

**PLASTICS
ENGINEERING
HANDBOOK**

of the

SOCIETY

of the

**PLASTICS
INDUSTRY,**

Inc.



Fifth Edition

Edited by
Michael L. Berins

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of the Society of the
Plastics Industry, Inc.

Fifth Edition

Edited by
Michael L. Berins



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Joining and Assembling Plastics

This chapter is concerned with basic techniques for joining plastics to themselves, to other plastics, and to other materials.

The techniques vary considerably in terms of the plastic involved and the application for which it is intended. Adhesives, for example, are widely used in plastics assembly; but they, in turn, are subdivided into solvent or dope cements, which are suitable for most thermoplastics (not thermosets), and monomeric or polymerizable cements, which can be used for most thermoplastics and thermosets. It should also be noted that there are some plastics with outstanding chemical resistance, such as the polyolefins, that preclude the use of many cements and generally require some form of surface treatment prior to adhesion.

To accommodate these distinctions, this chapter is subdivided into sections on adhesive bonding of plastics, solvent cementing of thermoplastics, adhesives, cementing of specific plastics, cementing of thermosetting plastics, welding of thermoplastics, ultrasonic assembly, mechanical joints, and automation.

A good starting point is Table 24-1, which summarizes available bonding and joining techniques in terms of their basic advantages and limitations.

ADHESIVE BONDING OF PLASTICS

Adhesive bonding has found wide use in the assembly of plastics by virtue of low cost and adaptability to high-speed production. In ad-

dition, adhesives provide a more uniform distribution of stresses over the assembled areas and a high strength/weight ratio.

Three different types of cements are commonly used in bonding plastics:

(1) Solvent cements and (2) dope cements are used for most thermoplastics and function by attacking the surfaces of the adherends so that they soften and, on evaporation of the solvent, will join together. The dope cements, or bodied cements, differ from the straight solvents in that they also contain, in solution, a quantity of the same plastic that is being bonded. In drying, these cements leave a film of plastic that contributes to the bond between the surfaces to be joined.

(3) Monomeric or polymerizable cements consist of a reactive monomer, identical with or compatible with the plastic to be bonded, together with a suitable system of catalyst and promoter. The mixture will polymerize either at room temperature or at a temperature below the softening point of the thermoplastic. In order to hasten setting and to reduce shrinkage, a quantity of the solid plastic may be dissolved in the monomer. In addition to chemical bonding (specific adhesion), there may or may not be a degree of solvent attack by the monomer on the plastic. Adhesives of this type may be of an entirely different chemical type from the plastics being bonded; for example, many thermoplastics may be bonded by means of a liquid mixture of resin and hardener based upon epoxy resins, where the chemical reactivity and hy-

Table 24-1. Bonding and joining techniques for plastics materials.*

<i>Technique</i>	<i>Description</i>	<i>Advantages</i>	<i>Limitations</i>	<i>Processing Considerations</i>
SOLVENT CEMENT AND DOPES	Solvent softens the surface of an amorphous thermoplastic; mating takes place when the solvent has completely evaporated. Bodied cement with small percentage of parent material can give more workable cement, fill in voids in bond area. Cannot be used for polyolefins and acetal homopolymers.	Strength, up to 100% of parent materials, easily and economically obtained with minimum equipment requirements.	Long evaporation times required; solvent may be hazardous; may cause crazing in some resins.	Equipment ranges from hypodermic needle or just a wiping medium to tanks for dip and soak. Clamping devices are necessary, and air dryer is usually required. Solvent recovery apparatus may be necessary or required. Processing speeds are relatively slow because of drying times. Equipment costs are low to medium.
THERMAL BONDING				
1. Ultrasonics	High-frequency sound vibrations transmitted by a metal horn generate friction at the bond area of a thermoplastic part, melting plastics just enough to permit a bond. Materials most readily weldable are acetal, ABS, acrylic, nylon, PC, polyimide, PS, SAN.	Strong bonds for most thermoplastics; fast, often less than 1 sec.	Size and shape limited. Limited applications to PVCs, polyolefins.	Converter to change 20 kHz electrical into 20 kHz mechanical energy is required long with stand and horn to transmit energy to part. Rotary tables and high-speed feeder can be incorporated.
2. Hot plate and hot tool welding	Mating surfaces are heated against a hot surface, allowed to soften sufficiently to produce a good bond, then clamped together while bond sets. Applicable to rigid thermoplastics.	Can be very fast, e.g., 4-10 sec in some cases; strong bonds.	Stresses may occur in bond area.	Uses simple soldering guns and hot irons, relatively simple hot plates attached to heating elements up to semiautomatic hot plate equipment. Clamps needed in all cases.
3. Hot gas welding	Welding rod of the same material being joined (largest application is vinyl) is softened by hot air or nitrogen as it is fed through a gun that is softening part surface simultaneously. Rod fills in joint area and cools to effect a bond.	Strong bonds, especially for large structural shapes.	Relatively slow; not an "appearance" weld.	Requires a hand gun, special welding tips, an air source and welding rod. Regular hand gun speeds run 6 in./min.; high-speed hand-held tool boosts this to 48-60 in./min.

4. Spin welding	Parts to be bonded are spun at high speed, developing friction at the bond area; when spinning stops, parts cool in fixture under pressure to set bond. Applicable to most rigid thermoplastics.	Very fast (as low as 1-2 sec); strong bonds.	Bond area must be circular.	Basic apparatus is a spinning device, but sophisticated feeding and handling devices are generally incorporated to take advantage of high-speed operation.
5. Dielectrics	High-frequency voltage applied to film or sheet causes material to melt at bonding surfaces. Material cools rapidly to effect a bond. Most widely used with vinyls.	Fast seal with minimum heat applied.	Only for film and sheet.	Requires RF generator, dies, and press. Operation can range from hand-fed to semiautomatic with speeds depending on thickness and type of product being handled. 3-25 kW units are most common.
6. Induction	A metal insert or screen is placed between the parts to be welded, and energized with an electromagnetic field. As the insert heats up, the parts around it melt, and, when cooled, form a bond. For most thermoplastics.	Provides rapid heating of solid sections to reduce chance of degradation.	Because metal is embedded in plastic, stress may be caused at bond.	High-frequency generator, heating coil and inserts (generally 0.02-0.04 in. thick). Hooked up to automated devices, speeds are high. (1-5 kW used.) Work coils, water cooling for electronics, automatic timers, multiple position stations may also be required.

ADHESIVES^a

1. Liquids—solvent, water base, anaerobics	Solvent- and water-based liquid adhesives, available in a wide number of bases—e.g., polyester, vinyl—in one- or two-part form, fill bonding needs ranging from high-speed lamination to one-of-a-kind joining of dissimilar plastics parts. Solvents provide more bite, but cost much more than similar-base water-type adhesive. Anaerobics are a group of adhesives that cure in the absence of air, with a minimum amount of pressure required to effect the initial bond. Adhesives are used for almost every type of plastic.	Easy to apply; adhesives available to fit most applications.	Shelf and pot life often limited. Solvents may cause pollution problems; water-base not as strong; anaerobics toxic.	Application techniques range from simply brushing on to spraying and roller coating-lamination for very high production. Adhesive application techniques, often similar to decorating equipment. Anaerobics are generally applied a drop at a time from a special bottle or dispenser.
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Table 24-1. (Continued)

<i>Technique</i>	<i>Description</i>	<i>Advantages</i>	<i>Limitations</i>	<i>Processing Considerations</i>
2. Mastics	Highly viscous single- or two-component materials, which cure to a very hard or flexible joint depending on adhesive type.	Does not run when applied.	Shelf and pot life often limited.	Often applied via a trowel, knife, or gun-type dispenser; one-component systems can be applied directly from a tube. Various types of roller coaters are also used.
3. Hot melts	100% solids adhesives that become flowable when heat is applied. Often used to bond continuous flat surfaces.	Fast application; clean operation.	Virtually no structural hot melts for plastics.	Hot melts are applied at high speeds via heating the adhesive, then extruding (actually squirting) it onto a substrate, roller coating, using a special dispenser or roll to apply dots or simply dipping.
4. Film	Available in several forms including hot melts, these are sheets of solid adhesive. Mostly used to bond film or sheet to a substrate.	Clean, efficient.	High cost.	Film adhesive is reactivated by a heat source; production costs are in the medium-high range, depending on heat source used.
5. Pressure-sensitive	Tacky adhesives used in a variety of commercial applications (e.g., cellophane too). Often used with polyolefins.	Flexible.	Bonds not very strong.	Generally applied by spray with bonding effected by light pressure.
MECHANICAL FASTENERS (Staples, screws, molded-in inserts, snap fits and variety of proprietary fasteners.)	Typical mechanical fasteners are listed on the left. Devices are made of metal or plastic. Type selected will depend on how strong the end product must be, appearance factors. Often used to join dissimilar plastics or plastics to nonplastics.	Adaptable to many materials; low-to-medium costs; can be used for parts that must be disassembled.	Some have limited pull-out strength; molded-in inserts may result in stresses.	Nails and staples are applied by simply hammering or stapling. Other fasteners may be inserted by drill press, ultrasonics, air or electric gun, hand tool. Special molding—i.e., molded-in-hole—may be required.

^aBecause of the thousands of formulations available within the various adhesive categories, it is not practical to attempt an analysis here of which adhesives will satisfy a particular application's need. However, typical adhesives in each class are: Liquids: (1) solvent—polyester, vinyl, phenolics, acrylics, rubbers, epoxies, polyamide; (2) water—acrylics, rubber, casein; (3) anaerobics—cyanacrylate. Mastics—rubbers, epoxies. Hot melts—polyamides, PE, PS, PVA. Film—epoxies, polyamide, phenolics. Pressure-sensitive—rubbers.

*Reprinted from the August 1970 issue of *Plastics Technology*, published by Bill Communications, "Bonding and Joining Plastics," by J. O'Rinda Trauernicht.

drogen bonding available from the epoxy adhesive contribute to excellent specific adhesion to many materials.

Techniques

Regardless of the composition of the cement employed, the following general rules should be observed in cementing plastic materials:

1. The surfaces to be cemented must be clean; a slight film of oil, mold-release agent, water, or polishing compound will cause poor bonding.
2. The surfaces must be smooth, and aligned as nearly perfectly as practicable.
3. Where solvent or dope is used, it must be sufficiently active to soften the surfaces to such a depth that when pressure is applied, a slight flow occurs at every point in the softened area.
4. The solvent or cement must be of such composition that it will dry completely without blushing.
5. Light pressure must be applied to the cemented joint until it has hardened to the extent that there is no movement when it is released. (If the required clamping process actually deforms the parts, the stress due to spring-back of the flexible parts must be relieved before the joint hardens thoroughly, or else the joint may subsequently fail. This may be accomplished by releasing the clamps while the adhesive is just slightly "wet.")
6. Subsequent finishing operations must be postponed until the cement has hardened.
7. Care must be taken that the vapor from solvent cements is not confined, in order to prevent the surface of the molded piece from becoming etched.
8. Adequate ventilation and attention to fire hazards also are required for the protection of personnel.

In the application of adhesives, it is very important that the surfaces of the joint be clean and well matched. Poor contact of mating surfaces can cause many troubles. The problem of getting proper contact is aggravated by war-

page, shrinkage, flash, marks from ejector pins, and nonflat surfaces.

Care must be taken to prevent application of adhesive to surfaces other than those to be joined, in order to avoid disfigurement of the surface. The adhesives should be applied evenly over the entire joint surface in sufficient quantity to preclude voids. The assembly should be made as soon as the surfaces have become tacky, which usually means within a few seconds after application. Enough pressure should be applied to ensure good contact until the initial bond strength has been achieved. Stronger bonds result when the adhesive is applied to both pieces of an assembly.

Joints

The design of the joint plays a large part in the effectiveness of the cement, the appearance of the joint, and the ease and cost of assembly. Butt, lap, and tongue-and-groove joints are in most frequent use, but angled or scarf joints and V-joints are used in some assemblies (see Fig. 24-1). If the strength of the joint is to be equivalent to that of the adjacent wall, the area

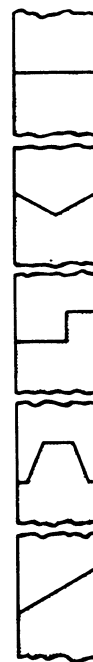


Fig. 24-1. Joint designs. From top to bottom: butt, "V," lap, tongue-and-groove, scarfed. (Courtesy GE Plastics)

of the joint should be increased by at least 50% over that of the original contiguous edge. A joint that combines both shear and tensile strength is most effective.

Lap Joint. The lap joint has some advantages over the others, in regard to both appearance and, to some extent, strength. For best appearance, the solvent should be applied by a felt pad to the half of the joint that fits on the inside of the article. Then no exudation of adhesive will appear at the outer parting line.

When two pieces of annular cross section are to be cemented with a lap joint, it is advantageous to make the outer lip thin in proportion to the inner (e.g., in a ratio of 1:4), as the greater periphery thus gained adds to the area, and hence the strength, of the joint. Lap joints are generally used for adhesive joining, whereas butt joints are preferred for solvent cementing.

Butt Joint. A butt joint gives less contact area than most lap joints. The butt joint often has the disadvantage of unsightly bond lines, but it is probably the easiest type to provide for in molding. The butt joint is not a self-locating joint, and locating pins or fixtures often are required to prevent slipping during clamping.

Tongue-and-Groove Joint. A tongue-and-groove joint is self-positioning, but unless it is very shallow, it will require application of adhesive by other than felt-pad methods. If the adhesive is applied by a flow gun into the groove, the amount must be controlled so that after assembly the fluid will come to the edge of the joint, but not flow out to mar the outer appearance of the finished article.

Other Joints. The V-joint and the scarfed joint are variations of the preceding joints. They have the disadvantage of requiring a somewhat more complex method of application of cement. The V-joint is self-positioning, and the scarfed bond is self-positioning on certain types of articles. It is difficult to mold the component parts to the close tolerance required by these joints.

SOLVENT CEMENTING THERMOPLASTICS

Structural bonds of up to 100% of the strength of the parent material are possible with solvent

bonding, a technique suitable for the amorphous plastics such as polystyrene and acrylic. It cannot be used for the polyolefins. Cellulosics, vinyls, polycarbonate, polysulfone, and polyphenylene ether copolymers are all good candidates for solvent cementing.

Solvent cementing basically involves softening the bonding area with a solvent or a solvent containing small quantities of the parent material, referred to as *dope* or *bodied cement*, generally containing less than 15% resin. A bodied cement serves several purposes: it can slow the solvent evaporation rate, it can provide a more workable solution, and it can fill in spaces where mating surfaces are not perfectly matched. (This last use should not be considered a final solution to mismatched parts that match up as closely as possible.)

A resin dissolves best in a solvent whose solubility most closely approaches its own. (See Table 24-2 for a list of solvents for various plastics.) Solvent bonding of dissimilar mate-

Table 24-2. Solvents for cementing of plastics.

