# Polymers: Characteristics and Compatibility for Ultrasonic Assembly

## Weldability of Polymers

The principle of ultrasonic assembly involves the use of high-frequency mechanical vibrations transmitted through thermoplastic parts to generate a frictional heat build-up at an interface. This bulletin provides guidelines on the welding characteristics of thermoplastics as well as an understanding of how polymer structure and other factors affect the weld ability of various polymers. The term "weld ability" is used generically and includes the ability to stake, swage, insert, or spot weld the resin.

## Polymers: Thermoset Versus Thermoplastic

A polymer is a repeating structural unit formed during a process called polymerization. There are two basic polymer families: thermoset and thermoplastic. A *thermoset* is a material that, once formed, undergoes an irreversible chemical change and cannot be reformed with the reintroduction of heat and pressure; therefore, thermosets cannot be ultrasonically assembled in the traditional sense. A *thermoplastic* material, after being formed can, with the reintroduction of heat and pressure, be remelted and reformed, undergoing only a change of state. This characteristic makes thermoplastics suitable for ultrasonic assembly.

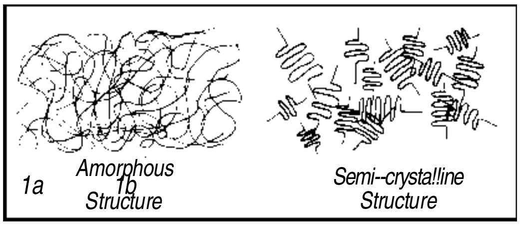
All the information contained in this information sheet and others covering ultrasonic processes is based on the use of *thermoplastic* polymers (resins).

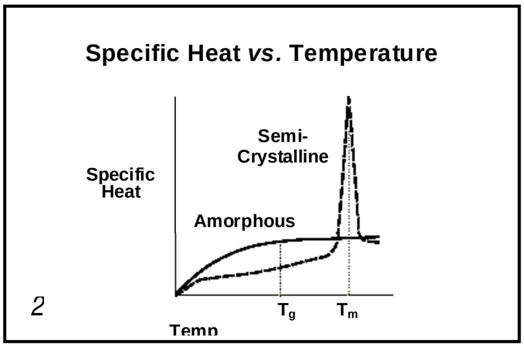
## Factors That Affect Weldability

When discussing the weldabiity of thermoplastics, it must be recognized that there are a number of factors that affect the ultrasonic energy requirements and, therefore, weldabiity of the various resins. The major factors include polymer structure, melt temperature, melt index (flow), modulus of elasticity (stiffness), and chemical makeup.

### Polymer Structure

*Amorphous polymers* have a structure characterized by a random molecular arrangement (Figure 1a). They have a broad softening temperature ($T_g$, glass transition temperature) range (Figure 2) that allows the material to soften gradually, melt and flow without prematurely solidifying. These polymers generally are very efficient with regard to their abiity to transmit ultrasonic vibrations, and can be welded under a wide range of force/amplitude combinations.




*Semi--crystaline polymers* are characterized by regions of orderly molecular arrangement (Figure 1b). They have sharp melting ($T_m$, melt temperature) and resolidification points (Figure 2). The molecules of the polymer, when in the solid state, are spring-like and internally absorb a percentage of the high-frequency mechanical vibrations, thus making it more difficult to transmit the ultrasonic energy to the joint interface. For this reason, high amplitude is usually required. The sharp melting point is the result of a very high energy requirement (high heat of fusion) necessary to break down the semi-crystalline structure to allow material flow. Once the molten material leaves the heated area, these resins solidify rapidly with only a small reduction in temperature. These characteristics therefore warrant special consideration (i.e., higher amplitude, careful attention to joint design, horn contact, distance to the weld joint, and fixturing) to obtain successful results.

### Melt Temperature

The higher the melt temperature of a polymer, the more ultrasonic energy is required for welding.

### Stiffness (Modulus of Elasticity)

The stiffness of the polymer to be welded will influence its abiity to transmit the ultrasonic energy to the joint interface. Generally the stiffer a material the better its transmission capability.

