

AWS G1.1M/G1.1:2006
An American National Standard

Guide to Ultrasonic Assembly of Thermoplastics



American Welding Society



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AWS G1.1M/G1.1:2006
An American National Standard

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American National Standards Institute
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Guide to Ultrasonic Assembly of Thermoplastics

1st Edition

Prepared by the
American Welding Society (AWS) G1 Committee on Joining of Plastics and Composites

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This guide details the ultrasonic equipment and the processes used in industry for fabricating thermoplastic parts, including welding, staking, swaging, insertion, forming, degating, cutting, and trimming. Included are sections on safety, equipment setup, joint and part design, testing, and process optimization.



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Foreword

This foreword is not a part of AWS G1.1M/G1.1:2006, *Guide to Ultrasonic Assembly of Thermoplastics*, but is included for informational purposes only.

This guide was developed by the AWS G1 Committee on Joining Plastics and Composites in response to an industry demand for a document on ultrasonic welding of plastics that would serve as a guide for management personnel, engineers, foremen, and welders. The AWS G1 Committee on Joining Plastics and Composites was formed in 1988. This is the first issue of this standard.

This document defines this welding process, the materials that can be welded, and the required welding equipment. Included are part and joint design, welding process overview and optimization, testing, and the ultrasonic techniques of staking, swaging, insertion, forming, degating, cutting, trimming, and spot welding.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS G1 Committee on Joining of Plastics and Composites, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director, Technical Services Division, American Welding Society (see Annex A). A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures.

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Guide to Ultrasonic Assembly of Thermoplastics

1. General

1.1 Scope

This guide details the ultrasonic equipment and the processes for welding thermoplastic parts. It also describes staking, swaging, insertion, forming, degating, cutting, and trimming. Included are discussions on joint and part design, testing, and process optimization. The information provided should be sufficient to enable the reader to understand the processes and select a suitable method.

Safety and health issues and concerns are beyond the scope of this standard and therefore are not fully addressed herein (see 1.8). Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* and applicable federal and state regulations.

Information on welding procedure and performance qualification for thermoplastics is available in AWS B2.4, *Specification for Welding Procedure and Performance Qualification for Thermoplastics*.

1.2 Introduction

Clauses 4, 5, and 6 provide overviews of the materials, process, and equipment used in ultrasonic welding. Specific information regarding joint design appears in Clause 7. Clauses 8 and 9 provide guidelines for optimization and troubleshooting which will be useful in process setup. Clauses 10 and 11 discuss testing methods for ultrasonic welds and other applications for ultrasonic energy. Included in Clause 3 is a glossary of terms commonly used in ultrasonic assembly.

The use of polymers and polymeric composites in both structural and nonstructural applications is rapidly growing due to their many advantages. These include high strength-to-weight and stiffness-to-weight ratios, corrosion resistance, long service life, design flexibility, and relatively low manufacturing costs.

Generally, thermoplastic joints must meet specific mechanical, physical, environmental, and aesthetic requirements, and be produced at high speed and low cost. Therefore, the selection of the most suitable assembly or joining methods is critical to both the design and manufacture of the product.

Several methods are commercially used for joining plastics and composites. These include mechanical fasteners, adhesive bonding, and welding by fusing the parts with heat. Mechanical joining and adhesive bonding methods can be used for thermosets and thermoplastics. Welding is restricted to joining thermoplastic materials. Welding of thermoplastics can be achieved by three heating methods:

1. *External*. The heat is supplied by a hot plate, hot gas, resistance, induction, laser, or infrared;
2. *Internal*. The welding results from mechanical motion applied to the parts resulting in energy dissipation and heating. Examples are ultrasonic, vibration, and spin welding; and
3. *Electromagnetic*. The heat is generated by an electric current or electromagnetic field passing through the polymer joint interface. Examples are radio-frequency (r-f), microwave, and induction.

The selection of a joining process depends on the requirements for the joint, the materials used, and the geometry of the part or structure.

1.3 Ultrasonic Assembly

In this process, low-amplitude, high-frequency mechanical vibration (ultrasonic energy) is used to soften or melt thermoplastic materials to effect blending, and upon cooling, a weld.

Ultrasonic energy can also be used for insertion of metal components into plastic parts, and to reform thermoplastic studs or ridges to mechanically join parts using

staking or swaging processes. Ultrasonic vibration is also used to degate (separate) injection molded components from their runners.

In each of these processes, the thermoplastic parts are subjected to low-amplitude, high-frequency mechanical vibrations. This energy is converted into heat within the thermoplastic through intermolecular friction, which softens or melts the polymer. The processes of welding, insertion, staking, swaging, and degating use essentially the same equipment. The joint requirements, materials and geometries determine which of these processes will best meet the final assembly needs.