ABS	Methyl ethyl ketone, methyl isobutyl ketone, tetrahydrofuran, methylene chloride
Acrylics	Methylene chloride, ethylene dichloride, trichloroethylene
Cellulosics	Methyl ethyl ketone, acetone
Nylons	Aqueous phenol, solutions of resorcinol in alcohol, solutions of calcium chloride in alcohol
PPO/PPE	Trichloroethylene, ethylene dichloride, chloroform, methylene chloride
PVC	Cyclohexane, tetrahydrofuran, dichlorobenzene; methyl ethyl ketone
Polycarbonate	Methylene chloride, ethylene dichloride
Polystyrene	Methylene chloride, ethylene ketone, ethylene dichloride, trichloroethylene, toluene, xylene.
Polysulfone	Methylene chloride

These are solvents recommended by the various resin suppliers. A key to the selection of solvents is how fast they evaporate: a fast-evaporating product may not last long enough for some assemblies; too-slow evaporation could hold up production.

rials is possible where the materials can be bonded with the same solvents.

The suitability of solvents or solution-dispersed adhesives may depend upon: the mechanical structure of the plastic; the importance of optical clarity in the bond; the presence or absence of molding stresses, which could result in crazing when released by solvent; the composition of the solvent; and the presence of highly soluble compounding ingredients in the plastic.

Built-in molding stresses must be relieved, or else solvent crazing is likely to occur. The avoidance of solvents of a low boiling point or diluting the solvent through the addition of polymer is generally desirable, and at the very least delays the appearance of crazing cracks. To minimize strains and resulting stresses that may be caused by flexing or by change of temperature, the layer of adhesive should always be as thin as possible, and no more rigid than the adherends.

Application

The solvent usually is applied by one of the devices or techniques discussed in the following paragraphs.

Dip Method. In the dip method, one of the two parts to be joined is dipped into the cement just enough so that the solvent will act on the desired area for the maximum time. After dipping, the parts should be assembled immediately and held under light pressure for a short time. Bonding takes place by the formation of a "cushion" of solvent-swollen plastic surface. To avoid squeezing out this cushioned material from the dipped plastic surface before the solvent can act on the mating dry surface, about 15 to 30 seconds should be allowed before pressure is increased.

Specially designed dipping fixtures, clamps, and conveyors should be considered for each job. The area of solvent attack on the piece can be controlled by laying a roll of glass rods in the cementing tray, on which the piece to be cemented can be rested. The level of the cement should be kept equal to the diameter of the rods. Skillful operators can assemble pieces by this method without spilling or wasting ce-

ment. The areas of contact of cement and solvent can be controlled also by lining the bottom of the cement tray with a felt pad. Pieces to be cemented then are placed on the felt pad, which is kept thoroughly wet with the liquid solvent cement.

Capillary Method. For some applications where the surfaces to be cemented fit very closely, it is possible to introduce the cement by brush, eyedropper, or hypodermic needle into the edges of the joint. The cement is allowed to spread to the rest of the joint by capillary action. In other cases it is possible to insert fine wires into the joint when the parts are assembled in the jig. The cement then is introduced into the joint. After the cement has reached all parts of the joint, the wires are removed. This procedure is useful also in removing air bubbles and in filling voids in joints made in other ways.

Soak techniques are available in which pieces are immersed in the solvent, softened, removed, and quickly brought together. Areas adjoining the joint area should be masked to prevent them from being etched. After soak, parts should be assembled rapidly.

No matter which technique is selected, the surfaces to be joined should be clean (use of a cleaning solvent, e.g., acetone, often is recommended), not below 65°F, and fit together as flat surfaces. If the parts do not fit well, the time for a part to soften after application of cement must be increased to aid in obtaining a satisfactory fit.

Once the parts are mated, they must be fastened together by spring clamps, C clamps, or toggle clamps so that uniform pressure is exerted on bonded areas. Pressure should be low—100 to 200 psi often is recommended—so that the part will not be flexed or stressed. The pressure should be sufficient to squeeze all air bubbles from the joint and to assure good contact of the mating surfaces.

When the clamps are removed, an elevated-temperature cure is often called for; for example, acrylic to 120°F and heating ABS to 130 to 150°F, PPO over 200°F, and polycarbonate up to 175°F.

Precautions. Cementing trays should be made of materials that are inert to the cement-

ing solvents. Care should be taken to avoid excessive contact of the hands or skin with cement solvents; as most of them will remove natural oils from the skin and may cause chapping or even mild dermatitis after too-frequent exposure. Where glacial acetic acid is used, contact should be carefully avoided because of its corrosive nature.

Working areas must be well ventilated. Breathing of concentrated vapors of ethylene dichloride, methylene chloride, glacial acetic acid, and so on, may cause toxic effects. Cementing tanks, trays, and storage containers should be equipped with tight covers to reduce evaporation when they are not in use.

Because solvent vapors as well as solvents themselves can cause crazing, assemblies within enclosed spaces should be adequately ventilated. An air line can be inserted to sweep the vapors out, or vacuum can be used, along with a tube to bleed fresh air to the side opposite the vacuum takeoff. Where it is impossible to remove solvent vapors from the joint itself, after the bond has been made, the joint should be designed so that solvent vapors can be excluded from the adjacent area.

ADHESIVES*

Adhesive bonding is a process in which the adhesive acts as an agent to hold two substrates together (as opposed to solvent welding, where the parent materials actually become an integral part of the bond). Because of the smooth surfaces of plastics, adhesion must be chemical rather than mechanical.

Table 24-3 lists various adhesives and their typical applications in plastics. The list is not complete, but it does give a general idea of what types of adhesives are used where. One should remember, of course, that thousands and thousands of variations of standard adhesives are available off the shelf.

Among the most important criteria in selecting an adhesive are:

1. Substrates involved, including additives used in the plastic.

2. Joint configuration and size.
3. Stresses the joint will be subjected to in use.
4. Environmental elements the joint can be expected to encounter.
5. Economics (performance/cost ratio).

Application

Just about anything from a finger to high-speed spray and laminating equipment is used to apply adhesives.

Before bonding, most plastics require surface preparation. Common surface treatment could include: (1) chemical cleaning with a solvent such as acetone; (2) abrasive cleaning by sandblasting, vapor honing, sandpaper, or wire brush; (3) degreasing to remove residual contaminants from surfaces to be joined. In cases where a mold release agent has been used, one should be certain that no traces remain.

Some key application techniques are listed below.

Tube, Knife, Spatula, Brush, Roller, Squeeze Bottle. These hand-type techniques are used for the liquids and the mastics. Equipment is simple, and costs are low. Besides the actual application device, equipment should consist of mixing vessels (for multicomponent materials), clamps where required, and dryers where elevated cure is necessary. Depending on production requirements, labor costs are generally high. However, for some adhesives (e.g., some epoxies and silicones), this is the only practical method of application. Some of the less viscous adhesives can be applied via a self-feeding brush that speeds hand application somewhat. One epoxy supplier offers a two-part adhesive in a two-component pouch. The seal between the components is broken, and the components are mixed and then dispensed right from the pouch.

Hot Press Bonding. Use of a hot press is common for reactivating sheet-type adhesives. It is also used to reactivate dual-component adhesives that work by applying one component of the adhesive to a substrate and the second to the second substrate, and then allowing the adhesives to dry. This is a widely used lamination technique. When the substrates are brought together under the heat and pressure of the press,

*Adopted from "Bonding and joining plastics," by J. O'Rinda Trauernicht, *Plastics Technology*, August 1970. Reprinted with permission from the publishers.

reactivation and bonding take place. A hot tool (e.g., an iron) can be used for some field and low-volume production.

Meter/Mix/Dispense. This type of equipment is widely used for accurate handling of multicomponent adhesives, especially those with long cure times or requiring elevated cures. Some of the newer fast-cure adhesives must be applied by one of the hand techniques to ensure that they do not set in the dispensing equipment.

Spray Application. Spraying is fast and provides a means of reaching inaccessible areas quickly. It is often used for high-speed production application of liquids, and for application of rubber-type contact adhesives. Spraying is largely confined to one-component types. It is identical to the process used for spray painting, except that a simplified nozzle, called a siphon nozzle, is used and the process is slower than painting. During spraying, it is essential that checks be made to assure that proper coverage is reached.

Roll Coaters. Essentially, roll coating consists of a glue reservoir, a roll that automatically picks up the glue from the reservoir, and a second roll that picks up the glue from the first roll and transfers it to a moving substrate. A doctor blade can be used to control the amount of glue on the roll. Other variations include a single-roll setup, a system in which the substrate is dipped into the glue and the roll used to remove the excess adhesive. An engraved roll can be used to deposit a noncontinuous pattern of glue, generally in an even pattern of dots.

The actual lamination, using either water- or solvent-based adhesives, can be done in one of two ways: wet combining or thermoplastic mounting. In wet combining, an adhesive is applied to either substrate, and the materials are joined immediately and stacked for drying. In mounting, an adhesive is applied to one substrate (the board in panel lamination), allowed to dry, and then reactivated to a tacky state and mated. Thermoplastic mounting is said to be faster and more versatile than wet combining, although it is more expensive.

Curtain and Screen Coating. Both curtain (applying a molten sheet of adhesive to a substrate passing underneath the flow) and screen

(forcing adhesive through a specially prepared screen onto the substrate below) techniques can be adapted for adhesive processing. Curtain coating is commonly used for packaging, and screen processing for high-quality printing. Both, when used with adhesive instead of molten plastic or printing inks, provide a closely controlled deposition process.

Hot Melt Application. Over a half-dozen techniques can be used to apply hot melts, with some suppliers requiring that their equipment be used and others recommending a wide range of commercial equipment. The job of a hot-melt applicator is to melt the material (most melt from 300 to 500°F), and to apply it at a controlled rate to the substrate.

Two basic types of application equipment are melt-reservoir and progressive feed. In melt-reservoir, the adhesive is put into the melting pot and heated to a predetermined temperature; in progressive feed, a rope of hot melt is fed through the heating system, keeping the amount of adhesive molten to a minimum at any one time.

Some application methods are: (1) extrusion—actually squirting the molten resin onto the substrate via a pistol-type or automated, air-operated dispenser; (2) hot-drop application with either manual or automatic dispensing, in which a wide variety of droplet patterns can be applied; (3) hot-melt coating using a roller.

Adhesive Forms

The form that adhesives take (i.e., liquids, mastics, hot melts, etc.) can have a bearing on how and where they are used, as explained in the following paragraphs.

Liquids. Liquid adhesives lend themselves very well to high-speed processing techniques such as spray and automatic roller coating. They may be solvent- or water-based; the anaerobics (cyanoacrylate-based bonding agents that cure in the absence of air) also fall into this class, as do a number of epoxies.

An extensive area of activity in liquids is the increased use of wood-grain printed vinyl sheet bonded to particle board or other inexpensive solid substrate. Both solvent-based and water-based adhesives are used. The solvent-type adhesive gives a better bite (14–20 psi peel

Table 24-3. Typical adhesives for bonding plastics.*

	ABS	Acetal	Acrylic	Cellulosics	Fluoro-carbons	Nylon	PPO	PVC	Poly-carbonate
Metals	23	3,23	2,3	2,3	22,23	2,23	2,4,23	2,3,15, 23,36, 43	23
Paper		3,23	42	42	22,23	3,41	6,23	42	36
Wood	23	23	2,3,42	3	23	2,3	2,4,23	3,23, 36,42	23,36
Rubber	23	3	1-4	1-4	23	2	2,4,23	3,4, 15	4,36
Ceramics		23	2,3	3	23	3,23	4,23	3,4	23,36
ABS	23,43	2,4, 11,23				21,23		23	4,23
Acetal	2,4, 11,23	3,23	23		23	23		23	
Acrylic	2,4, 11,23	2,4,11, 23	S		23	2,3, 15,22		3,4, 11,23	
Cellulosics				3,4 14,36	23	2,3, 15,22		23	
Fluorocarbons		23			22,23			23	
Nylon	21,23	21,23	2,3, 15,22	2,3, 15,22		2,22, 23,36	21,23		
PPO							4,23, 43		
PVC	23	23	3,4, 11		23			3,4,11, 36,42	
Polycarbonate	23							3,4,11, 36,42	S
Polyethylene	23				23				
Polypropylene									
Polystyrene					23				
Polysulfone									
Alkyds							4,23, 43	23	
Epoxy							4,23, 43	23	
Melamines and Ureas							4,23, 43		
Phenolics	23,43	43	4,21, 23	4,21, 23	23		4,23, 43	4,15	
Polyesters			23	23			4,23, 43	23	
Polyurethanes			4,23		23		4		

Table 24-3. (Continued)

Poly-ethylene	Poly-propylene	Poly-styrene	Poly-sulfone	Alkyds	Epoxy	Melamines & Ureas	Phenolics	Polyesters	Poly-urethanes
2,31, 41	1	31	4,23		4	3,43	2	4	3,4
41	1,41	4,31, 36			3	41,42	42	41	4,36
2,41	1,41	31,36			23,31	2,3	2,42	2	36
2,41	1,41	5			3	2,3,43	2,3	1-4	4,36
2,41	1,41	41,42			23,31	2	2	2	3
23									
							23		
							4,21, 23	23	4,23
							23		
23		23							23
				21,23	21,23	21,23	21,23, 43	21,23	
				4,23, 43	4,23, 43	4,23, 43	4,23, 43	4,23, 43	4
			23				4,15	23	
23,31 41			4						
	23,31 41								
		4,5,13, 23,31, 36					4,23, 43		
4			4,23						
					2,3,23, 31,36				
						2,3,23, 31,36			
		4,23				3,21, 23,24	2-4,23, 31,43		
								3,23, 31,36	
									3,4, 23,36

Key and footnotes for Table 24-3.

Elastomeric

- | | | |
|-------------------|----------------------|--------------|
| 1. Natural Rubber | 2. Neoprene | 3. Nitrile |
| 4. Urethane | 5. Styrene-Butadiene | 6. Silicones |

Thermoplastic

- | | | |
|-----------------------|-----------------------|-------------|
| 11. Polyvinyl acetate | 12. Polyvinyl alcohol | 13. Acrylic |
| 14. Cellulose nitrate | 15. Polyamidine | |

Thermosetting

- | | | |
|------------------------------------|-----------------------------------|-----------|
| 21. Phenol Formaldehyde (Phenolic) | 22. Resorcinol, Phenol-Resorcinol | 23. Epoxy |
| 24. Urea-Formaldehyde | | |

Resin

- | | | |
|--------------------------------|-------------------------------|--------------------|
| 31. Phenolic-Polyvinyl Butyral | 32. Phenolic-Polyvinyl Formal | 33. Phenolic-Nylon |
| 36. Polyester | 37. Acrylic | |

Other

- | | | |
|-----------------------------|---------------------|-------------------|
| 41. Rubber Latexes | 42. Resin Emulsions | 43. Cyanoacrylate |
| S. Solvent only recommended | | |

NOTE: This information contains a compilation of suggestions and guidelines offered by various adhesive and materials and manufacturers and plastics molders. It is intended only to show typical adhesives used in various applications. Lack of a suggested adhesive for two materials does not mean that these materials cannot be bonded, only that suppliers do not commonly indicate which adhesive to use. Before making a final selection, consult both materials supplier and materials manufacturer. Key for Table and part of the data were supplied by USM Corp., Chemical Div.

*Reprinted from "Bonding and joining plastics," by J. O'Rinda Trauernicht, *Plastics Technology*, August 1970.

strength compared to 4–6 psi for the water-based), but also will be more expensive. Application is by direct roll coaters, with speeds of 50 to 80 ft/min being typical.

