Ultrasonic Welding

Ultrasonic welding is a unique method of joining two parts together without using additional fasteners, adhesives or mechanical features like snap fit or living hinges.

Compared with other welding methods – which include heat staking, hot plate welding, spin welding, and vibration welding – ultrasonic welding offers advantages in cycle time and ease of automation.

The process uses low amplitude, high frequency vibration to create friction between the parts to be joined to generate enough heat to melt the plastic at the interface. The frequencies used are above the range of human hearing, hence the label ultrasonic. One of the parts to be joined is fixed firmly within a stationary holding jig, while the mating part is subjected to a sinusoidal-ultrasonic vibration perpendicular to the desired bond contact area. As a result of the friction between the parts and internal friction in the parts, heat is generated, causing the polymer to melt at the interface. When vibration stops, the polymer solidifies as it cools, and forms the bond.

Ultrasonic Welding Equipment

A typical ultrasonic welding machine consists of a power supply, a converter, a booster, and a horn. The power supply converts normal electrical supply frequency of 50 Hz or 60 Hz to 20 kHz. The converter or piezoelectric transducer converts the high-frequency electric energy to mechanical motion. The motion is transmitted through the booster which increases the amplitude of the motion to the horn. The horn transfers the vibratory energy to the parts being joined.

Basic Theory

According to the basic theory of ultrasonic welding, the strength of a given weld joint depends upon the total amount of energy.

Energy (e) = Power (p) x Time (t)

Power (p) = Force (f) x Velocity (v)

The force is derived from applied pressure and velocity is derived from frequency and amplitude of the vibration. The heat generated at the joint is proportional to the square of the amplitude. Therefore, any change in the amplitude has a greater effect than a change of any other parameter. The amplitude can be calculated by multiplying the amplitude of the converter by the gain factor of the booster and horn. Typically, a booster is necessary to weld Amodel® polyphthalamide (PPA) due to its melting point.

Control Methods

For a consistent weld joint, it is important to control the total amount of energy applied to the joint area during the welding process. Relatively new computer controlled systems greatly enhance the process by allowing direct control of the energy applied to the joint area rather than controlling only time or amplitude.

Designing for Ultrasonic Welding

Joint design plays an important role in weld strength and appearance. Here are some basic guidelines for optimum weld strength:

- Design a small initial contact area between the mating surfaces to minimize and concentrate the energy required for melting.
- Use design features such as tongue and groove, pins, or steps to properly align the mating parts.
- The fixture should be rigid to prevent side wall bulging under welding pressure.
- The horn contact area should be flat and even to prevent marking.
- Allow progressive contact from the center to avoid air trap.
- Provide 0.25 mm (9.8 mils) clearance between two assembled parts to trap the flash.
- Avoid sharp corners, edges and junctions to prevent part damage due to magnification of stress concentration due to ultrasonic vibration.

Joint Designs

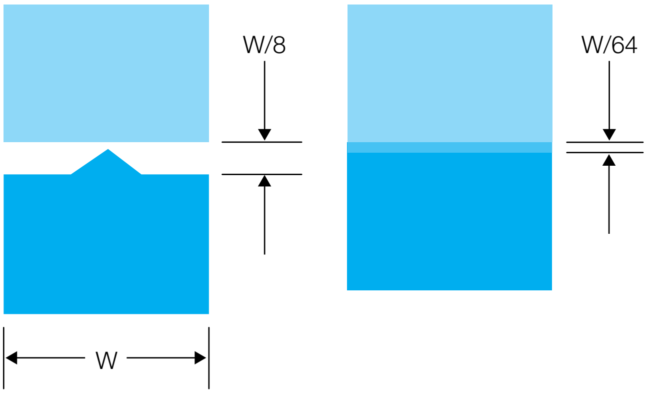
The two most important requirements for a joint are that the parts are free to vibrate relative to each other in the plane of the joint and the parts are rigidly supported to prevent any flexing.

The geometry of the part and the materials used are important considerations in determining the type of joint to be used. The two major joint types are butt joint and shear joint.

