3030

**Morton International**
**Bee Chemical Division**
2701 East 170th Street
Lansing, IL 60438
708-474-7000

## Shielding Principles and Shielding Effectiveness

The concern for shielding sensitive electronic circuits from unwanted EMI noise, or from equipment containing EMI emissions around a source, is growing with government regulation being imposed to control emissions to acceptable levels. To achieve these limits, designers and manufacturers need to integrate shielding in their product designs and have a working knowledge of EMI behavior, shielding techniques and design details such as joint, aperture and fastening considerations. Successful packages with effective EMI shields are well-thought-out design strategies utilizing robust manufacturing processes.

**Figure 5-41.** Shielding Effects.



### *The Faraday Cage Principle*

Shielding is provided by a conductive barrier which harmlessly reflects or transmits electrical interference to ground. The concept that an enclosed conductive housing has a zero electrical field was first introduced by Michael Faraday in 1821, and forms the basis of today's shielding technology. This principle is known as the "Faraday Cage".

An example may be useful in demonstrating the Faraday Cage Principle. EMI emitted from a power transformer of a piece of analytical apparatus affects the associated measuring device. Expected peaks in the output trace are obscured by interference. The problem is solved by enclosing the transformer in a metal "cage" which is grounded. The EMI is blocked and the peaks in the output trace are now clearly visible.

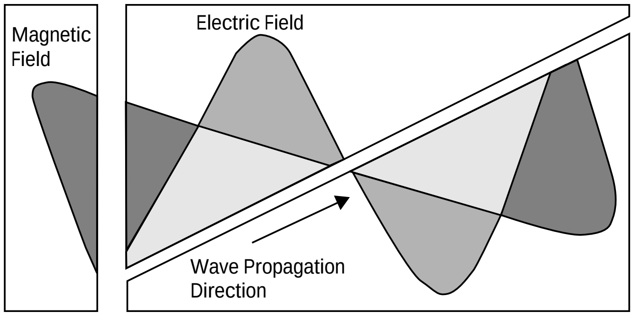


**Figure 5-42.** Electromagnetic Radiation.

*The ratio of the electrical field (E) to the magnetic field (H) is called the wave impedance (Zw) and is measured in ohms: Zw = E/H = volts per meter/amperes per meter.*

## Shielding Theory

Generated electromagnetic energy “moves” in a specific direction and consists of two waves perpendicular to each other, an electrical component and a magnetic component, as illustrated. These waves, when combined, are known as electromagnetic radiation (Figure 5-42).

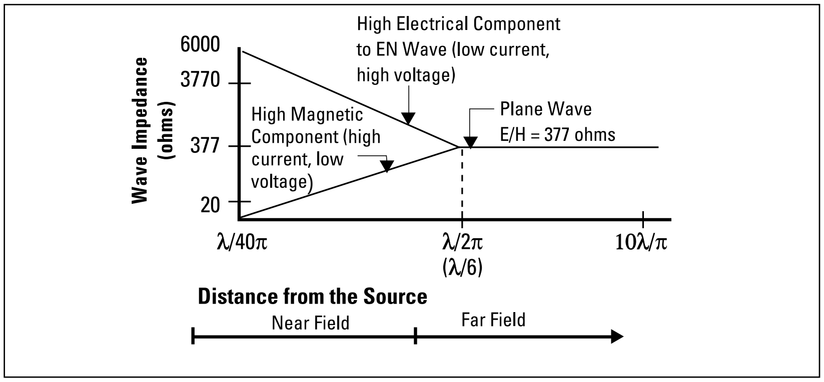


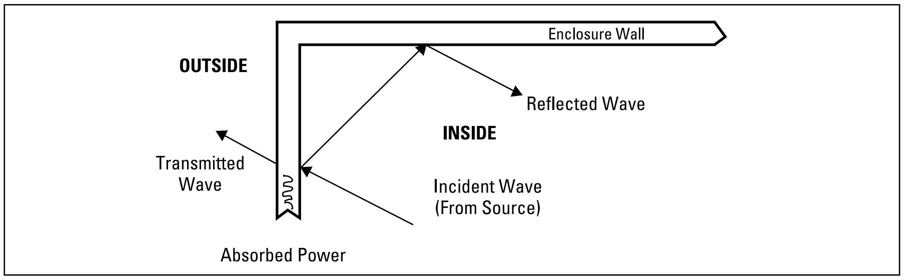
**Figure 5-43.** Electromagnetic Fields.

The electrical and magnetic components of the wave each have a different effect upon EMI depending upon their frequency range and their distance from the source of radiation. In general, the intensity of the interference caused by the signal diminishes with increasing distance from its source (Figure 5-43).

| | |
|---|---|
| **Near Field Effects:** | At a point close to the radiating source (measured in wavelengths), the impedance of the wave is determined primarily by the source characteristics (near field effects). |
| **Far Field Effects:** | Far from the source, the wave impedance depends mainly upon the medium through which the wave is propagating (far field effect). |

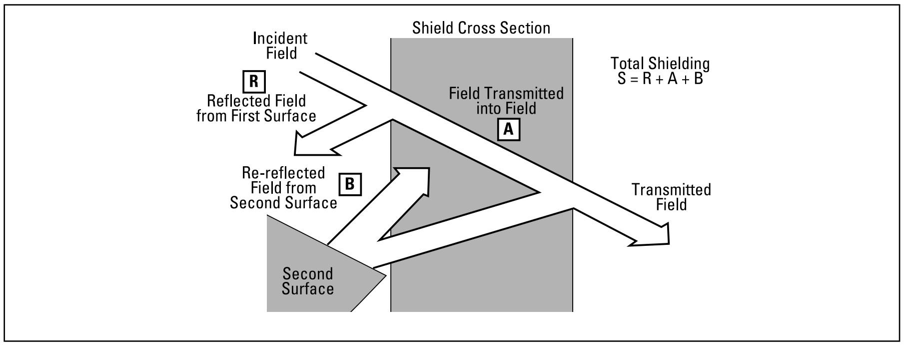
Because the EMI characteristics are so different, reference to them as Near Field or Far Field carries significance. This effectively partitions the space surrounding a radiation source.

**Figure 5-44.** Mechanisms of EMI Shielding.



When electromagnetic radiation reaches a conductive medium, some of the energy of a wave is reflected, some may be absorbed in the shield and some minimal portion of the residual energy of the wave may be transmitted when it reaches the back surface of the shielding material. This latter amount is minor, however, and usually plays little part in determining shielding effectiveness.

**Figure 5-45.** Shield Action of a Barrier.



The relationship of reflection and absorption to shielding effectiveness is well known and generally stated as follows:

S = R + A + B
S = Shielding effectiveness (defined as the reduction in energy level of an electromagnetic wave at a point in space when a conductive shield is inserted somewhere between that point and the source of the wave). (measured in decibels, dB)
R = EMI wave intensity lost due to reflection of the EMI wave from the front surface of the shield. (measured in dB).
A = EMI wave intensity lost due to penetration or absorption of the EMI wave inside the shield. (measured in dB)
B = A positive or negative factor, calculated in dB. The factor is caused by the reflecting wave inside the shield. B can be neglected if the absorption loss is more than 10 dB. In practical terms, B can also be neglected for electrically dominant fields and for plane waves.

The reflection loss, R, is dependent on the type of field (near or far) and on the wave impedance. The absorption loss, A, in contrast, is described the same in either the near or far field and for electric or magnetic fields. The amount of reflection is dependent on the impedance of the wave and of the shield. When an electromagnetic wave encounters a shield, if the wave's impedance differs significantly from that of the shield, the wave will be partially reflected back. Conversely, if the wave's and the shield's impedance are closely matched, energy will be able to pass through the shield with minimal reflection.

As mentioned earlier, an electrically dominant wave in the near field has a high impedance (greater than 377 ohms). Higher conductive metals have a low impedance and, therefore, are successful at reflecting back electrically dominant waves because of the impedance mismatch. Reflection of EMI is the primary shielding mechanism for electrically dominant waves.

Magnetically dominant waves, on the other hand, have a low impedance (less than 377 ohms). With these waves, absorption plays an important role in shielding. Magnetic waves are more difficult to shield, but generally their energy diminishes as the distance from the source increases. Over greater distances, the electric field component dominates the wave and it is this electrical component that must be dealt with through EMI/RFI shielding.

**Table 5-5.** Relative* Electrical Conductivity of Metals Used for EMI Shielding

| | | | |
|---|---|---|---|
| Silver | 1.05 | Nickel | 0.20 |
| Copper | 1.00 | Iron | 0.17 |
| Gold | 0.70 | Tin | 0.15 |
| Aluminum | 0.61 | Steel | 0.10 |
| Magnesium | 0.38 | Lead | 0.08 |
| Zinc | 0.29 | Stainless Steel | 0.02 |
| Brass | 0.26 | | |

*Relative to Copper

The relative thickness of the shielding material has an effect on the amount of the wave's energy which is absorbed. However, thickness has little effect on the amount of the wave's energy which is reflected. Both the absorption and reflection of EMI are important considerations in the selection of a shielding method.

Attenuation of "electric" fields can be handled effectively by thin metal coatings (such as those obtained with electroless plating and vacuum metalization). Primary reflection occurs at the front surface of the shield. Very thin sections of conductive material provide good reflection properties. Multi-layer shields provide increased reflection loss due to the additional reflecting surfaces. Conversely, where absorption plays a key role in attenuation, strong magnetic fields are better handled by thick-skin shields (such as those provided by conductive paints).

For a given thickness, magnetic materials such as steel provide higher absorption losses than non-magnetic materials such as copper and silver. In general, absorption losses are low at low frequencies and rise gradually to high levels at high frequencies. Absorption performance can be improved by increasing the thickness of the shield. Absorption can also be increased by using a metal with high "permeability." Generally, metals with high permeability exhibit low electrical conductivity. Additionally, only "magnetic" materials effectively shield against magnetic fields at low frequencies. At higher frequencies, where both reflection and absorption losses increase, the higher electrically conductive materials provide better electrical and magnetic shielding.

Conductivity of pure metals may not always relate to shielding effectiveness. The surface of the metal, if exposed to air, may be chemically oxidized. Conductivity of the metal oxide would then be a better indication of shielding effectiveness. For example, pure copper has excellent conductivity, but its oxide exhibits relatively poor conductivity. Therefore, any shielding system that uses copper must protect its surface against oxidation. The use of a top coat that acts as an oxidation barrier is the most common method of protection.

## Designing For Electromagnetic Compatibility

In today's modern product development effort, a team approach is preferred over a sequential passing of plans through a chain of functional individuals. The preferred process allows early involvement by all key parties and moves issues like shielding to early consideration. This integration into the overall design is important to meeting regulations and a successful introduction.

Considerations which can be addressed when utilizing a plastic enclosure requiring shielding are:

1. The application of metallic coating to the plastic substrate
2. Reduction of leakage through apertures or seams
3. Adaptation of the shielding method to various assembly methods

Effective shielding is normally measured by a definition of EMI performance levels as required by federal and/or international agencies. Commonly used options for achieving a conductive shield for a thermoplastic enclosure are noted below:

1. Two-sided Electroless Plating normally provides the highest level of shielding. The enclosure is protected by two shields, one on the inside and one on the outside surface. Selective Plating resists masking. Single-sided Electroless Plating thus far has not been practical or economical for as-molded aesthetics. Some new developments that allow for single-sided plating may allow this method to be a viable approach in the future.

   Limitation:
   To utilize as-molded part aesthetics on the exterior of an enclosure, the shielding must be restricted to the inside surfaces. This restriction favors the use of:

2. Conductive paints
3. Vacuum Metalization is another possibility, especially when larger volumes justify the cost of fixture masking.
4. A metal box-in-a-box may be used depending on configuration complexity and "total systems" cost.

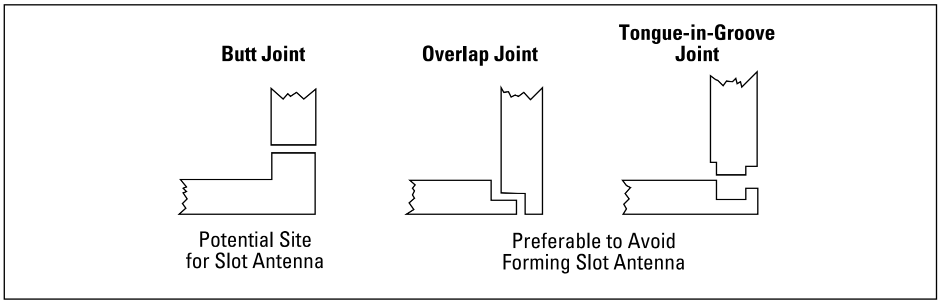


**Figure 5-46.** Types of Joints.

Frequently, actual shielding effectiveness obtained in practice is determined by the EMI "leakage" at seams, joints and holes. EMI leakage between mating surfaces at joints or seams is the main reason why shielding effectiveness is reduced. The contact between mating surfaces usually is not continuous. Shielded members may be connected by snap fits, screws, spot welds, etc. The discontinuous connection results in slits or gaps along the joint or seam which allows leakage of EMI waves. When the length of the slit approaches wavelength/2 the shielding drops to Zero dB.

> Frequency and wavelength are related by the velocity of wave propagation (i.e., the speed of light);
>
> F[Hz] x wavelength[meters] = velocity [3 x 10E8 m/sec]
>
> This type of EMI leakage is known as a slot antenna.

Butt joints are more prone to slot antenna effects due to the difficulty of maintaining acceptable electrical contact across the seams. Overlap or tongue-in-groove joints are preferable to lower the susceptibility to slot antenna effects. Additionally, round-shaped groove designs should be used over sharp "V" grooves to avoid forming a site for stress concentration. Overlap of mating surfaces should be 1.5 to 2.5 times the enclosure wall thickness. Overlap and tongue-in-groove joints also assist in part positioning during assembly. If the electronics are located well away from the seams and joints, better shielding performance can also be achieved.

Electrical continuity must be maintained across the joint so that a slot antenna is not formed. Electrical contact between mating surfaces should be made at least every wavelength/6 (2 inches when the frequency is 1000 MHz). This suggested contact spacing is one third of the slot antenna length which is when maximum EMI leakage occurs. In addition, a high level of surface conductivity is critical to maintaining electrical continuity across the seams and joints and for dissipating any static charges which may build up.

To provide a continuous conductive path, a gasket may be necessary. One of the most common types of EMI gaskets is made of a knitted wire mesh. They are available in strips, with rectangular or round cross sections, or in preformed shapes. Gaskets can be made of various materials. The gasket material should be galvanically compatible with the metallic coating to minimize corrosion. The gasket should lie in the groove of a tongue-in-groove joint. The gasket then sits in the groove forming near continuous electrical contact between the mating surfaces. If an enclosure is to be painted for aesthetics, the decorative paint must not extend inside and cover the gasket groove. The conductive coating (paint, plating, etc.) should cover the gasket groove to maintain the electrical continuity. If screws are used, the gasket should fit on the inside of the screw to protect against leakage around the screw hole.

**Design Guidelines for Apertures**

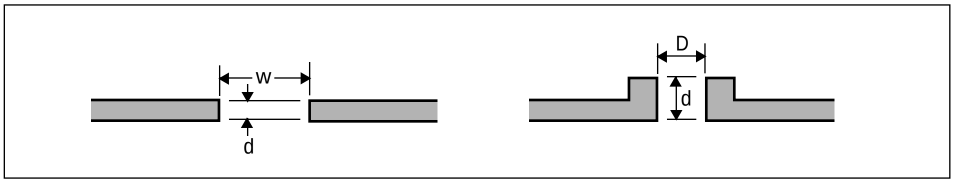
- Many small holes allow less leakage than a large hole of the same area
- Short, wide openings are better than long thin openings
- Thicker wall sections at the opening will minimize leakage (when the hole wall is conductively coated)

### Apertures

Apertures are another source of EMI leakage. The size of vents and apertures should be limited to avoid radiation or penetration of EMI waves. Leakage from an aperture is affected by three items:

1. The maximum linear dimension (not the area) of the opening. In a rectangular slot, the maximum linear dimension is the diagonal of the slot, not the length of the slot.
2. EMI leakage depends on the frequency of EMI waves from the source. As frequency increases, wavelength decreases, shortening the allowable discontinuity length and increasing the potential for leakage.
3. The amount of leakage depends on the EMI wave impedance. The impedance, or “resistance”, of a wave describes the source conditions; i.e., is the electromagnetic wave predominantly electric or magnetic and how far is the wave from the source (near field or far field).

**Figure 5-47.** Waveguide.



Additional attenuation can be obtained from a hole if it is shaped to form a waveguide. This attenuation is sometimes referred to as tunnel attenuation. A waveguide has a cut-off frequency, fc, below which it becomes an attenuator.

fc (Hz) = 3 × 10(8) (m/s)/wavelength c (m)
where wavelength = 2 × maximum dimension (slot)
= 1.7 × diameter (hole)

When the frequency of the signal is below the cut-off frequency of the waveguide (which is equivalent to saying that the wavelength of the signal is longer than the cut-off wavelength of the waveguide) the theoretical attenuation of the waveguide is:

$$\begin{aligned} SE\ (\mathrm{dB}) &= 27.3\ d/w\ \text{(slot)} \\ &= 32.0\ d/D\ \text{(hole)} \end{aligned}$$

where d = depth of opening
w = width of opening
D = diameter of hole

For example, a 1/4" diameter hole has a cut-off frequency of 2.8 GHZ and a corresponding cut-off wavelength of 1.1 cm (0.43 inches). A one inch slot has a f(c) = 600 MHZ and wavelength(c) = 5 cm (2 inches).

Assembly issues must also be considered when designing for electro-magnetic compatibility. Part assembly is moving towards a “snap fit” approach to achieve a higher degree of manufacturability and a higher level of sub-assembly integration. These fasteners can be molded into the plastic enclosure allowing for simplified assembly.

In addition to snap fits, a unit can be mechanically held together by using molded-in bosses. Bosses act as position guides and can electrically tie the device together. Metal inserts can be fixed into the bosses and the device assembled with threaded fasteners. The inserts line up so that through boss to boss contact, mating sections of the device are in electrical contact and form a continuous conductive path.

A durable uniform metallic coating is important with “snap fit” assembly, especially if parts will be separated often. A durable coating is also needed at hinged areas on an access panel that is periodically opened and closed. The metallic coating has to be tough enough to resist normal abrasion and wear in service to maintain the effectiveness of the EMI shield.

Thickness variations of the coating also alters point-to-point conductivity and this variation in conductivity can result in impedance variations that lead to poorer shielding effectiveness.

Difficulty in achieving a uniform coating on deep or hidden areas is one drawback of “line of sight” coating methods.

The shielding effectiveness and durability of the coating can be optimized by following basic design guidelines for moldability (reference Part Design information on pages 3-23 to 3-46). Wall sections should be uniform.

Although these design suggestions are primarily targeted at suppressing internal EMI emission levels, it can be equally important to shield against susceptibility from external noise sources. Ideally, if every part were properly designed and shielded to attenuate emitted EMI waves, susceptibility would not even be an issue.

### *Methods of Controlling EMI*

Techniques which offer protection against EMI are varied, but generally fall into two categories. The first involves attacking the problem from within the electronic components themselves; the second category works on the equipment housing to block EMI.

### *The Electronic Approach*

The principles behind the electronic approach are circuit design, filtering, good earth contact, and careful component selection and placement. These techniques rely heavily upon circuit re-design to make the circuits less susceptible to EMI and, more importantly, to reduce the amount of EMI the device emits.

The advantage to this approach is that it attacks the problem at the source, reducing the level of radiated emissions dramatically. Unfortunately, redesigning the electronic circuitry is expensive and does not protect the circuit from external interference. Furthermore, as circuitry becomes more and more complex and design cycles compress, it becomes more difficult to implement.

### *Housing Approaches*

Placing a Faraday Cage around an electrical device is the fundamental principle underlying the housing techniques for shielding against EMI. There are two basic ways to utilize this principle. One is to coat a “transparent” plastic housing with a conductive material; the other is to make the housing material itself conductive. This can be accomplished in three ways – coating methods, filled polymers (conductive plastics), or combine these two methods through coinjection.

### *Coating Methods*

Coating methods on plastic parts are by far the most popular of shielding techniques. Basically, they all involve coating the finished plastic housing with a layer of conductive material to create a Faraday Cage around the equipment, hence an EMI shield. The coating techniques used in conjunction with plastic housings are well-established. The majority of them were first developed for use on metal, either as decorative or protective coatings.