1.4 Process Description

Ultrasonic assembly is the joining or reforming of thermoplastics using high-frequency vibrations to generate heat. For example, a metal object becomes warmer when repeatedly struck with a hammer. The kinetic energy of the hammering transforms into thermal energy (heat) as the molecules in the object move more vigorously. These molecules are likewise excited to move vigorously when subjected to the impact (hammering) of high-frequency ultrasonic vibrations.

An ultrasonic welding system applies high-frequency energy (vibrations) through one part, focusing the energy into the junction of the two parts. The focusing of the energy is critical. The details of this method are presented elsewhere in this document.

1.5 System Component Functions

The basic assembly system consists of four major components:

1. Power supply/generator,
2. Converter,
3. Booster, and
4. Horn.

The power supply/generator converts commonly available line voltage electrical power into high-frequency electrical energy. Although any frequency between 15 kHz and 70 kHz could be used, 20 kHz is the most popular.

The converter changes the electrical energy into longitudinal (axial), low-amplitude mechanical vibrations of the same frequency.

The booster couples the mechanical vibrations from the converter to the horn, and depending on its size and

shape, can increase or decrease the amplitude of these vibrations.

The horn transmits the vibrational energy from the booster into the workpiece. The horn design is critical, since, like the booster, its size and shape affect the amplitude of the vibrations and consequently the heating of the thermoplastic parts.

1.6 Systems for Applying Energy to Work

A press system is recommended for critical, precisely controlled applications. When consistency and appearance are not critical, a hand-held unit may be adequate. Many manufacturers use compact actuators in applications where an automated press system would be too large. These actuators offer press control in a smaller package that is better suited to custom mounting. When production rates demand faster speeds than standard press systems can provide, rotary index systems can be used. Fully automated systems are available for ultra-high-speed assembly operations.

1.7 Process Advantages and Limitations

1.7.1 Advantages. Ultrasonic assembly can have the following advantages over other joining techniques:

1. Uniform joining is achieved because heating occurs rapidly and is confined to the immediate joint area;
2. The weld strength can be as strong as the unreinforced base material;
3. No solvents, adhesives, or external heating are required;
4. Dissimilar materials can be assembled using ultrasonic process; and
5. Ultrasonic assembly is considerably faster than other methods, resulting in higher efficiency and greater economy.

1.7.2 Disadvantages

1. Ultrasonic assembly equipment is moderately expensive;
2. Initial equipment and process setup can be complicated; and
3. Flash, particulates, and stresses occasionally appear at the joint after welding.

1.8 Safety and Health

Ultrasonic assembly operations involve potentially hazardous equipment and materials. Personnel should be trained in the proper use of the equipment, and the safety and health practices mandated by OSHA and local codes, and those recommended by the equipment and materials suppliers. Proper work attire, including safety glasses and hearing protection, should be specified and enforced. Material safety data sheets (MSDSs) should be available to personnel for all materials and chemicals used in the manufacturing area. For additional help on improving plant safety, consult ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, available from American Welding Society. Some basic safety rules to observe include:

1. Keep hands away from under the horn. An energized horn in contact with skin can cause burns. Also, a moving horn can cause rapid, crushing forces;
2. To prevent electrical hazards, verify all equipment is electrically grounded, verify the power supply is OFF

before making any electrical connections, and unplug the power supply before removing its cover. Never operate the unit with the cover removed;

3. Do not press the power supply TEST if either the RF cable or the converter is disconnected as this may cause potential damage to the generator;
4. Verify no one is in contact with the horn when the TEST button is activated to prevent skin burns; and
5. Use hearing protection to prevent hearing loss if the operation is noisy.

1.9 Units of Measurement

This standard makes use of both International System of Units and U.S. Customary Units. The latter are shown within parentheses or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system shall be used independently.

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2. Referenced Documents

The following standards contain provisions which, through reference in this text, constitute provisions of this AWS standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this AWS standard are encouraged to investigate the possibility of applying the most recent editions of the documents shown below. For undated references, the latest edition of the standard referred to applies.

1. ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*¹

2. ASTM D 256, *Test Method for Determining the Izod Pendulum Impact Resistance of Notched Specimens of Plastics*²

1. ANSI Z49.1 is published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

2. ASTM standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

3. ASTM D 4065, *Practice for Determining and Reporting Dynamic Mechanical Properties of Plastics*

4. AWS A3.0, *Standard Welding Terms and Definitions*³

5. AWS B2.4, *Specification for Welding Procedure and Performance Qualification for Thermoplastics*

6. DIN 53455, *Testing of Plastics Tensile Test*⁴

7. DVS 2203, *Testing of Welding Joints of Thermoplastics*⁵

3. AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

4. Available from Deutsches Institut für Normung e.V., 10772 Berlin, Germany.

5. Available from Deutscher Verband für Schweißen und verwandte Verfahren e.V. (German Welding Society), Aachener Str. 172, D-40223 Düsseldorf, Germany.