The anaerobics, which can give some very high bond strengths and are usable with all materials except PE and fluorocarbons, are dispensed by the drop. A thin application of the anaerobics is said to give better bond strength than a heavy application.

Mastics. The more viscous, mastic-type cements include some, although not all, of the epoxies, urethanes, and silicones. Mastics normally can be applied at low-to-medium production speeds, but in some cases can be heated for higher production speeds.

Epoxies adhere well to both thermosets and thermoplastics, but are not recommended for most polyolefin bonding.

Developments in epoxies include the introduction of more fast-cure types (pot life of 5 minutes or less), and lower-temperature cure requirements for some of the elevated-cure materials.

Urethane adhesives have made inroads into flexible packaging, the shoe industry, and vinyl bonding. Polyester-based polyurethanes have surpassed polyether systems because of their higher cohesive and adhesive properties.

Silicones are especially recommended where both bonding and sealing are desired.

Hot Melts. Hot melts are 100% solids adhesives that are heated to produce a workable material. They bond simply by cooling and solidifying in place. Thermoplastic hot melts can be based on polyolefins (polyethylenes and EVAs), polyamides, or polyesters. For high-temperature applications, there are thermoset hot melts based on epoxies and/or polyurethanes. Hot melts generally are supplied in granule, pellet, chunk, or rope form, depending on the type of dispensing equipment used.

Major advantages of hot melts over solvent-based adhesives are their speed of curing and the elimination of potentially dangerous volatiles.

Hot melts are employed widely in packaging applications, shoe manufacturing, furniture assembly, and other commercial uses. They can be applied on high-speed lines on either a continuous or intermittent basis.

Pressure-Sensitives. Contact-bond adhesives—usually rubber-base—provide a low-strength, permanently tacky bond. They have a number of consumer applications (e.g., cellophane tape); but they also are used in industrial applications: (1) where a permanent bond is not desirable, and (2) where a strong bond may not

be necessary. The adhesive itself is applied rapidly by spray. Assembly is a mere matter of pressing the parts together.

Film Adhesives. Film adhesives overlap several areas, but exist as a separate group because of their processing similarity. All of the materials in this group require an outside means such as heat, water, or solvent to reactivate them to a tacky state. Among the film types are some hot melts, epoxies, phenolics, elastomers, and polyamides. Production rates for film adhesives are generally slow but very precise.

Film adhesives can be die-cut into complicated shapes to ensure precision bonding of unusual shapes.

Applications for this type of adhesive include bonding plastic bezels onto automobiles, attaching trim to both interiors and exteriors, and attaching nameplates on luggage.

Pretreatment

Although most materials bond without trouble once the proper adhesive has been selected, a few, notably polyolefins, fluorocarbons, and acetals, require special treatment prior to bonding.

Untreated polyolefins adhere to very few substrates; this is why polyethylene is such a popular material for packaging adhesives. Treating methods include electronic or corona-discharge, flame treating (especially recommended for large, irregular-shaped articles), acid treating by dipping the articles in a solution of potassium dichromate and sulfuric acid, and solvent treating. A rubber-based adhesive that remains permanently tacky is generally recommended.

Fluorocarbons must be cleaned with a solvent such as acetone and then treated with a special etching solution.

Acetals can be prepared for bonding by several techniques. One method involves immersing articles in a special solution composed mainly of perchloroethylene, drying at 250°F, rinsing, and then air drying.

CEMENTING OF SPECIFIC PLASTICS

The same basic handling techniques apply to almost all thermoplastic materials. In the fol-

lowing discussion, each thermoplastic will be treated separately, with mention of the specific cements most suitable for each. However, the first subsections that follow (on the cementing of acrylic) include discussions of bonding jigs and bonding techniques that are equally applicable, in most cases, to all other thermoplastics. To avoid duplication, this detail has been largely omitted from the subsections dealing with other thermoplastics. These sections on acrylics should be read in connection with the cementing of any of the other thermoplastics.

Cast Acrylic Sheeting

Articles of considerable size and complexity can be fabricated from methyl methacrylate plastics by cementing sections together. The technique described in this subsection applies to cast sheeting. The cementing of articles made from methyl methacrylate molding powders of extruded rod, tubing, or other shapes is more specialized, and reference should be made to the instructions applicable to these materials in the following subsection.

With care and practice, the transparency of acrylic resin can be retained in cemented joints; the joint will be clear and sound as a result of the complete union of the two surfaces brought into contact. In order to accomplish this, the surfaces to be cemented are thoroughly softened by means of a solvent, to the extent that a soft layer or cushion is produced on each; then the uniting and hardening will effect a homogeneous bond. This principle underlies all solvent-cementing of acrylic resins.

Usually one of the two surfaces to be joined is soaked in the cement until a soft layer has been formed upon it. This soft surface then is pressed against the surface to be attached and, in contact with it, softens it also, by means of the excess of cement contained in the soaked area. (See Fig. 24-2).

For some purposes it may be desirable to dissolve clean shavings of methyl methacrylate resin in the cement, in order to raise its viscosity so that it may be handled like glue. However, even with a thickened cement it still is necessary to establish a sound bond.

Most of the conventional types of joint construction can be employed, such as overlap,

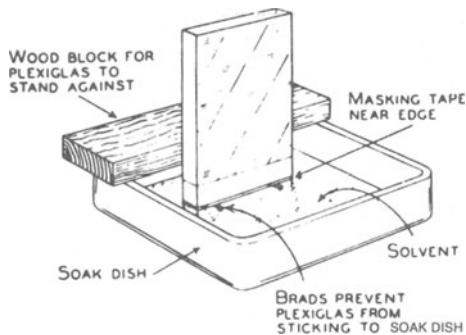


Fig. 24-2. Cementing acrylic. Edges are soaked until swollen into a cushion. Then the edges are joined, and pressure is applied. (Courtesy Cadillac Plastic and Chemical Co.)

butt, rabbet, miter, scarf, and so on, depending on the service requirements of the article. The area of the joint must be large enough to develop sufficient strength, and must be so designed as to give even distribution of stresses.

An accurate fit of mating pieces is essential in cementing acrylic resins. This need is primarily due to their rigidity, and the inability of a solvent cement to compensate for discrepancies in fit. In butt joints, it is necessary that both edges be true and square before cementing. Flat surfaces are more easily cemented than curved ones; so, wherever possible, it is desirable to rout or sand curved surfaces to form flat ones. When two curved surfaces are to be cemented, both must have the same radius of curvature. It is not good practice to force either piece in order to bring the surfaces into complete contact. The only exception to this is the case of very thin sheeting, such as 0.060 or 0.080 inch, and even here the deviation must not be great.

The surfaces to be cemented should be smooth and clean, but need not be polished. A smooth machined surface is most satisfactory for cementing.

When ribs are to be cemented to curved pieces, such as panels for airplane enclosures, each rib should be machined from flat sheet stock, heated in an oven to shaping temperature, and then, without cement, and with the aid of a jig, shaped against the surface to which it is later to be cemented, and allowed to remain in contact until cool. Then the curved rib

is soaked in cement, and cemented to the curved panel with the aid of the same jig.

In soaking the plastic in the cement, the softening action should be confined to the immediate region of the joint, by masking the rest of the surface with a tough paper or cellophane tape coated with a pressure-sensitive adhesive. The tape should be applied firmly, and with special care at the edges. The tape used should be impervious to the cement, and should not be applied long before cementing, as its adhesive may loosen if it is allowed to stand too long.

The role of the cushion formed by soaking the surface in the cement is solely to enable the two surfaces to be brought into complete conformity, so as to exclude air bubbles and to compensate for lack of perfect fit between the two surfaces. The thickness of the cushion must be adequate to provide complete contact but preferably no greater than this, as an excess reduces the strength of the joint and prolongs unnecessarily the setting of the bond. With solvent cements and unplasticized sheets, a soaking time of 15 minutes is usually enough to form an adequate cushion. Inadequacy of the cushion is one cause of bubbles or uncemented areas in the finished joint.

The soaked surface, after removal from the cement, should be brought rapidly, while still wet, into contact with the surface to which it is to be joined because soaked surfaces that have become dry do not wet the mating surface adequately. The softened surface, however, should not be dripping because superfluous cement will run off and cause smears. The tray of cement, and the work, should be so situated that the transfer from cement to jig can be made conveniently and rapidly. A soaked surface that has become dry can be wetted again by brushing additional solvent cement on it.

Too-early application of pressure on the joint will result in squeezing out some of the solvent needed to soften the dry surface. After the two surfaces have been brought into contact, only very slight pressure should be applied at first. Then, after about 15 to 30 seconds, the cementing jig can be tightened, to apply pressure.

Small pieces often can be weighted with bags of shot, tied with cord, or taped to supply the required pressure. However, assembly is best

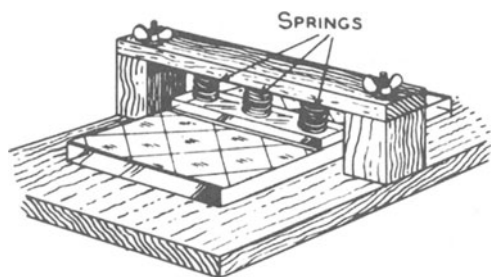


Fig. 24-3. Typical clamping method for cementing a rib on acrylic sheet. (Courtesy Cadillac Plastic and Chemical Co.)

accomplished in well-designed cementing jigs (Figs. 24-3, 24-4, and 24-5) capable of holding the pieces firmly together until the joint is hard, without forcing either of them out of shape. Excessive pressure should be avoided because it would be likely to cause stress crazing. The pressure should be adequate to squeeze out bubbles or pockets of air from the joint, evenly applied over the entire joint, and maintained throughout the period of setting. Those requirements are met through the use of spring clips or clamps, either alone, in the case of simple assemblies, or in conjunction with cementing jigs of wood or metal in more complicated cases. For most joints, a pressure in the neighborhood of 10 psi is suitable, provided that it does not force either of the parts appreciably out of shape.

After assembly of the work in the jig, any excess cement that has been extruded from the joint should be removed by scraping it onto the

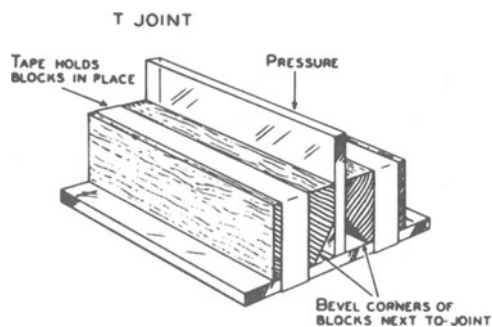


Fig. 24-4. Another typical clamping method. (Courtesy Cadillac Plastic and Chemical Co.)

masking paper, which is subsequently to be removed. Prompt cleaning up of the excess of soft cement will save time in finishing after the bond has set.

The assembly should be allowed to remain in the jig for from 1 to 2 hours, and an additional 4 hours should elapse before the work is subjected to heat treatment or to finishing operations. These times are approximate only, depending on the complexity of the job.

Methylene chloride, a solvent that produces joints of medium strength, requires a soaking time of 3 to 10 minutes and sets very quickly. Ethylene dichloride is a trifle slower and is less apt to produce cloudy joints.

The most universally applicable type of solvent cement is the polymerizable type, comprising a mixture of solvent and catalyzed monomer. These mixtures are mobile liquids, volatile, rapid in action, and capable of yielding strong sound bonds. They should be used with adequate ventilation. An example is a 40–60 mixture of catalyzed methyl methacrylate monomer and methylene chloride.

Additional cement formulations, and their adaptability to specific types of acrylic resin, are detailed in the wealth of literature available directly from the resin manufacturers.

Heat treatment or annealing of joints made with solvent cements is highly desirable because it greatly increases the strength of the joint, but it frequently is not necessary because joints are adequately strong without it. Solvent joints never become completely dry; that is, they are never entirely freed of solvent through evaporation and diffusion. If the cemented piece is placed in an oven, the penetration of the diffusing solvent progresses farther away from the bond, with some resulting increase in the strength of the cemented joint. The heat treatment of joints made with solvent cement should be done carefully, so as not to warp the assembly or to approach the boiling point of the cement and thus produce bubbles.

The optimum and maximum heat-treating (annealing) temperatures depend upon the specific plastic. The recommendations of the resin manufacturer should be consulted.

Hardening of the joint, with or without heat treatment, should be completed before finish-

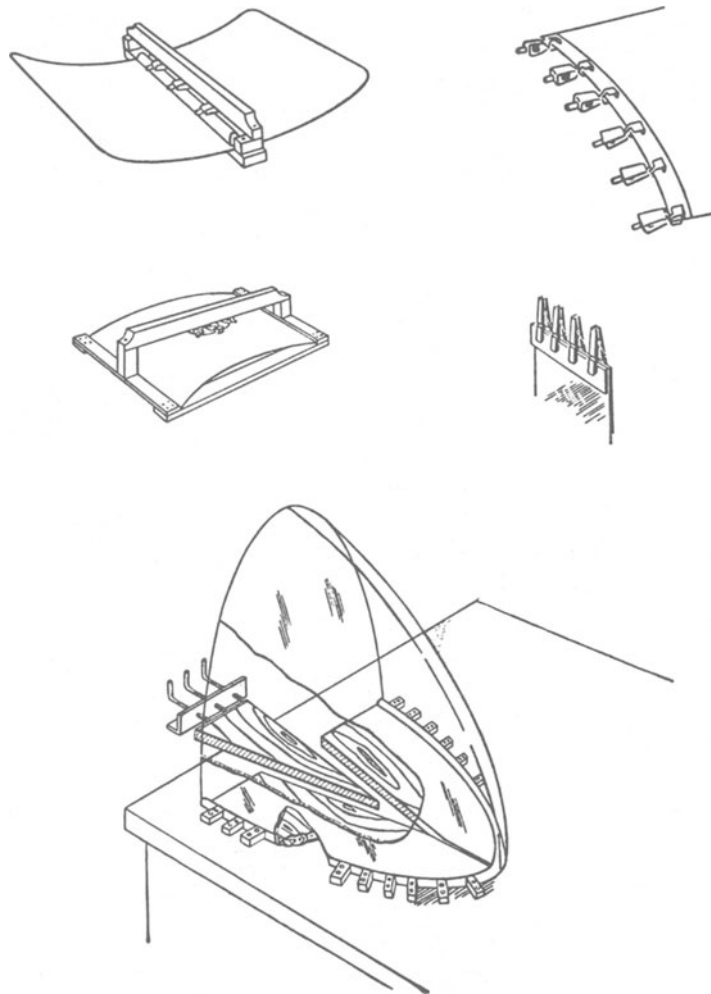


Fig. 24-5. Clamping setups for various contoured acrylic parts. (Courtesy Cadillac Plastic and Chemical Co.)

ing operations such as sanding, machining, or polishing are carried out. Otherwise, the softened material in the joint will subsequently recede into the joint.

Molded Acrylic Pieces

With molded acrylics, cemented joints are generally not as satisfactory as with cast sheeting. Fabricators frequently experience considerable difficulty with these joints, and many precautions must be taken to obtain satisfactory results. It is preferable to design molded articles to employ mechanical fasteners or closures rather than cemented joints, but this is not al-

ways feasible, and recourse sometimes must be had to solvent cement.