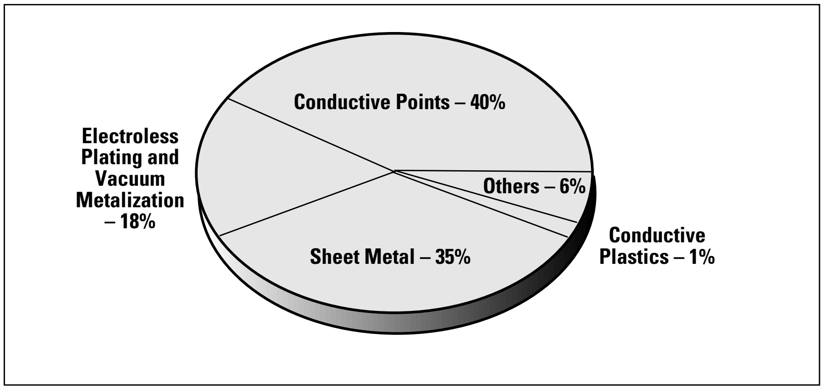


**Figure 5-48.** Shielding Methods.

### *Shielding Methods*

There are currently a number of ways to prevent the leakage or intrusion of high-frequency radiation through a plastic housing. However, other than the so-called “box-in-box” method, which entails placing a metal box within a plastic housing to act as a shielding medium, most technologies rely on coating the plastic enclosure with some kind of conductive material.

Application of a conductive coating and its subsequent performance as a proper electromagnetic shield can depend considerably on the design of the plastic enclosure.

Typical coating techniques include:

- Sheet Metal
- Foil Application
- Conductive Paints
- Electroless Cu/Ni Plating
- Electroplating
- Vacuum Metallization
- Direct Thermal Evaporation
- Cathode Sputtering
- Zinc Arc Spray

Table 5-6 on pages 5-62 and 5-63 includes information on typical coating techniques.

**Table 5-6.** EMI/RFI Shielding Techniques.

| | Sheet Metal | Foil Application | Conductive Paints | Electroless Cu/Ni Plating |
|---|---|---|---|---|
| **Effectiveness: (Attenuation)** | >65 dB (Ag) | 60-120 dB | 30-60dB (Ni)<br>>65 dB (Ag) | 65-100dB (cu) |
| **Thickness** | .009 to .040 in. (structure integrated) | .101 to .025 in (2.57 to 0.635 mm) (including substrate) | 50 to 70 microns (Ni) | 1 to 2 microns (Cu) |
| **Relative Cost** | - Cost effective in simple parts<br>- "Box-in-box" is not cost effective<br>- Cost Index: 1* | Not economical for mass production | High<br>Cost Index: 1.5 (NI)* | High<br>Cost Index: 1.75 (Cu)* |
| **Relative Environmental Impact** | Low | Minimal | High | High - disposal of plating chemicals |
| **Aesthetics** | Cosmetics achieved through paint or plastic covers | Suitable for simple shapes much like "Box-in-Box" approach | Cosmetics possible with selective coating | Surfaces normally painted over plating |
| **Size** | Not a limitation | Can adapt to most sizes Simple shapes, good for confined spaces | Not a limitation | - Must be matched to plating baths<br>- Can accept large parts |
| **Part Complexity** | Most effective on simple shapes with few holes required and surfaces in constant plane | Cost effective for low production volume | Limited - internal detail may obscure surfaces required for effective coverage | Typical of injection molding process |
| **Advantages** | - Experience factor high<br>- Very good shielding chacteristics | - Good for experimental work<br>- Good conductivity<br>- "Band-aid" to bridge across seams metalized using another method | - Numerous suppliers<br>- Economical<br>- Low capital expense | - Uniform film thickness via solution process<br>- Very good metal adhesion<br>- Very good abrasion resistance<br>- Durable in corrosive & temp./humid environments |
| **Disadvantages** | - Steel tools have long lead times, expensive<br>- Part consolidation is minimal/expensive<br>- Dimensional accuracy is difficult<br>- Corrosion protection is required | - Time consuming and labor intensive<br>- Can peel and reduce effectiveness | - Lower shielding effectiveness<br>- Operator inconsistencies | - Highly filled & foamed parts may pose a challenge<br>- Plating may depend on molding conditions<br>- Use of mold release can lead to adhesion loss<br>Note: for single-sided plating as a sprayable base coat can be used |

* Costs based on high unit build (>30K/Month). Application and material cost only. Costs normalized to Sheet Metal Liners.

| Electroplating | Vacuum Metalizing | Direct Thermal Evaporation | Cathode Sputtering | Zinc Arc Spray | Conductive Plastic |
|---|---|---|---|---|---|
| 65-120 dB | 65-120 dB | 40-100 dB | 60-120 dB (est.) | 45 -90 dB (cu) | 20-60 dB |
| 2 to 20 microns (est.) | .05 to 1.2 microns | 2.5 to 15 microns | 1.2 to 10 microns (est.) | 70 to 120 microns (Cu) | .050 to .120 in<br>(1.27 to 3.05 mm) |
| High<br>Cost Index: 1.5* | High<br>Cost Index: 1.5* | High<br>Cost Index: 1.5* | - 3 to 4 times higher than thermal systems<br>- High capital investment<br>- Cost Index: 4.5 to 6.0* | Capital costs are high | Moderate to high |
| High-must handle, store and dispose of plating solutions | - Minimal metal/chemical waste<br>- Metalized parts are suitable for regrind and reuse | Minimal | Minimal | Hazardous-must deal with Zn fumes | None |
| Difficult to mask appearance surfaces, would need paint over plasting | - Cosmetics possible with selective coating<br>- Adhesion promotion technique uses plasma “cleaning” | Cosmetics are possible with masking fixtures | Sometimes a base coat and a top coat are necessary | Paint undercoat is usually used | Painting is usually necessary |
|  | Must fit inside vacuum metalizing chamber | Must fit in chamber | Must fit in vacuum chamber | Can accommodate large parts | - Smaller, more complex parts<br>- Material costs grow with size and determine fit |
| Suitable for typical injection molded design | Limited - line of sight coverage is common | Line of sight coverage limits detail on side to be covered | Line of sight coverage | Limited by line of sight application | Acceptable with typical injection molding design |
| - Decorative<br>- Very good electrical parameters<br>- Good conductivity<br>- Resistant to chipping<br>- Cost effective in high volumes<br>- Suitable for military tempist requirements | - Base coat eliminated on all commonly used plastics<br>- Adhesion is strong enough to pass the UL 746C adhesion test | - Increased metal thickness enhances abrasion resistance<br>- Stable oxide layer eliminates a protective top coat | - Good adhesion and coating density<br>- Good conductivity | - Good conductivity<br>- Hard dense coating<br>- Effective over a wide frequency range | - Polymer matrix is inherently conductive<br>- Single process for quality assurance<br>- No secondary shielding required |
| - More costly process than electroless plating<br>- Only done for small parts<br>- Limited to certain thermoplastics<br>- Expert knowledge required<br>- High cost equipment | - Chamber size needed<br>- Level of expertise required<br>- Equipment costly<br>- Limited suppliers |  | - Expensive equipment<br>- Microscopic cracking<br>- Heat of application could cause deterioration<br>- High power required | - Special equipment required<br>- Adhesion concerns<br>- Secondary operation | - Low electrical continuity at the surface<br>- Economically unfavorable in large material intensive parts |

## Shielding Effectiveness

The techniques used to measure the effectiveness of any shielding system are extremely varied, sometimes not reproducible, and are not comparable. One further complication is that as far as regulations are concerned, it is the finished item – the business machine, the computer or the chip connector – that must be tested for effectiveness, and not the individual coating or shielding system.

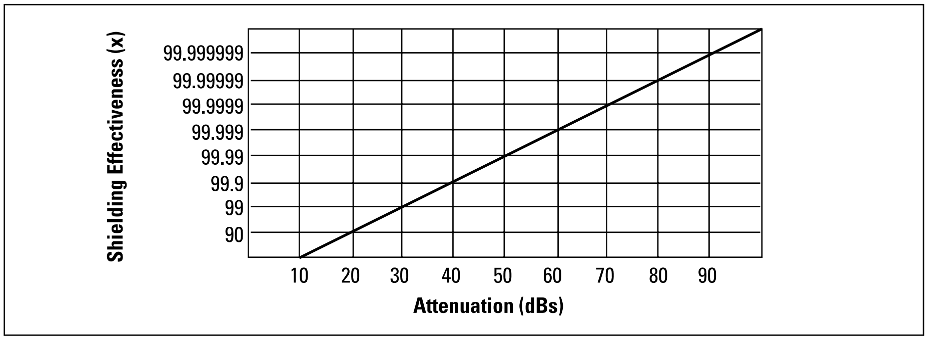


**Figure 5-49.** Relationship Between Shielding Effectiveness and Attenuation.

The measurement of EMI is an extremely complex subject, and it is not the purpose of this document to cover fully all the different problems surrounding the technology.

Electromagnetic energy can be measured using several different techniques, but generally the objective is to measure "attenuation". Attenuation is the amount by which the intensity of an electromagnetic signal is reduced by the introduction of a shielding medium. In practical terms, attenuation is measured in decibels (dB) and is the ratio of the field strength without the shield to the field strength with the shield. Written mathematically, the formula is:

Electric field strength effectiveness (dB) = 20 log Ei/Et
Ei = Incident Electrical Field Strength in V/m
(or received signal)
Et = Transmitted Electrical Field Strength in V/m
(or transmitted signal)

Magnetic field strength effectiveness (dB) = 20 log Hi/Ht
Hi = Incident Magnetic Field Strength in amps/m
Ht = Transmitted Magnetic Field Strength in amps/m

Total electromagnetic shielding effectiveness (dB) = 10 log Pi/Pt
Pi = Incident Power in Watts/m2
Pt = Transmitted Power in Watts/m2

**Table 5-7.** Shielding Effectiveness.

| Decibel Rating | Attenuation Level | Comparative Rating |
|---|---|---|
| 20 db | 90% | minimum of meaningful shielding |
| 40 db | 99% | average shielding |
| 60 db | 99.9% | good shielding |
| 80 db | 99.99% | good/excellent shielding |
| 100 db | 99.999% | excellent shielding |

Shielding effectiveness measured in decibels is a logarithmic scale, which means that an attenuation measurement of 50 dB is ten times more effective than a measurement of 40 dB.

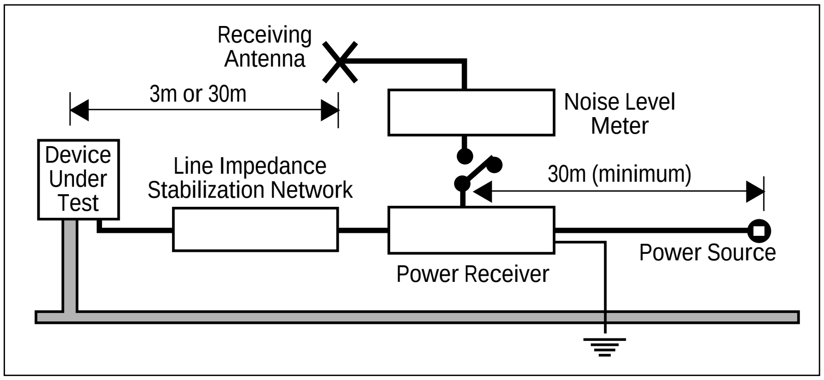


**Figure 5-50.** Shielding Effectiveness Measurement – Open Field Technique.

## *Open Field Testing Technique*

The Open Field Technique most closely resembles actual usage situations. The FCC, CSA, EN 55022, and VCCI radiation limits are all based on this technique. Only tests conducted on the finished "product" can be used to determine compliance with agency standards. Test results for a metalized plaque will differ from test results for a complete commercial electronic device.

The test actually takes place in an open field, which allows free space measurements to be taken for both radiated and conducted emissions. To perform radiated emissions tests, the device must be mounted as illustrated. The receiving antenna should be mounted either 10 meters or 3 meters away, depending on whether the equipment is FCC Class A or Class B. If the testing is done for European compliance, the receiving Antenna should be mounted 30 meters away for Class A and 10 meters for Class B. Radiated emission levels are then recorded on the noise level meter and must fall below the limits specified by the particular agency to be in compliance.

The conducted emissions test measures signals transmitted down the power line itself, with the switch on the circuit linked into the noise meter.

### Material Conductivity Measurement

Please refer to Electrical Properties. See page 2-35.

### Adhesion Testing

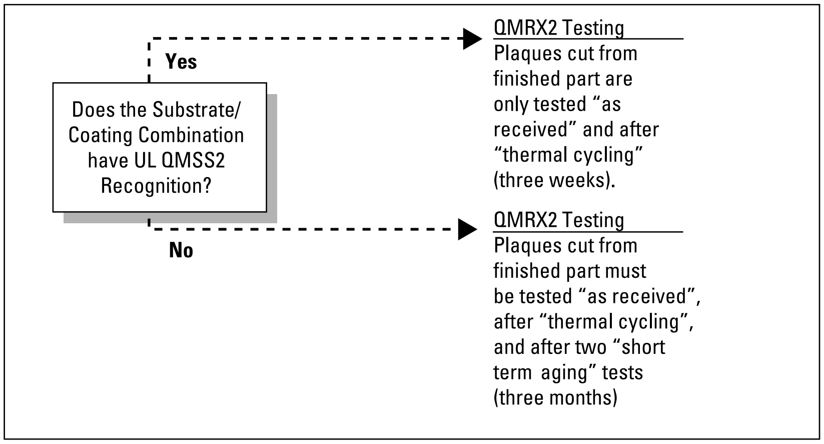
Proper adhesion between a shielding material and a substrate is an important criterion for the selection of a shielding method. If the shield layer begins to separate from the substrate, the loose particles of conductive material may fall onto electronic components of the device and these flakes may bridge "live current" carrying spots. Loss of adhesion can also cause sites of EMI leakage and slot antennas.

**Adhesion Testing**

- QMRX2
- QMSS2

For the above reasons, Underwriters Laboratories requires that all devices submitted for their recognition (as outlined in UL 746C) undergo adhesion testing. See page 2-44. These tests are designated in QMRX2 and QMSS2.

**Table 5-8.** Decision Tree for QMRX2.



Does the Substrate/ Coating Combination have UL QMSS2 Recognition?

QMRX2 Testing
Plaques cut from finished part are only tested "as received" and after "thermal cycling" (three weeks).

QMRX2 Testing
Plaques cut from finished part must be tested "as received", after "thermal cycling", and after two "short term aging" tests (three months)

## Notes

# Aesthetic/Decorative

**Decorating**

- Design
- Substrate
- Surface
- Process
- Adhesion
- Environment
- Application

## Decorating

Decorating in the plastics industry can be termed as a surface covering or impression onto a substrate by application of heat, pressure or a combination of these parameters. Decorating may be divided into two separate categories: appliques and printing.

- Appliques include decals, hot stamping, in-mold, hot and water transference.
- Printing covers screen pad transfers, diffusion printing and laser printing.

Also included is a section on surface treatment which we all know is as important as the process itself. Surface preparation discusses both chemical and mechanical processes performed in order to prepare a part for decorating.

### *Appliques*

An applique is a surface covering applied by heat, pressure, time or a combination of these parameters. Applique forms used on GE Plastics resins include Decals, Hot Stamping, Hot Transfer, In-Mold and Water Transfer.

### *Decals*

Decals can be either decorations or product instruction labels. They may be printed on precut plastic, paper or other carriers with a pressure sensitive adhesive backing. When a protecting release sheet is removed, the decal is positioned over the part surface and pressed into place. As with all surface contacts, the compatibility of the adhesive to the plastic part is important. The typical areas of concern include peel-strength, abrasion, temperature, ultraviolet and chemical exposures.

Some decals are applied by automated equipment. Others have punched or drilled holes and are affixed by various mechanical means such as threaded fasteners, rivets or staking. Consult the appropriate assembly technique for design information.

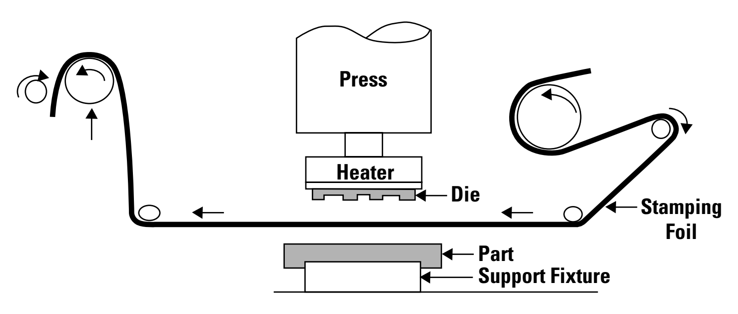


**Figure 5-51.** Hot Stamping Procedure.

## *Hot Stamping*

The dry process of hot stamping uses a combination of heat, pressure and a dwell time to apply a pattern to a substrate. This pattern is created, in reverse, by etching a metal or rubber die to leave a raised surface. A pigmented, metallic or woodgrain foil is placed between the die and the plastic part to be stamped. The simultaneous application of heat and pressure for a specific dwell time stamps the raised pattern onto the plastic surface.

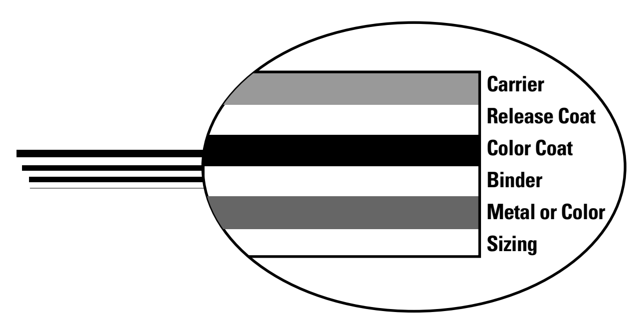


**Figure 5-52.** Stamping Foil Layers.

## *Hot Stamp Foils*

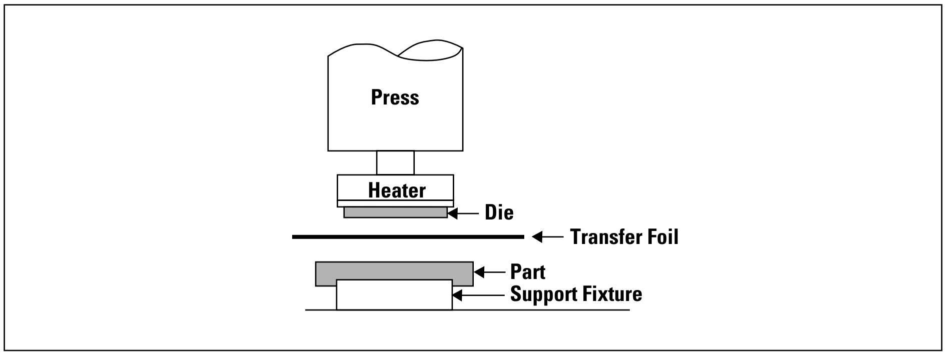
Hot stamp foils are multilayer laminates. Their composition is dependent upon the material to be decorated, built-in physical properties such as mar and chemical resistance, and color. Melt profile and surface characteristics of the plastic material to be stamped are important. Therefore, foils are usually developed for the specific plastic and occasionally the unique grade to be decorated.

### Hot Transfer

The hot transfer process is similar to hot stamping in that a dry coating system is transferred via a heated die onto a plastic surface. The uniqueness of hot transfer is that the die is flat faced and the carrier contains the pattern which is transferred under heat and pressure.

This process is usually more expensive than hot stamping because of the cost and complexity of the multi-color image. However, it offers the advantage of simultaneous multi-color transfer. The same design and carrier considerations for hot stamping apply to this technique.

**Figure 5-53.** Hot Transfer Procedure.

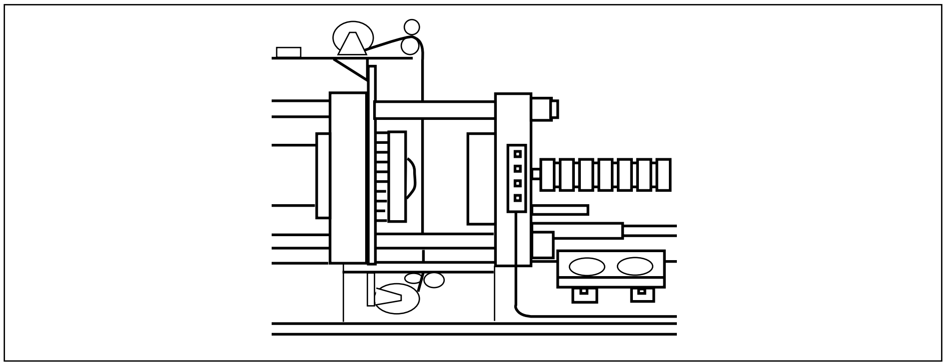


### In-Mold Decorating

In-mold decorating consists of a predecorated carrier (e.g., hot stamp foil) which is placed directly into the mold. During processing, the molten resin being injected contacts the film and fuses with it.

A predecorated carrier may be laminated onto film stock which would then be thermoformed and fit into the mold cavity before processing (insert molding). The film stock can also be decorated by printing methods such as silk-screen or hot stamping, prior to thermoforming and molding. Decorating films must have good thermal stability due to their exposure to high injection molding temperatures. Complex surfaces may result in problems caused by air entrapment or stretching of the film.