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3. Terms and Definitions

Plastics welding terms are defined in this section. Other welding terms used in this specification shall be interpreted in accordance with the definitions given in the latest edition of AWS 3.0, *Standard Welding Terms and Definitions*.

acoustical property. The ability of a material to transmit vibratory energy.

actuator. The unit that houses the converter, booster, and horn assembly in a rigid mounting allowing it to move up and down either mechanically or pneumatically to apply a predetermined pressure on the workpiece. (Same as **thruster**.)

amorphous plastic. A plastic in which the polymer molecules have no orderly structure or crystalline form.

amplitude. The peak-to-peak displacement of the horn at its work face as expressed in μm or in.

antinode. The area of maximum mechanical amplitude at the end surfaces of a horn or booster.

anvil. A device that provides support for the plastic workpiece during the welding operation. It is usually made of aluminum or steel.

assembly stand. The base, column, and frame that support the actuator and other components.

autotune. A feature that automatically changes the power supply frequency to match the horn stack resonant frequency without any operator assistance.

BNC (coax connector). Acronym for Bayonet Neill Concelman, denoting a connector style used with coaxial cables. Also, miniature quick connect/disconnect RF connectors.

booster. A one-half wavelength long resonant metal section mounted between the converter and horn, it may have a change in cross-sectional area between the input and output surfaces. It usually mechanically increases or decreases the amplitude of the system, or acts as a coupling bar.

boss. A raised portion in the workpiece, usually a circular, hollow feature for pin location and insertion.

butt joint. Two flat contacting surfaces.

catenoidal horn. A horn having a longitudinal shape that follows a catenoidal curve.

clamping force. The pressure exerted by the horn on the workpiece.

coax connector (BNC). Acronym for Bayonet Neill Concelman, denoting a connector style used with coaxial cables. Also, miniature quick connect/disconnect RF connectors.

compatibility. The weldability of dissimilar polymers.

composite horn. A full-wavelength device, usually consisting of a main half-wavelength driver to which one or more half-wavelength horn extensions are attached.

conditioned. Any condition other than dry as molded (i.e., moisture content, aging, annealing, etc.).

continuous welding. A mode of operation in which the horn contacts the part or material being welded and remains in constant contact as the workpiece moves under it. With rigid parts, it is called scan welding.

contoured horn. A horn that has a work face machined to conform to the surface of the workpiece.

converter. An electromechanical device which transforms electrical energy to mechanical energy. (Same as **transducer**.)

coupling. An intimate surface contact between two components.

coupling bar. A booster with unity gain, i.e., does “not” “change the amplitude (1:1 gain ratio).”

crystalline plastic. A polymer having its molecular chains ordered in a regular arrangement of crystal cells, as opposed to having an amorphous or random arrangement.

deflashing. The removal of excess material from a molded part.

degating. The separation of a molded part from its runner system.

displacement. The total collapse of the part during the welding process expressed in mm or in.

displacement amplitude. Refer to **amplitude**.

DOE. Acronym for Design of Experiments, a statistical tool or set of tools used for gathering test data. Emphasizes planning before the test is run and outlines clear objectives.

down speed. The rate of travel of the horn from the home position to the part. Expressed in mm/s or in/s.

dry-as-molded (DAM). The moisture condition of the test sample as it is ejected from the mold.

energy director butt joint. A joint that contains a triangular-shaped projection of plastic material at the joint interface of a plastic part that concentrates the ultrasonic energy against a flat surface.

energy. In welding, energy required to melt the plastic equals the power delivered multiplied by the time power is applied. Measured in watt-seconds (W-s) or joules.

exponential horn. A horn having a longitudinal shape that follows an exponential curve.

far-field welding. Configuration where the joint surface plane is typically more than 6 mm (0.25 in) from the plane of horn contact with the workpiece.

faying surface. The mating surface the energy director contacts during the weld.

filler. An inert material added to a resin to modify its physical characteristics.

fixture. A device for locating and supporting the workpiece in position for assembly.

flash. Material displaced from the joint area as a result of welding.

flash trap. Provision in joint design to capture and contain flash.

forming. Reshaping a section of thermoplastic part to a new configuration.

frequency. The number of complete oscillations per second, or cycles produced by the converter, booster, and horn. Expressed in hertz (Hz) or kilohertz (kHz).

full-wavelength horn. A resonant bar or metal section one-wavelength long that transfers vibratory energy to the workpiece.

gain. The relationship of masses, input or output, on either side of the nodal point of a horn or booster.

glass transition temperature. The temperature at which a polymer changes from hard and brittle to soft and pliable.

ground detect. A process control that terminates the weld segment of an ultrasonic welding cycle whereby the weld segment is terminated upon contact between the ultrasonic horn and a conductive fixture which is interfaced to the controlling hardware of an ultrasonic welding cycle.

half-wavelength horn. A resonant bar or metal section one-half wavelength long that transfers vibratory energy to the workpiece.

hermetic seal. A weld able to withstand positive pressure or negative pressure (vacuum) without leaking.

hold cycle. Time period after the welding process in which the parts are held under force in order to allow the weld joint to resolidify.