Cemented joints in molded methyl methacrylate frequently are unsightly as a result of stress crazing. Hence the recommended procedure must avoid stress as much as possible, to keep it well below the working stress.* In the presence of solvents, the working stress of thermoplastics is lowered appreciably. Stresses

*Working stress is defined as that stress which can be applied, internally or externally, to an article for a period of time, on the order of years, without causing failure. Working stress is a function of the environment, and will be lowered by exposure to most solvents and chemicals or by thermal strain.

built in during fabrication, combined with the effect of exposure to solvent during the bonding operation, may exceed the working stress and cause cracking or crazing. Mechanically built-in stresses may be greatly reduced by annealing.

If crazing appears, the cracks may be of such a size as to be easily visible to the eye, or so minute as to appear merely as surface clouding. In either case, crazing spoils the appearance of the article, promotes mechanical failure, and in some cases degrades electrical properties.

Crazing may occur either locally or generally. It may be caused by excessive local mechanical stresses (internally or externally applied), or it may be the result of localized loss of volatile constituents. The crazed cross section must withstand tensile loads and elongations beyond its ability, and it finally fails.

When articles must be cemented, stress avoidance should be considered in the design of the dies because the conditions of molding and the design and location of the gates determine to a large extent the degree of stress that will be present in the molded articles. The gate should be located away from the area to be cemented because frozen stresses usually are greatest near the gate. In designing two pieces to be cemented, the exact dimensions should be very carefully considered, so that the pieces will fit together easily and accurately without forcing, as stresses developed by forcing during assembly will promote solvent crazing.

When a cover is to be cemented into a recess or a groove, right-angled corners should, if possible, be replaced by bevels. This promotes the escape of air, when the surfaces are brought together, and reduces the excess cement that must be wiped away.

A cover that must be cemented should be made circular, if possible, to permit it to be twisted in place, immediately after cementing, to remove air bubbles.

The finishing operations that will be required should be anticipated when the original design is made. The design of the gate should be such as to minimize chipping during its removal because surface fractures occasion solvent crazing. For the same reason, degating of the molded article should be very carefully done.

The conditions of molding are important. To minimize stress, injection-molded articles should be run with the mold as hot as possible and with as short a cycle as will permit ready removal of the shot from the mold.

The selection of a cement is of less importance than the foregoing precautions to minimize strain. A minimum amount of cement should be used. The cement generally is applied to well-fitting molded pieces by a brush, but in some cases the use of a hypodermic needle is advantageous. Solvent-type cements may be employed.

Cellulosic Plastics

Sheeting and molded articles of cellulose acetate can be cemented readily to pieces of the same plastic with a bond practically as strong as the material itself. The usual precautions needed for the best results in cementing plastics must be observed.

The cements used with cellulose acetate plastics are of two types: (1) solvent-type, consisting only of a solvent or a mixture of solvents; and (2) dope-type, consisting of a solution of cellulose acetate plastic in a solvent or mixture of solvents.

The solvent-type cement generally is employed when the surfaces to be cemented are in a single plane and simple in nature, and can be readily held to a perfect fit. The dope-type cement is used when the surfaces are irregular or not easily accessible.

Acetone and mixtures of acetone and methyl "Cellosolve"* are commonly used as solvent cements for cellulose acetate. Acetone is a strong solvent for the plastic, but evaporates rapidly. The addition of methyl "Cellosolve" retards the evaporation, prevents blushing, and permits more time for handling the parts after application of the cement.

A cement of the dope type for cellulose acetate plastic, by virtue of its containing plastic in solution, upon drying leaves a film of plastic that forms the bond between the surfaces to be joined. These cements are generally used when

*"Cellosolve," in this chapter, denotes ethylene glycol monoethylether (2-ethoxyethanol).

an imperfect fit of the parts requires filling. Dope cements, satisfactory for many purposes, can be made by dissolving cellulose acetate plastic in solvents. A typical formula is:

	<i>Parts by weight</i>
Cellulose acetate plastic	130
Acetone	400
Methyl "Cellosolve"	150
Methyl "Cellosolve" acetate	50

A general formula, suitable for use with a wide variety of ingredients, would be the following:

	<i>Parts by weight</i>
Cellulose acetate (low viscosity)	8-12
Low- and medium-boiling solvents and diluents (under 100°C)	45-75
High-boiling solvents (over 100°C)	20-50

After being cemented, the pieces being united should be held under light pressure for 1 to 10 minutes, depending on the nature of the bond and the type of cement used. The assembly should be allowed to stand at least 24 hours before subsequent operations are performed, such as sanding, polishing, testing, and packing.

Cellulose acetate butyrate and propionate. Plastics are cemented in accordance with the technique described for cellulose acetate.

In the case of dope cements, the plastic to be dissolved in solvents is cellulose propionate.

The strongest bonds between pieces of ethyl cellulose plastic are made by solvents or by solvents bodied with ethyl cellulose plastic.

Nylon

The recommended adhesives for bonding nylon to nylon are generally solvents, such as aqueous phenol, solutions of resorcinol in alcohol, and solutions of calcium chloride in alcohol, sometimes bodied by the inclusion of nylon in small percentages.

Aqueous phenol containing 10 to 15% water is the most generally used cement for bonding

nylon to itself. The cement is prepared by melting phenol (available from chemical supply houses) and stirring in the necessary water. The bond achieved by use of this cement is water-resistant and flexible, and has strength approaching that of nylon.

The surfaces to be cemented should be cleaned thoroughly with a conventional degreasing agent such as acetone or trichlorethylene. The cement is applied with a brush or cotton swab to the mating surfaces, which should be wetted completely using one or more coats as needed.

If the parts fit well, they can be assembled immediately. However, if the fit is poor or loose at the interface, a waiting period of 2 to 3 minutes to soften the surface will help in obtaining a satisfactory fit. A few experiments at this point will determine the time required to form an adequately softened surface for the formulation of the best joint.

The parts are fastened together by means of spring clamps, C clamps, or toggle clamps in such a way that uniform pressure is exerted on the bonded areas.

If the phenol is exposed to moist air, the cemented joint may turn white as it cures. A pre-cure after the parts are fastened, for 1 hour at 100°F or overnight in a dry atmosphere at ambient temperature, will prevent the joint from whitening.

The assembly next is immersed in boiling water in order to remove the excess phenol and to ensure a strong bond. The immersion time is dependent on the area of the bonded section. Five minutes of immersion is used for $\frac{1}{8}$ -inch-wide bonds; for 1-inch-wide surfaces, boiling as long as 1 hour may be necessary. As a general guide, the assembly should be boiled until the odor of phenol has disappeared from the joint.

In cases where it is objectionable to immerse the sample in boiling water, the sample may be cured by prolonged air exposure at ambient temperature, or an oven temperature of 150°F. Adequate bond strength for handling will be reached in 48 hours, and maximum strength in 3 or 4 days. The curing time is dependent on the quantity of phenol used.

Calcium chloride-ethanol bodied with nylon

is recommended for nylon-to-nylon joints where there is potential contact with foods, or where phenol or resorcinol would be otherwise objectionable. Such solvents produce bonds that are equivalent in strength to those obtained with phenol or resorcinol, except when used with high molecular weight nylons. This adhesive also has the added advantages of forming a nonbrittle bond, of being less corrosive than phenol or resorcinol, and of being easy to apply.

Bonding Nylon to Metal and Other Materials. Various commercial adhesives, especially those based on phenol-formaldehyde and epoxy resins, sometimes are used for bonding nylon to other materials. (Although these commercial adhesives also can be used for bonding nylon to nylon, they usually are considered inferior to solvent-type adhesives in that application because they result in a brittle joint.)

Epoxy adhesives, for example, have been used to produce satisfactory joints between nylon and metal, wood, glass, and leather.

These adhesives are two-part systems, which are prepared before each use by mixing a curing agent with the adhesive resin according to the manufacturer's description. Thorough mixing is essential to obtain optimum performance.

Surfaces to be bonded must be thoroughly cleaned with a suitable degreasing agent. For best results, the nylon should be roughened with an emery cloth, and the metal should be sandblasted.

The catalyzed epoxy adhesives are best applied with a wooden paddle or spatula. They will cure at room temperature in 24 to 48 hours. To accelerate the cure, they may be heated in a circulating air oven for 1 hour at 150°F.

Polycarbonate

Solvent cementing of parts molded of polycarbonate may be effected by the use of a variety of solvents or light solutions of resin in solvents.

The selection of the solvent system best suited for a particular application depends upon the area to be bonded, the speed with which

parts can be assembled, and the practical limitation of necessary drying conditions.

The following solvents are recommended for solvent-cementing of parts molded of polycarbonate:

1. Methylene chloride, which has a low boiling point of 40.1°C and an extremely fast evaporation rate. This solvent is recommended for most temperate climate zones.
2. A 1 to 5% solution of polycarbonate in methylene chloride, which can be used in extreme cases to obtain smooth, completely filled joints where perfectly mated bonding areas are impossible to obtain. It also has the advantage of a decreased evaporation rate. Higher concentrations of this solution are not recommended because of the great difficulty in obtaining completely bubble-free joints.
3. A mixture of methylene chloride and ethylene dichloride, with a maximum of 40% ethylene dichloride, which may be used where it is difficult to join both halves fast enough to prevent complete evaporation of methylene chloride.

The evaporation rate of methylene chloride to ethylene dichloride is 6.7 to 1. This is important because methylene chloride, after bonding, will dry completely in a much shorter time than ethylene dichloride.

For solvent cementing parts molded of polycarbonate, one should use the minimum amount of solvent necessary for good adhesion. This is the opposite of the procedure recommended for other thermoplastics, where one or both halves are soaked in solvent for a considerable period. Solvent should be applied to only one of the bonding surfaces; the other half remains dry and ready in the clamping fixture.

Parts must fit precisely without pressure or any contact-inhibiting irregularities. Locating pins, tongue-and-groove shapes, or flanges may be used to align bonding areas and to effect rapid part matching after the application of solvent. These devices should be kept shallow to avoid trapping solvent in the mating surface.

As soon as the two parts have been put to-

gether, pressure should be applied immediately. A pressure between 200 and 600 psi is suggested for best results. The holding time in the pressure fixture should be approximately 1 to 5 minutes, depending on the size of the bonding area.

Although the cemented parts may be handled without damage after the holding time in the pressure fixture, sufficient bond strength for room-temperature use normally is developed by drying the cemented parts for 24 to 48 hours at room temperature. If the solvent-cemented part is to be used at high temperatures, a longer solvent-removal program is necessary.

Adhesive Bonding of Polycarbonate. Parts molded of polycarbonate can be bonded to other plastics, glass, aluminum, brass, steel, wood, and other materials, using a wide variety of adhesives. Generally, the best results are obtained with solventless materials such as epoxies and urethanes. However, each application has unique requirements for flexibility, temperature resistance, ease of application, and appearance, requiring careful adhesive selection. Room-temperature-curing products such as RTV silicone elastomers work well, as do a number of air-curing and baking-type products.

Parts should be cleaned vigorously before adhesive bonding. All oil, grease, paint, mold releases, rust, and oxides must be removed by washing with compatible solvents, such as petroleum ether, isopropyl alcohol, heptane, VM and P naphtha, or a light solution of detergents, such as Joy. Bond strength may be improved by sanding, sandblasting, or vapor honing the bonding surfaces.

Polyethylene

The good solvent resistance of polyethylene and other polyolefins precludes the use of solvent-type cements, and maximum bonds can be made only when the surfaces of the parts are prepared to give anchor points for selected adhesives.

One technique for surface preparation is to dip polyethylene in a chromic acid bath (made up of concentrated sulfuric acid, 150 parts by weight; water 12 parts; and potassium dichromate 7.5 parts) for about 30 seconds at 160°F.

The parts are rinsed with cold water after this treatment.

Still another effective surface treatment for producing cementable surfaces on polyethylene is electrical discharge. The discharge and arc resulting from the electrical breakdown of air are an effective source of energy. Several types of commercial electrical discharge treating equipment are available. The open oxidizing flame method also is used extensively to give cementable surfaces of molded and extruded polyethylene.

Several commercial rubber-base adhesives produced moderate adhesion with polyethylene that had been surface-treated. Cements were applied with a cotton swab, and the coated areas were air-dried for 3 minutes before assembly. After assembly, the samples were conditioned overnight at room temperature.

Polystyrene

Complex assemblies of polystyrene, usually molded in sections, may be joined by means of solvents and adhesives. Polystyrene plastics are soluble in a wide variety of organic solvents, and solvent action on the surface is the usual means by which parts are held together.

Care must be exercised in the fabrication (especially by injection molding) of polystyrene pieces that are subsequently to be joined by the use of solvents, to keep internal stress as low as possible.

External loads should not be applied until the residual solvent in the joint has evaporated completely. This may require drying at room for a week, or as long as a month, before the article is placed in service, the drying time depending upon the amount of solvent used and the opportunity for escape.

Typical solvents, listed in Table 24-4, may be divided into three groups according to their relative volatilities. Those with a low boiling point, and thus high volatility, are "fast-drying." They are low in cost, are readily available, and dry rapidly; but they are unsatisfactory for transparent articles of polystyrene because they cause rapid crazing. Solvents of the second type are classified as "medium-drying," and have higher boiling temperatures.

Table 24-4. Solvent cements for polystyrene.

<i>Solvent</i>	<i>Boiling Point (°C)</i>	<i>Tensile Strength of Joint (psi)</i>
Fast-drying		
Methylene chloride	39.8	1800
Carbon tetrachloride	76.5	1350
Ethyl acetate	76.7	1500
Benzol	80.1	—
Methyl ethyl ketone	79.6	1600
Ethylene dichloride	83.5	1800
Trichloroethylene	87.1	1800
Medium-drying		
Toluol	110.6	1700
Perchlorethylene	121.2	1700
Ethyl benzene	136.2	1650
Xylols	138.4–144.4	1450
<i>p</i> -Diethyl benzol	183.7	1400
Slow-drying		
Amylbenzol	202.1	1300
2-Ethyl naphthalene	251	1300

High-boiling or “slow-drying” solvents often require excessive time for the development of sufficient bond strength to permit handling; but these solvents will not cause crazing to appear quickly, and thus may be useful where a “clean” joint is essential. It is desirable to add up to 65% of a fast- or medium-drying solvent to a slow-drying solvent, to speed up the development of initial tack without greatly reducing the time before crazing appears.

A bodied, or more viscous, solvent may be required for certain joint designs and for producing airtight or watertight seals. These adhesives can be easily made by dissolving polystyrene in a solvent. Usually 5 to 15% of polystyrene by weight is adequate. Grinding the plastic to a powder will aid in making a solution. The choice of solvent depends upon the properties desired, such as setting time, flammability, safety hazard, and so on.

Solvents may be applied by dipping, a felt pad, a syringe, and so on. Bodied solvents are best applied by brush, flow-gun, doctor-knife, and so forth. The assembly should be made as soon as the surfaces have become tacky, usually within a few seconds after application. Enough pressure should be applied to ensure

good contact until the initial bond strength has been achieved. Stronger bonds result when solvent is applied to both surfaces to be joined. Experience will show how long the joint must remain clamped in order to develop enough strength to be handled. Considerable additional time will be required before the bond can be expected to withstand service loads.