**Figure 5-54.** In-Mold Decorating.



## *Water Transfer*

Water transfer is a generic term for a process which offers three-dimensional multi-color decorating. It imparts an overall pattern that requires no precise orientation, such as woodgrains and marbling, on curved, contoured or rough surfaces as well as around corners. Parts with handles, thru-holes or sharp projections which may tear the film are difficult to decorate by this technique. The process utilizes a very flexible water soluble carrier film on which a pattern is printed. This film is floated on the surface of a water bath, ink side up, and the plastic part is dipped into it causing the inked film to conform to the shape of the part. When the part is removed from the bath, the soluble film is washed off, leaving the ink. After this, a protective transparent topcoat is applied to provide abrasion resistance. Performance properties and adhesion can be improved by applying a basecoat or primer to the part before decorating. Background tones may be varied by the same means.

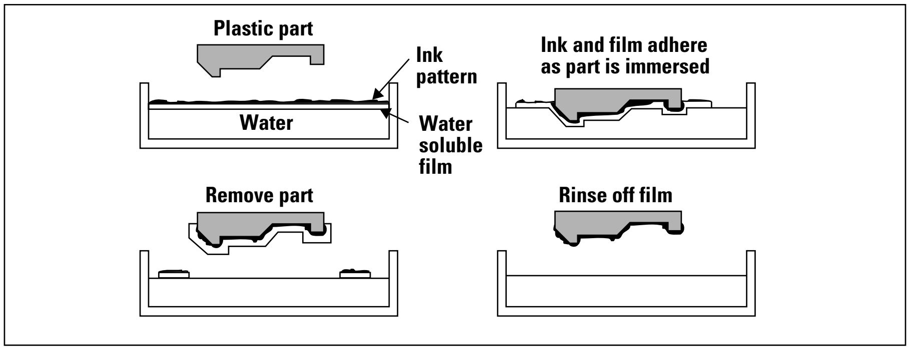


**Figure 5-55.** Water Transfer Process.

## *Hot Stamping Equipment Suppliers*

**Acromark**
60 locust Avenue
Berkeley Heights, NJ 07922
908-464-6474

**Dri-Print Foils**
329 New Brunswick Avenue
Rahway, NJ 07065
908-382-6800

**Foilmark**
40 Melville Park Road
Melville, NY 11747
516-694-4300

**Foilmark Technology Group**
25 Hale Street
Newburyport, MA 01950
508-462-6010

**Kurz-Hastings Incorporated**
Dutton Road
Philadelphia, PA 19154
215-632-2300

**Thermark**
650 West 67th Place
Schereville, IN 46375
219-322-5030

**Transfer Print Foils, Inc.**
9 Cotters Lane
P.O. Box 518T
East Brunswick, NJ
908-238-1800

**United Silicone**
4471 Walden Avenue
Lancaster, NY 14086
716-681-8222

## *Hot Transfer Suppliers*

**Color-Dec. Inc.**
420 Andbro Drive
Pitman, NJ 08071
609-589-3800

Electrocal Division
78 Edwin Road
South Windsor, CT 06074
203-289-8658

## Printing

Printing is a process of making a mark or impression on a substrate for decorative or informational purposes. Various techniques are employed for printing on GE resins. They include screen, pad, diffusion, dyeing, flexography, offset and laser printing.

**Printing**

- Dyeing
- Screen
- Pad Transfer
- Diffusion
- Flexography
- Offset
- Laser

### *Dyeing*

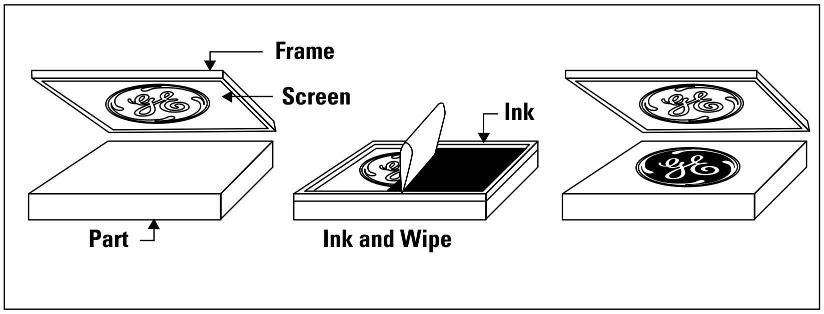
Dyeing provides low cost surface color in applications where abrasion resistance is not a concern. Typically, parts are placed into an agitated water bath containing the dyestuffs. The bath is set between 190-212°F (88-100°C). Parts to be dyed are left until the desired color tone is reached, usually from 3 to 10 minutes. The parts are then removed, rinsed and allowed to air dry.

### *Screen Printing*

Screen printing is accomplished by means of a fine-mesh synthetic material held in a frame. A pattern is produced by selectively sealing some holes in the mesh, leaving those of the design area open. Ink is placed in the screen frame and a fixture positions the screen slightly above the plastic part. A squeegee is moved across the screen, forcing ink through the open holes of the pattern and onto the part surface. The screen is then lifted, and the part is removed and dried.

The screen printing process is limited to parts having a planar surface, and to one color per step. For multi-color designs, a separate screen is required for each color and drying time between steps is necessary.

**Figure 5-56.** Screen Printing.



### *Pad Transfer Printing*

Pad transfer is a simple, low pressure process for printing on flat or irregular shaped surfaces. In the pad transfer process, a metal plate or "cliche" containing an etched pattern is covered with ink. A "doctor blade" then removes the ink from all but the etched pattern. A soft silicone rubber pad contacts, presses on and picks up the ink from the etched recesses in the plate. This pad, carrying the inked pattern in reverse, is pressed against the part to be printed and transfers the pattern to its surface.

Although the shape and flexibility of the rubber pad permits printing on irregular surfaces, sharp corners are to be avoided because they tend to cut the pad, reducing its functional life.

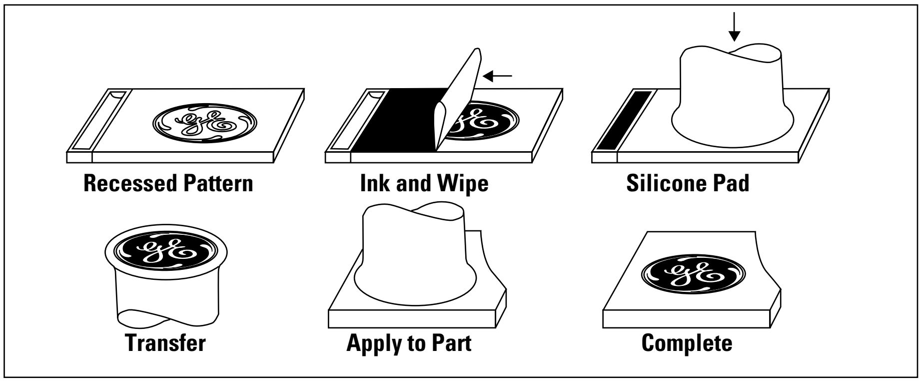


**Figure 5-57.** Pad Transfer Printing.

### *Diffusion Printing*

Diffusion is a printing process which involves the transfer of dye solids below the surface of a plastic substrate by means of heat and pressure or heat alone. The key element of this process is the ink or dye system employed. The inks used for diffusion printing are capable of a conversion process know as sublimation: changing from a solid state to a gas and back to a solid without passing through a liquid phase.

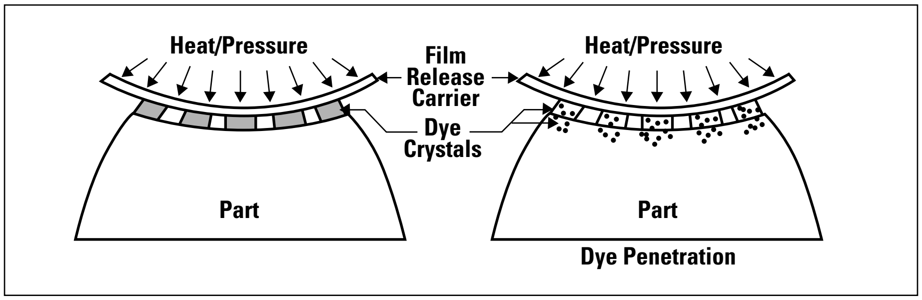


**Figure 5-58.** Dry Diffusion Printing.

**Limitation**

Dark color on light colored materials.

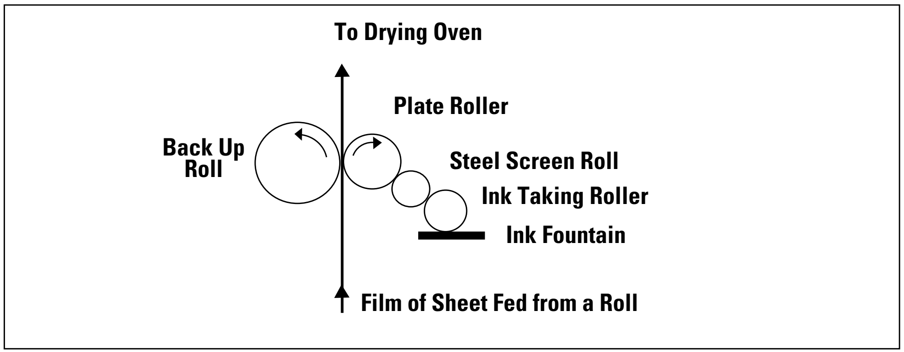
This enables the inks to penetrate the surface of a plastic part and blend into the molecular structure of the material to a depth of 2 to 4 mils. Dry diffusion is similar in procedure to hot stamping or hot transfer appliques in that the characters or designs are first reverse printed on a carrier. The design is then transferred to the plastic substrate by means of heat, pressure and time. The main advantage of dry diffusion is that the carrier can accept multiple colors.

Wet diffusion is accomplished with standard pad transfer techniques and equipment. The sublimation inks in suspension with a solvent evaporate after providing directional barrier resistance for the ink. Exposure to heat allows the dye solids to diffuse into the substrate material. The wet process is lower in cost than dry diffusion. Although it is a one-step, one-color procedure, multicolor processing is possible with curing between successive operations. Even so, the time is minimal.

## *Flexography*

Flexographic printing is a low cost, roll-fed, rotary operation employed in decorating thin gauge plastic sheet. Items decorated by this technique are typically seen in packaging applications.

**Figure 5-59.** Flexographic Printing.



The equipment consists of an ink fountain, a rubber ink roller, a steel screen roll, an aluminum plate roll to which rubber printing plates are attached, and a steel backup roll. During the printing process, the ink rollers, immersed in the ink fountain, coat the screen roll, which transfers a thin layer of ink to the raised surface of the printing plate. The ink is then deposited onto the sheet material as it passes between the printing plate roll and the backup roll. Several printing stations, as the one described above can be used to apply the desired number of colors.

## *Dry Offset Printing*

Offset is a two-stage, economical printing method which provides quality reproduction and tight registration control.

Dry offset uses a raised acid-etched metal plate which is roller coated with ink. The ink from the plate is transferred to an intermediate surface called a blanket cylinder and then to the plastic part. More than one color can be laid down in a single pass by adding a different plate and color station for each color desired. The inks used dry rapidly or can be cured by ultraviolet or electron beam exposure.

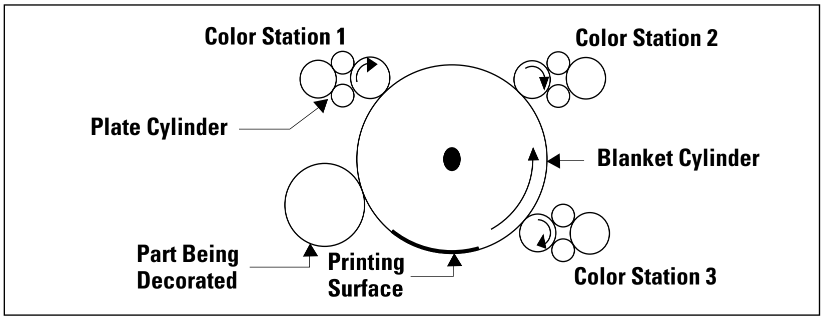


**Figure 5-60.** Offset Printing Process.

## *Laser Printing*

Laser, an acronym for Light Amplification by Simulated Emission of Radiation, is useful for coding parts too small for conventional printing processes. Codes or marks are made by directing a CO2 laser through a series of stencils and a focusing optic at set distances from the part. The beam essentially vaporizes the plastic surface, usually changing its color wherever it hits. The amount of contrast produced by the printing is the most important determination. Pulse power, rate and marking speed control the depth of etching.

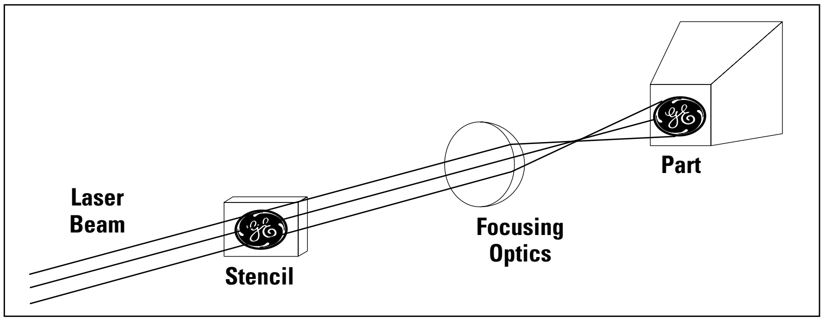


**Figure 5-61.** Laser Printing.

# Product Assembly

## Laser Systems Suppliers

**Control Laser Corp.**
7503 Chancelor Drive
Orlando, FL 32809
407-438-2500

**Laser Fare Ltd., Inc.**
1 Industrial Drive South
Smithfield, RI 02917
401-231-4400

**Lumonics/Laserdyne**
6690 Shady Oak Road
Eden Prairie, MN 55344
612-941-9530

**Convergen Tenergy**
1 Picker Road
Sturbridge, MA 01566
508-347-2681

**General Scanning**
32 Cobble Hill Road
Somerville, MA 02143
617-625-5200

**Lasertechnics**
5500 Wilshire Avenue
Albuquerque, NM 87113
505-822-1123

**Lumonics, Inc.**
105 Schneider Road
Kanata, Ontario
Canada, K2K 1 Y3
613-592-1460

**Lumonics Laser**
**Systems Group**
19776 Haggerty Road
Livonia, MI 48152
313-591-0101

## Pad Printing Equipment Suppliers

**Autoroll Dennison Corp.**
River Street
Middleton, MA 01949
508-777-2160

**Service Tectronics Inc.**
2827 Treat Street
Adrian, MI 49221
517-263-0758

**Printex**
7755 Arsons Drive
San Diego, CA 92126
619-621-2000

**United Silicone**
4471 Walden Avenue
Lancaster, NY 14086
716-681-8222

**Markem Corp.**
150 Congress Street
Keene, NH 03431
800-462-7536

**Transfer Print Foils, Inc.**
9 Cotters Lane
P.O. Box 518T
East Brunswick, NJ
908-238-1800

## Screen Printing Ink Suppliers

**Colonial Printing Inks**
180 East Union Avenue
East Rutherford, NJ 07073
201-933-6100

**Westfield Coatings**
**Corporation**
P.O. Box 815
Westfield, MA 01086
413-562-9655

**General Formulations**
320 South Union Street
Sparta, MI 49345
616-887-7387

**Ink Dezyne Corporation**
P.O. Box 456
Sparta, MI 49345
616-887-8879

**Nor-Cote Chemical Company**
P.O. Box 668
605 Lafayette Avenue
Crawfordville, IN 47933
317-362-9180

**Sericol Midwest Coatings, Inc.**
20 West 14th Avenue
N. Kansas City, MO 64116
816-474-0650

**The Naz-Dar Company**
1087 North Branch Street
Chicago, IL 60622
312-943-8338

**Spraylat Company**
716 South Columbus Ave.
Mt. Vernon, NY 10550
914-699-3030

## Diffusion Printing Suppliers

**Keytech**
1280 Jefferson Boulevard
Warwick, RI 02886
401-732-7788 Phone
401-732-5669 Fax

**Comtec Inc.**
7837 Custer School Road
Custer, WA 98240
604-536-1114

**Color-Dec**
420 Andbro Drive
Pitman, NJ 08071
609-589-3800

**Kurz-Hastings**
Dutton Road
Philadelphia, PA 19154-3284
215-632-2300

**Xpres**
111 Cloverleaf Drive
Winston-Salem, NC 20173
800-334-0425

**Borden Decorative**
1154 Reco Avenue
St. Louis, MO 63126
314-822-3880

**Caprock**
2303 120th Street
Lubbock, TX 79423

## Sublimation Transfer Ink Manufacturers

**Union Ink Co., Inc.**
453 Broad Avenue
Ridgefield, NJ 07657
201-945-5766

**Coates Screen, Inc.**
180 East Union Avenue
East Rutherford, NJ 07073
201-933-6100

**Naz-Dar Co./KC Coatings**
1087 North Branch Street
Chicago, IL 60622
312-943-8338

**Superior Printing Ink Co.**
70 Bethune Street
New York, NY 10014
212-741-3600

## Painting

Although GE Plastics' resins are available in an extensive range of attractive colors, painting may sometimes be required to add a special decorative effect or to improve the functionality of the part. Some typical reasons why paints are chosen include:

- Improved chemical, abrasion or weathering resistance.
- Color matching with adjacent parts or components.
- Woodgrain, luminescent or metalflake appearance.
- Electrical conductivity.
- Extra high gloss or matte finish.
- Textured appearance where molded-in texture is not possible.
- Coverage of surface imperfections due to imperfect processing techniques.

**Painting Plastic Parts**

Painting may be desired to add a special decorative effect or to improve functionality of a part.

| PAINT SUPPLIERS | | PAINT SUPPLIERS FOR INJECTION MOLDED SUBSTRATES | |
|---|---|---|---|
| **Red Spot Company, Inc.**<br>Evansville, IN<br>812-428-9100 | **Sherwin Williams**<br>Cleveland, OH<br>330- 528-0124 | **Akzo Coatings**<br>Troy, MI<br>248-637-0400 | **Sherwin Williams**<br>Chicago, IL<br>773-821-3000 |
| **Bee Chemical Co.**<br>Lansing, IL<br>708-474-7000 | **Eastern Chem-Lac Corp.**<br>Malden, MA<br>781-322-8000 | **Red Spot Company, Inc.**<br>Evansville, IN<br>812-428-9100 | **PPG Industries**<br>Atlanta, GA<br>404-761-7771 |
| **C.F. Jamison & Co.**<br>Bradford, MA<br>978-374-4731 | **Tenax Finishing Products**<br>Newark, NJ<br>973-589-9000 | **Spraylat Corp.**<br>Mt. Vernon, NY<br>914-699-3030 | **Lilly Industrial Coatings**<br>Indianapolis, IN<br>317-634-8512 |
| **Lilly Industrial Coatings**<br>Indianapolis, IN<br>317-634-8512 | **U.S. Paint**<br>St. Louis, MO<br>314-621-0525 | **Bee Chemical Co.**<br>Lansing, IL<br>708-474-7000 | |
| | **Koppers Company Inc.**<br>Pittsburg, PA<br>412-227-2103 | | |

### *Molding Effects on Secondary Finishing*

Whether you are a molder, molder/finisher, finisher or end user, some knowledge of molding effects on secondary finishing is essential for the attainment of high-quality finished parts. Unfortunately, since finishing represents one of the last steps of part production, the finisher often finds himself faced with the need to not only finish the part, but also to cover up the minor flaws of previous production steps. Additional help in correcting processing and design issues can be found in the Technology Information and Troubleshooting modules.

### *Splay*

The most common cause of splay is improper drying of the resin. This type of splay is often called silver-streaking or moisture splay. Although moisture splay obviously affects the appearance of the parts, it may also affect the physical properties of the part. Moisture splay is easily prevented by following the suggested drying procedures for the specific resin grade involved.

Another common type of splay is the result of burning of the resin. It is generally accompanied by degradation of the plastic's properties, such as impact strength, and it can be caused by a number of molding conditions and/or tooling design.

Minor splay can generally be well-hidden by paint. Major splay with cell structure which can be picked apart with your fingernail is very difficult to cover. While it can often be hidden initially, the cell structures can break apart at a later date, resulting in an unsightly appearance. Additionally, the amount of splay which can be covered with paint is somewhat related to the paint thickness, gloss and solvent line-up. Lower gloss paints, increased paint thickness and less aggressive solvents generally aid in the coverage of splay. Of course, paint is not a solution where splay has degraded an important aspect of the part.

### *Venting*

Minor amounts of volatile components can condense on the surface of molded parts which are not sufficiently vented, which can cause adhesion problems when the parts are painted. Proper vent design and occasional cleaning of mold vents with organic solvents are suggested to eliminate these problems.

### *Sinks*

Another aspect of molding which often interfaces with finishing is the development of sinks in the part. Sinks generally result from improper rib and boss design, with the sink appearing on the opposite side of the rib or boss.

Minor sink marks can often be hidden by texturing the part surface prior to secondary finishing. While this technique does not eliminate the sink, it can be quite effective in making the flaw less noticeable.