### Welding Dissimilar Resins

A *similar melt temperature* between the materials to be welded is a basic requirement for successful welding of rigid parts, because a temperature difference of 40°F (22°C) can be sufficient enough to hinder weldabiity (even for a like resin). The lower melt temperature material melts and flows preventing generation of sufficient heat to melt the higher melt temperature material. For example, with an energy director on a part composed of high-temperature acrylic opposing a parallel surface composed of a low-temperature acrylic, the weld surface of the high-temperature part will not reach the necessary temperature to melt. The opposing surface will be in a molten state before the energy director begins to soften, and if the energy director fails to melt, bond strength will be impossible to predict.

In addition, to weld dissimilar plastics, the plastics to be welded must possess a *like molecular structure* (i.e., be chemically compatible) with some component of the material, usually a blend. Close examination of compatible thermoplastics reveals that like radicals are present, and the percentage of the like chemical radical will determine the molecular compatibility.

*Note: Compatibility exists only among amorphous polymers or blends.. Semi--crystaline polymers are welåble only to themselves..*

*Melt index,, or flow rate,,* is the rate at which a material flows when it becomes molten. Different grades of the same material may have different flow rates (e.g., an injection molded nylon and an extruded nylon). Such differences may result in the melting of one component of an assembly and not the other. Thus, a melt or flow is created, but not a homogeneous bond. When selecting resins that are dissimilar or different grades of the same material, consult the resin manufacturer's specifications to acquire the melt index or flow rate. The flow rates should be fairly close (i.e., 2 to a 4) in order to achieve compatibility.

## Other Variables That Influence Welda bility

### Moisture

Some materials are hygroscopic; that is, they absorb moisture from the atmosphere which can seriously affect weld quality. Nylon (and to a much lesser degree polyester, polycarbonate, and polysulfone) is the material most troubled by this characteristic.

If hygroscopic parts are allowed to absorb moisture, when welded the water will evaporate at 212° F (100°C), with the trapped gas creating porosity (foamy condition) and often degrading the resin at the joint interface. This results in difficulty in obtaining a hermetic seal, poor cosmetic appearance (frostiness), degradation, and reduced weld strength. For these reasons, if possible it is suggested that nylon parts be welded directly from the molding machine to insure repeatable results. If welding can't be done immediately, parts should be kept dry-asmolded by sealing them in polyethylene bags with a desiccant pouch or other suitable means directly after molding. Drying of the parts prior to welding can be done in special ovens; however, care must be taken to avoid material degradation. Keep in mind

that 100% dry nylon can be very brittle. Some moisture within the material may be beneficial in eliminating an over-stress condition (which can cause cracking).

If several batches of hygroscopic parts have varying levels of moisture, the energy levels required during the welding process will have to be varied by the ultrasonic welder.

### Resin Modifiers

Using additives or processing aids during preparation of a resin compound may result in properties not inherent in the base resin. These additives, which can enhance certain areas of processing, can in some cases create problems in ultrasonic welding. Parts molded with differing parameters may require minor variations in welding process parameters.

*Mold release agents,,* often called parting agents, are applied to the surface of the mold cavity to provide a release coating which facilitates removal of the parts. External release agents, such as zinc stearate, aluminum stearate, fluorocarbons and siicones can be transferred to the joint interface and interfere with surface heat generation and fusion, inhibiting welding; siicones are generally the most detrimental. If it is absolutely necessary to use an external release agent, the paintable/printable (non-transferring) grades should be used. These grades prevent the resin from wetting the surface of the mold, with no transfer to the molded part itself, thus permitting painting and silk-screening and the least amount of interference with ultrasonic assembly. Detrimental release agents can in some cases be removed by using a solvent, such as TF Freon. Internal molded-in release agents, since they are generally uniformly dispersed internally in the resin, usually have minimal effect on the welding process.

*Lubricants* (internal and external) are materials that enhance the movement of the polymer against itself or against other materials. (Examples include waxes, zinc, stearate, stearic acid, esters.) Lubricants reduce intermolecular friction (melt viscosity) within the

polymer and reduce melt flow friction against primary processing equipment surfaces. Since molecular friction is a basis for ultrasonically induced temperature elevation, lubricants can inhibit the ultrasonic assembly process. However, since they are generally dispersed internally, like internal mold release agents their effect is usually minimal.