The impact grades of polystyrene are not so readily soluble as general-purpose polystyrene; hence good bonds are more difficult to make with them. Most of the impact polystyrenes can be successfully joined by using the medium-drying solvents and those solvents with the highest boiling points in the fast-drying range.

Numerous commercial adhesives, mostly of the solvent-dispersed, lacquer, or rubber-based type, are available for polystyrene plastics.

Polystyrene plastics can be joined also by conventional heat-sealing techniques such as friction spinning and welding.

Polystyrene-to-Wood. Solvent-based contact cements provide the strongest bond between polystyrene and wood. These adhesives all have a neoprene (polychloroprene) base and a ketonic–aromatic solvent system. The significant difference among solvent-based contact cements is in the solids content. The resistance of the joint to cleavage-type stresses increases with an increase in the solids content of the adhesive.

Solvent-based contact cements should exhibit excellent stability during exposure to the temperatures of a finish drying oven. However, the use of this type of adhesive can present the manufacturer with a potential problem, as excessive amounts of the adhesive can induce crazing of polystyrene because it contains polystyrene-active solvents (ketones and aromatics). This crazing could propagate into cracks and thereby produce premature failure of a polystyrene component during end-use.

Water-based contact cements produce joint strengths between polystyrene and wood only slightly inferior to that obtained with solvent-based contact cement having a similar solids contents. Despite the slightly lower bond strength values, a comparable amount of wood failure was noted during the testing of joints with water-based contact cements.

A definite disadvantage of these adhesives is that they do not wet the surface of the polystyrene, and the water must be totally absorbed by the wood. (Polystyrene samples joined with a water-based contact cement were still wet after 24 hours of drying at room temperature.) Consequently, the bond strengths of joints made with water-based contact cement shortly after assembly (3 hours) are considerably less than that exhibited by joints made with solvent-based contact cements of similar solids contents. In assembly situations where the speed of adhesive set is relatively unimportant and the degree of solvent crazing is critical, water-based contact cements with high solids contents (40%), should produce a satisfactory bond between polystyrene and wood.

PPO Resins

Modified PPO (Noryl, General Electric) may be solvent-cemented to itself or a dissimilar plastic using a number of commercially available solvents, solvent mixtures, and solvent solutions containing 1 to 7% PPO resin.

The choice of the cementing technique best suited to each application is dependent upon the evaporation rate of the solvent (or assembly time), the type of joint to be cemented, and the area to be bonded. One should follow these recommended cementing procedures to obtain maximum bond strength:

1. Remove all traces of grease, dust, and other foreign matter, using a clean cloth dampened with isopropyl alcohol.
2. Lightly abrade the surface with fine sandpaper or treat the surface with chromic acid (E-20 etchant, Marbon Chemical Company). For best results, immerse the area to be bonded in an 80°C acid bath for 30 to 60 seconds, depending upon part design.
3. Wipe the surface a second time with a cloth dampened with isopropyl alcohol.
4. Apply solvent to bond surfaces, and quickly assemble the two parts. The rapid connection of bonded surfaces will prevent excessive solvent evaporation.
5. Apply pressure as soon as the parts have

been assembled. The amount of pressure required will generally depend upon part geometry; however, moderate pressure (100–600 psi) usually is sufficient. Clamping pressure should be sufficient to ensure good interface contact, but not be so high that the materials are deformed, or that solvent is extruded from the joint.

Maintain pressure for 30 to 60 seconds, depending upon the part design, bonding area, and part geometry. Bonded parts may be handled safely after the original hold time, although maximum bond strength is not usually attained for 48 hours at room temperature or 2 hours at 100°C. The cure time necessary to achieve maximum bond strength will vary with the shape of the part.

Apply solvent in an area of good ventilation, and avoid direct solvent contact. Isopropyl alcohol may be used to clean clothing and equipment.

Adhesive Bonding of PPO. Parts molded of PPO resins may be bonded to one another as well as to dissimilar materials, using a wide range of commercially available adhesives. Because adhesive bonding involves the application of a chemically different substance between two molded parts, the end-use environment of the assembled unit is of major importance in selecting an adhesive. Operating temperatures, environments, bond appearance, and shape and flexural and tensile properties must all be taken into consideration. Epoxy adhesives, because of their versatility, are generally recommended.

The following recommendations should be followed in selecting an adhesive:

1. The cure temperature of the adhesive must not exceed the heat deflection temperature of the resin.
2. Adhesives containing solvents or catalysts that are incompatible with the resins should be avoided.
3. Adhesives should be tested for compatibility and bond strength under expected operating conditions.

With the exception of the holding pressure and the cure cycle, the bonding procedures used

for solvents can be used with adhesives. One should be sure that part surfaces are free of dirt, grease, dust, oil, or mold release agents. The surface of the part should be sanded or chromic acid-etched before bonding for maximum strength. To ensure against misalignment during the cure cycle, only "finger-tight" pressure should be applied. One should follow recommended cure times and temperatures outlined by the adhesive manufacturer.

Polyvinyl Chloride and Vinyl Chloride-Acetate Copolymers

Greater diversity of composition, and, correspondingly, of the ability to be cemented by solvents, exists among the vinyl chloride-acetate copolymer resins than in most of the other plastics that are cemented. This is due to the relative insolubility of the polyvinyl chloride component of the copolymer.

As the percentage of vinyl acetate is increased in the copolymer resins, the effect of solvents is markedly increased. For this reason, the cements that depend upon solvent action for strength will be the more effective with copolymers containing the greater percentage of vinyl acetate. In general, cementing by use of solvent is less satisfactory with the vinyl copolymers than with the more soluble plastics, such as those of the cellulose esters.

Copolymer resins are available also in plasticized forms, and these, particularly in the more highly plasticized formulations, are more rapidly cemented than are the unplasticized resins.

In the case of cements depending on their tackiness alone for adhesion, little difference between the resins will be encountered. In heat-sealing operations, also, there will be little difference in weldability, provided that the optimum temperature for the particular composition is used.

Cements for copolymer resins are usually of two types: (1) solvent cements (also called laminating thinners) and (2) dope-type cements.

Cementing with Solvent. Where smooth, rigid surfaces are to be joined, the solvent ad-

hesives can be readily used. The adhesive is applied to the edges of the two pieces, which are held closely together, and flows between them by capillary action. Initial bonding takes place rapidly, usually within a few seconds, but the full strength of the joint is not reached until the solvent has completely evaporated. The ultimate strength of properly prepared bonds is practically as high as that of the original plastic.

The vinyl chloride-acetate copolymer resins are most rapidly dissolved by the ketone solvents, such as acetone, methyl ethyl ketone, and methyl isobutyl ketone. The cyclic ketones, such as cyclohexanone, form solutions of the highest solids content, but they evaporate slowly and ordinarily are used only for copolymers of high molecular weight and straight polyvinyl chloride polymers. Propylene oxide also is a very useful solvent in hastening solution of copolymer resins, especially those of high molecular weight, and of straight polyvinyl chloride. Mixtures of ketones and aromatic hydrocarbons have a more rapid softening action than do the ketones alone. Mixtures of solvents and nonsolvents are preferable to solvents alone, and additions of aliphatic hydrocarbons and alcohols are sometimes advantageous. Two percent glacial acetic acid, added to the solvent cement, improves wetting and speeds the capillary flow of the cement between the two surfaces being joined. It should not be used, however, in formulations containing propylene oxide.

Embrittlement by the solvent is one of the most troublesome factors in the bonding of rigid sheets by the use of laminating thinners. This is probably caused by molecular orientation and release of stress when the solvent is applied. Two procedures that minimize this embrittlement have been used in solvent bonding, with considerable success. In the first, mixtures based on the less powerful solvents are used; these apparently do not penetrate the sheet at a rate rapid enough to bring about embrittlement. In the second method, resin solutions are used for the bonding; their viscosity apparently minimizes penetration by the solvent.

The formulations of a number of typical laminating thinners are shown in Table 24-5. The

Table 24-5. Laminating thinners.

	A	B	C	D
	(parts by weight)			
Diocetyl phthalate	5	2.5	2.5	
Methyl acetate (82%)	58			
Ethyl acetate (85%)	10			
Butyl acetate	10			
Methyl ethyl ketone		63		40
Dioxane		20		
Isophorone		2.5	2.5	
Methylene chloride			50	
Ethylene dichloride			43	
Cyclohexanone				40
Propylene oxide				20
Petroleum solvent (p.p. 94.4-121.7°C)	15			
Acetic acid	2	2	2	
Methanol		10		
	100	100	100	100

solvents are arranged in order of increasing solvent power and decreasing rate of setting of the joint.

Propylene oxide penetrates vinyl chloride-acetate copolymer resins very rapidly and, in amounts up to about 20 to 25%, improves the "bite" into the resin. Under conditions where propylene oxide evaporates too rapidly, acetone may be substituted. Solutions containing propylene oxide should be stored with care and well stoppered to prevent evaporation, since its boiling point is only 34°C.

The chlorinated hydrocarbons also are excellent solvent for the vinyl chloride-acetate copolymer resins, and are suitable for use in cements.

Cyclohexanone and isophorone are extremely high-boiling solvents which impart slow drying and prolonged tackiness. By themselves they are very slow penetrants, and hence they are usually used in combination with low-boiling solvents.

Since many of the solvents discussed above present possible toxicity hazards, they should always be used with adequate ventilation.

Dope-Type Cements. These are prepared by the addition of small amounts of resin to solvent cements to thicken them. Dope-type cements are used where the surfaces to be cemented are in contact only over a very small

area or are mated so inaccurately that a thin solvent cement will not fill the gap.

Small percentages of vinyl chloride-acetate resin, in the form of shavings, turnings, or chips, may be dissolved in the previously mentioned solvent cements to impart viscosity. In conjunction with the vinyl resin there should be included 0.2 to 0.5% of propylene oxide to help stabilize the solution against discoloration by light and heat when stored. Adhesion may be increased by the addition of about 5% of a plasticizer, such as tricresyl phosphate.

In general, the dope-type adhesives set slowly with vinyl chloride-acetate copolymer resins, and have little strength immediately after application. The strength of the bond develops as the solvent evaporates.

The vinyl chloride-acetate resin cements do not possess a high degree of tackiness when wet. However, this can be greatly increased by incorporation of certain other compatible resins, to yield cements of improved adhesion. Data covering resins suitable for this purpose may be obtained from suppliers.

TFE-fluoroplastic

As there are no solvents for TFE-fluoroplastic (Teflon, Du Pont), techniques other than conventional solvent cementing must be used. The surfaces of parts fabricated of TFE are first modified with strong etching solutions, making them receptive to conventional self-curing adhesive systems. Actually, self-curing adhesives of the epoxy and phenolic types are the most suitable means of bonding modified TFE to itself and to other materials.

CEMENTING OF THERMOSETTING PLASTICS

The cementing of thermosetting materials to themselves, or to other materials, poses problems that are not inherent in the cementing of thermoplastics. The insolubility of thermosetting materials makes it impossible to apply the solvent techniques used with thermoplastics, and the surface smoothness of molded thermosetting plastics adds to the difficulty of cementing them.

The surfaces to be joined must mate perfectly, unless a gap-filling cement can be used. The smooth surface must be roughened; if machining is not required for mating, then the surfaces should be sanded. This process removes the gloss and the mold-release agent. However, where the specific adhesive strength to the plastic is high, sanding occasionally reduces the net bond strength by providing nuclei for cohesive failure of the plastic.

Cementing of Dissimilar Materials

The great strength of reinforced and thermosetting plastics, and their usefulness under a wide range of environments and conditions, have led to many applications, frequently in combination with metals and other rigid materials.

The new synthetic resin and elastomer adhesives are chemically related to the new plastic materials, particularly those used in "reinforced" applications, which also are being adapted for structural (load-bearing) applications. Adhesive bonding is, for various reasons, the logical method of fastening for the production of structures composed of reinforced or rigid plastics, as explained in the following paragraphs.

In applications where exposed metal must not be used because of corrosion, metallic fasteners obviously must not be used with the plastic; nor can a plastic be used to cover or protect a metal in such cases. The plastic article may not be able to accept the piercing and the concentration of stress involved with a metallic fastener.

Many plastics, and particularly the cross-linked and thermoset reinforced plastics, cannot be bonded to themselves, or to other materials, by thermal welding or heat sealing. However, adhesives are available for joining dissimilar materials, and for bonding plastics to very thin metal structures. Their use provides means of achieving smooth contours, free from projecting fasteners, and also of ensuring uniform distribution of stress over the area bonded. The adhesive contributes sealing action, insulation, and damping of vibration. In many cases, the use of an adhesive rather than me-

tallic fasteners reduces the cost of production, reduces the weight of the assembly, or provides longer life in service.

Adhesive Formulations. The general chemical similarity of adhesives to plastics not only contributes to their good specific adhesion to plastics, but also assures that properly formulated adhesives closely match the plastics with regard to modulus, flexibility, toughness, resistance to thermal degradation, resistance to solvents and chemicals, and cohesive strength.

In cemented assemblies of reinforced plastics and metals, where structural strength is generally desired, the adhesive must be more rigid than those used for bonding plastic to plastic; that is, it must have a modulus, cohesive strength, and coefficient of thermal expansion between those of the plastic and the metal. In many cases, such adhesives are stronger than the plastic itself.

As most reinforced plastics are quite resistant to solvents and heat, heat-curing solvent-dispersed adhesives may be used; obviously, these could not be considered for bonding many thermoplastics. Such adhesives consist of reactive or thermosetting resins (e.g., phenolics, epoxies, urea-formaldehydes, alkyds, silicones, and combinations of these), together with compatible film-formers such as elastomers or vinyl-aldehyde condensation resins. Isocyanates are frequently added as modifiers to improve specific adhesion to surfaces that are difficult to bond. These adhesives may be applied not only in solvent-dispersed form, but also in the form of film, either unsupported, or supported on fabric, glass mat, and so on.

One type of solvent-dispersed formulation includes a monomer (such as vinyl or acrylic) as the solvent; a dissolved polymer of the monomer as the film-former, to increase viscosity and decrease shrinkage; and a catalyst, packaged separately and added just before use, to polymerize the monomer. Crosslinking monomers in small proportion, such as divinylbenzene and triallylcyanurate, improve the bond strength of adhesives of this type, as well as their resistance to heat and solvents. It will be recognized that these adhesives are related to the monomer cements previously discussed.

A great many outstanding formulations are based on epoxy resins. The use of polymeric hardeners such as polyamides and polyamines, phenolics, isocyanates, alkyds, combinations of amines with polysulfide elastomers, and so on, and the "alloying" of the epoxy with compatible polymeric film-formers, such as polyvinyl acetate and certain elastomers, has led to the development of a broad spectrum of adhesive formulations with a wide range of available properties. In general, these adhesives are characterized by toughness, high cohesiveness, and specific adhesion to a great many materials, including most plastics. In addition, many of these adhesives contain no solvent.

By the selection of the proper hardener (and several chemical families of various degrees of reactivity are available: monomeric polymeric, or mixed), the adhesive can be formulated to cure at room temperature, "low" temperature, or elevated temperature. Generally speaking, the phenolic-epoxy and the elastomer-phenolic-epoxy blends are characterized by outstanding resistance to high temperature.