## *Painting Structural Foam Parts*

The surface of structural foam parts differs greatly from parts that are produced by conventional injection molding. The internal structure of foam molded products is produced by what are known as "blowing agents". These substances are available in solid, liquid and gas forms and are used to produce gas bubbles in the melted resins. This foaming action produces a rough swirled pattern on the surface of the part. For this reason, the finishing techniques involved with foam are somewhat different than those used with conventional molded parts. There are new foam molding technologies emerging, such as counter pressure, that produce a more aesthetically pleasing surface. Even so, the majority of foam parts finished today are of the rougher surface variety.

**Painting Structural Foam**

- Outgassing
- Surface Preparation
- Primer
- Color Coat
- Texture

### *Part Preparation*

In most cases, it is possible to finish a foam molded part with no secondary surface preparation; but, as with all finishing operations, there are times when it is necessary. An uncontaminated surface is the key in achieving satisfactory finishing results. Parts should be checked for oils, mold release agents and mold cleaning agents. If contamination is found, the substance should be removed with an appropriate solvent or sanding. Sanding may also be necessary to promote paint adhesion or to remove molding imperfections that would mar the surface of the finished part.

Unlike solid molded parts, foam molded parts cannot be finished immediately after molding. The gasses produced by the blowing agents must be allowed to come to equilibrium with surrounding air. This "outgassing" process will take from 24 to 48 hours, the time being dependent on temperature and relative humidity. It is important that sufficient air flow be provided around the parts to allow them to "breathe". If the parts are enclosed or improperly spaced during the set time, outgassing may not proceed to completion. If painting is attempted before this process is complete, blistering of the finish may result.

### *Coatings Selection*

There are one, two and three coat paint systems available, each having a certain area of application. The success of the one and two coating systems is highly dependent upon the surface quality of the part to be finished. A higher quality surface will require fewer coats of paint to achieve an acceptable surface quality.

*Finishing Systems*

There are many factors affecting the choice of a paint system. End-use environment, physical properties of the cured film, applications techniques and EPA regulations will all have an effect in the selection process. For this reason, careful consideration should be given to which aspects are prevalent in a given application.

**Rough Foam Surface**

- Multiple paint coats
- Texture more forgiving

The poor quality of the foam molded surface makes it difficult to achieve an acceptable surface with one coat of paint. In many cases it is necessary to use two or three coats: primer, color coat, texture. The primer, sometimes called a filler, is used to fill the rough surface of the part. The color coat provides the color and is also used for the final surface texture of the part. In some cases, it may be possible to use a higher solids paint system to eliminate the need for one of the coats.

**Gloss Finishes**

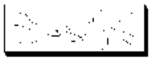
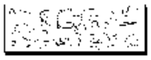
Highlight imperfections

Even with the use of high solids paints, high gloss finishes are difficult to obtain. Many primer coats and sanding operations are needed to smooth the surface enough to apply a gloss coat. If the surface has any remaining imperfections when the final coat is applied, the gloss of the finish will make them more evident. The difficulty and labor intensity of this process makes gloss finishing foam molded parts relatively expensive.

Higher solids paints and water based systems have gained popularity in recent times due to high costs and governmental regulations concerning organic solvents. The lower solvent content of high solids paints allows a greater amount of film to be deposited per amount of solvent released into the atmosphere. Water borne systems offer the advantages of low solvent content and cost stability. The drawback of water borne systems is the need for a primer to cover the surface before the color and texture coats are applied.

The cure times of some coating systems can be decreased by the use of heat. Baking at elevated temperature decreases cure times and speeds the evaporation of solvents. Parts should not be baked above the heat deflection temperature of the material. This can cause distortion and post blow of the part.

## *Paint Troubleshooting Guide*

| **Problem** | **Possible Cause** | **Possible Solution** |
|---|---|---|
| Blistering | • Water in system.<br>• Oil in system.<br>• Surface contamination. | • Check air lines, paint gun, etc. for contaminants.<br>• Check surface for cleanliness, possible silicone contamination.<br>• Clean part with isopropyl alcohol. Eliminate source of contaminant. |
| Spotty Adhesion | • Localized contamination on part or in paint<br>• Non-homogeneous paint/thinner ratio, i.e., incorrect mixing. | • Check for mold release or other foreign substances, clean part, filter paint.<br>• Mix paint. |
| Poor Adhesion | • Mold release or other contaminant on part.<br>• Insufficient etch caused by incorrect thinner ratio.<br>• Thinner too fast.<br>• Incorrect paint selection. | • Check necessity of mold release or alter cycle to eliminate need, or clean part.<br>• Change to correct solvent.<br>• Correct paint/thinner ratio. Use slower evaporating thinner.<br>• Recheck paint selection. |
| Soak-In<br> | • Highly stressed area in part.<br>• “Overly aggressive solvent.”<br>• Poor molded part appearance.<br>• Insufficient film thickness. | • Adjust molding conditions to reduce stress in area.<br>• Change to less aggressive thinner.<br>• Minimize knit lines, sink marks and gate blush.<br>• Increase film thickness. |
| Cracking<br> | • Thinner too aggressive.<br>• Part highly stressed. | • Adjust thinner.<br>• Adjust molding. Anneal part. Correct applied stress condition. |
| Solvent Popping<br> | • Solvent trapped below paint surface which boils out on baking.<br>• Solvent trapped in minute cracks and porous areas which boils out on baking. | • Increase flash time.<br>• Increase high boiling solvent concentration, build film thickness slowly, bake in stages by slowly increasing temperature.<br>• Adjust molding condition to eliminate porosity or use sealer primer. |
| Blushing<br> | • High humidity conditions. | • Increase high boiling solvent concentration. |
| Mud Cracking<br> | • Excessive film thickness.<br>• Incorrect solvent/paint.<br>• Incorrect paint/thinner ratio.<br>• Surface contamination. | • Check spraying technique.<br>• Change solvent/paint combination.<br>• Correct paint/thinner ratio.<br>• Check part for cleanliness. |
| Fisheyes<br> | • Minute particles or globules of oil, silicone or other.<br>• Solid contaminants in paint system. | • Check cleanliness of part surface.<br>• Check system. |
| Orange Peel<br> | • Improper thinner; under-thinning.<br>• Insufficient atomization.<br>• Spray head too far from surface.<br>• Improper mixing.<br>• Very high or low humidity conditions. | • Adjust thinner composition<br>• Increase high boiling solvent concentration.<br>• Adjust atomizer head and/or air pressure.<br>• Adjust distance.<br>• Blend paint uniformly.<br>• Adjust environment or solvents to compensate. |

## Glossary of Painting Terms

**Accelerator –** Additive which speeds up the rate of a cure reaction, much like a true chemical catalyst, not truly a part of the reaction or otherwise required by or consumed in the reaction.

**Air-Less Spraying –** A method of atomizing paint by hydraulic pressure.

**Bite –** Solvent attack directly on the surface of the substrate.

**Blister –** Bubble on surface of part.

**Bloom –** A whitish material migrating to the surface of the coating.

**Blush –** A whitish surface appearance where moisture has condensed before solvent is all evaporated.

**Catalyst –** In the true chemical sense, catalyst is a material which speeds up a reaction without truly being a part of the reaction or consumed by it. Red Spot and others in the trade incorrectly also call the polyisocyanate prepolymers portion of their two component polyurethane products "catalyst."

**Chalking –** Dry chalk-like appearance or deposit on the surface of the part.

**Conductive –** Possessing the ability to maintain a flow of electrons; i.e., to carry a current.

**Coverage –** Amount of surface which can be covered by a given product at a given dry film thickness, usually expressed in square feet covered at one mil coating thickness per gallon.

**Cracking –** Removal of color upon abrasion or rubbing.

**Crazing –** Fine cracks at or under the surface of a plastic.

**Cryptometer –** Meter used for measuring opacity or hiding power of wet paint film.

**Cure –** To form a resin binder by chemical reaction and volatilization of solvents if the paint system is an enamel: to volatilize solvents if the paint system is a lacquer.

**Curtain Coating –** A method used to apply barrier coatings and clear topcoats or standard pigmented coatings to flat sheets whereby a "curtain" of coating is applied via passage of a panel beneath the curtain of coating.

**Dip Coating –** The application of a coating by immersion of the part into a dye solution.

**Dispersion –** A heterogeneous system in which a finely divided material is distributed in another material.

**Dropthru –** A penetration of a solvent or resin through another film to or into the basecoat.

**Electrostatic Spraying –** A method of applying paint by oppositely charging the atomized paint particles and the surface to be coated, thus causing attraction resulting in paint savings.

**Film Thickness –** Thickness of coating after solvent has evaporated and system has cured. Usually measured in mils.

**Fisheyes –** Describes a very small void which has not blended completely with the surrounding material. Usually caused by a minute quantity of silicone, oil or other surface contaminate on the surface of the substrate.

**Flashpoint –** The temperature at which solvents volatilize sufficiently to produce a flammable mixture.

**Flocculating –** Electrical charge on pigment causes them to attract each other in liquid medium. Result is poor color uniformity in dried film.

**Flowcoating** – A system of applying surface finishes by allowing the coating composition to flow over the surface and then allowing the excess to drain away.

**Gloss** – Measure of percent reflected light from surface of coating. High gloss has most reflected light.

**Kick-Out** – A sudden precipitation when two dissimilar solutions are mixed.

**Monomer** – A molecule or compound of relatively low molecular weight and simple structure capable of combining with itself on other similar molecules through reactive sites to form a polymer.

**Mud Cracking** – The appearance of a coated film similar to that of a dried river bed. Normally caused by shrinking of the film.

**Non-Conductive** – Not capable of carrying an electric current. A term used in the electronics industry referring to the lack of ability of a coating to conduct a current when a high potential voltage is applied to its surface.

**Orange Peel** – Surface irregularity similar in appearance to that of an orange skin. Usually caused by improper solvent balance, poor atomization or spray adjustment.

**Polymer** – A macromolecule consisting of an indefinite number of monomer units.

**Polymerization** – A chemical reaction usually carried out with a catalyst, heat or energy, in which two or more relatively simple compounds cause polymer formation.

**Potlife** – Time, usually in hours, during which a two or three component product can be used after it is mixed. Sometimes measured in terms of time to gel and/or double in viscosity.

**Soak In** – Paint being absorbed in low density areas which is the result of inadequate mold packing.

**Solvent Pop** – Disruptions appearing in an applied paint film from which residual solvents are forced out too rapidly. Too fast into too hot an oven, too fast solvents, too fast chemical cure (short potlife), and heavy films can all be factors aggravating this problem.

**Splay Marks** – Surface imperfections in a plastic molded part usually caused by improper drying of plastic prior to molding.

**Stress Cracking** – Cracking of the plastic part, by certain solvents, as a result of improper molding conditions.

**Tail Solvent** – The slowest evaporating solvent in a reduced coating.

**Two Component Equipment** – Refers to equipment designed to spray two component coating products, particularly those with short potlife when premixed. Two components can be mixed immediately before the spray head, at the spray head, or just beyond the spray head in the atomized mist cone.

**VOC** – Abbreviation for “Volatile Organic Compounds”, the terms used by the EPA to describe non-exempt paint solvents, usually measured for air quality regulations as “pounds per gallon minus water” in ready to spray paint.

**Waterborne** – A general term applied to all coatings which include significant amounts of water either as packaged or as reducer for application.

GE Plastics

## GE Engineering Thermoplastics
## DESIGN GUIDE

# Specific
# Industry
# Design Considerations

- *Electrical Design*
- *Optical Design*

# Industry Specific Design Considerations

Two major attributes of an engineering thermoplastic resin are the capability of performing at elevated temperatures and a general balance of other key properties based on the polymer's structure. The first step in identifying a general product for any application is to define its maximum use temperature and whether mechanical or chemical properties are critical to successful performance. A review of electrical, thermal and optical design criteria is helpful to the design engineer in this regard.

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The standards and specifications discussed in this Design Guide are complex and subject to revision. The general information contained in this publication is an overview only and is not intended to substitute careful and independent examination of applicable standards and specifications.

# Electrical Design

Engineering plastics are very well-suited for electrical and electronic equipment housings because of overall systems cost savings, elimination of secondary operations, inherent electrical insulative properties, outstanding impact strength, flammability ratings, molded-in color, and dimensional stability. However, engineering thermoplastics are transparent to EMI and RFI radiation. For this reason, some type of electrically conductive coating or additive must be used if shielding is required. Refer to pages 5-50 through 5-66 for information on coatings and shielding techniques.

## Flame Resistance

Most electrical applications which are intended for home or industrial use must meet some type of flammability specification. The intent of these specifications is to reduce the potential for fires resulting from sparks, arcing or overheating of electrical components. A common flame rating specification is Underwriters Laboratories Test Number 94 (UL 94).

## Heat Deflection Temperature

The heat resistance of a plastic part in an electrical application is a typical concern and may be split up into short term concerns and long term concerns. Short term concerns would deal with the capability of the plastic part to withstand abnormal heat without distorting, loss of properties which would impair function or create a safety hazard. Long term concerns would deal more with the retention of properties which may gradually diminish due to thermal aging over the life of the product.

Short term thermal properties refer to Heat Deflection Temperature, Vicat softening temperature, and Ball pressure temperature. In general, these properties are used to compare materials as opposed to quantitatively comparing to temperatures anticipated or measured in the application. UL, however, does provide guidelines for using these property values. A preferred method for selecting a material for use at a specific temperature is to examine the mechanical properties at that temperature using information such as the stress-strain curves in the Tensile Module. For a first estimate, 30°F (-1°C) below the HDT at 264 psi can be considered a conservative practical limit.

Long term concerns over thermal aging of the materials can be addressed by checking the relative thermal index of the material found in the UL listings. These values are tested for tensile strength, tensile impact and dielectric strength. The maximum normal temperature can be measured on a part and then compared to the appropriate thermal index.

## Chemical Resistance

The chemical resistance of plastic materials used in electrical applications is important. The chemical compatibility of plastic parts is dependent on temperature, mode and concentration of exposure, total stress, which includes molded-in stress, applied stress and assembly stress. End use compatibility testing is generally suggested. However, a large amount of test data is available for individual GE resins under specific test conditions. This data can be used in a qualitative manner to help with the material selection process.

The specific end use environment as well as the manufacturing environment of the electrical application must be considered.

Typical chemicals worth checking are listed below:

- Solvent cleaners used to degrease parts
- Hydrocarbon based lubricants containing cutting agents
- Direct or indirect exposure to chlorine in pools/saunas
- Industrial chemical contact

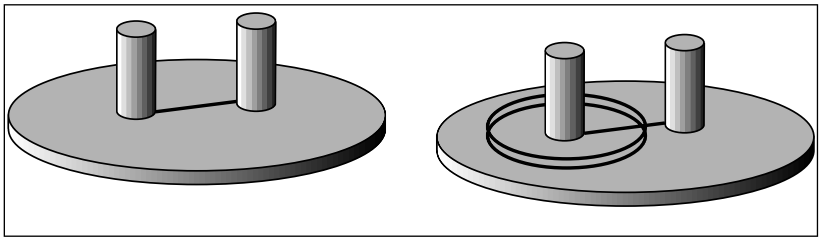
Other electrical applications such as board/chip carriers and connectors perform in controlled end use environments but do face significant chemical exposure in the manufacturing stage. The soldering and flux removal processes which are commonly used often involve exposure to extremely aggressive solvents or solvent vapors at room or elevated temperatures. These types of operations can lead to significant chemical attack on plastic parts. In general, crystalline products such as VALOX and SUPEC resins tend to have better chemical resistance to a broad array of substances. Amorphous products such as LEXAN and NORYL resins tend to interact more with the chemical environment.

# Industry Specific Design Considerations

## Creepage

Creepage is the distance over the surface of the insulator which separates two conductors. This requirement is specified in UL standards and can be accommodated with ribs or slots in molded parts. Consideration should be given to the application environment as these features may retain conductive substances and change the insulation effectiveness.

**Figure 6-1.** Creepage.



## Component Retention

The design flexibility of injection molded thermoplastic parts allows the integration of many component retention features, such as:

locating pins
slots
threaded holes
bosses
snap fits
hinges
latches
ultrasonic welding joints

Possible Uses

card locators

wire clips

cable slots

## Designing Enclosures

When designing an enclosure which will contain live electrical components, in environments which contain moisture, humidity or direct water contact, it is often necessary to design seals between mating parts. Many devices which are used outdoors must pass a set of sealing tests when subjected to various mechanical and environmental conditions. There are a variety of NEMA classifications for different types of applications. For most applications, there are design techniques which are likely to be successful. There are a variety of tests which are done for NEMA classification. (See Table 6-1.)

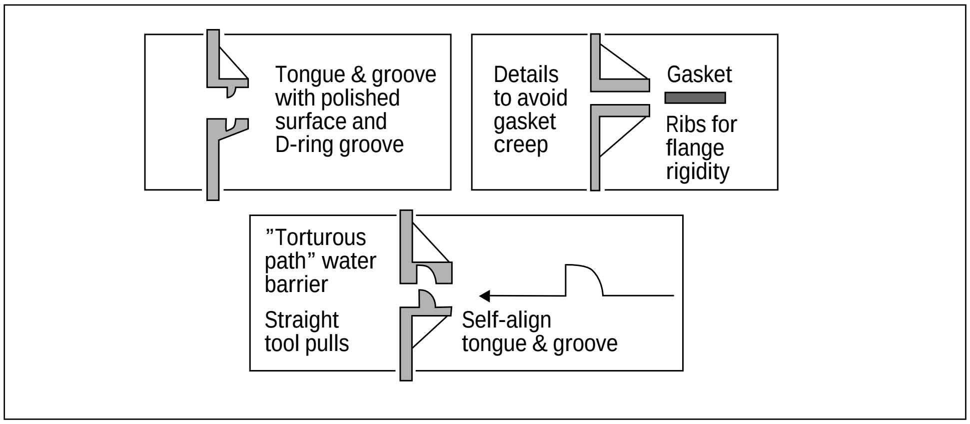
**Table 6-1.** NEMA Test Descriptions.

| TEST | DESCRIPTION | SIGNIFICANCE | ENCLOSURE TYPE |
|---|---|---|---|
| **Rod Entry** | An attempt is made to insert a rod of a specified diameter into an opening in the enclosure. For the enclosure to pass, the rod must not enter. | Demonstrates that enclosure will protect internals from incidental contact. | 1,2,3R |
| **Drip** | The enclosure is mounted directly beneath a drip pan for 30 minutes. If no water has entered the enclosure at or above a level higher than the lowest live part (the equipment is constructed such that no water is visible on the live parts), then the enclosure has satisfied the requirements. | Demonstrates that enclosure will protect internals when exposed to dampness such as dew or light showers. | 2,11,12,12K |
| **Rain** | The enclosure is mounted with the conduit connected without the use of sealing compound. Continuous sprays (5 psi) are directed against the top and all exposed sides for an hour. If no water has entered the enclosure at or above a level higher than the lowest live part (the equipment is constructed such that no water is visible on the live parts), then the enclosure has met the requirements of this test. | Demonstrates that enclosure will protect internals when exposed to rain. | 3,3R,3S |
| **Dust** | The enclosure is subjected to compressed air (90-100 psi) mixed with dry type 1 portland cement or similar material. This blast is directed at all points of potential entry. No dust may enter the enclosure. | Demonstrates that enclosure will protect internals when exposed to water spray from high pressure hose. | 3S,4 |
| **External Icing** | The enclosure is mounted next to a 1 in (25 mm) diameter horizontally mounted test bar. Water is sprayed on the bar and enclosure so as to produce an ice build up on the bar at a rate of 1/4 inch per hour. This is continued until 3/4 inches of ice has accumulated on the bar. The enclosure meets the requirements of this test if while ice laden, it can be manually operated by one person without damage. | Demonstrates that ice accumulation will not damage enclosure. | 3,3R,3S,4,4X,6,6P |
| **Hosedown** | The enclosure is subjected to a stream of water (65 gal/min) from a 1 in (25 mm) diameter hose. This stream is directed at all joints from all angles. No water may enter the enclosure. | Demonstrates that enclosure will protect internals when exposed to windblown dust or other dry particles. | 3,3S,4,4X,5,12,12K |
| **Submersion** | The complete enclosure is mounted in a tank with conduit connected using sealing compound. The tank is filled with water to a level six feet above the highest point on the enclosure. The enclosure is removed after 30 minutes. No water may enter the enclosure. | Demonstrates that enclosure will protect internals when submerged in water. | 6 |
| **Air Pressure** | The complete enclosure, with conduit connected, is pressurized to an internal air pressure of 6 psig for 24 hours. Pressure may not drop more than 2 lbs and deformation may occur. | Demonstrates that enclosure will prevent fluctuations of internal pressure. | 6P |
| **Oil Exclusion** | The enclosure is subjected to a stream of water and wetting agent (2 gal/min) from a 3/8 inch diameter hose. This stream is directed at the enclosure from all angles. No liquid may enter the enclosure. | Demonstrates enclosure will prevent oil inclusion via wetting solution. | 13 |

## Sealing

There are a variety of seal designs which can be considered for specific enclosure applications (including NEMA). The designer should carefully consider the end use environment of the application. A gasketless design is normally favored when possible because of the economic advantages of reduced part count and assembly operations.