hold time. The length of time the clamping force is maintained on the workpiece after ultrasonics has stopped to allow the plastic to solidify, expressed in seconds.

horn. Usually a one-half wavelength long bar or metal section which transfers vibratory energy to the workpiece.

horn abrasion. Wear of the horn face.

horn analyzer. A test system for exciting and measuring the modes of vibration of the horn. The frequency can be adjusted and measured through wide range.

horn down switch. A device which signals that the horn is in contact with the workpiece or in position for the ultrasonic vibrations to begin.

hygroscopic resin. A plastic that absorbs moisture.

insertion. The process whereby a metal component is embedded in plastic.

integrated welder. A self-contained unit comprised of an assembly stand, power supply, and actuator. The preferred term is "integrated welding machine."

joint interface. The weld contact surface of two mating parts.

LVDT. Acronym for Linear Variable Differential Transformer, a common type of electromechanical trans-

ducer that can convert the rectilinear motion of an object to which it is coupled mechanically into a corresponding electrical signal.

loading. The percent of power drawn from the power supply during the ultrasonic process.

loading meter. A meter which indicates the power drawn from the power supply.

magnetostrictive effect. The changes in dimensions of a body resulting from application of a magnetic field.

MS connector. Acronym for Military Standard/Specification, denoting a family of recognized connector types and styles.

near-field welding. Configuration where the joint surface plane is typically less than 6 mm (0.25 in) from the plane of horn contact with the workpiece.

nest. A device for locating and supporting the workpiece in position for assembly, a fixture.

node/nodal point. Point or plane in acoustic tooling, such as converter, booster, or horn, where the mechanical amplitude in the axial direction is at its minimum.

part. References the components to be welded.

piezoelectric. A material which converts electrical energy to mechanical vibration. The alternating applied voltage produces a corresponding expansion and contraction resulting in a mechanical vibration at the driven frequency.

power control. A device used with a power supply or welding machine to control the amplitude at the horn face.

preloading. Application of a preset load on a part prior to triggering ultrasonics.

pretriggering. Initiation of ultrasonics before the horn contacts the workpiece

programmer. The electronic component that controls the pneumatic and electronic functions.

resonance. The condition of highest vibratory motion of a body in response to an applied excitation. Ultrasonic converters have maximum electromechanical conversion efficiency when operated at resonance.

resonant unit. A unit that exhibits highest vibratory motion at a given frequency.

RPN (reference point numeric). Refers to a weld by distance function.

scrub time. A process control which allows a post weld segment activation of the ultrasound signal for a predetermined duration of time during a welding cycle.

semicrystalline plastic. Semicrystalline polymers have both amorphous and crystalline structures

sewing (ultrasonic). The joining of thermoplastic fabrics by passing the materials between an ultrasonic horn and a patterned stitching anvil wheel.

shear joint. A joint design that utilizes a dimensional interference between the mating parts to accomplish a weld.

slotted horn. A horn that due to its dimensions must be slotted to reduce lateral motion.

sonotrode. See **horn**.

spot welding. The process of joining two thermoplastic components or sheets at localized points with no pre-formed hole or energy director.

stack. An assembly consisting of the converter, booster, and horn.

staking. The process of melting and reforming a plastic stud to mechanically lock a dissimilar material in place.

step horn. A horn consisting of two sections of different but uniform cross-sectional areas.

step joint. A variation of the energy director joint in two planes that provides alignment between the mating parts.

stalling. Operating the system at an improper resonant mode.

stud welding. One or more studs or rivets welded to a second piece at localized points using the shear joint principle.

swaging. The process of capturing another component of an assembly by melting and reforming a ridge of plastic.

TEC. Acronym for Time-Energy-Compensation, denoting a specific welding mode that sets and monitors both time and energy during the welding cycle.

thermoplastics. Polymers that can be repeatedly melted and resolidified by heating and cooling making them suitable for ultrasonic welding.

thermoset. A resin that is cured, set, or hardened, usually by heating, into a permanent shape. The polymerization is an irreversible reaction known as cross-linking. Once set, a thermosetting plastic cannot be remelted, although most soften with the application of heat.

thruster. The unit that houses the converter, booster, and horn assembly in a rigid mounting allowing it to move up and down either mechanically or pneumatically to apply a predetermined pressure on the workpiece. (Same as **actuator**.)

transducer. An electromechanical device which transforms electrical energy to mechanical energy. (Same as **converter**.)

tuning the system. Adjusting the system frequency to optimize power supply performance.

ultrasonic welding. Using ultrasonic vibrations to generate heat and cause melting and blending at the mating surfaces of two thermoplastic parts. When the ultrasonic vibrations stop, the molten material solidifies and a weld is achieved.

ultrasound. Vibrations above the limit of human hearing (>18 kHz).

upper limit switch. A switch that indicates the actuator/thruster is in the “home” position.

vacuum horn. A horn that uses a vacuum to hold a part in place prior to assembly.

velocity (horn). The rate of motion of the horn face. Also called downspeed.

weld force. The load applied to the parts during welding. This load is normally generated through pneumatic pressure in an air cylinder.

welding cycle. Time from initial descent of the horn to retraction of the horn to home position. This includes weld and hold times.

weld time. The length of time ultrasonic energy is applied to the workpiece. Expressed in seconds or milliseconds.

workpiece. Item being assembled.