WELDING OF THERMOPLASTICS

Welding by heat, or thermal welding, provides an advantageous means of joining most thermoplastics. All such techniques use heat to soften (or melt) the bonding areas of the mating surfaces to fusion temperature. After joining, the area is cooled, causing the plastic to harden (resolidify) and forming the joint or weld.

Several techniques are available for welding thermoplastics, including: (1) dielectric heat sealing; (2) thermal heat sealing (non-high-frequency); (3) hot gas welding; (4) hot tool welding; (5) hot plate welding; (6) induction heating; (7) spin welding; and (8) ultrasonic assembly (this last discussed below in a separate section).

In determining the techniques best suited for a job, several factors must be considered: the strength required; the shape and size of the parts to be joined; the plastics involved; the equipment to be used (i.e., whether to use available machines or invest in new facilities); and whether or not the joint must be concealed. By careful part design, it should be possible to weld most thermoplastics with strong joints.

With each type of weld, however, it is important to establish time, temperature, and pressure combinations that melt the polymers at the mating surfaces and hold them firmly in contact while cooling. Excessive heating in any type of welding can result in melt flow, and in some instances, even resin degradation. Insufficient heating, on the other hand, can produce weak joints.

High-frequency or Dielectric Heat Sealing

In its simplest explanation, dielectric sealing involves the use of electricity or electronic waves from an ac generator passing through a plastic sheet or film. These waves cause a high level of molecular "friction" within the plastic, so that (given a plastic with sufficient dielectric loss) heat will be generated within the plastic and the plastic will melt at the point of contact (i.e., where the energy field is concentrated). By applying pressure at this point and allowing sufficient cooling time, a permanent bond is formed.

Dielectric sealing can handle many of the thermoplastics: ABC, acetate, polyester film, PVC, polyurethane, acrylics, to mention several; it is even possible to dielectrically weld some of the tougher engineering plastics, such as acetal film, but in many such instances, where the plastic has a relatively low loss factor, fairly high frequencies must be used, necessitating more expensive equipment. The biggest use for this technique is in sealing vinyl film and sheeting into such products as rainwear, inflatables, shower curtains, swimming pool liners, blister packages, medical bags, auto interior panels, and loose-leaf binders.

The most usual line for a high-frequency sealing operation consists of an RF generator (with an oscillator tube), a sealing press to apply pressure to the bonding area, and heat sealing dies set up in the press to determine the shape of the sealing area (commonly fabricated from brass strips bent into the desired pattern). Operating ranges from 1 to 100 kW are available, but the most commonly used range is from 3 to 25 kW; the higher the frequency, the faster a material with a given dielectric constant, can be fused or bonded.

Materials handling systems for feeding the sealing machines also vary widely. The most simple, of course, involves hand-feeding the part to be sealed into the press. More complex setups mount the sealing equipment on trolleys that move on a track alongside the film to be sealed or use conveyors or moving the tables to automatically feed the film into the press.

Another design for increasing production the rotary table machine with automated indexing work areas. A typical unit of this type might incorporate a rotary table with four workstations: loading, sealing, cooling, and unloading. Such machines can seal as many as 400 to 500 units an hour.

Over the years, the dielectric sealing technique has become an extremely versatile process. Although originally developed for sealing plastic to itself (i.e., PVC to PVC), the technique is now available for sealing different materials together. In the automotive industry, for example, door panels based on vinyl overlays welded to hardboard sheets with a urethane foam core in between, are being dielectrically sealed together. In many of these applications, vinyl chloride latex adhesives are involved. These adhesives are bonded directly to a solid skin or impregnated into a porous material such as urethane foam. Once dried, the treated parts can be bonded dielectrically.

Finally, dielectric sealing has also come into use as a method of decorating plastic products. For example, by sealing two sheets of vinyl together in a predetermined pattern, it is possible to achieve a textured quilted effect. Another method is known as applique bonding. Basically, this is achieved by applying the "tear seal" system. In a tear seal, the sealing die is forced farther into the plastic than is normally the case, causing it to thin out (as the melted plastic is displaced by the die) to the point where excess material can easily be torn off or separated by hand; the shape of the die, of course, determines which areas will be torn off. Thus, if a separate film is laid on top of the base film and the tear seal technique is applied (i.e., cutting through the top film and not the base film), it is possible to create an applique pattern by tearing off the excess material from around the sealing area and leaving a pattern defined by the sealing die.

Thermal Sealing of Film and Sheet

Non-high-frequency thermal sealing of film and sheet also is available, and it does not require the high-frequency energy that goes into dielectric sealing. This method usually involves a press with at least one moving platen bar. Bars are heated by low-voltage, heavy electric current. Heat is applied to the outer surface of the product and must travel through the material to the interfaces to make the weld. A variation of this process, similar to high-energy induction bonding, involves putting a metal wire or other insert between the two sheets to be sealed, to make the heating step more efficient.

Some of the most common types of heat-sealing-equipment are:

- *Jaw-type bar sealers:* Sealing takes place between an electrically heated bar and a stationary base; TFE or other high-temperature-resistant coverings should be used to cover the hot bar to prevent molten material from sticking to it.

- *Rotary sealers:* For continuous operation, rotaries operate by passing the film over a revolving drum that acts as a base for the heated sealing bar to press against. In an alternative method, the material is carried on belts between thin heated rollers or wheels revolving in opposite directions.

- *Band rotary sealers:* In this process, the film moves between metal bands, traveling first between heated jaws and then between pressure rollers, and finally between cooling jaws.

- *Impulse-type sealers:* As mentioned above, impulse sealing involves the use of a metal wire. Heat is supplied on an intermittent basis so that the heat exposure time is reduced.

- *Hot knife or side weld sealers:* A seal is made by pressing a continuously heated knife-edge bar across the film.

- *Multi-point sealing:* Heat is transmitted to the product at closely spaced points so that only a small portion of the surface of the film is actually sealed. The result is a peelable seal that will not open under normal conditions.

As with most sealing operations, temperature and pressure are the important factors. Low- and medium-density PE melt at about 230

to 240°F, and linear PE melts about 25°F higher than this.

Hot Gas Welding

Most thermoplastics can be joined via hot gas welding, but PVC is still the major material being assembled by this technique, into such products as tank liners and ducting. Other candidates for hot gas welding are polyethylene, polypropylene, acrylics, some ABS blends, polystyrene, and polycarbonate. The process is not good for filled materials and is used only to join materials thicker than $\frac{1}{16}$ inch. Parts thicker than $\frac{3}{8}$ inch are not generally gas welded although they have been. Applications are usually in large, structural parts (such as signs, piping, fans, ducts, and fume scrubbers), and equipment manufacturers note that the weld is not an appearance joint but a functional bond.

Basically, heated gas (generally air, but nitrogen is used for PE and acetals, which oxidize in air, and is recommended for polypropylene that will be subjected to UV exposure) is used to soften both the mating surfaces and the welding rod. This rod is made of the same material as the parts being joined, and as the welding tool moves down the joint, the softened rod is deposited into the mechanically beveled joint area. On cooling, the mating surfaces and the rod filling the joint between are fused into an integral weld.

The following is a more detailed description of the hot gas welding process.*

Joints. The types of welded joints used in hot gas thermoplastic welding (Fig. 24-6) are similar to those in metal welding. The same material preparations are required in plastic welding as in metal welding, except that beveling of thermoplastics edges is *essential*. Flux is not required; however, some materials weld more satisfactorily in an inert gas atmosphere.

In thermoplastics, the materials do not melt and flow; they simply soften, and the welder must apply pressure to the welding rod to force

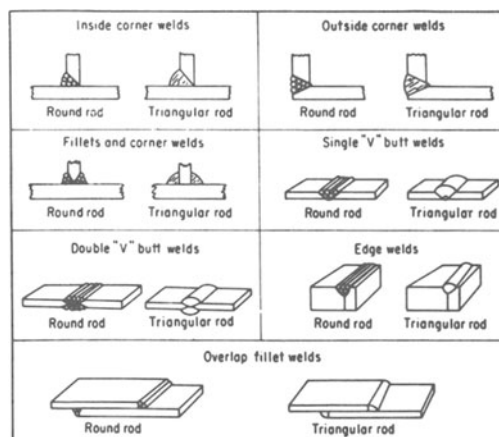


Fig. 24-6. Joint designs produced by hot gas welding. (Courtesy Kamweld Products Co., Inc.)

the softened surface into the joint to create the required permanent bond.

Triangular welding rods can be used in "V" welds or fillet welds up to $\frac{3}{8}$ inch wide, which can be filled with one pass. Thus the weld can be completed in less time and with better appearance, especially inside tank corners. When triangular rod is used, the chances of porosity (or leaks) occurring between one round rod and another one are eliminated.

Triangular rod can be hand-welded in the same way as hand welding of round rod; however, it can be applied more evenly with a properly designed high-speed tool. A speed weld also produces a much neater appearance than a hand weld. It must be understood that the use of heavy triangular rod, especially in horizontal runs, can be more tiring to the welder; but, at the same time, the weld can be accomplished in one pass rather than in a series of passes, as with round rod. In some cases, a small-diameter round rod is welded in the bottom of the "V" to join the pieces together and prepare the joint for the larger triangular rod.

Welding guns contain a heating unit (electric or gas) through which is passed a stream of compressed air or inert gas that reaches the nozzle or tip at a temperature of between 400 and 900°F. For production work, a gun of the type whose air hose also encloses its electrical cable is the more efficient and flexible in operation. The wattage of the heater determines the effective range of available heat; the air

*Adapted from an article by S. J. Kaminsky, Kamweld Products Co., Norwood, MA 02062, appearing in the 1971-1972 issue of *Modern Plastics Encyclopedia*, reprinted with permission of the publishers, McGraw-Hill, Inc., New York, NY.

pressure determines the actual amount of heat attained at the tip.

Tack welding is used to hold pieces in place for final welding. It can be effective in reducing or eliminating the need for clamps, jigs, or additional personnel during assembly. Tack welds are produced simply by running a heated tacker tip along the joint at intervals or in a continuous line.

In hand welding, the welder uses both hands, one to hold the welding gun and the other the welding rod. Using a round tip on the gun, the welder directs a hot air stream with a fanning motion onto both sides of the joint to be welded, as well as onto the welding rod. After the weld is started, the welding rod is bent back slightly and enough pressure is exerted uniformly to fuse the heated surfaces.

Only experience and careful observation can assure good joints with maximum strength and minimum degradation of the material through overheating. Underheating makes a “cold weld” with poor tensile strength. The aim is always to produce adequate pressure at the joint to permit complete fusion, yet not so much as to cause the welding rod to “catch up” with the welding tip. This will cause the rod to stretch, resulting in a poor weld.

High-Speed Hand Welding. Speed of making welds can be greatly increased through the use of welding gun tips that hold the welding rod in the correct position and simplify applying optimum pressure while making the weld.

Flat strip may be used instead of round rod in a tip for welding tank linings and similar applications. Only a single pass is made, the wide strip providing adequate surface to give strength in the finished joint.

Hot Plate Welding*

Hot plate welding can readily join plastic parts that have complex contours: a hermetic seal is easily obtained if a proper joint design and material are selected. The hot plate welding process works extremely well with a wide variety of plastic materials and is often the welding

process chosen for welding softer plastics such as polypropylene, polyethylene, and the thermoplastic polyimides, where solvent-based adhesives and ultrasonic welding are ineffective. It also does an excellent welding operation on large parts such as automotive vent ducts, fuel tanks, liquid reservoirs, and washing machine tubs, agitators and spray arms.

Each welder is designed to accommodate a specific range of product requirements. Depending on the requirements, machines are available for hot plate welding on either horizontal or vertical planes. In most cases, machines can handle a range of varying part designs. A change in part design may mean a change in holding fixtures, but not necessarily a change in machines. The hot plate welding process consists of six steps as shown in Fig. 24-7.

For accurate mating and alignment, the hot plate welding process relies on holding fixtures to support the parts to be joined. Collets, gripping fingers, mechanical devices or vacuum cups may be used for folding or gripping the parts.

To plasticize the part edges, the fixtures press the parts against a heating platen. As the platen melts the part's mating surface, plastic material is displaced. This initial melting produces a smooth mating edge by removing surface imperfections, warps, and small sinks. Melted material continues to be displaced until the “melt stops” on the platen contact the “tooling stops” on the holding fixture. Once the melt stops and tooling stops are in contact, material ceases to be displaced and the parts are held fixed against the platen until each part's edge is plasticized to a predetermined depth. Melt depth is regulated by the contact time of the plastic part against the platen, usually one to six seconds, and by the placement of the melt stops.

The temperature at which the platen is set depends on the type of plastic being welded. Each thermoplastic has a characteristic time/temperature curve for melting, and a bond or weld can be produced at any temperature on the curve. Typically, the highest possible temperature (and, thus, the shortest time) is selected to maximize production speed. The normal

*Courtesy Forward Technology Industries, Inc., Minneapolis, MN.

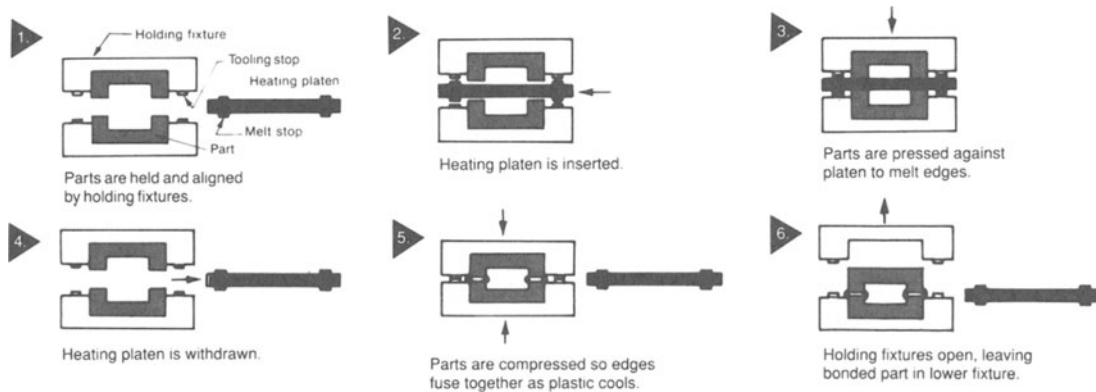


Fig. 24-7. Six steps for hot plate welding thermoplastics. (Courtesy Forward Technology Industries, Inc.)

temperature range is 300 to 700°F. Aluminum platens are used for temperatures to 500°F and are usually coated with PTFE-impregnated fiberglass cloth to prevent parts from sticking. Bronze and steel platens are used for temperatures over 500°F.

After the part edges are plasticized, the holding fixtures open and the heating platen is withdrawn. The fixtures then close, forcing the two parts together until the tooling stops on the fixtures come into contact. The parts are held together under pressure, allowing the melted plastic material to cool and weld together. Cooling time is normally from three to six seconds. When cooling is complete, the gripping mechanism on one of the holding fixtures releases the part, the fixtures open, and the finished part is manually or automatically removed.

Total cycle time, from start to finish, generally is twenty seconds or less, well within the cycle range of injection-molding systems often used in conjunction with hot plate welders.