**Figure 6-2.** Seal Designs.



## Weather Resistant Seals-Gasketless

Generally, enclosures designed for less severe environments (rain tight) require a simple tongue and groove arrangement at the base and lid mating surfaces. The following guidelines are useful in obtaining the best seal possible:

- Tongue and groove design to provide a "torturous path" (see Figure 6-2) for water penetration.
- Slight interference fit to ensure tight seal.
- Self alignment features such as lead-in angles can be helpful in reducing tolerancing requirements.

The gasketless seal design discussed above is typically used for NEMA Types 1, 2, 3R, 3S, 5, and 11 enclosures.

## Weather Resistant Seals-Gasket/O-Ring

Generally, enclosures designed for more severe environments (hosed down, standing water) require a gasket or an O-ring seal design. An effective method for obtaining a good seal of this type is to combine some of the features of the gasketless design with the use of a gasket. Some issues to bear in mind when designing this type of seal include the following:

- Gasket/O-ring material must be chemically compatible with the enclosure material.
- Silicone gaskets are generally compatible with GE resins.

- PVC gaskets should not be used with LEXAN resin.
- Plasticizers from some rubbers can attack thermoplastics.
- Check gasket/O-ring dimensions carefully, consider over entire operating temperature range of application.
- Design for even pressure distribution on the seal, stiff lid design generally preferred.

This type of seal design is typically used for NEMA Types 4, 4X, 6, 6P, 12, 12K, and 13 enclosures.

## UL746C Overview

Underwriters Laboratory UL746C (Standards for Polymeric Materials – Use In Electrical Equipment Evaluations). This specification is considered the standard specification for use of polymeric materials in equipment containing live electrical components. New products are evaluated according to established tests to demonstrate safety with regard to electrical shock hazards, fire and personal injury.

The notable concerns of the specification identified with a plastic design are:

- flammability resistance and/ or characteristics
- long term thermal aging
- heat resistance to avoid distortion due to heat rise
- distortion due to molded in stress
- impact
- stability in moist environments
- UV resistance

Applications submitted for testing are initially categorized according to their function. Applications which involve direct or indirect support must meet a particular series of tests.

Direct support: A material that is in direct contact with uninsulated live parts.

Indirect support: A material that physically supports and maintains the relative position of live parts, but does so without direct physical contact with uninsulated live parts.

Polymeric enclosures which also provide direct or indirect support of live electrical components must comply with both the enclosure requirements and the appropriate support requirements.

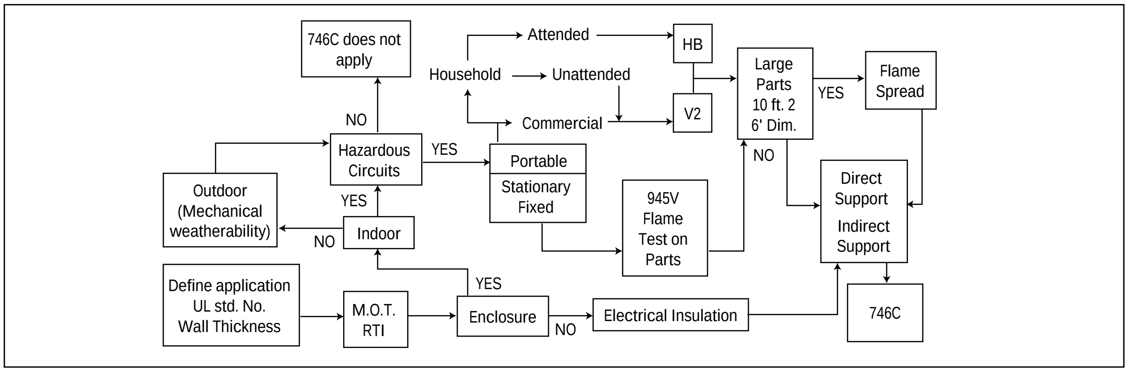


**Table 6-2.** UL 746C Polymeric Materials Used in Electrical Equipment.

## Enclosure Requirements

Electrical enclosures (excluding direct and indirect support) are grouped according to their use.

- portable
- stationary
- fixed

Each group has its own set of test requirements and options. Flammability of the material is specified with some options available. As the flammability rating of the material changes, the number of tests required is affected.

Table 6-3 may be used as a guide to some of the options for the selection of materials and flammability.

**Table 6-3.** Selection of Material and Flammability.

| **Portable** | |
|---|---|
| Material is used to enclose uninsulated live electrical parts. | UL 94*HB, V0, V1, V2<br>attended intermit.duty<br>UL 94V0, V1, V2<br>unattended intermit.duty |
| Material is used to enclose insulated parts: insulated thickness, t>.028 in [0.711 mm] | UL 94HB, V0, V1, V2<br>attended intermit.duty<br>UL 94V0, V1, V2<br>unattended intermit.duty |
| Material is used to enclose a metal housing that encloses insulated parts. (t>.028 in [0.711 mm]) | UL 94HB, V0, V1, V2 |
| **Fixed/Stationary** | |
| Material is used to enclose live electrical insulated or uninsulated parts. | UL 94 5VA |
| Material is used to enclose a metal housing. | UL 94 5VA or 5VB, V0, V1<br>V2, HB |

* This test is not intended to reflect hazards presented by any material under actual fire conditions.

## Enclosure Performance Requirements

A brief description of the tests in UL 746C and the required values is provided in Table 6-4. Depending on the application classification and the selection of material where flame retardant options are available, some tests may be omitted.

**Table 6-4.** Enclosure Performance Requirements.

| | |
|---|---|
| Volume Resistivity | dry 50x10^6 ohm cm.<br>wet 10x10^6 ohm cm. |
| Resistance to Hot Wire Ignition | portable 7 sec. minimum<br>stationary and fixed 15 sec. minimum |
| Heat Distortion Under Load (264 psi) | 10˚C greater than the use temp. but not less than 90˚C. |
| Vicat Softening point | 50˚F greater than the use temp. but not less than 105˚C. |
| Ball Pressure Temperature | At least equal to 104˚F (40˚C) minus the ambient temp. greater than the continuous use temp. but not less than 95˚C. |
| Impact | Devices are subjected to specified impact and then examined for damage to the unit. Impact shall not:<br>A. make uninsulated live parts accessible to contact (use of a probe is permissible).<br>B. produce a condition that might affect the safe mechanical performance of the device.<br>C. produce a condition that would increase the likelihood of an electric shock. |
| Tests for portable equipment | Drop each of 3 samples 3 ft. onto a specified hardwood floor. Orientation would be to result in most severe damage.<br>Continue to drop each sample 3 times with different orientations. |
| Tests for stationary fixed or floor mounted | Each of three samples will be subjected to a single impact by a 2.0 in (51 mm) dia. steel ball dropped or swung from a specified height. Produce an impact of 5 ft/lbs for floor-supported equipment or 0.75 ft/lbs for counter-supported equipment. 12<br>The test sample will be placed on a UL specified hardwood floor and may also be braced by a rigid wall. Impact sight may be on any exposed surface. Outdoor Conditioning: 3 hr at -31˚F (-35˚C) Impact cold. Indoor with cold exposure: 3 hr at 32˚F (0˚C) Impact cold |
| Crush Test | The sample is placed on a rigid surface in normal operating position. An array of 4 x 10 in (102 x 254 mm) pressure pads with 6 in (152 mm) spacings between them applies 100 lb load each on the sample for 1 min. The unit should maintain minimum spacing for internal live components. Bare wires should not be exposed or accessible to contact. Breakage or cracks should not affect insulation. Likelihood of shock or fire should not increase. |
| Mold Stress | The sample is subjected to a heat soak in an air relief circulating oven at 50˚F (10˚C) higher than the maximum temp. measured under normal operation but not less than 158˚F (70˚C). Check as in previous tests for increase in hazard. |
| Input to Motor Operated Equipment | After thermal conditioning as above, motor operated equipment operating under no load shall have no greater current than 150% of the current measured on the unconditioned unit. Conditions are run at the upper limit of the ratings. |

# Industry Specific Design Considerations

**Table 6-5.** Direct Support Requirements.

| Test | Method | Units | Related to Flammability Classification | | | |
|---|---|---|---|---|---|---|
| **Flammability** | UL 94* | ——— | 94V-0 | 94V-1 | 94V-2 | 94HB |
| **Volume Resistivity** | UL 746A | ohm-cm<br>dry<br>wet | <br>——— 50x10^6 min.———<br>——— 10x10^6 min.——— | | | |
| **Dielectric Voltage - Withstand** | UL 746A | Min. Volts | ———5000——— | | | |
| **Comparative Tracking Index Under Moist Cond.** | UL 746A | Min. Volts | 100 – indoor clean environment<br>175 – indoor/outdoor moderate contamination<br>250 – indoor/outdoor severe contamination | | | |
| **Dimensional Change after Water exp.** | UL 746A | % chg | ———2——— | | | |
| **HDT at 264 psi<br>or<br>Vicat Softening Point<br>or<br>Ball Pressure Temperature** | UL 746A | ˚F min.<br>˚F min.<br>˚F min. | -8˚C greater than use temp. but not less than 90˚C.<br>7˚C greater than use temp. but not less than 105˚C.<br>40˚C minus ambient temp. greater than the use temp. but no less than 95˚C. | | | |
| **High Current Arc Resist to Ignition** | UL 746A | Arcs | 15 | 30 | 30 | 60 |
| **Hot Wire Ignition** | UL 746A | sec. | 10 | 15 | 30 | 30 |
| **High Volt. Arc Resist to Ignition** | UL 746A | sec. | 120 | 120 | 120 | 120 |
| **Relative Thermal Index** | UL 746B | ˚C | Not to exceed general use temp. for required properties. | | | |

* This test is not intended to reflect hazards presented by any material under actual fire conditions.

**Table 6-6.** Indirect Support Requirements.

| Test | Method | Units | Related to Flammability Classification |
|---|---|---|---|
| **Flammability** | UL 94* | ——— | 94V-0 94V-1 94V-2 94HB |
| **Dimensional Change after Water exp.** | UL 746A | % chg | ————2———— |
| **HDT at 264 psi**<br>**or**<br>**Vicat Softening Point**<br>**or**<br>**Ball Pressure Temperature** | UL 746A | °F min.<br>°F min.<br>°F min. | -8°C greater than use temp. but not less than 90°C.<br>25°C greater than use temp. but not less than 105°C.<br>40°C minus ambient temp. greater than the use temp. but not less than 95°C. |
| **Relative Thermal Index** | UL 746B | °C | Not to exceed general use temp. for required properties. |

* This test is not intended to reflect hazards presented by any material under actual fire conditions.

# Industry Specific Design Considerations

## UL 508 Industrial Control Equipment

These requirements cover industrial control devices, and device accessories thereto, for starting, stopping, regulating, controlling or protecting electric motors. These requirements also cover industrial control devices or systems that store or process information and are provided with an output motor control function. Also covered are industrial control panels and other devices associated with control of motor operated and related industrial equipment.

The requirements are determined with regard to safety and risk of fire, electrical shock and personal injury. The standard covers assorted materials in addition to polymers.

**Table 6-7.** Industrial Control Equipment.

| Test | Related to Flammability Classification |
|---|---|
| Flammability | UL 94* 5V |
| Thermal index | Thermal index should be no less than operating temperature. Material softening must not occur. |
| Heat distortion | Heat deflection temperature at 66 psi to be 50˚F (10˚C) greater than maximum normal operating temperature, but not less than 158˚F (70˚C) |
| Molded-in stress | No distortion after 7 hours at 50˚F (10˚C) over maximum normal operating temperature. |
| Impact resistance | 5 ft-lb at 23 and -31˚F (-35˚C) from a falling ball of 2 in (51 mm) diameter, 1.18 lbs. |
| Water immersion | 50% retention of physical properties and no loss of flammability after 7 days immersion at 180˚F (82˚C). Less than 1% dimensional change after 24 hours at 73˚F (23˚C). |
| UV resistance | 85% retention of physical properties and no change in flammability after 720 hours of Weather-Ometer exposure. |

* This test is not intended to reflect hazards presented by any material under actual fire conditions.

## EMI/RFI Shielding

Electro Magnetic Interference (EMI) and Radio Frequency Interference (RFI) are particularly important issues for computer and communication equipment applications. This is critical both for protecting components from incoming interference and for preventing excessive emission of interference (must meet FCC specs). Despite the wide variety of reasons why plastics are preferable to metals for these types of applications, the electrically insulative properties of plastics cause most parts to be transparent to EMI and RFI.

Two options exist to deal with this issue:

- Redesign internals/electronics
- Shield with a conductive part coating or a conductive reinforcement in the material

For more information regarding techniques for designing around EMI and RFI please see pages 5-52 through 5-66.

## Regulations and Standards

Three major sets of technical limits on electromagnetic emissions (EME) from business machines exist today. These standards were issued by the United States, West Germany and Japan. However, the European Economic Community (EEC) has adopted CISPR Publication 22, implemented as a European Standard in 1992. All EEC member countries (12) will incorporate this EME standard into their legislation. In general, it is not possible to test a product once and comply with all three (U.S., European, and Japanese) standards because of the differences in required testing procedure. For example, the specified measurement distance for radiated emissions from Class B devices is 3m for the FCC and 10m for the European and Japanese standards. The results from the tests at different distances are not related and cannot be converted. Thus, to market a digital device globally, it is necessary to test for agency compliance according to each separate standard.

## United States

The Federal Communications Commission (FCC) rules governing EME from digital devices have been fully in place for all digital devices, regardless of when they were first manufactured, since October 1, 1983. These FCC rules cover both radiated emissions from the product and conducted emissions. Conducted emissions may pass through the alternating current power line, or through signal or control leads entering or leaving a system. The regulations were revised in March of 1989 and are set forth in FCC Docket No. 87-389.

## Part 15

Part 15 applies to any device that generates and uses radio frequency (RF) energy in excess of 9,000 cycles per second. The Commission recognizes two basic types of devices subject to Part 15, intentional radiators and unintentional radiators. The difference between the two types of devices is the intentional radiator is intended to emit the RF energy by radiation or induction while the unintentional radiator is not intended to emit RF energy. For example, computers are unintentional radiators.

The FCC regulates the amount of EMI/RFI radiated into the atmosphere or conducted back onto the AC power line by digital devices. These regulations do not address the issue of protecting the operating integrity of computer equipment (i.e., EMI susceptibility from external noise sources). That concern is left up to the manufacturer and the end user. Further, these regulations apply to "finished" devices and testing for compliance is performed only on the complete commercial system.

**Table 6-8.** FCC RFI Conduction Limits.

| FCC RFI Conduction Limits for Class A Digital Devices (Commercial & Industrial) | | FCC RFI Conduction Limits for Class B Digital Devices (Home or Residential) | |
|---|---|---|---|
| Frequency (MHz) | Conduction Limits (Microvolts) | Frequency (MHz) | Conduction Limits (Microvolts) |
| 0.45 – 1.705 | 1000 | 0.45 – 1.705 | 250 |
| 1.705 – 30.0 | 3000 | 1.705 – 30.0 | 250 |

**FCC RFI Radiation Limits for**

| | Class A Digital Devices | | Class B Digital Devices | |
|---|---|---|---|---|
| Frequency (MHz) | Distance (m) | Maximum Field Strength (uV/m) | Distance (M) | Maximum Field Strength (uV/m) |
| 30 – 88 | 10 | 90 | 3 | 100 |
| 88 – 216 | 10 | 150 | 3 | 150 |
| 216 – 960 | 10 | 210 | 3 | 200 |
| above 960 | 10 | 300 | 3 | 500 |

Notes:
CLASS A – Equipment sold exclusively for use in a commercial business and industrial environment

CLASS B – Equipment sold for use in a home or residential environment, regardless of whether it might also be used in a commercial business or industrial environment

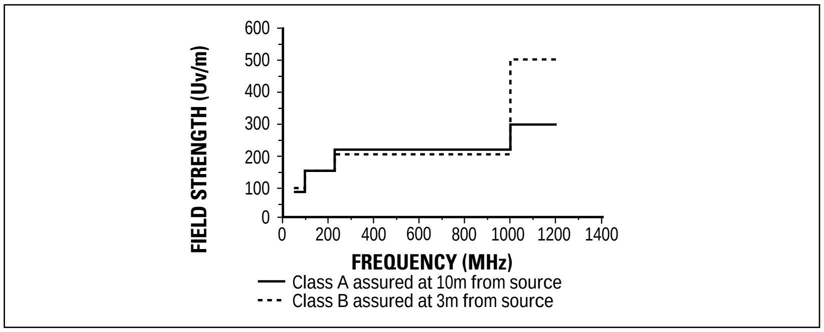


**Figure 6-3.** Comparison of FCC Class A and Class B Regulations.

The requirements for residential applications (Class B) are more stringent than for commercial or industrial applications (Class A).

### *Canada*

In Canada, the EMI issue is not controlled by legislation but by voluntary compliance with a standard issued by the Canadian Standards Association (CSA). This standard, C108.8-M1983, "Electromagnetic Emissions from Data Processing Equipment and Electronic Office Machines: Limits and Measures," is derived from and is similar to the FCC regulation.

### *Europe*

Standards that limit the use of radio frequencies and associated interference exist in the majority of European countries. However, at present, West Germany is the only European country with governmental regulations. The limits on EME are covered in Verband Deutscher Elektrotechniker (VDE) 0871 and VDE 0875 standards.

**Table 6-9.** German (VDE) RFI Field Strength Limits.

| | Class A Digital Devices | | Class B Digital Devices | |
|---|---|---|---|---|
| Frequency (MHz) | Distance (m) | Maximum Field Strength (uV/m) | Distance (M) | Maximum Field Strength (uV/m) |
| 0.01 to 0.15 (1) | 100 | 50 | 30 | 50 |
| above 0.15 to 0.205 | 100 | 50 | 30 | 50 |
| above 0.205 to 0.49 | 100 | 50 | 30 | 50 |
| above 0.49 to 1.605 | 100 | 50 | 30 | 50 |
| above 1.605 to 3.95 | 100 | 50 | 30 | 50 |
| above 3.95 to 30 | 100 | 50 | 30 | 50 |
| above 30 to 41 | 30 | 500 | 10 | 50 |
| above 41 to 68 | 30 | 30 | 10 | 50 |
| above 68 to 174 | 30 | 500 | 10 | 50 |
| above 174 to 230 | 30 | 30 | 10 | 50 |
| above 230 to 470 | 30 | 500 | 10 | 200 |
| above 470 to 760 | 10 | 180 | 10 | 200 |
| above 760 to 1000 | 10 | (2) | 10 | 200 |

Notes: (1) In the 10 to 150 kHz frequency range, the values shown are only recommended.
(2) RFI field strength of 900 uVm at 750 MHz and decreasing linearly to 700 uV/m at 1000 MHz.

In 1992, the standards regulating EMI were standardized through out Europe. The European Economic Community (EEC) Council has issued Directive 89/336/EEC which says that all information technology equipment has to be in compliance with CISPR Publication 22 “Limits and Methods of Measurement of Radio Interference Characteristics of Information Technology Equipment.” CISPR (Comite International Special des Perturbations Radio Electriques) is a European organization formed in 1934 “to promote international agreement regarding the protection of radio reception against radio frequency interferences caused by electrical equipment.” CISPR has no direct authority to make laws or issue regulations, only to propose recommendations.

European Standard, EN 55022 defines two classes of devices. Class A is generally for larger products that are less widely distributed. Class B products are those that are smaller and more widely distributed, such as personal computers.

**Table 6-10.** European RFI Conduction Limits.

**European RFI Conduction Limits**
**Class A Digital Devices**

| Frequency (MHz) | Quasi-Peak Limits (dB(uV)) | Quasi-Peak Limits (uV) | Average (dB(uV)) | Average (uV) |
|---|---|---|---|---|
| 0.15 to 0.50 | 79 | 8912.5 | 66 | 1995.3 |
| 0.50 to 30 | 73 | 4456.8 | 60 | 1000 |

**Class B Digital Devices**

| Frequency (MHz) | Quasi-Peak Limits (dB(uV)) | Quasi-Peak Limits (uV) | Average (dB(uV)) | Average (uV) |
|---|---|---|---|---|
| 0.15 to 0.50 | 66 to 56 | 1995.3 to 631 | 56 to 46 | 631-199.5 |
| 0.50 to 5 | 56 | 631 | 46 | 199.5 |
| 5 to 30 | 60 | 1000 | 50 | 316.2 |

**European RFI Conduction Limits**
**Class A Digital Devices**

| Frequency (MHz) | Distance (m) | Quasi-Peak Limits (dB(uV/m)) | Quasi-Peak Limits (uV/m) |
|---|---|---|---|
| 30 – 230 | 30 | 30 | 31.6 |
| 230 – 1000 | 30 | 37 | 70.8 |

**Class B Digital Devices**

| Frequency (MHz) | Distance (m) | Quasi-Peak Limits (dB(uV/m)) | Quasi-Peak Limits (uV/m) |
|---|---|---|---|
| 30 – 230 | 10 | 30 | 31.6 |
| 230 – 1000 | 10 | 37 | 70.8 |

NOTE: dB(uV) is relative to 1 uV. Because voltages are usually measured, dB(uV) = 20 log x where x has the units uV. So, 0 dB = 1 uV and 60 dB = 1000 uV. dB(uV/m) is relative to 1 uV/m. Because the field strength is usually measured, dB(uV/m) = 20 log x where x has the units uV/m. So 0 dB = 1 uV/m and 60 dB = 1000 uV/m.