4. Material Overview

Understanding the polymer from which a plastic part is made is helpful in attaining a successful ultrasonic weld. A polymer is a long molecular chain composed of repeating units. The repeating units may be identical or may vary throughout the chain. The long chain is formed by a chemical process called polymerization. The polymer structure has a direct bearing on the success of ultrasonic assembly, as does a wide array of variables and additives that can be found in a plastic part.

The two major types of plastic materials are thermoset (4.1.1), and thermoplastic (4.1.2). Thermoset materials are fully cured in the solid state and simply degrade when reheated. Thermoplastics, on the other hand, can be remelted with heat. Since the ultrasonic process depends on the ability of the material to be remelted, only thermoplastics are suitable for ultrasonic assembly.

Polymer molecules are long chains, 500 to 10,000 times greater in length than in thickness. The molecular structure of a thermoplastic determines its physical properties, melting and resolidification, and indeed its welding characteristics. They are classified as either amorphous or crystalline. The molecules of amorphous materials are arranged randomly like noodles on a plate that cross-link when formed (see Figure 4.1). In contrast, crystalline molecules have a very orderly and repeated structure that is aligned and interlocked in the processed part (see Figure 4.2).

Some examples of amorphous thermoplastics are polystyrene, ABS, acrylic, PVC, and polycarbonate. Amorphous materials do not have a defined melting point. When heated, they gradually soften as they pass from a rigid state, through a glass transition temperature (T_g), into a rubbery state, followed by a liquid flow in a true molten state. Solidification is likewise gradual.

Other thermoplastics like acetal, nylon (polyamide), thermoplastic polyester, polyethylene, polypropylene, polyphenylene sulfide, and fluoropolymers are crystalline (4.1.2.2). Unlike amorphous materials, crystalline materials have a sharp melting point primarily due to the

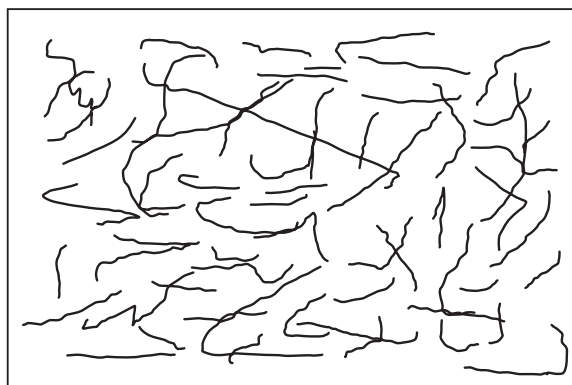


Figure 4.1—Amorphous Structure

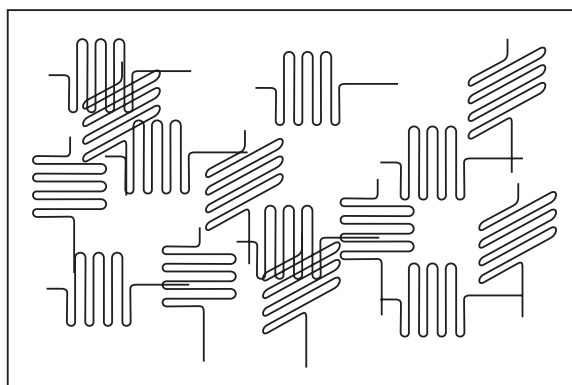


Figure 4.2—Crystalline Structure

heat of fusion required to break their structure before melting can occur. These materials remain solid until reaching the melt temperature (T_m), and then rapidly become liquid (ice to water). The molecules can now flow. When the heat source is removed and the polymer's temperature drops, resolidification occurs rapidly.

The higher amount of energy (temperature) required to melt crystalline materials is one reason they are more difficult to weld than amorphous materials. Another major factor relates to the ability of a plastic to transmit mechanical energy in the form of vibrations. The orderly molecular structure of crystalline materials absorbs the vibration energy, making it more difficult to transmit motion from the horn contact point through to the joint interface. With amorphous materials, however, the random arrangement of molecules allows the vibrations to pass easily through to the weld area with little attenuation.

4.1 Polymers

Polymers fall into two basic categories: thermosets and thermoplastics.

4.1.1 Thermosets. Thermosets undergo an irreversible chemical change during processing. After they are formed, these polymers cannot be melted or reshaped and will degrade when exposed to intensive heat. Since thermosets cannot be reprocessed after polymerization, they are unsuited for ultrasonic assembly. Some examples of thermosets are phenolics, ureas, allyls, thermoset polyesters, epoxies, and silicone rubbers.