Hot plate welding joint design is limited only by the designer's imagination. Figure 24-8 illustrates a few of the more commonly used joints.

In the hot plate welding process, a small amount of material is displaced from each of the mating parts. This displaced material creates a weld bead. From the designer's point of view, displacement must be taken into consideration for two reasons: 1) In intricate assemblies where dimensional tolerance is critical, material needs to be added at the mating surface. 2) In parts requiring external aesthetics, the weld bead must be hidden or removed. If there is insufficient design flexibility to hide the bead, it can be easily removed in the welding process.

The hot plate welding process produces a joint which, in many cases, is consistently equal to or stronger than any other area of the part. As a result, the weld area can be exposed to the same strains and stresses as any other area of the part.

Induction Welding

Induction welding is exceptionally fast and versatile. Heat is induced by a high-frequency electrodynamic field in a metallic insert placed in the interface of the areas to be joined, and this heat brings the surrounding material to fu-

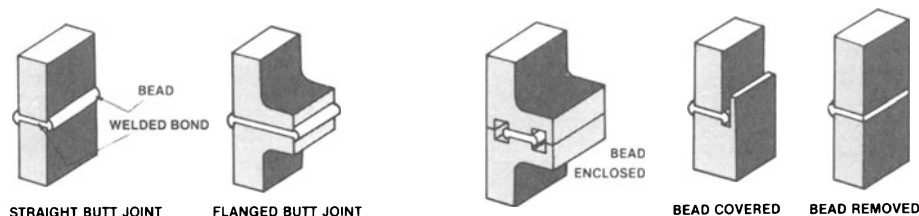


Fig. 24-8. Possible joint designs for hot plate welding. (Courtesy Forward Technology Industries, Inc.)

sion temperature. Pressure is maintained as the electromagnetic field is turned off, and the joint solidifies. The weld strength depends on the size and geometry of the metal insert.

Induction welding is one of the fastest methods of joining plastics. Some applications require as little as 1 second of welding time; typical applications require from 3 to 10 seconds. The rate of production generally is limited only by the speed with which the parts may be assembled in and removed from the welding jig.

Successful welds can be obtained by using stamped foil inserts, standard metallic shapes, such as wire screen, or various other configurations of conductive metal. The shape of the insert is not limited to the normal pattern of a closed resistance circuit; thus it may be made in a shape that provides a decorative effect in the finished article (e.g., stars or letters). Wire can be used, preferably of diameter from 0.010 to 0.030 inch. Printed or metallized inserts may be feasible, but have not yet been fully evaluated.

The higher the pressure applied on the joint during welding, the higher the permissible temperature. The feasible pressure appears to be limited only by the strength and stiffness of the materials being welded. In most applications a pressure of 100 psi of joint is required, but greater pressure may be needed with some plastics, to minimize development of bubbles from thermal decomposition at the joint. The joint should be designed so that pressure is distributed uniformly throughout, and over the metal insert. The insert should be located as closely as possible to the generator coil. It should be centered accurately within the coil, to avoid its being pulled out of position by the attraction of the coil. A tongue-and-groove joint or a similar configuration is desirable, to locate and hold the metal insert. In any case, the insert must be located in the interface so that no portion of it is exposed to air, as such exposure could cause rapid heating and subsequent disintegration of the insert.

Strengths of induction welds are limited by the relative smallness of the area in which the actual weld is formed. Welding occurs only in the area immediately adjacent to the metallic insert. In most cases this is a band, $\frac{1}{16}$ to $\frac{1}{8}$ inch

wide, along the periphery of the insert. Very little if any strength is obtained by metal-to-plastic bonding over the area of the insert.

Weld strengths can be determined by multiplying the unit weld strength by the area over which actual welding takes place. With wire screen as the insert between polyethylene slabs, weld strengths of better than 50% of that of the parent material can be consistently produced. Acrylics have been processed equally well, and from all indications welds of significant strength can be obtained in almost all thermoplastics.

Another adaptation of induction bonding involves replacing the metal insert with a metal-filled plastic. In essence, magnetic materials, in the form of micron-size particles, are dispersed within a thermoplastic matrix that is compatible with the material to be joined (e.g., a polypropylene matrix when polypropylene parts are being joined). The matrix can be supplied in the form of a liquid, or it can be molded into a shape (e.g., a gasket) that will conform to the shape of the weld area.

The metal-filled plastic bonding agent is simply applied to the parts to be joined and then subjected to the high-frequency magnetic field of an induction heating coil. The magnetic flux reaches through the work and generates heat in the bonding. Heating is the result of internal energy losses within the material that cause the temperature to rise. It is, of course, the metal particles (with magnetic properties) within the plastic that generate these losses through hysteresis and eddy current. (See Figs. 24-9 and 24-10).

As a consequence, the thermoplastic matrix in which the particles are confined melts and is subsequently fused to the two abutting surfaces, forming a structural bond on cooling.

The process is available for polypropylene, polyethylene, nylon, ABS, polystyrene, and PVC. Its advantages include: adaptability to bonding most of the thermoplastics; speed of bonding; the ability to make structural bonds in either butt, peel, or shear; adaptability to hermetic seals; flexibility in bonding area in terms of size (can be a small spot weld or a long, continuous weld) and shape (irregular as well as symmetrical); and the fact that the physical

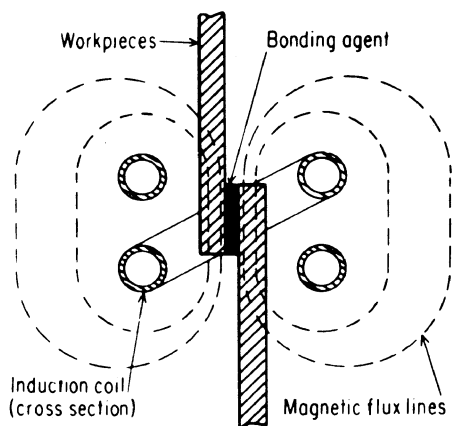


Fig. 24-9. Electrical induction heat is produced by the high-frequency magnetic field of an induction heating coil. The magnetic flux (dashed lines) reaches through the work and produces heat in the bonding agent. (Courtesy McGraw-Hill)

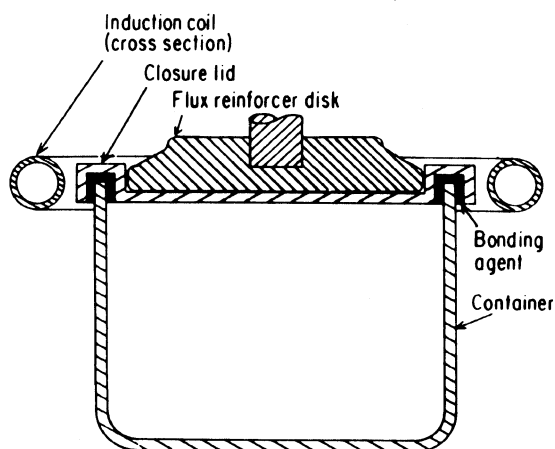


Fig. 24-10. Plastics lids are bonded to plastics containers using the induction bonding method. (Courtesy McGraw-Hill)

and chemical properties of the bond area are similar to those of the material being joined. It is also claimed that by using small particles of metal as opposed to larger pieces of metal or wire, stresses are not molded into the bond area.

Spin or Friction Welding

In this process, the two surfaces of thermoplastic are rubbed together until enough friction heat develops to fuse and weld them. The

strength of the welded joint approaches that of the parent material.

Typical welding cycles are 1 to 2 seconds. High-speed feeding devices (e.g., vibratory feeders) can be hooked into the operation for continuous production.

Nearly all the rigid thermoplastics can be spin-welded, although there are some problems with the softer rigids, such as low-density polyethylene or ethylene vinyl acetate.

The advantages of the process are: (1) the strength and good appearance of the joint; (2) the exclusion of oxidizing effect, in that the heated surfaces are directly in contact with each other throughout the process; and (3) the economy resulting from adaptability to standard shop equipment, such as drill presses and lathes.

Its disadvantages are: (1) limitation to a circular or annular area (but sometimes a circular area of weld can be made part of the design of a noncircular article); and (2) the squeezing out (flashing) of soft material beyond the area of the weld before the weld is completed (but this can frequently be made unobjectionable by designing so that the flashing is directed to an internal area of the article).

Another drawback has generally been considered to be the technique's limitation to fairly small parts. However, work has been done in spin-welding parts up to 20 inches in diameter.

Spin welding involves the rotating of one of the pieces against the other, which is held stationary. Rubbing contact is maintained at a speed and a pressure sufficient to generate frictional heat and melt the adjacent surfaces. The frictional heat is sufficient to effect almost immediate melting of the two surfaces without substantially affecting the temperature of the material immediately beneath the surfaces. When sufficient melt is obtained, the spinning is stopped, and pressure is increased to squeeze out all bubbles and to distribute the melt uniformly between the two surfaces. Pressure is maintained until the weld solidifies. In many instances, a single pressure setting has been found adequate. For thermoplastics having sharp melting points, braking sometimes is required, in order to stop the rotation of the parts quickly to avoid tearing of the partially solidified weld.

Spin Welding Equipment.* Prototype or low-production-volume spin welding can be performed on a standard drill press with a driving tool and chuck. High-volume applications require either a drill press equipped with a spin-welding tool, air cylinder, valves, and timer or specially designed spin-welding equipment.

The basic equipment requirements for a spin welder are diagrammed in Fig. 24-11. Parts to be welded are shown held in a chuck. A spinning tool is attached to an electric motor by a drive shaft and V-belt. An air cylinder advances the tool and applies force to the parts during welding. A timer and an air valve are used to control the air cylinder. A motor speed control, motor brake, and clutch may be required.

Variables of Spin Welding. Basic variables of spin-welding are rotational speed, joint pressure, and spin time.

Rotational speed depends on the joint diameter.

Joint pressure is a convenient means for establishing the thrust required to generate heat between spinning parts. During welding, joint pressure forces bubbles, contamination, and excess material from the weld. The actual thrust will depend on the joint design.

Spin time is the duration of relative motion between the rotating surfaces before melting takes place. Once melting has occurred, relative motion must be stopped to allow the weld to solidify under pressure because failure to arrest motion will cause tearing of the weld and result in low weld strength.

Spin Welding Methods.* There are two basic methods for spin welding, which differ only in the type of driving tool used: pivot and inertia methods. With both methods, rotational speed and joint pressure are adjusted similarly to control the welding process. Spin times are controlled differently, however. With the pivot method, the spin time is controlled by a timer, which activates withdrawal of the pivot tool. In the inertia method, the spinning tool is disengaged from the motor after the start of the weld

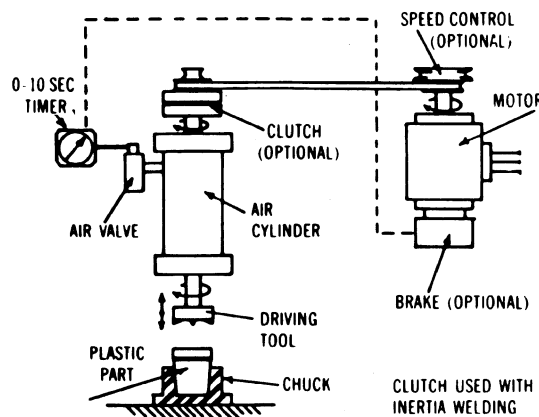


Fig. 24-11. Basic equipment requirements for spin welding. (Courtesy E. I. du Pont de Nemours & Co., Inc.)

cycle. The kinetic energy of the freely spinning inertia tool is converted into heat energy during welding. Thus, the spin time may be varied markedly by adjusting the mass of the inertia tool or more finely by varying the speed of rotation. Pivot tools are generally used for joints having a projected area of $\frac{1}{2}$ in.² (3 cm²) or less. Inertia tools are better for joints of large area because they offer fine control of input energy.

Essential parts of the pivot tool are the driving element, such as teeth or rubber facing, and the pivot pin. The pivot tool turns at constant speed throughout the weld cycle. A load is applied to parts by the spring-loaded pivot pin before the driving element engages the parts. At the end of the cycle, the tool retracts, and the driving element disengages while joint pressure is maintained by the pivot pin. The relative motion between parts stops almost instantly, and the weld solidifies.

When part design does not permit the use of a pivot pin, a thrust bearing may be used. A rubber facing may be used on the driving elements if no tooth indentations can be tolerated on the welded part.

Essential elements of the inertia tool are the driving element and the rotating mass or fly-wheel. The clutch for disconnecting the inertia tool from the motor may be part of the main welder drive system, or it may be built into the inertia tool. With this inertia tool design, the rotating mass is supported by needle and ball bearings around a central shaft. A conical clutch connects the shaft and mass when no

*Adapted from a Du Pont technical data brochure on machining Delrin acetal.

vertical load is applied to the tool. When the spinning tool engages the upper part to be welded, the clutch disengages the rotating mass. Joint pressure is maintained during welding by a vertical load applied through the tool shaft and lower thrust ball bearing to the rotating mass. The tool is raised after the rotating mass comes to rest.

ULTRASONIC ASSEMBLY*

Ultrasonic plastics assembly equipment currently is being used for a wide variety of applications in many different industries.

Typical ultrasonic processes are welding injection molded plastics, inserting metal into plastics, staking over plastic studs or bosses, spot-welding sheet material, continuous film or synthetic fabric sealing and cutting, degating parts from a runner system, swaging, and forming.

The basic principle of ultrasonic assembly is that when two pieces of thermoplastic are vibrated together fast enough with an appropriate amplitude, heat will be developed, and a flow of plastic will occur at the joint interface. The method can provide strong (95–100% strength), hermetically sealed components at a high production rate. It is clean, fast (20 to 60 parts/min.), and relatively inexpensive as compared with other assembly methods. Materials handling equipment can easily be interfaced with an ultrasonic system. (Figure 24-12 shows a microprocessor-controlled ultrasonic welder.)

Equipment

An ultrasonic assembly system can be broken down into seven major components (Fig. 24-13).

1. Power supply or ultrasonic generator
2. Converter or transducer
3. Booster horn
4. Horn

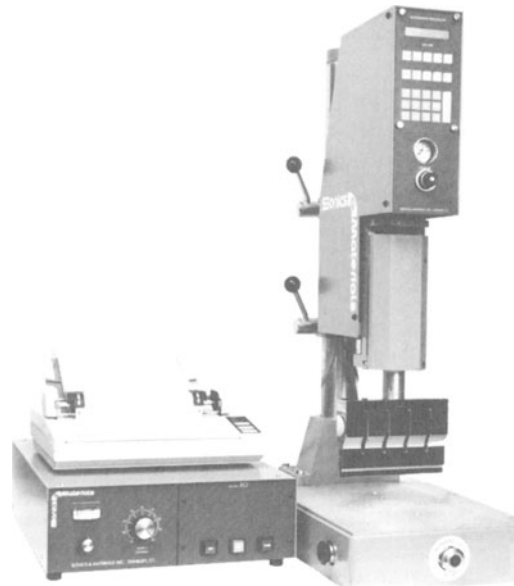


Fig. 24-12. Microprocessor-controlled ultrasonic welder with 2000 watt, 20 kHz power supply and a printer for recording various parameters. (Courtesy Sonics and Materials, Inc.)