*Plasticizers* are high-temperature boiing organic liquids or low-temperature melting solids which are added to resins to impart flexibiity. They do this through their ability to reduce the intermolecular attractive forces of the polymer matrix. They can also interfere with a resin's ability to transmit vibratory energy. Attempting to transmit ultrasonic vibrations through a highly plasticized material (such as vinyl) is like transmitting energy through a sponge. Even though plasticizers are considered an internal additive, they do migrate to the surface over time, and the combination of internal as well as surface

| Material | Welding Near* | Welding Far* | Swaging Staking | Insertion | Spot Welding |
|---|---|---|---|---|---|
| *Amorphous Polymers* | | | | | |
| ABS | 1 | 2 | 1 | 1 | 1 |
| ABS/polycarbonate alloy | 2 | 2 | 2 | 1 | 1 |
| Acrylic | 2 | 3 | 3 | 1 | 1 |
| Butadiene-styrene | 2 | 3 | 2 | 2 | 2 |
| Phenylene-oxide based resins | 2 | 2 | 2 | 1 | 1 |
| Polycarbonate (a) | 2 | 2 | 3 | 2 | 2 |
| Polyetherimide | 2 | 4 | 4 | 3 | 3 |
| Polyethersulfone (a) | 2 | 4 | 4 | 4 | 4 |
| Polystyrene (general purpose) | 1 | 1 | 4 | 2 | 3 |
| Polystyrene (rubber modified) | 2 | 2 | 1 | 1 | 1 |
| Polysulfone (a) | 2 | 3 | 3 | 2 | 3 |
| PVC (rigid) | 3 | 4 | 2 | 1 | 3 |
| SAN-NAS-ASA | 1 | 1 | 3 | 2 | 3 |
| PBT/polycarbonate alloy | 2 | 4 | 3 | 2 | 2 |
| *Semi–Crystalline Polymers* (b) | | | | | |
| Acetal | 2 | 3 | 3 | 2 | 2 |
| Cellulosics | 3 | 5 | 2 | 1 | 3 |
| Fluoropolymers | 5 | 5 | 5 | 5 | 5 |
| Liquid crystal polymers (c) | 3 | 4 | 4 | 4 | 3 |
| Nylon (a) | 2 | 4 | 3 | 2 | 2 |
| Polyester, thermoplastic | | | | | |
| Polyethylene terephthalate/PET | 3 | 4 | 4 | 3 | 3 |
| Polybutylene terephthalate/PBT | 3 | 4 | 4 | 3 | 3 |
| Polyetheretherketone - PEEK (c) | 3 | 4 | 4 | 3 | 3 |
| Polyethylene | 4 | 5 | 2 | 1 | 2 |
| Polymethylpentene | 4 | 5 | 2 | 1 | 2 |
| Polyphenylene sulfide | 3 | 4 | 4 | 2 | 3 |
| Polypropylene | 3 | 4 | 2 | 1 | 2 |

**Code: 1 = Easiest, 5 = Most difficult.**

The codes in Table 1 indicate *relative ease of welding* for the more common thermoplastics. In addition to the material factors covered in the preceding sections, ease of welding is a function of part size and geometry, joint design, energy requirements, amplitude, and fixturing.

Note: The ratings *do not* relate to the strength of the weld obtainable.

Use these tables as a *guide only,,* since varia-- tions in resins, fillers, and part geometry may produce slightly different results.

Notes:

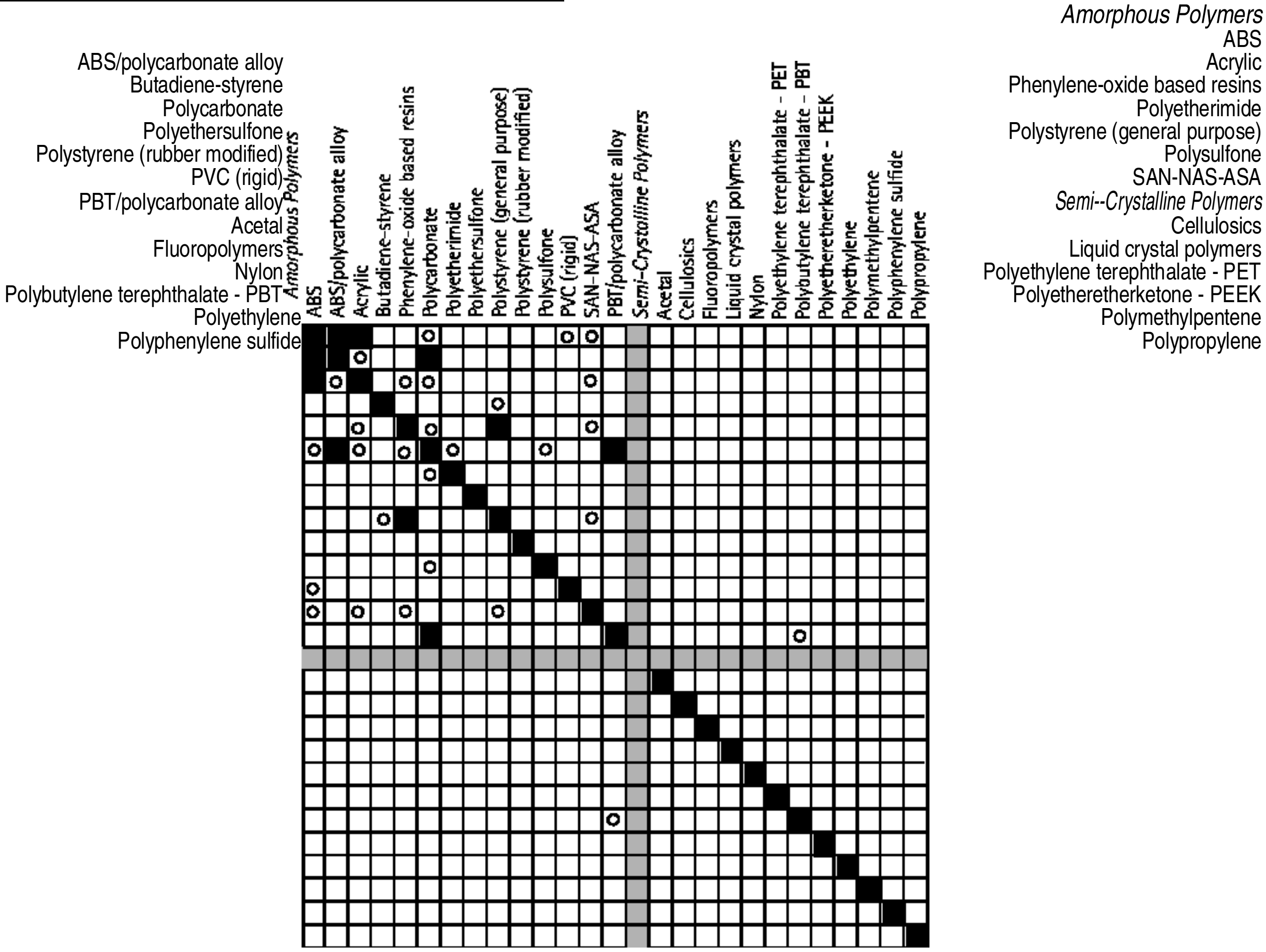
* Near-field welding refers to a joint 0.250 inch (6.35 mm) or less from the horn contact surface; far-field welding refers to a joint more than 0.250 inch (6.35 mm) from the horn contact surface. You should con-sider using 15 kHz equipment when welding far field with difficult-to-weld materials.

a Moisture will inhibit welds. Consider using a 2000f welder with force profiling for achieving hermetic seals.

b Semi-crystalline resins in general require higher amplitude and energy levels due to polymer structure, higher melt temperatures, and heat of fusion. c Consider using 40 kHz for near-field welding.

■ Denotes compatibility

○ Denotes compatibility in some cases (usually blends)



lubricity make plasticized vinyl all but impossible to weld. FDA-approved plasticizers do not present as much of a problem as metallic plasticizers, but experimentation is recommended.

*Impact modifiers* such as rubber can affect the weldabiity of a material by reducing the amount of thermoplastic available at the joint interface. They can also reduce the resin's abiity to transmit ultrasonic vibrations, making it necessary to increase amplitude to generate a melt.