4.1.2 Thermoplastics. Thermoplastics are polymers that can be repeatedly melted and resolidified, by heating and cooling, making them suitable for ultrasonic welding. When thermoplastic parts are subjected to ultrasonic vibrations, a combination of surface and intermolecular friction produces a temperature rise at their joint interface. When this temperature rise is sufficient to melt the resin, a fusion or molecular bond will produce a uniform weld.

The weldability of a thermoplastic assembly depends upon a number of factors; including, melt temperature, ability to transmit vibrations, joint design, part geometry, amount of regrind and additives, whether it is amorphous or crystalline.

4.1.2.1 Amorphous Thermoplastics. Amorphous thermoplastics are generally easily melted and require low energy levels. They are characterized by a random molecular arrangement and a broad melting temperature range that allows the material to soften gradually, melt and flow without prematurely solidifying. These thermoplastics generally are very efficient with regard to their ability to transmit ultrasonic vibrations, and can be welded under a wide range of force-amplitude combinations.

4.1.2.2 Crystalline Thermoplastics. Crystalline thermoplastics have orderly crystal structures that require higher energy levels to melt than the amorphous thermo-

plastics. They also exhibit sharp melting and solidification temperatures.

Most polymers commonly referred to as “crystalline” materials are in fact “semicrystalline” in nature (see Figure 4.3). Crystalline polymers have both amorphous and crystalline structures and the ratio of these influence the performance and welding characteristics of a thermoplastic. The molecules in the solid state are spring-like and absorb mechanical vibrations. This makes it more difficult to pass ultrasonic energy through to the welding surface. The sharp melting point is a result of a very high energy requirement (heat of fusion) necessary to break down the crystalline structure to allow for material flow. Once the molten material leaves the heated area, these thermoplastics solidify rapidly with only a small reduction in temperature.

For these reasons crystalline thermoplastics require special attention to joint design, horn contact, and fixturing to achieve a quality weld. For the remainder of this document the word crystalline will be used for both semicrystalline and crystalline thermoplastics.

4.1.2.3 Welding Characteristics. Characteristics of thermoplastics are shown in Table 4.1.

4.2 Property Effects

The properties of a plastic material are important indicators and dramatically affect its weldability. Weldability of any thermoplastic depends on its stiffness or modulus of elasticity, density, coefficient of friction, thermal conductivity, specific heat, and melt temperature (T_m) or glass transition temperature (T_g). Several of these properties are discussed below.

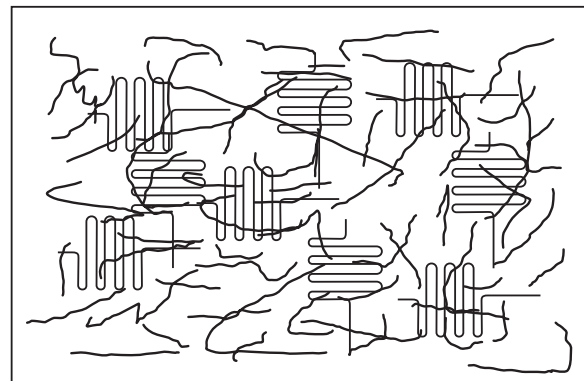


Figure 4.3—Semicrystalline Structure

Table 4.1
Characteristics of Thermoplastics

Material	Spot Welding	Staking Swaging	Inserting	Field of Welding	
				Near	Far
Amorphous					
ABS	E	E	E	E	G
ABS/Polycarbonate	G	G	G	G	F
ABS/PVC	G	G	F	G	F
Acrylic	G	F	G	G	F
Acrylic Multi-Polymer-XT Polymer	G	G	G	G	F
Acrylic/PVC	G	G	F	G	F
Acrylic Impact Modified	F	F	P	F	P
Butadiene Styrene (BDS)	G	G	G	G	F
Cellulosics CA, CAB, CAP	P	G	E	P	X
Modified Phenylene Oxide	E	E	E	E	G
Polyarylate	F	F	G	G	F
Polycarbonate	G	F	G	G	F
Polyetherimide	G	G	E	E	G
Polystyrene, G.P.	F	F	G	E	E
Polystyrene, Impact Modified	F	F	G	G	P
PVC Rigid	F	G	E	P	P
PVC Flexible	P	X	X	P	X
SAN NAS ASA	F	F	G	E	E
Styrene-Maleic-Anhydride	E	E	E	E	G
Sulfone Polymers	F	F	G	G	F
Crystalline					
Acetal Copolymer	F	F	G	G	F
Acetal Homopolymer	F	F	G	G	F
Fluoropolymers	X	X	X	P	X
LCP	F	P	F-P	G	F
Nylon	F	F	G	G	F
Polyester	G	G	E	E	G
Polyester PBT	F	F	G	G	F
Polyester PET	F	F	G	G	F
Polyetheretherketone	G	G	E	E	G
Polyethylene (LDPE, HDPE)	G	F	G	P	P
Polyethylene (UHMW)	X	X	X	X	X
Polymethylpentene	G	F	E	F	P
Polyphenylene Sulfide	F	P	G	G	F
Polypropylene	E	E	G	F-P	P

E—Excellent G—Good F—Fair P—Poor X—Not suitable for ultrasonic assembly

4.2.1 Modulus. Modulus, more specifically the Modulus of Elasticity (tension or compression) or Flexural Modulus defines relative stiffness. Unfilled plastic resins suitable for ultrasonic welding vary in modulus between 2100 MPa and 3400 MPa (300,000 psi and 500,000 psi). Modifiers and additives can affect this range significantly.