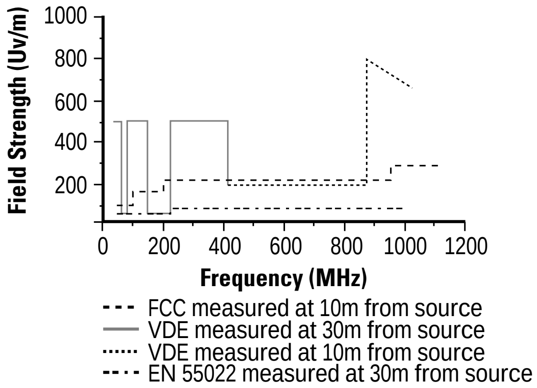


**Figure 6-4.** Comparison of FCC, VDE and European Radiation Limits for Class A Digital Devices.

The radiation limits specified by the FCC, the VDE and the 1992 European standard are compared graphically for class A digital devices (Figure 6-4).

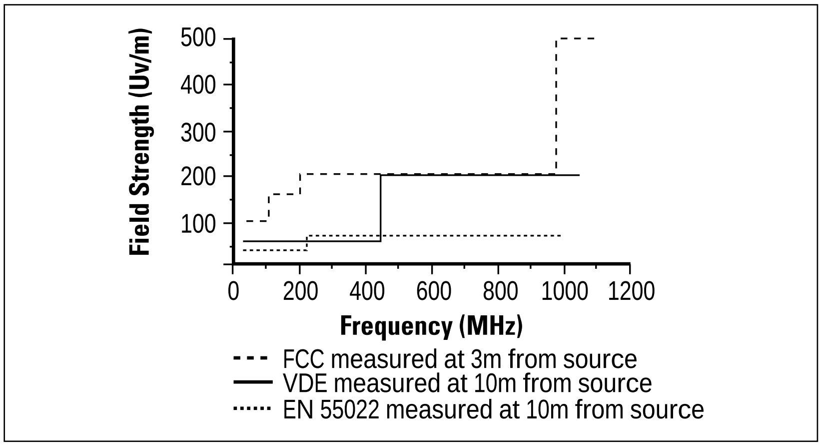


**Figure 6-5.** Comparison of FCC, VDE and European Radiation Limits for Class B Digital Devices.

The radiation limits specified by the FCC, the VDE and the 1992 European standard are compared graphically for class B digital devices (Figure 6-5).

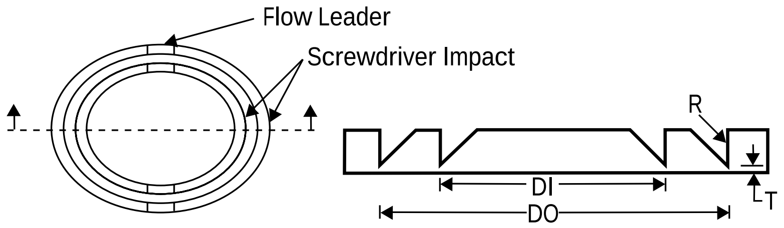
### *Japan*

In March of 1986, Japan released a set of voluntary technical standards limiting electromagnetic emissions from computers. The Japanese standards were developed by the Voluntary Control Council for Interference by Data Processing and Electronic Office Machines (VCCI). Two classes of equipment are established in VCCI standards. Class 1 limits apply to information technology equipment (ITE) used in industrial and commercial applications. Class 2 limits apply to ITE used in residential applications. Japanese limits have been gradually implemented and emission standards apply to all digital equipment manufactured after December 1989. The Japanese limits are equal to CISPR 22 and the European Standard EN 55022. The VCCI does not regulate EMI emission levels below 30 MHz.

Although the standards are strictly voluntary, they are strongly supported by the Japanese electronics industry.

## Knockouts

Knockouts are very convenient design features for electrical enclosures. They allow for the attachment of conduits at a variety of locations with simple hand tools. Underwriters Laboratory has a specific testing procedure for knockouts which is part of UL 508 specification for industrial control equipment. This testing procedure consists of a conduit pull, conduit torque, and knockout push test.



$D_{I,O}$ = Diameter - Internal, Outside knockout
$T_{I,O}$ = Root Thickness - Internal, Outside
$R_{I,O}$ = Root Radius - Internal, Outside

**Figure 6-6.** Knockout Nomenclature.

### *UL 508 Tests & Design Considerations*

Table 6-11 shows the following for each of the UL 508 Knockout Tests:

- Name of test
- Paragraph where detailed test description can be found in Underwriters Laboratory UL 508 Test Manual
- Brief description of test
- Design considerations which significantly affect the performance of the knockout in the specific test

The UL 508 test procedure is device specific.

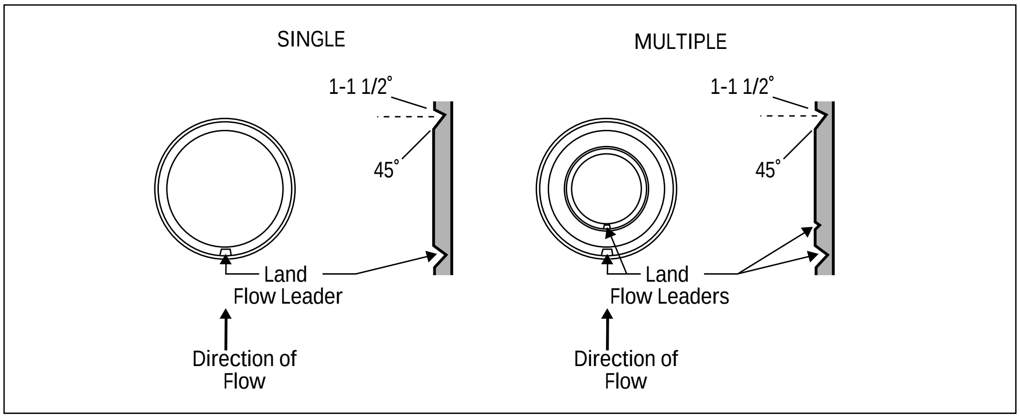
**Table 6-11.** UL 508 Test Procedures.

| Test | Paragraph | Design Considerations | Design Considerations |
|---|---|---|---|
| Conduit CANTILEVER | 34.43 | 10 foot cantilever is attached to inner knockout and deflected 10 in (254 mm) at end. Outer knockout must remain intact. | Root thickness<br>Root radius<br>Material shear strength |
| Conduit PULL | 34.41 | Conduit is attached to knockouts in turn. Axial load of 200 pounds is applied to conduit. Knockout must remain intact for over 5 min. | Root thickness<br>Root radius<br>Outside diameter<br>Material shear strength |
| Conduit TORQUE | 34.42 | Conduit is attached to inner knockout. Torque of 800 in-lbs is applied so as to tighten lock-nut. Outer knockout must remain intact. | Root thickness<br>Material shear strength |
| Mandrel PUSH | 34.45 | 20 lb load is applied by a 0.25 in (6.35 mm) diameter mandrel to the area of the inner and outer knockouts most likely to fail (over the root at a location 90° from the flow leaders). | Root thickness<br>Material shear strength<br>Root radius |

### Knockout Design Suggestions

Knockouts are typically designed with a circular geometry containing two different standard knockout sizes, molded concentrically. In general, some fine tuning may be required to assure proper function and satisfaction of agency requirements. Knockout areas are typically inserts in tools so that they can easily be modified. These inserts (or slides, if the inserts are not in the direction of the pull of the tool) should be shimmed +/- 0.005 in (-0.127 mm) for final adjustment of the root thickness in increments of 0.001 in (0.025 mm).

**Figure 6-7.** Electrical Enclosure Knockouts.



The flow leaders on the knockout should be oriented in the direction of flow of the material during molding. This orientation will help to minimize the amount of material which flows through the root of the knockout and experiences significant shear.

The following dimensions are suggested for the listed materials. One should note that the outer root radius often incorporates a radius to reduce the notch effect. These suggestions are given as starting points from which fine tuning can be used to achieve the desired results.

**Suggested Knockout Dimensions (1/2" and 3/4" concentric)**

**Table 6-12.**

| Resin | Internal Radius | Knockout Thickness | Outside Radius | Knockout Thickness |
|---|---|---|---|---|
| NORYL HS2000X resin | knife | 0.015 | 0.005 | 0.020 |
| NORYL HS1000X resin | knife | 0.016 | 0.005 | 0.022 |
| NORYL N190X resin | knife | 0.023 | 0.005 | 0.030 |

**All dimensions are in inches. Suggested internal diameter = 0.875 +/-.005. Suggested external diameter = 1.075 +/-.005**

## Notes

# Optical Design

Transparent thermoplastics are successfully used in optical applications such as glazing, lenses, reflectors, compact discs and light pipes. The application requirements are well matched with the materials and manufacturing capabilities offered by injection molding. Parts can be produced economically with high quality surfaces and in complex shapes. This allows the designer to explore multifunctional designs with minimal secondary operations required.

When considering an optical application, the design will likely be guided by some fundamental relationships for reflection, refraction, losses at an interface and losses through a medium. A brief treatment of these fundamentals is noted below followed by their application in light pipes.

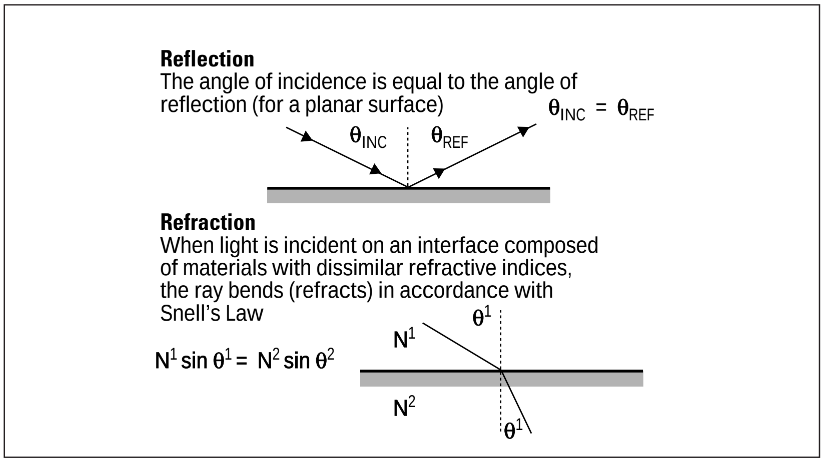


**Figure 6-8.** Reflection and Refraction.

**Reflection**
The angle of incidence is equal to the angle of reflection (for a planar surface)

$\theta_{INC} = \theta_{REF}$

**Refraction**
When light is incident on an interface composed of materials with dissimilar refractive indices, the ray bends (refracts) in accordance with Snell's Law

$N^1 \sin \theta^1 = N^2 \sin \theta^2$

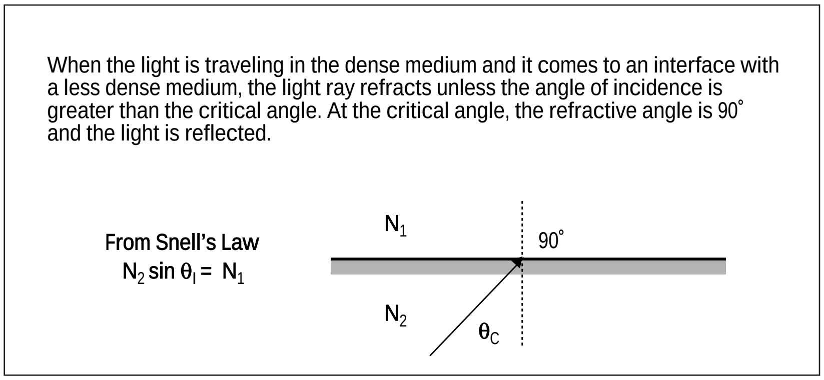


**Figure 6-9.** Critical Angle.

When the light is traveling in the dense medium and it comes to an interface with a less dense medium, the light ray refracts unless the angle of incidence is greater than the critical angle. At the critical angle, the refractive angle is 90˚ and the light is reflected.

From Snell's Law
$N_2 \sin \theta_I = N_1$

**Reflection and Refraction**

At an interface, part of the light is reflected and part of the light is refracted. Fresnell's equation provides the relationship between the incident angle and the refractive indices which determine the amount of light reflected.

$$R_F = \frac{N_2 \cos \theta^1 - N_1 \cos \theta}{N_2 \cos \theta^1 + N_1 \cos \theta}$$

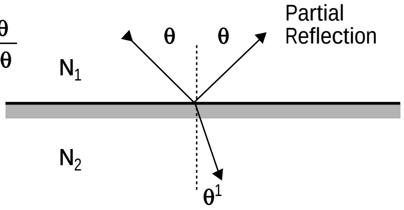


**Figure 6-10.** Reflection and Refraction.

**Light Absorption and Scatter in Medium**

As light travels through a medium, imperfections and impurities scatter and attenuate the intensity. This occurs exponentially with length traveled in the medium. The relationship is:

$$I_{(x)} = Io\, e^{-\mu x}$$

$I_{(x)}$ = is the intensity of the beam at x
Io = is the free air density
$\mu$ = is the material attenuation coefficiencies
x = is the distance traveled in the medium

**Figure 6-11**. Light Absorption and Scatter in Medium.

**Light Absorption Scattering at the Interface**

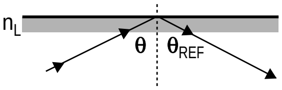
When light reflects off the interface of the medium and the surroundings, surface imperfections will scatter some of the light. The amount of light scattered at each reflection is given by the power loss.

$$\text{Loss per Reflection} = 1 - e\left[\frac{4\pi\,\sigma\, r_2 \cos\theta}{\lambda_n}\right]^2$$

$\sigma$ - surface roughness - surface height of the surface features measured from the mean

$\lambda_n$ - wave length of the light source in the medium

$n_1 = \lambda_o/\lambda_n$ where $\lambda_o$ is the free air wavelength



$\theta$ = angle of incidence
$\theta_{REF}$ = angle of incidence

**Figure 6-12.** Light Absorption Scattering at the Interface.

## Typical Indices of Refraction

| | |
|---|---|
| Empty Space | 1.000 |
| Air | 1.0001 |
| Water | 1.33 |
| Glass | 1.5 to 1.19 |
| LEXAN resins | 1.58 |

# Industry Specific Design Considerations

## Light Pipes

Light pipes are designed to transmit light from a source through a transparent pipe to an outlet using internal reflection at the air/pipe interface to keep the light beams within the pipe. LEXAN resin performs well in these applications because of its clarity and excellent transmission properties.

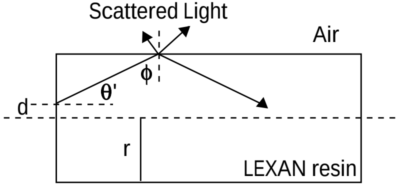
## Light Pipe Considerations

Light pipes use the internal reflections of light rays to direct light from a source to a remote object which is illuminated. A typical concern is how much light will be conveyed through the light pipe and what are the losses. The total attenuation coefficient can be used to calculate the amount of light "lost". Assuming that no light is lost by refraction from the critical angle being violated, the total attenuation coefficient is given by:

**Figure 6-13.** Variables Used to Calculate Surface Scattering of Light.

$$\#\text{ of reflections} = \frac{\tan\theta'}{2(r^2-d^2)^{1/2}}$$

$$\text{Loss per Reflection} = 1 - \exp\left[\frac{-(4\pi\,\sigma\,n_L\cos\phi)^2}{\lambda_n}\right]$$



WHERE $\sigma$ = Surface Roughness
$n_L$ = Refractive Index of Light Pipe Material
$\lambda_n$ = Wavelength in Light Pipe Material
$\lambda_o$ = Wavelength of Free Air. $\lambda_n = \lambda_{o/n}$

**Figure 6-14.** Total Attenuation Coefficient.

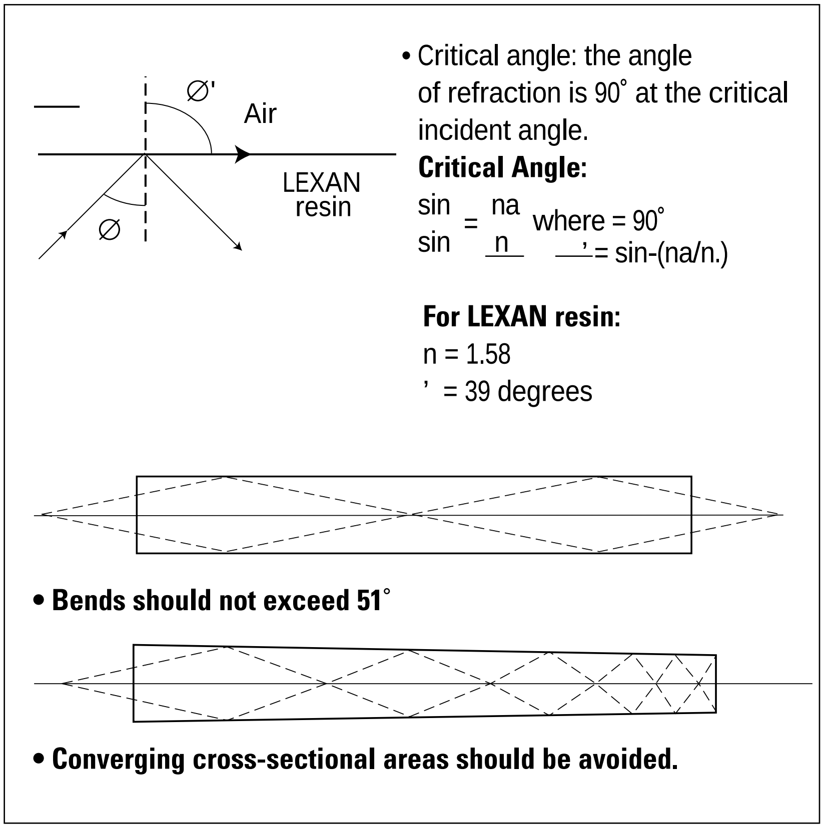
The total attenuation coefficient can be used to calculate the amount of light "lost". Assuming that no light is lost by refraction from the critical angle being violated, the total attenuation coefficient is given by:

$$\alpha_t = \underbrace{R_{f(ent)} + R_{f(exit)}}_{\text{Reflection at Entrance and Exit}} + \left[\underbrace{\frac{\alpha mat}{\cos\theta}}_{\text{Material Absorption per unit length}} + \underbrace{(1 - \exp\left[-\frac{(4\pi\sigma\,n_L\cos\theta)^2}{\lambda}\right])}_{\text{Loss at Each Reflection}} x\,\underbrace{\frac{\tan\theta`}{2(r^2-d^2)^{1/2}}}_{\text{Number of Reflections per unit length}}\right] x1$$

where l is the length of the light pipe. The amount of light transmitted can be calculated by:

$$I_t = (1-\alpha_t)\,I_o$$

Key design tips are offered in Figure 6-15 to help the designer with some of the basic considerations.



- Critical angle: the angle of refraction is 90° at the critical incident angle.

**Critical Angle:**

$$\frac{\sin}{\sin} = \frac{na}{n} \quad \text{where} = 90^\circ \quad ' = \sin\text{-}(na/n.)$$

**For LEXAN resin:**

n = 1.58

' = 39 degrees

- **Bends should not exceed 51°**
- **Converging cross-sectional areas should be avoided.**

**Figure 6-15.** Design Tips For Basic Considerations of Total Reflection. *For total reflection, the incident light ray should exceed the critical angle.*

Light pipes are designed to transmit light from a source through a transparent pipe to an outlet using internal reflection at the air/pipe interface to keep the light beams within the pipe. LEXAN resin performs well in these applications because of its clarity and excellent transmission properties.

## Light Pipe Interface

Along the light pipe interface, improved transmission is possible by:

- Specifying a highly polished surface. Rougher surfaces will result in "bleeding" of the light.
- Avoiding knit lines, voids, sinks or splay in molded light pipes.
- Avoiding steps, ribs, bosses or holes in light pipe walls.
- Avoiding dirt, grease or mold release.
- Specify a LEXAN resin with no pigmentation: color #111N.
- Avoiding tints or black specs in material.

## Design Considerations

The objective in designing a light pipe is typically to transmit the greatest amount of incident light. The amount of reflected light at the entrance and exit of the light pipe, path length, number of reflections and the loss at each reflection should be minimized for a given design.