Butt Joint

The butt joint is the most commonly used design for amorphous materials; however, it can be used for semi-crystalline materials. It uses an energy director, which is a conical peak molded on one of the joint surfaces. Figure 1 shows the geometry for a typical energy director. It is very important to remember that the size and location of the energy director depends upon the material, part size and joint requirements. The peak of the energy director should be as sharp as possible. In case of a semi-crystalline material, the width of the base of the energy director derives the joint strength. For increased strength, a maximum included angle of 90 ° should be specified, and the height of the director should be at least 0.4 mm (15.7 mils).

Figure 1: Butt joint



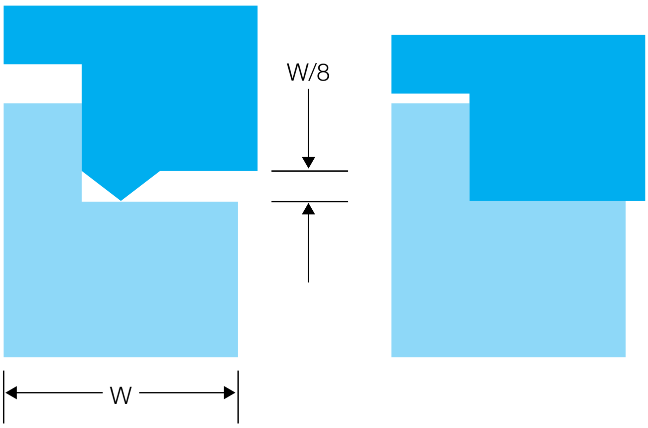
For an assembly with parts made out of two different materials, it is a general practice to design the energy director on the part with the material that has the highest melting temperature and stiffness.

Variations of the Energy Director Joint

Step joint

The step joint is used to aid alignment and can result in a better appearing assembly because any flash or excessive melt will not be visible on the exposed surface. Including a small gap in the design results in a thin line on the perimeter of the part providing a more consistent appearance from part to part. If the gap were completely eliminated, it is likely that some parts would have flash and some parts would have a small gap.

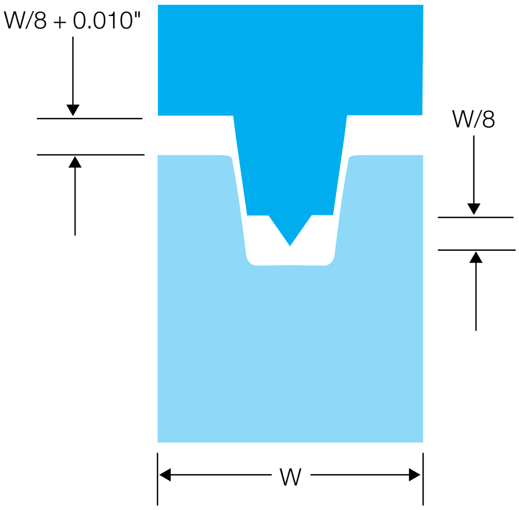
Figure 2: Step joint



Tongue and Groove Joint

The major benefits of using a tongue and groove design are that it prevents flash both internally and externally, and it provides good alignment.

Figure 3: Tongue and groove joint



Shear Joint

A butt joint design does not produce the desired results with semi-crystalline materials such as polyamide, acetal, polypropylene and thermoplastic polyester. This is due to the fact that semi-crystalline materials change rapidly from a solid to a molten state over a relatively narrow range of temperature. The molten material flowing from an energy director, therefore, could re-solidify before fusing with the adjoining interface. The weld joint strength for a semi-crystalline material is limited by the base width of the energy director. In general, a shear joint is recommended for crystalline materials.

In case of a shear joint, welding is accomplished by first melting the small, initial contact area and then continuing to melt with a controlled interference along the vertical walls as the parts slide together. The shearing action of the two surfaces eliminates a possible leak path, resulting in a strong structural joint as the molten area of the interface is never allowed to come in contact with the surrounding air. For this reason, the shear joint is especially useful for semi-crystalline materials.