Generally speaking, plastics with modulus above 3400 MPa (500,000 psi) exhibit good weldability because they readily transmit the vibratory energy. Soft plastics having modulus less than 2100 MPa (300,000 psi) attenuate the ultrasonic vibrations, and are difficult to weld or form.

4.2.2 Elongation. The elongation of a resin describes its ductility and energy-absorbing characteristics. The base material elongation can be modified by the addition of various fillers or modifiers. High elongation materials (low modulus) can be very difficult to weld because of their energy attenuation and flexibility. For low elongation materials the converse is true.

4.2.3 Impact Strength. The impact capability of a resin is generally measured by IZOD (ASTM D 256) Impact Values. These tests and other similar measurements are not generally a direct indicator of weldability. Modifiers used to enhance impact strength also generally increase the energy absorbing characteristics of the resin making transmission of ultrasonic energy more difficult.

4.2.4 Moisture Absorption. The moisture absorption of hygroscopic resins has a direct influence on the overall strength and quality of a weld joint. High moisture content lowers the strength and can cause porosity, burning, bubbles, and excessive flash generation. Moisture control of certain polymers is essential in controlling their weldability.

When welding immediately after processing is impractical, the parts should be sealed in moisture-proof packages. Parts exposed to moisture must be properly dried before welding.

4.2.5 Coefficient of Friction. Ultrasonic welding processes require the introduction of frictional energy and its efficient conversion to heat. Reducing the coefficient of friction can make welding more difficult, but the effect is generally small.

4.2.6 Melt Temperature. The higher the melt temperature of a resin, the more ultrasonic energy is required for welding. It is generally recommended that one requirement for successful dissimilar welding is that the materials melt temperatures or glass transition temperatures differ by less than 20°C (36°F).

4.2.7 Melt Flow. The viscosity (molten flow resistance) of a plastic material, measured through Melt Flow Index (MFI) or Melt Viscosity (MV), is another material char-

acteristic which may impact the relative weldability of a thermoplastic resin. High-molecular-weight materials flow harder (are more viscous) than those with low molecular weight and thus require greater pressures to flow into thin wall sections. If a difference exists between the materials to be welded, the performance will be affected. Viscosity information is available from the resin supplier.

4.3 Fillers, Alloys, and Additives

4.3.1 Fillers and Reinforcements. Fillers and reinforcements are usually added to a base polymer to improve the strength or stiffness of the formed product. Fillers are typically just mixed into the base resin, where reinforcements tend to have a chemical or mechanical bond to the polymer molecules. Common fillers and reinforcements are glass fibers, glass beads, talc, minerals, graphite, metals, and other fibrous materials.

Generally, low filler/reinforcement levels ($\leq 10\%$) have little effect on the welding process. Additions of glass and mineral products often help the process by more efficiently transmitting the ultrasonic energy through the part. When additive content exceeds 10%, premature horn wear may result, and specially treated steel or carbide-faced titanium horns may be required. As the filler content increases, there may be insufficient resin at the surface to obtain “hermetic” seals; and resin-to-resin bonding becomes limited.

Highly filled materials should be molded or formed to provide a resin-rich layer on the part surface to facilitate the joining process. Permitting the filler/reinforcement material to form at the surface can reduce the strength or sealing of the structural or “hermetic” joint. In addition, high filler content at the surface increases horn and fixture wear.

4.3.2 Alloys. Polymer alloys or blends are increasingly employed to produce materials with physical properties matched to specific requirements. The physical properties enhanced through alloying or blending include impact strength, tensile strength, stiffness, heat resistance, chemical resistance, and processability.

Ultrasonic welding of an alloyed material to itself can usually be accomplished without encountering any unusual problems, as long as the base resins of the alloy are generally weldable. Typically, an alloy can be welded to one or more of the component resins comprising the blend. For example, an ABS/PC alloy can be welded to either ABS or polycarbonate, as well as to itself.

The ultrasonic welding compatibility of resins is shown in Table 4.2.