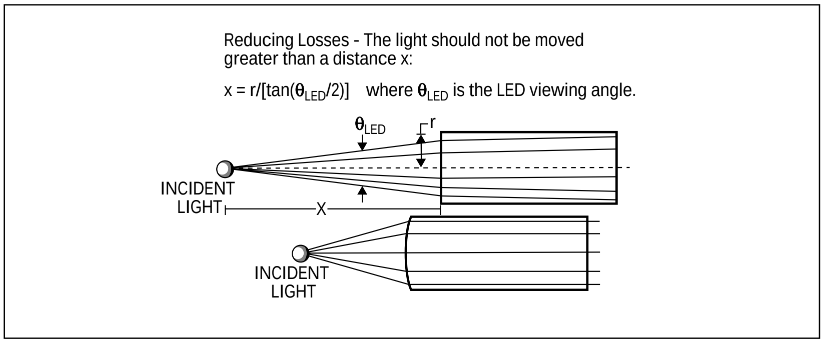


**Figure 6-16.** Methods for Forming Columns of Light.

## Reducing Losses

The number of reflections and path length can be reduced by forming columns of light, either by moving the light source farther away from the entrance, or by having a convex entrance (see above). As the light source is moved farther away from the light pipe, the incident light becomes less intense. However, a convex surface will have increased reflectance at the light pipe entrance. Therefore, the amount of additional light transmitted by avoiding any reflections and decreasing the path length will have to be weighed against the amount of light "lost" from either of these methods.

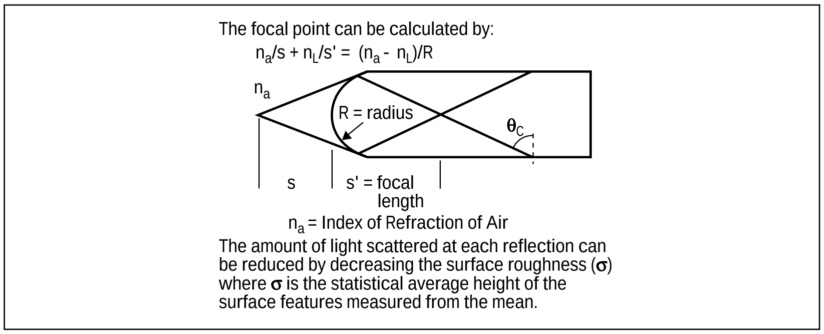


**Figure 6-17.** Variables Used to Calculate Focal Length.

In addition, care should be taken to avoid violating the critical angle by forming a convex surface with too small of a radius of curvature (see Figure 6-17). The focal point for the image should be past the exit end of the light pipe.

The surface roughness can be reduced by specifying a finer mold finish, or through a secondary operation such as methylene chloride vapor polishing for LEXAN resin. The surface can be coated with a reflective material to further decrease the losses due to surface scattering.

## Bends and Curvature

If a light pipe needs to be bent or curved, the angle at which it is bent, or the radius of curvature, needs to be considered. The angle will, in some cases, be superimposed with an indicent angle to violate the critical angle. With LEXAN resin, the angle of bend should not exceed 51˚. However, even at angles less than this, there will be light “lost”.

$$\frac{R_{min}}{t} = \frac{n_L + n_a}{2(n_L - n_a)}$$

Where: t is the light pipe thickness or diameter

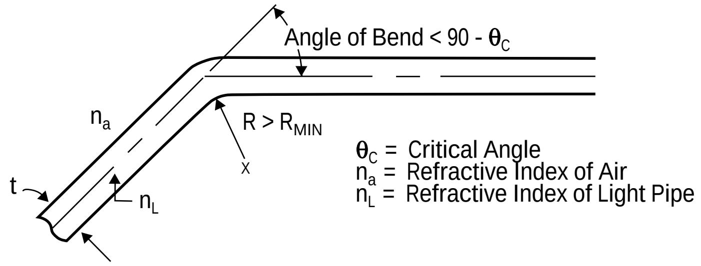


**Figure 6-18**. Angle of Bend.

## Converging and Diverging Sections

A light pipe that has a converging cross section can have issues with lost light by violating the critical angle. A diverging section will not incur this light loss; however, the light’s path length through the medium can be increased resulting in greater absorption of light in medium.

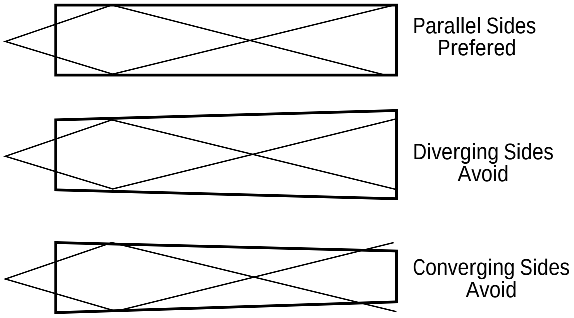


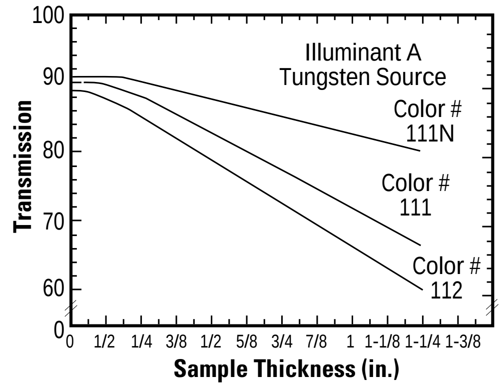
**Figure 6-19.** Converging and Diverging Sections.

# Industry Specific Design Considerations

## Material Considerations

The consideration as to which grade of LEXAN resin to use depends on mechanical requirements and cost. Most unreinforced grades of LEXAN resin with a color #111N should have similar optical properties if processed correctly. A color #111N indicates a natural clear LEXAN resin with no tint.

**Figure 6-20.** LEXAN Resin Direct Light Transmission.



*The color numbers 111 and 112 signify different concentrations of blue tint. Number 111N signifies the absence of any tint. Note that at thicknesses of 1/4" and less for 111N, LEXAN resin exhibits direct light transmissions comparable to most other optical materials. In the same concentrations, other available tint colors will behave as well as the blue tinted examples. This data applies to all transparent LEXAN resin grades.*

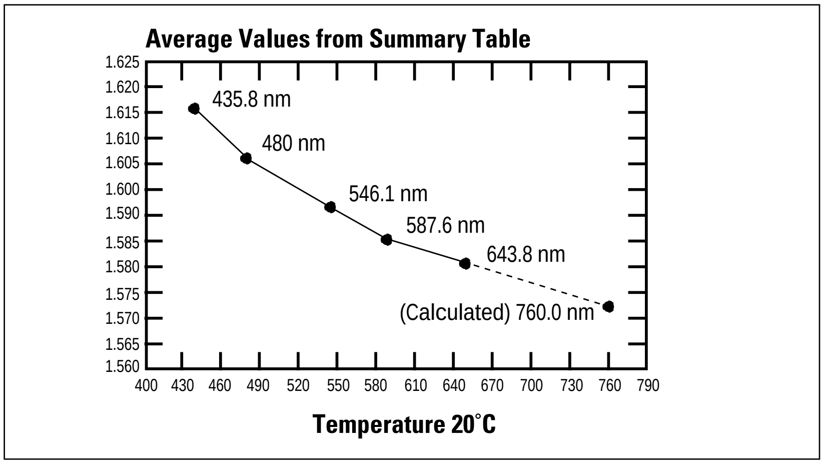


**Figure 6-21**. LEXAN Resin Dispersion Curve.

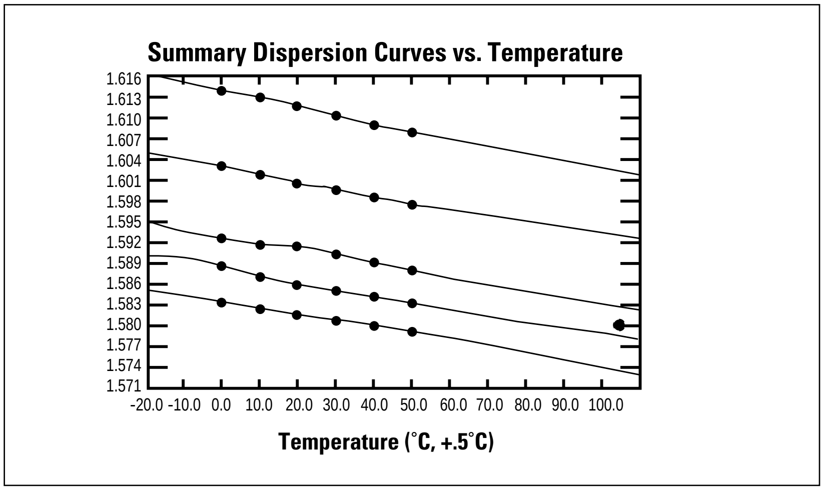


**Figure 6-22**. Index of Refraction Curves.

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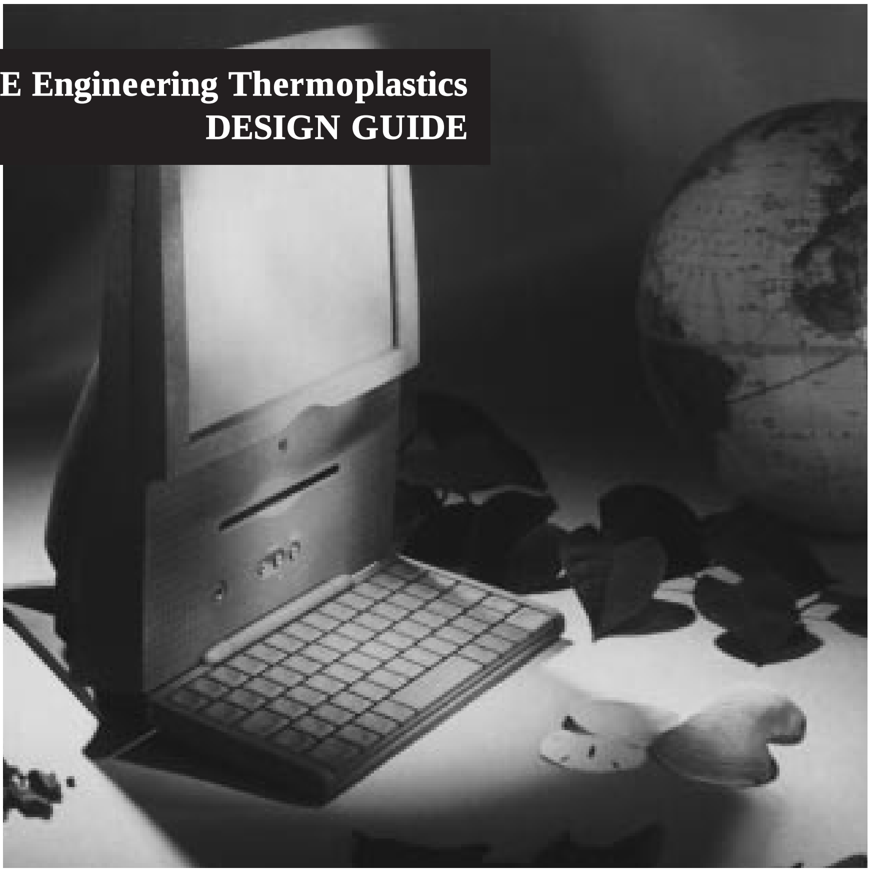
GE Engineering Thermoplastics
DESIGN GUIDE

# Testing
## Prototyping



- *Machining*
- *Annealing*

# Prototyping & Testing

Working in close collaboration with customers is at the core of the GE Plastics business culture. GE offers many services that are yours to use such as a prototyping service to help speed and prove mold and product design prior to production. Our application and performance testing services help customers validate feasibility and reduce time between design and production. These services, along with those like machining and annealing, enable an exchange of information focused on helping you get your products to market faster and at a better price.

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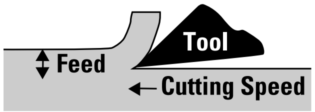
# Machining

Machining of a molded thermoplastic part is a very common secondary operation. In addition to machining of stock shapes for prototyping purposes, various types of machining are used to remove gates, trim flash and add unmoldable holes and openings.



- Plastic Memory
- Frictional Heating
- Coolants
- Annealing
- Quality Control

The machining characteristics of many thermoplastics are similar to those of non-ferrous metals; conventional wood and metal working tools are usually satisfactory. However, the unique physical properties of thermoplastics result in a few specific concerns for machining:

## Plastic Memory

Plastic recovery occurs in plastic materials both during and after machining. The expansion of compressed material due to elastic recovery can cause increased friction between the cut surface and the cutting tool. A generous clearance angle will help reduce this source of frictional heat. In addition, when large masses of material are to be removed, it is often advisable to leave a final cut of 0.005 to .010 in (0.127 to 0.254 mm) to compensate for any material movement due to plastic recovery or annealing.

## Frictional Heating

Frictional heating at the machined surface is a common problem due to the low thermal conductivity and low softening point for thermoplastics as compared to metals. Sharp tools are critical in minimizing frictional heating. Carbide tips are suggested to maximize tool life. Since frictional melting will result in visible deterioration of the smooth cut surface, visual examination is often used for quality control.

## Coolants

The use of coolants or lubricants during machining is not generally suggested due to the possibility of chemical attack of the plastic. If necessary, air or water can be used with most thermoplastics. Light, pure mineral oils are also compatible with some resins, but should be removed from the part after machining. Standard cutting oils should be avoided.

# Annealing

When a large mass of material has been removed, parts are often annealed to alleviate high residual stresses that may result from the machining process.

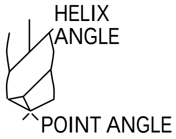
## Quality Control

Visual examination of the machined surface provides an excellent indication of the quality of the process. In general, the cut surface should be smooth. Jagged surfaces (which can be stress concentrators) or melted surfaces (from frictional heating) may be corrected by :

- Sharpen or replace cutting tool
- Reduce cutting speed or feeding speed
- Reduce depth of cut
- Check cutting tool design
- Use air, water or mineral oil as coolant/lubricant

## Drilling

Although standard drill bits are generally acceptable, specialized bits are available to optimize performance with thermoplastics. Wide, polished flutes with low helix angles enhance piloting and chip removal, and the standard 118° point angle can be sharpened to 70 to 90° for a smoother cut. Tests were conducted with standard drill bits using visual evaluation of quality. These values are guidelines only, and significant variations in parameters may still provide acceptable results.



| RESIN | LEXAN | VALOX | NORYL | ULTEM | CYCOLAC |
|---|---|---|---|---|---|
| CUTTING SPEED (in/min) | 1000-2000 | 1000-2000 | 200-800 | 3600 | 700-2000 |
| FEED RATE (mils/rev) | 3 to 10 | —— | —— | 5 to 15 | 1 to 5 |

**Figure 8-1.** Drilling.

## Sawing

Circular saws, band saws and jig saws can all be used to cut thermoplastics. Some tooth set will prevent binding; however, too large a set may result in surface roughness. Typical conditions given above for standard saw blades were found to yield good results based on visual evaluation of quality. Significant variations in parameters may still provide acceptable results.

**Figure 8-2.** Sawing.

| RESIN | LEXAN | VALOX | NORYL | ULTEM | CYCOLAC |
|---|---|---|---|---|---|
| BAND SAW<br>Speed (ft/min) | 2000-3000 | — | — | 3000-5000 | 900 |
| Feed (ft/min) | — | medium | — | — | 25-30 |
| Teeth/in. | 10-13 | 4-10 | 10-18 | 10 | 14 |
| CIRCULAR<br>Speed | 6000-8000 | — | — | — | 8000-12000 |
| Teeth/in. | 10-12 | — | — | — | 6-7 |

## Guidelines for the Annealing of Thermoplastics

Injection molding of plastic parts will generally produce molded in stresses. These stresses arise from a number of sources. Differential flow patterns in the mold, sharp wall transitions, different wall thicknesses and machining all contribute to non-uniform distribution of inherent stresses.

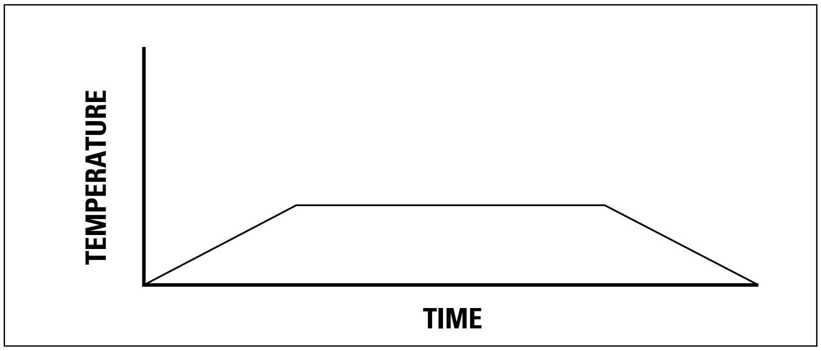


**Figure 8-3.** Time vs. Temperature Profile For a Good Annealing Procedure.

Annealing is a secondary operation that may be used to remedy this stress imbalance. Annealing may be accomplished by exposing the molded or machined parts to elevated temperatures for extended periods of time. This has the effect of accelerating the stress relaxation process that occurs in all thermoplastics. Through this process the internal stresses are reduced, thus improving dimensional stability and uniformity of properties throughout the part.

While useful for reducing stresses, annealing should not be thought of as a cure-all for a number of reasons:

1. Annealing is not suggested for glass filled parts due to their composite nature.
2. Studies have shown that post molded heat histories may result in increased notch sensitivity and reduced chemical compatibility with certain substances.
3. The extended periods of time needed for annealing may prevent it from being used economically in actual production.

Problems with molding procedures and part design should be considered before annealing is decided upon as the solution to a problem.

# Prototyping & Testing

Each resin and resin grade produced by GE Plastics is manufactured to provide certain physical properties and characteristics. Consequently, each resin family has a different annealing procedure. The following are guidelines for the annealing of the various resins.

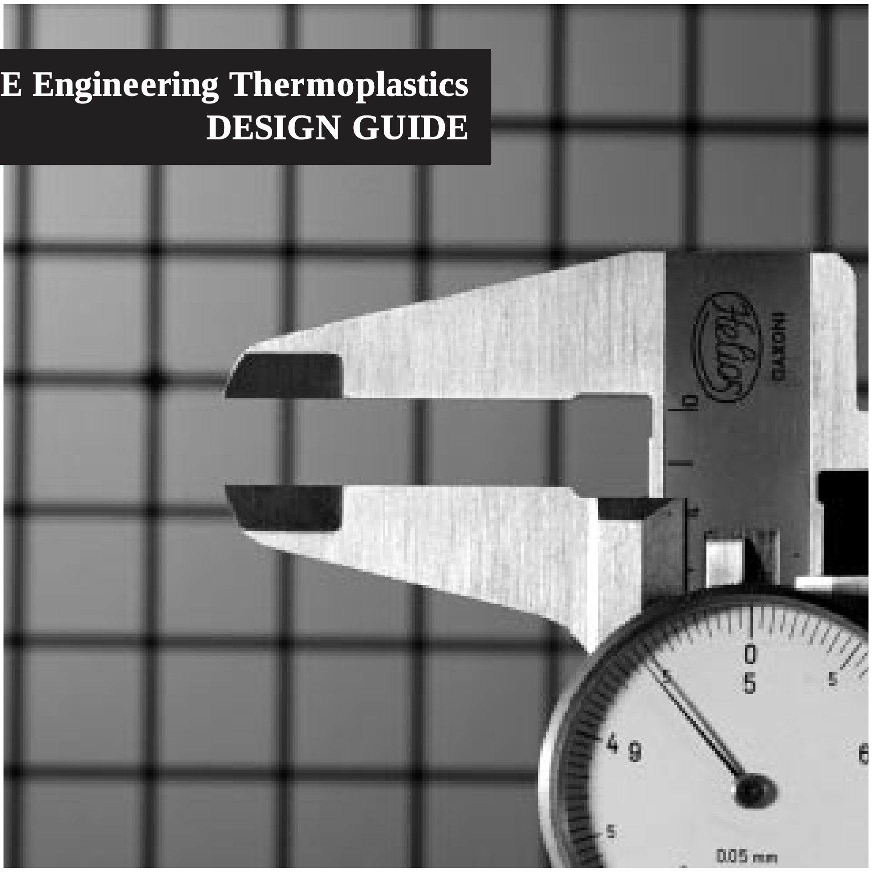
| | |
|---|---|
| **CYCOLAC ABS resin** | Annealing of CYCOLAC ABS resins should be performed at the specific resin grade's heat deflection temperature at 264 psi. This temperature should be attained in an air circulating oven and the parts to be annealed should be held at this temperature for 1 to 2 hours. |
| **LEXAN PC resin** | Annealing should be performed at 250˚F (121˚C) for as short a time as possible to achieve acceptable part performance. This time should be determined experimentally using actual end use testing. |
| **NORYL Modified PPO resin** | Parts molded of NORYL resin should be annealed in an air circulating or vacuum oven at 30˚F (-1˚C) less than the resin's heat deflection temperature at 264 psi. An annealing time of 1 hour per 1/8 in. of thickness should be used. |
| **SUPEC PPS resin** | SUPEC resins should be annealed at 400˚F (204˚C) for 4 hours. This temperature should be attained in an air circulating or vacuum oven. |
| **ULTEM PEI resin** | To anneal ULTEM resins, the part in question should be brought to a temperature of 400˚F (204˚C) over a period of 2 hours. It should then be held at 400˚F (204˚C) for an additional 2 hours. |
| **VALOX PBT resin** | Annealing of glass reinforced VALOX resin parts should be conducted at 30˚F (-1˚C) less than the heat deflection temperature at 264 psi for the specific grade. A annealing time of 30 minutes per 0.125 in (3.175 mm) thickness is suggested for unfilled grades. Unfilled grades should be annealed at the 264 psi HDT. |

In all cases, the annealed parts should be cooled slowly to prevent thermal "shock". Fast cooling rates may reintroduce stresses into the part causing warping and cracking. To avoid overly quick cooling rates it is suggested that the parts be cooled by turning off the ovens used to anneal them and allowing the parts in the oven to slowly return to ambient temperatures.