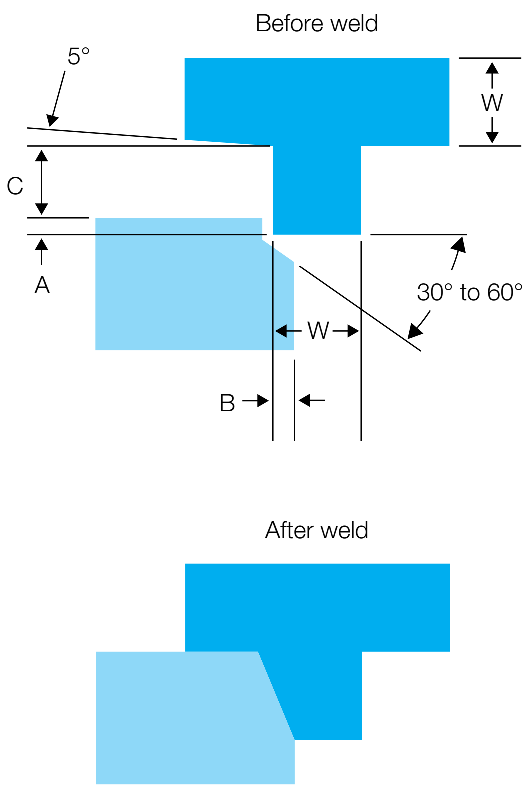
The strength of the welded joint is a function of the vertical dimension of the shear joint, which can be adjusted to meet the requirements of the application. For joint strength meeting or exceeding that of the wall, a depth of 1.25 x the wall thickness is recommended.

It is important to note that the shear joint requires rigid side wall support to maintain proper interference. This type of joint is not recommended for parts with a maximum dimension of 90 mm (3.5 inch) or greater.

Another important factor in the welding process is the use of near-field and far-field. The field refers to the distance between the weld joint and the surface where the horn comes in contact with the part. For distance more than 6 mm to 7 mm (0.25 inch), the joint is referred to as a far-field. When distance is less than 6 mm to 7 mm (0.25 inch), it is a near-field weld.

Semi-crystalline materials like Amodel® PPA do not readily transmit ultrasonic energy, therefore, they need higher energy levels than amorphous materials. Near-field joints work much better with these types of materials.

Figure 4: Shear joint



A = 0.41 mm to 0.61 mm (16 mils to 24 mils)
B = See Table 1
C = 1.25 x W to 1.50 x W

Table 1: Part dimension and interference

Part Dimension [mm (inch)]	Interference (B) [mm (mils)]
< 19 (< 0.75)	0.2 – 0.3 (8 – 12)
19 – 38 (0.75 – 1.50)	0.3 – 0.4 (12 – 16)
> 38 (> 1.50)	0.4 – 0.5 (16 – 20)

Factors Affecting Weldability

The main parameters influencing the quality of a weld joint are relative surface velocity, contact pressure and weld time. Material properties such as coefficient of friction and heat transfer capacity also affect the joint performance. Here are some additional factors to consider that can affect weldability.

Melt Temperature

A similar melt temperature between the materials to be welded is a basic requirement for successful welding of rigid parts, because temperature differences of 36 °C to 42 °C (40 °F to 50 °F) can hinder weldability even for a like resin. The lower melt temperature material melts and flows easily and prevents generation of sufficient heat to melt the higher melt temperature material.

Some high-performance polymers may require more power (energy) due to their higher glass transition temperature (T_g) and melting temperature. For example, compared to polyamide (PA) and polyphenylene sulfide (PPS), Amodel® PPA requires a larger amplitude (i.e., more power), and/or increased clamp pressure.

For the parts made out of a material with a higher melting point, preheating before welding works better. For this reason, in some cases the parts are welded as they are ejected from the molding machine.

Moisture

During welding the water evaporates at 100 °C (212 °F) and generates trapped gas creating porosity and often degrades the resin at the joint surface. This makes it difficult to obtain a hermetic seal and results in poor cosmetic appearance, degradation, and reduced weld strength. For these reasons, it is suggested that, if possible, the parts should be welded directly from the molding machine to insure repeatable results.

Resin Modifiers

Using additives or processing aids during resin compounding may result in properties that are not inherent in the base resin. Additives such as mold release agents, lubricants, plasticizers, and impact modifiers can create problems in ultrasonic welding.

Fillers

Fillers enhance the ability of resins to transmit ultrasonic energy by imparting higher rigidity. Fillers up to 40 % can actually enhance weldability due to increased stiffness, giving better transmission of energy to the joint. In general, when the filler content approaches 50 %, there may be insufficient resin at the joint surface to obtain reliable hermetic seals.

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