Table 4.2
Resin Compatibility Chart

	Amorphous Resins																Semi-Crystalline Resins															
	ABS	ABS/Polycarbonate Alloy	Acrylic	Acrylic Multipolymer	Butadiene-Styrene	Phenylene-Oxide Based Resins	Polyamide-Imide	Polyarylate	Polycarbonate	Polyetherimide	Polyethersulfone	Polystyrene (General Purpose)	Polystyrene (Rubber Modified)	Polysulfone	PVC (Rigid)	SAN-NAS-ASA	Acetal	Cellulosics (CA, CAB, CAP)	Fluoropolymers	Ionomer	Liquid Crystal Polymers	Nylon	Polybutylene Terephthalate—PBT	Polyetheretherketone—PEEK	Polyethylene Terephthalate—PET	Polyethylene	Polymethylpentene	Polyphenylene Sulfide	Polypropylene			
Amorphous Resins																																
ABS																																
ABS/Polycarbonate Alloy																																
Acrylic																																
Acrylic Multipolymer																																
Butadiene-Styrene																																
Phenylene-Oxide Based Resins																																
Polyamide-Imide																																
Polyarylate																																
Polycarbonate																																
Polyetherimide																																
Polyethersulfone																																
Polystyrene (General Purpose)																																
Polystyrene (Rubber Modified)																																
Polysulfone																																
PVC (Rigid)																																
SAN-NAS-ASA																																
Semi-Crystalline Resins																																
Acetal																																
Cellulosics (CA, CAB, CAP)																																
Fluoropolymers																																
Ionomer																																
Liquid Crystal Polymers																																
Nylon																																
Polybutylene Terephthalate—PBT																																
Polyetheretherketone—PEEK																																
Polyethylene Terephthalate—PET																																
Polyethylene																																
Polymethylpentene																																
Polyphenylene sulfide																																
Polypropylene																																

 Denotes compatibility.

 Denotes compatibility in some cases (usually blends).

4.3.3 Additives. One way to change the properties of resins is with additives, modifiers, or both.

Additives often increase the difficulty in achieving a good welded joint, even though they may improve the overall performance or forming characteristics of the base resin. Typical additives are lubricants, impact modifiers, plasticizers, colorants, flame retardants, and reground polymers.

Lubricants reduce the intermolecular and external friction, and impact modifiers and plasticizers absorb and dampen the ultrasonic vibrations. The effect of these is a reduction of the energy input to the joint. Sometimes higher weld energy, longer weld time, or greater weld pressure will compensate for this energy loss and produce an acceptable joint. The required process adjustments will depend on the type and relative quantity of the additives.

Colorants and flame retardants can affect joint integrity. Uniform particle size and dispersion will help maintain constant welding conditions.

Welding resins with either high or varying amounts of reground content should be carefully evaluated. Optimum ratios are generally less than 25%. Multiple heat cycles degrade some resins, producing a brittle weld line that can affect ultimate part performance.

Mold release agents are often introduced into a resin or applied onto a mold to improve its release characteristics. These release agents should be removed from the joint surface prior to welding because they represent a contaminant in the weld and act as a surface lubricant, thus reducing friction.

4.4 Injection Molding Effects

The conditions and end results of the injection molding process can affect the weldability of plastic parts. Some of these include: processing conditions, part surface appearance, part shape, molded part moisture content, etc. Listed below are a number of specific factors. Many of these will be expanded upon in the Troubleshooting section (Clause 9) of this guide.

1. Sinks,
2. Voids,
3. Splay,
4. Gas burns,
5. Flash,
6. Flow rate,

7. Cold flow,
8. Gate location,
9. Gate size,
10. Dimensional stability,
11. Sharp corners,
12. Delamination,
13. Jetting,
14. Cold slug,
15. Short shots,
16. Drying,
17. Poor surface finish,
18. Weld line, and
19. Warpage.

4.5 Post-Mold Characteristics

Each of the following characteristics can have a major effect on weldability. If one or more of these parameters cannot be optimized, and is causing a problem in welding, the material or welding equipment supplier should be consulted.

4.5.1 Contamination. Contamination in the weld joint during welding can lead to both “hermetic” and structural premature failure. Solid contaminants such as dirt or metal particles can act as stress concentrators when the joint is loaded, resulting in the initiation of a crack through the joint line. Liquid contaminants can reduce the frictional interaction or affect the resin properties within the joint. Contaminated parts must be thoroughly cleaned before welding with a non-residue cleaning solution. Consult the material supplier as to which cleaning solution may be applicable for the specific resin.

4.5.2 Moisture. Moisture content is one of the most important factors affecting the quality of an ultrasonic welded joint. Many thermoplastic materials absorb moisture from the atmosphere; they are hygroscopic. Polyamides are the most prone to this characteristic, but to lesser degrees, polyesters, polysulfones, polycarbonates, and other resins attract moisture.

During the welding process, the trapped moisture evaporates as steam giving a foamy joint interface which has poor appearance, strength, and sealing. Parts should be welded directly after molding. If this is not practical, the parts should be sealed in moisture-proof wrapping or other measures taken to assure dry-as-molded (DAM) conditions for welding.