NOTE: These are suggested guidelines only. Annealing conditions will vary from application to application, and those limits unique to each particular case should be determined by specific end use performance testing.

## Notes

**GE Plastics**



# GE Engineering Thermoplastics
# DESIGN GUIDE

# Quality Control

- *Failure Analysis*
- *Degradation*
- *Chemical Attack*
- *Stress*
- *Troubleshooting Guide*

# Quality Control

The global marketplace demands high speed to market, low cost and world class quality. GE Plastics is committed to providing customers with the highest quality products and services. Our Six Sigma quality initiative results in the virtual elimination of defects from every product, process and transaction. This effort will present opportunities to reduce cost, expand and improve customer service.

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# Failure Analysis

## The Most Obvious Cause Isn't

When trying to determine the cause or causes of a part's failure, it is good to maintain an open mind, best expressed by the phrase "The Most Obvious Cause Isn't." This reminds you to not assume anything during the analysis – to look for secondary or tertiary factors which may also be significant contributors to the part's failure.

The failure of a part molded from a thermoplastic resin can be caused by a number of factors during the life history of the part. Errors in design, processing, secondary operations, assembly and the end use environment can lessen the expected performance. Often two, three, or more factors can be found which may contribute to less than satisfactory performance of the part. However, of all the possibilities, by far the three most common problems are polymer degradation during processing, chemical attack and unexpected stress concentrations or accumulations.

**Failure Analysis**

- Degradation
- Chemical Compatibility
- Stress

# Degradation

Polymer degradation is almost always associated with the processing of a material. If the degradation is a sudden or new occurrence, it is probably a result of changes in drying, processing parameters or the material. If the degradation is ongoing, (i.e., it cannot be resolved by standard troubleshooting), then it is more likely caused by part design, tool design or the molding machine.

**Degradation Questions**

| Ongoing | New |
|---|---|
| • Gate/Sprue | • Drying |
| • Machine Size | • Dryers |
| • Cavity | • Regrind% |
| • Design | • Material |
| • Contamination | |

## Degradation Testing

For most unreinforced thermoplastics, the test used to determine the level of degradation is the melt flow, or melt viscosity test. If the material is glass reinforced, a more accurate measurement can often be obtained from an intrinsic viscosity test. For a few resins, neither of these tests are accurate, and an alternative test must be used, such as the thermal gravimetric analysis – TGA.

## Degradation Test Results

The results of any analytical degradation test must be compared to some base value and reported as a percent change. The most accurate results are obtained by testing parts and pellets from the same lot of resin, in the same test equipment. The next best control value would be QC data from the manufacturer for the same lot of resin.

*Referring to the manufacturing specifications for a grade will introduce the allowable viscosity range into the uncertainty of the results. This could be a concern if moldings are borderline.*

There is always a small amount of degradation incurred in the molding process, due to the heat and shear that the material is subjected to in the mold. What percentage change is the dividing line between acceptable and unacceptable processing? General guidelines exist for most resins and processes. However, physical properties react differently to a particular level of degradation, and the needs of a specific part vary as well. Thus, the amount of acceptable degradation should be considered application dependent, and is determined either by the performance or failure of the part, or by thorough end use testing.

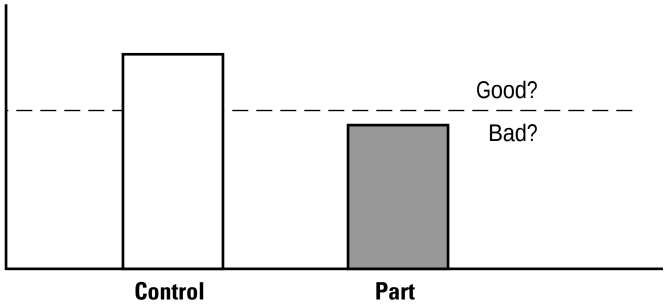


**Figure 9-1.** Degradation Testing Guidelines.

# Chemical Attack

Exposure of a thermoplastic part to an incompatible solvent, solution or chemical may result in a variety of effects, ranging from surface melting, cracking and crazing, to degradation of properties such as elongation with little apparent evidence.

When searching for a potentially incompatible material, it should be remembered that the attack may come from a minor component in almost any carrier – lubricants, cleaners, gaskets, adhesives, even mating plastic components! When in doubt, check it!

Chemical compatibility – or the resistance of a material to a specific agent – depends upon a number of factors. The contact time may be critical; a cleaning agent which evaporates quickly may be acceptable for a part in its intended use, but if a molded plastic is immersed for extended periods of time, the part may be severely attacked. Similarly, elevated temperatures or stress levels may initiate or accelerate an attack. Remember that stresses are cumulative – a part may pass a compatibility test as molded, but with externally applied stresses, induced by an assembly operation for example, the part may be more susceptible to attack.

**Polymer Degradation**

A decrease in average polymer length, generally due to heat and shear in the conversion process from pellets to part. Excessive degradation can result in the loss of some or all physical properties.

**Chemical Compatibility**

- Time
- Temperature
- Molded-in Stress
- Externally Applied Stress

**Characteristics of Chemical Attack**

- Glossy fracture surface
- Many crack from a feature

# Stress

A common factor in most part failures is stress. Compensating for all possible situations and their effects is virtually impossible. Even if all stresses are accurately evaluated, failure can still occur from some other unanticipated factor(s).

**Stress**

- Design Stress
- Processing Stress
- Assembly Stress
- End Use Stress
- Stress Concentration Factors

## Design Stress

Hand calculations are typically used as a first approximation in the basic design of a part - and sometimes as the final analysis. Thus, it is important to understand their limitations:

- Most conventional hand calculations are only valid for simple geometries such as beams and plates.
- Hand calculations assume a linear relationship between stress and strain. The nature of plastic materials is that most exhibit a non-linear relationship, beginning at relatively low stress levels.
- Most hand calculations assume that displacements are relatively small so that changes in geometry do not significantly affect the stiffness of the part. Due to their relatively low stiffness and high deflections, this assumption is rarely valid for plastic parts. Thus, larger factors of safety are needed to compensate for the inaccuracies of hand calculations.
- Finite Element Analysis (FEA) utilizes the capability of a computer and specialized software to reduce a design to elements, each of which can be studied alone or as part of a system (or part).

The most difficult area to analyze for both hand and FEA calculations is Stress Concentrations. Often, the best approach is simply to test actual parts and then modify the design accordingly.

## Processing Stress

Residual or molded-in stresses are inherent in all processing methods, but are most significant in injection molding. As the material is injected, the layer in contact with the mold quickly freezes. As the material filling the area between these frozen layers cools, it shrinks – pulling against the outside layers. This results in a slight compressive stress on the outside surface of a molded part and a slight tensile stress internally. The magnitudes of these stresses can be significantly affected by processing parameters and the cooling rate of the part. Warping of the part could indicate significant molded-in stresses.

The most critical areas for molded-in stresses are the gate area, the farthest end of the flow, and any areas of sudden change in the flow, such as sharp corners and wall thickness transitions. In these areas, the level of molded-in stress is particularly high, and they should be evaluated carefully before being subjected to additional stresses.

## Assembly Stress

Additional stresses are encountered when the part is joined as an element into an assembly. Mechanical fasteners are an obvious source of stress concentrations, but welding processes also induce residual stresses. Variations in tolerances and accumulations of tolerances can result in mismatched parts and cause sporadic high assembly stresses. Dissimilar materials will also cause additional stresses, if reactions to the assembly environment result in unequal size changes.

## End-Use Stress

All possible end-use conditions and loadings must be anticipated in part design. Environmental changes can be significant – for example, large temperature excursions in combination with differences in coefficient-of-thermal-expansion (CTE) between components can result in high induced stresses. Some end-use loadings, such as impact, can be difficult to analyze before parts are available for testing. The most impossible task of all is to envision abuses that the part was not meant to experience.

## Stress Concentration Factors

Stress Concentration Factors are a standard tool for design engineers. Developed from empirical data, they are used to approxi mate stress levels in areas that hand calculations cannot evaluate. Stress Concentration Factors are dependent upon the design only – they are the same regardless of the material. Since thermoplastic resins in general have relatively low stress limits compared to metals, consideration of Stress Concentration Factors is an important step in the design of thermoplastic parts.

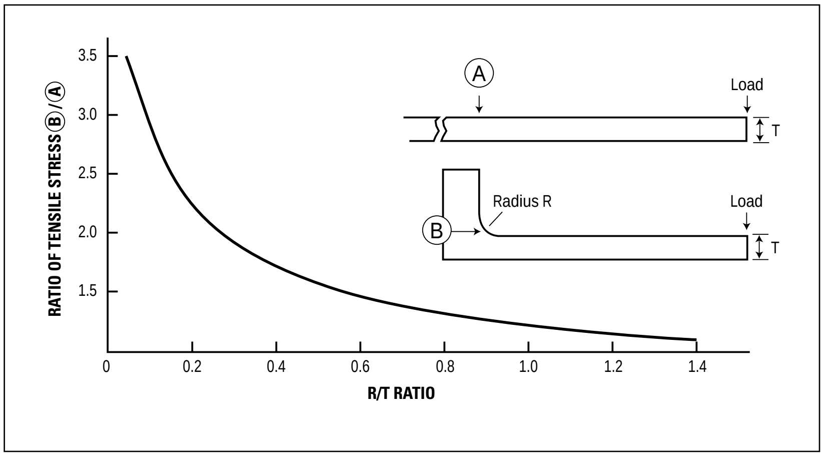


**Figure 9-2.** Stress Concentration Factors.

# Troubleshooting Guide

**Troubleshooting Guide**

1. Identify & Define Problem
2. Research Failure History
3. Hypothesis of Failure
4. Testing
5. Determine Source of Failure
6. Formulate Solution
7. Communicate Findings
8. Feedback

Failure of molded plastic parts can occur in several ways: mechanical failure, fatigue, thermal degradation, chemical attack, improper processing, design and tooling, material inconsistencies, etc. The following is an operational outline for troubleshooting and correcting failures of molded plastic parts.

The first step is to identify exactly what the problem is, and define what would constitute an acceptable solution. Then characterize as completely as possible the failure:

**TYPE** – brittle, ductile, single or multiple locations, etc.

**HOW** – minor, catastrophic, slow, fast, etc.

**MODE** – flexure, tensile, vibration, impact, creep, heat, etc.

**LOCATION** – crack origin, thin wall, corner, gate, hole, boss, etc.

**SYMPTOMS** – surface appearance, fracture surface, strength or properties reduction, snap, tear, etc.

## History

The next step of information gathering is the history of the application, as well as the specific failed parts:

**FUNCTION** – what exactly is the part expected to do

**PERFORMANCE** – specifications, requirements, etc.

**MATERIAL** – resin, grade, color, lot, QC specifications

**HISTORY** – has it ever worked, where did it happen, failure at inspection, percentage of failures, repeatability, etc.

**PROCESSING** – set-up, regrind, drying, gate and sprue, mold release, machine size and type, etc.

**DESIGN** – prints, analyses, testing, changes, etc.

**SECONDARY OPERATIONS –** fastening, bonding, welding, coating, painting, printing, etc.

**ENVIRONMENT** – chemicals, weathering, UV, loading, temperature, time, etc.

## Hypothesis of Failure

Use the accumulated information to determine the most likely contributing factor(s) to the failure. Decide if sufficient information is present to determine corrective measures or if there is a need for further information.

**Hypothesis of Failure**

- Processing
- Design
- Environmental
- Secondary Operations
- Material

## Testing

With justifiable hypotheses, testing may be instituted to provide verification of the cause(s) of failure. Such testing might include:

**DEGRADATION** – melt flow, melt viscosity, intrinsic viscosity, or TGA

**STRESS** – print review, finite element analysis, physical testing

**COMPATIBILITY** – data survey, chemical testing, chemical wash, microscopy, etc.

**FTIR** – composition, contamination

**ASH** – level of reinforcement, possibility and condition of regrind

## Source

Using the test data, visual inspections, design and processing information, and the general background information, a “supported” conclusion of the source(s) of the part failure may be drawn. In many cases, the “cause” of failure may include multiple sources.

## Formulate Solution

After having identified and rated the most likely cause(s) of failure, it is necessary to isolate the optimum solution. The solution should be feasible, adequate and economical. This is often difficult and may involve a series of compromises. If possible, alternative measures should always be provided so that improvements, cost and timeliness can be evaluated for the best solution.

**Formulate Solution**

- Processing Parameters
- Design Modifications
- Environmental Protection
- Sec. Ops. Modification
- Material Change

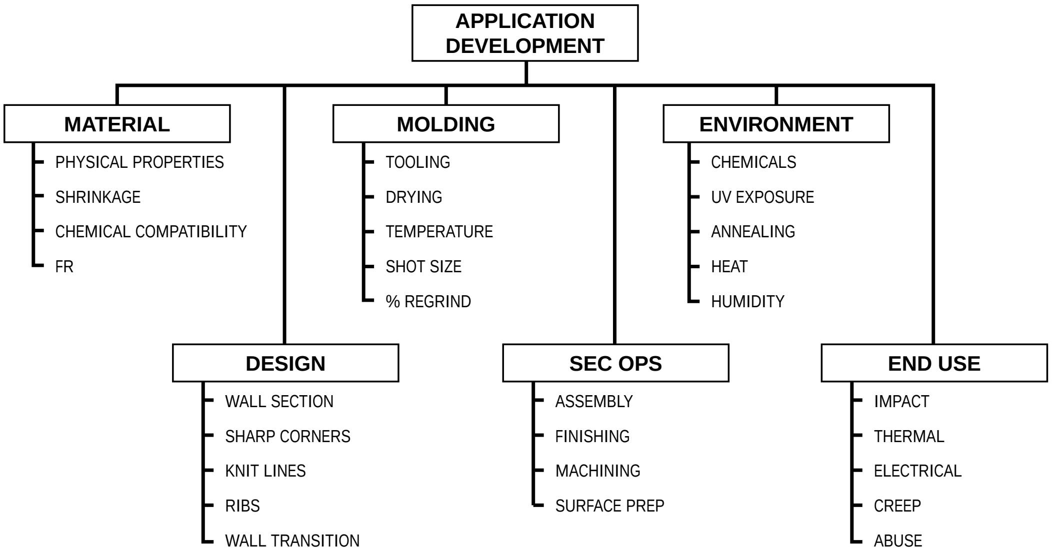
## Communicate

Proper communication of findings is an integral step in the solution process. The findings must be forwarded in a concise, clear and timely manner or they are of little use. Verbal communication is the quickest method, and is often used to speed results. However, formal reports are beneficial in documenting the activity for immediate and future reference.

## Feedback

Feedback is critical in that it reflects the effectiveness of the analysis. If the corrective measures did not resolve the problem, an alternative approach may be necessary. Even invalid conclusions provide important information, and can be used as the basis of a more focussed, in-depth evaluation.

This chart lists some of the factors that are considered in the design, development, manufacture and use of a part. When the part's performance does not meet expected levels, it may be helpful to recreate and question the thought process behind some of these decisions.



### Application History

- Did it ever work?
- When did it happen?
- How many parts?
- Chemical exposure?

### Material

- What material is it?
- What Grade? Lot?
- Color number?
- Any regrind? How much?

### Design

- Fail in the same place?
- Knit line location?
- Part to print comparison?
- Sharp corners?

### Molding

- Did it ever work?
- Was it dried properly?
- Any specific cavity?
- Shot size to capacity?

### Environment

- Appearance differences?
- Weathering effects?
- Chemical exposure?
- Compatibility checked?

### End-Use

- In-Use?
- In-Storage?
- Accidental?
- Abuse?

## Injection Molding Troubleshooting Considerations

### *Black Specs LEXAN*

- Purge with ground acrylic of LEXAN resin regrind as the purging material
- Start-up: Purge occasionally during start-up from 520˚F (271˚C) until the desired melt temperature is reached
- Shut-down: Purge periodically after shut off until cylinder temperature falls below 520˚F (271˚C); then continue with a purging material until shut-down is complete
- Check and adjust melt temperature
- Long-term interruption (from one hour through a weekend): adjust machine temperature to 350˚F (177˚C)
- Physically remove and clean screw and barrel

### *Brittleness*

- Lower material temperature by:
  a. Lowering cylinder temperature
  b. Decreasing screw speed
  c. Lowering back pressure
- Check for contamination
- Decrease amount of regrind in feed
- Dry material properly

### *Burn Marks*

- Decrease injection speed
- Decrease booster time
- Decrease injection pressure
- Improve mold cavity venting
- Change gate location and/or increase gate size
- Use proper melt temperature/lower barrel heats

### *Discoloration*

- Purge heating cylinder
- Lower material temperature by:
  a. Reducing cylinder temperature
  b. Decreasing screw speed
  c. Reducing back pressure
- Lower nozzle temperature
- Shorten overall cycle
- Check hopper and feed zone for contaminants
- Provide additional vents in mold
- Move mold to smaller shot size press

### *Delamination*

- Raise temperature of mold and/or material
- Eliminate contamination
- Dry material
- Increase or decrease injection speed
- Radius all sharp corners at gate, radius base of sprue if sprue gate
- Profile injection – slow, fast and back to slow at end of injection travel

### *Jetting*

- Decrease injection speed
- Increase resin temperature
- Increase gate size
- Decrease gate land length
- Change gate location to direct flow against wall or pin

## Injection Molding Troubleshooting Considerations (Cont.)

### *Splay Marks, Silver Streaks, Splash Marks*

- Lower material temperature by:
  - a. Lowering cylinder temperature
  - b. Decreasing screw speed (injection and RPM)
  - c. Lowering back pressure
- Lower nozzle temperature
- Shorten overall cycle
- Dry material before use
- Check for contamination (and water or oil leaking into mold cavity)
- Shorten or eliminate screw decompression
- Move mold to smaller shot-size press
- Check for drooling
- Decrease injection speed
- Raise mold temperature
- Open gates

### *Sticking in Cavity*

- Decrease injection pressure
- Decrease injection-hold pressure
- Decrease booster time
- Decrease injection-hold time
- Ensure that constant cushion exists
- Increase the cavity temperatures to a 20˚F (-7˚C) differential between mold halves
- Decrease cylinder and nozzle temperature
- Check cavity for undercuts, finish and/or insufficient draft

### *Sticking on Core*

- Decrease injection pressure
- Decrease injection-hold pressure
- Decrease booster time
- Decrease injection-hold time
- Adjust feed for minimum constant cushion

### *Sticking on Core (cont.)*

- Increase core temperature
- Decrease cylinder and nozzle temperature
- Check core for undercuts, finish and/or insufficient draft

### *Sticking in Sprue Bushing*

- Decrease injection pressure
- Decrease injection-hold pressure
- Decrease booster time
- Decrease injection-hold time
- Decrease mold temperature around sprue bushing
- Raise nozzle temperature
- Check size and alignment of holes in nozzle and sprue bushing (sprue-bushing hole must be larger)
- Provide more effective sprue puller

### *Sinks and/or Voids*

- Increase Injection Pressure
- Increase injection-hold time
- Raise mold temperature (voids)
- Lower mold temperature (sinks)
- Decrease injection speed
- Decrease cushion
- Increase size of sprue and/or runners and/or gates
- Relocate gates nearer heavy sections
- Core out heavy wall sections where possible

### *Warpage, Part Distortion*

- Equalize surface temperature of both halves of mold
- Observe mold for part-ejection uniformity
- Check handling of parts after ejection from mold
- Increase injection-hold

## Injection Molding Troubleshooting Considerations (Cont.)

### *Warpage, Part Distortion (Cont.)*

- Try increased pressure and reduced pressure
- Try higher and lower mold pressure
- Increase die-close time
- Lower material pressure
- Set differential mold temperatures to counteract warp due to part geometry (parts generally warp towards side that cools slowest)
- Jig the part and cool uniformly

### *Weld Lines*

- Increase injection pressure
- Increase injection-hold time
- Raise mold temperature
- Raise material temperature
- Vent the cavity in the weld area
- Provide an overflow-well next to the weld area
- Change gate location to alter flow pattern
- Increase injection speed

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