*Foaming agents* also reduce a resin's abiity to trans-mit energy. Voids in the cellular structure interrupt the energy flow, reducing the amount of energy reaching the joint area, depending on the density.

*Flame retardants* are added to a resin to inhibit ignition or modify the burning characteristics. They can adversely affect ultrasonic welding characteristics of the resin compound. Flame retardant chemicals are generally inorganic oxides or halogenated organic elements, and for the most part are non-weldable. Typical examples are aluminum, antimony, boron, chlorine, bromine, sulfur, nitrogen, and phosphorus. The amount of flame retardant material required to meet certain test requirements may vary from a few percent to 50% or more by weight of the total matrix, thus reducing the amount of available weldable material. This reduction must be compensated for by modifying the joint configuration to increase the amount of weldable material at the joint interface and by increasing ultrasonic energy levels.

*Regrind*.. Scrap formed during the molding process, e.g., sprues, runners, reject parts, can usually be recycled directly back into the process after the material has been reduced to a usable size. Control over the volume and quality of regrind is necessary, as it can adversely affect the welding characteristics of the molded part. In some cases the use of 100% virgin material may be required to obtain the desired results. If regrind is to be used, the percentage should be regulated +10% for proper control.

*Most colorants,,* either pigments or dyes, do not interfere with ultrasonic assembly; however, occasionally some pigments (white, black) can influence weldabiity. Titanium dioxide ($TiO_2$) is the main pigment used in white parts. Titanium dioxide is inorganic, chemically inert, and can act as a lubricant, and if used in high loadings (greater than 5%), it can inhibit weldabiity. Black parts on the other hand can be pigmented with carbon, which can also inhibit weldabiity. In any event, an application evaluation should be undertaken. Parts molded in different pigments may require minor variations in welding process parameters.

*Resin grade* can have a significant influence on weldabiity because of melt temperature and other property differences. An example is the difference between injection/extrusion grades and cast grades of acrylic. The cast grade has a higher molecular weight and melt temperature, is often brittle, and forms a skin that gives it greater surface hardness, all of which reduce weldability to the injection grade. A general rule of thumb is that both materials to be welded should have similar molecular weight, and melt temperatures within 40$^{o}$F (22$^{o}$C) of each other.

*Filers/extenders* constitute a category of additives (non-metallic minerals, metallic powders, and other organic materials) added to a resin that alter the physical properties of resins. Fillers enhance the ability of some resins to transmit ultrasonic energy by imparting higher rigidity (stiffness). Common mate-rials such as calcium carbonate, kaolin, talc, alumina trihydrate, organic filler, siica, glass spheres, wollastonite (calcium metasiicate), and micas, can increase the weldabiity of the resin considerably; however, it is very important to recognize that a direct ratio between the percentage of fillers and the improvement of weldabiity exists only within a predescribed quantitative range. Up to 20% can actually enhance weldabiity, due to increased stiffness, giving better transmission of vibratory energy to the joint.

Resins with a filler content up to 10% can be welded in a normal manner, without special procedures and equipment. However, with many fillers, when filler content exceeds 10% the presence of abrasive particles at the resin surface can cause horn and fixture wear. In this situation the use of hardened steel or carbide-faced (coated) titanium horns is recommended.

When filler content approaches 35%, there may be insufficient resin at the joint surface to obtain reliable hermetic seals; and when filler content exceeds 40%, tracking, or the accumulation of filler (typically fibers), can become so severe that insufficient base resin is present at the joint interface to form a consistent bond.

It should be noted that particular types of fillers can present special problems. When long fibers of glass are employed, they can collect and cluster at the gate area during molding, being forced through in lumps rather than uniformly dispersed. This agglomeration can lead to an energy director containing a much higher percentage of glass. If this were to occur, no appreciable weld strength could be achieved since the energy director would embed itself in the adjoin-ing surface, not providing the required molten resin to cover the joint area. If this problem occurs, it can be eiminated by utiizing short-fiber glass filler.

*Fibrous reinforcements* of resins can, like fillers or extenders, be used to enhance or alter physical prop-erties of the base resin. Continuous or chopped fiber strands of aramid, carbon, glass, etc., can in some cases improve the weldabiity of a resin; however, rules governing the use of fillers should be observed.