5. Stand or pneumatic press
6. Welding controls
7. Fixture

Power Supply. The power supply transforms 50/60 Hz electrical power from a wall outlet to ultrasonic power at a given frequency. The most common frequency used is 20 kHz. Other frequencies that are commercially available are 15, 30, 36, 40, and 70 kHz.

With lower frequencies such as 15 kHz, one can use very large horns and, therefore, weld large parts. Another important advantage of using 15 kHz is that there is significantly less attenuation through a thermoplastic, permitting the welding of many softer plastics and welding at a greater distance from the horn contact area. Higher frequencies allow the welding of small delicate parts with no disturbance of the adjoining plastic material.

A majority of welding applications are accomplished by using a power supply with an output of 1000 watts. Power supplies are available with power ranging from 50 to 3000 watts.

*By Robert S. Soloff, President, Sonics and Materials, Inc., Danbury, CT.

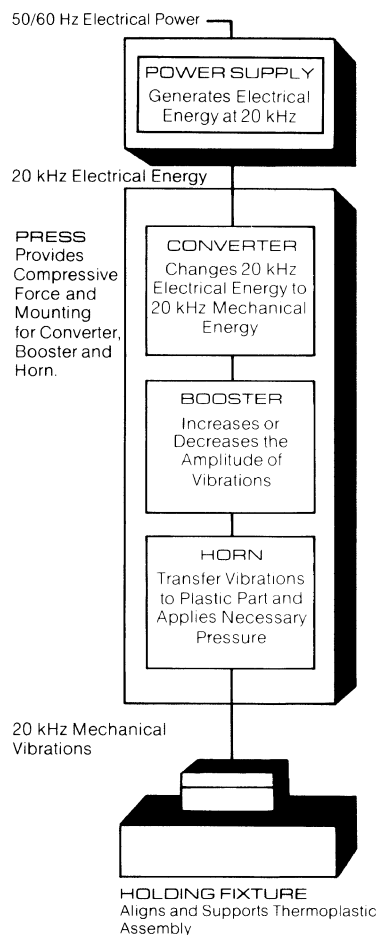


Fig. 24-13 Ultrasonic assembly system. (Courtesy Sonics and Materials, Inc.)

Converter. The electrical power output from the power supply is introduced into a stack of piezoelectric ceramics (PZT), causing the PZT material to expand and contract at a high frequency. This phenomenon converts the 20 kHz of electrical energy into 20 kHz of mechanical energy or vibrations. The distance that the mechanical vibrations move back and forth is called the amplitude. Typical amplitudes, at the converter output face at 20 kHz, are between 0.0006 inch and 0.0008 inch peak to peak.

Booster Horn. The success of an ultrasonic plastics assembly application depends on having the proper vibrational amplitude at the horn face. As it is impractical always to design the correct amplitude into the horn, booster horns

are necessary to either increase or decrease the amplitude to produce the proper amount of vibrational heat at the weld area of the plastic parts. The booster horn, which is a half-wave-length resonant element, is made of either aluminum or titanium and is mounted between the converter and the horn. Boosters usually are color-coded or marked to indicate their ratio.

Horn. The horn also is a tuned half-wave-length resonant element, which transfers the mechanical vibratory energy from the converter and booster horn to the workpiece. The horn can further modify the booster horn's amplitude output by the nature of its design. The horn's surface also must be machined to conform to the shape of the plastic part. Horns are made of materials that have a high strength-to-weight ratio and low losses at ultrasonic frequencies. Titanium has the best acoustical properties of the high-strength metals, whereas aluminum is the best of the lower-strength metals. Heat-treated steel horns are used when wear-resistant surfaces are required, but they are subject to higher ultrasonic losses. A variety of horn shapes are available, depending on the size, shape, and weldability of the plastic part being welded.

Press (Stand). The press consists of a base, column, actuator, and control panel, all housed in a frame and interconnected by cables. The base contains dual non-tie-down palm buttons (the operator must maintain both hands on the palm buttons during the weld cycle) and an emergency stop button, both for operator safety. The actuator housing contains the converter, booster horn, and horn, and is pneumatically raised and lowered to apply ultrasonics at a predetermined pressure and time to the workpiece. Each application requires different settings for an optimum weld. The weld pressure, trigger pressure, stroke speed, and stroke distance, among other functions, are all adjusted in the stand. In certain configurations, some of the controls are located in the power supply.

Timer or Microprocessor Controller. The variety of controls and the repeatability of each

of them determine the effectiveness of the ultrasonic system. The timer, which can be located in the power supply or in the stand, controls the weld and hold times. Typical weld times are usually less than 2 seconds, with most being under 1 second. The hold time is usually less than 0.5 second.

An alternative to the timer and a more effective means of controlling the various functions in the weld cycle is to use a small computer or microprocessor controller. Microprocessor controls were introduced for use with ultrasonic assembly in 1985. The advantage of the microprocessor is its ability to weld to an energy value rather than just to a preset time. Most microprocessors have the ability to set limits on preset parameters and sound an alarm or activate a reject control switch in order to sort out rejects.

Job storage, force triggering, rejects and part counts, internal calibration, lockout codes, self-diagnosis, and printer and computer interfaces are other features usually provided in the welder's microprocessor.

Welding to a preset distance, either from a fixed reference point or measuring the collapse of the plastic part during welding, is accomplished by using a linear encoder mounted on the welding press. When the preset distance is reached, a signal is sent to the controls to terminate the weld.

Fixtures. The fixture, mounted on the base of the stand, must hold the plastic parts in proper alignment during the weld cycle. Fixtures usually are made from chrome-plated aluminum and steel or poured epoxy to minimize tool wear and marking of the plastic parts.

Materials

The characteristics of a plastic determine its weldability. Thermoplastic materials generally are well suited to ultrasonic welding because they melt within a specific range, whereas thermosetting materials are not, because they degrade when heat is applied. The characteristics of thermoplastic materials, such as melt temperature, modulus of elasticity, and structure, determine the energy requirements of the weld.

Rigid plastics exhibit excellent welding properties because they readily transmit vibratory energy. Soft plastics, having a low modulus of elasticity, attenuate the ultrasonic vibrations and thus are more difficult to weld. In staking, forming, or spot welding, the opposite is true. Generally, the softer the plastic, the easier it is to stake, form, or spot-weld.

Resins are classified as amorphous or crystalline. Ultrasonic energy is easily transmitted through amorphous resins, so these resins lend themselves readily to ultrasonic welding. Amorphous resins are characterized by random molecular arrangements and a broad melting temperature range that allows the material to soften gradually before melting and to flow without prematurely solidifying.

Because the molecular structure in the crystalline resins attenuates a great amount of energy, crystalline resins do not readily transmit ultrasonic energy, and they require higher energy levels than amorphous resins. These resins are characterized by a high, sharply defined melting point that causes melting and resolidification to occur rapidly. For these reasons, in welding crystalline resins, higher amplitude and energy levels should be used, with special consideration given to joint design.

Before any discussion of welding characteristics, the difference between near-field and far-field welding must be understood. Near-field welding refers to welding a joint located $\frac{1}{4}$ inch (6 mm) or less from the area of horn contact. The greater the distance from the point of horn contact to the joint, the more difficult it will be for the vibration to travel through the material and for the welding process to take place.

The differential, if any, in the melt temperature of the materials being welded should not exceed 30° (17°C), and the materials' molecular structures should be compatible (i.e., blends, alloys, copolymers, and terpolymers).

The moisture content, mold release agents, lubricants, plasticizers, fillers, reinforcing agents, regrinds, pigments, flame retardants, and resin grade all can influence weldability. The moisture content of parts molded from resins that are hygroscopic (moisture-absorbent)

can be problematic. Nylon (and to a lesser degree polycarbonate and polysulfone) present most of the problem, and parts molded in these resins should be stored in sealed polyethylene bags with an appropriate desiccant immediately after molding. If moist parts are welded, the escaping vapors may cause voids and fissures in the molten material, resulting in a weld of poor integrity.

Mold release agents such as zinc stearate, aluminum stearate, fluorocarbons, and silicones are not compatible with ultrasonic welding. If it is necessary to use a mold release agent, the paintable/printable grades that permit painting and silk screening should be considered. Other release agents should be removed with either TF Freon for crystalline resins or a 50/50 solution of water and liquid detergent.

Lubricants, whether waxes, stearates, or fatty esters, reduce intermolecular friction within the polymer and inhibit the ultrasonic assembly process. However, because they generally are dispersed internally, their effect usually is negligible.

Plasticizers, which usually impart flexibility and softness to a resin, can interfere with a resin's ability to transmit vibratory energy. FDA-approved plasticizers do not present as much of a problem as metallic plasticizers, but experimentation is recommended.

Although fillers and reinforcing agents such as glass and talc can increase the ultrasonic weldability of thermoplastic considerably, they should be used judiciously. When the additive content exceeds 10%, premature horn wear may result, and specially treated steel or carbide-faced titanium horns might be required. When the filler content approaches 35%, there may be insufficient resin at the surface to obtain hermetic seals. When the filler content exceeds 50%, insufficient plastic is present at the interface to form a positive bond. Reinforcement composed of long glass fibers always is more problematic than reinforcement composed of short glass fibers.

Ultrasonic assembly is one of the few methods that permit regrinding of parts, as no foreign substance is introduced into the resin. Ultrasonically assembling parts have been

manufactured from regrind parts presents no problem, provided that the percentage of regrind is not excessive and the plastic has not been degraded. Regrind limitations suggested by the resin suppliers should be observed.

Although most pigments do not interfere with the ultrasonic assembly process, some oil-based colorants can adversely influence weldability. Non-oil-based pigments should be used.

Flame retardants greatly affect the weldability of thermoplastics, and the effects of the various additives should be investigated experimentally prior to resin selection. The grade of resin can have a significant influence on weldability. There is a great difference between injection/extrusion grades and cast grades; their molecular weight, melt temperature, and modulus of elasticity are quite different. Injection/extrusion grades should be used only with injection/extrusion grades and cast grades used only with cast grades.

Table 24-6 lists the welding characteristics of thermoplastics.

Figure 24-14 shows typical ultrasonic assembly processes.

Joint Design

Perhaps the most critical facet of part design for ultrasonic welding is joint design (the configuration of the two mating surfaces). It should be considered when the parts to be welded are still in the design stage, and incorporated into the molded parts. There are a variety of joint designs, each with specific features and advantages. Their selection is determined by such factors as type of plastic, part geometry, weld requirements, machining and molding capabilities, and cosmetic appearance.

Butt Joint with Energy Director. The butt joint with energy director is the most common joint design used in ultrasonic welding, and the easiest to mold into a part. The main feature of this joint is a small 90° or 60° triangular-shaped ridge molded into one of the mating surfaces. This energy director limits initial contact to a very small area, and focuses the ultrasonic energy at the apex of the triangle. During the welding cycle, the concentrated ultrasonic en-

Table 24-6. Ultrasonic welding 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 Multipolymer-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	—
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	—	—	P	—
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	—	—	—	P	—
Nylon	F	F	G	G	F
PC-PET	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)	—	—	—	—	—
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

—Not suitable for ultrasonic assembly

ergy causes the ridge to melt and the plastic to flow throughout the joint area, bonding the parts together.

For easy-to-weld resins—amorphous polymers such as ABS, SAN, acrylic and polystyrene—the size of the energy director is dependent on the area to be joined. Practical considerations suggest a minimum height between .008 and .025 inch (.2 and .6 mm).

Crystalline polymers, such as nylon, thermoplastic polyesters, acetal, polyethylene, polypropylene, and polyphenylene sulfide, as well

as high-melt-temperature amorphous resins, such as polycarbonate and polysulfones, are more difficult to weld. For these resins, energy directors with a minimum height between .015 and .020 inch (.4 and .5 mm) with a 60° included angle generally are recommended.

The 90° included angle energy director height should be at least 10% of the joint width, and the width of the energy director should be at least 20% of the joint widths. Figure 24-15 shows a butt joint with a 90° included angle energy director. With thick-walled joints, two

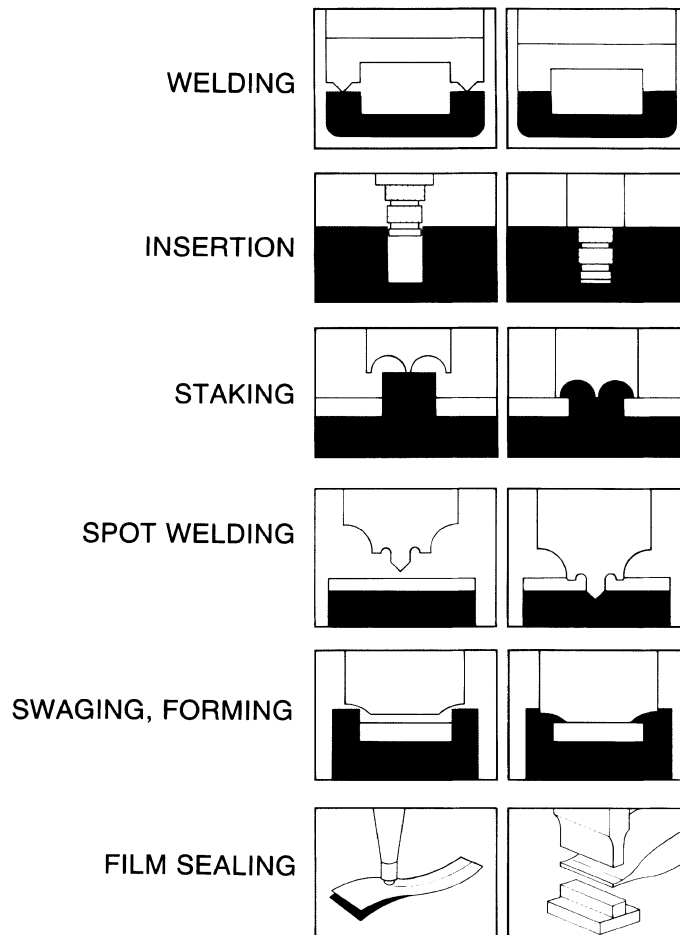


Fig. 24-14. Typical ultrasonic assembly processes. (Courtesy Sonics and Materials, Inc.)

or more energy directors should be used, and the sum of their heights should equal 10% of the joint width.

To achieve hermetic seals when welding polycarbonate components, it is recommended

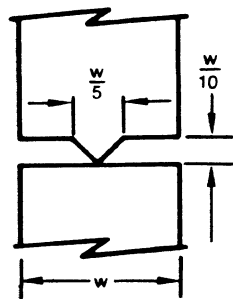


Fig. 24-15. Joint design. Butt joint with energy director. (Courtesy Sonics and Materials, Inc.)

that a 60° included angle energy director be designed into the part. The energy director width should be 25 to 30% of the wall thickness.

With assemblies whose components are made of identical thermoplastics, the energy director can be designed into either half of the assembly. However, in designing energy directors into assemblies consisting of a part made of copolymers or terpolymers, such as ABS, and another part made of a homopolymer, such as acrylic, for maximum strength, the energy director should always be incorporated into the half of the homopolymer assembly.

The step joint with energy director is illustrated in Fig. 24-16. This joint molds readily, and provides a strong, well-aligned joint with a minimum of effort. This joint is usually stronger than a butt joint because material flows

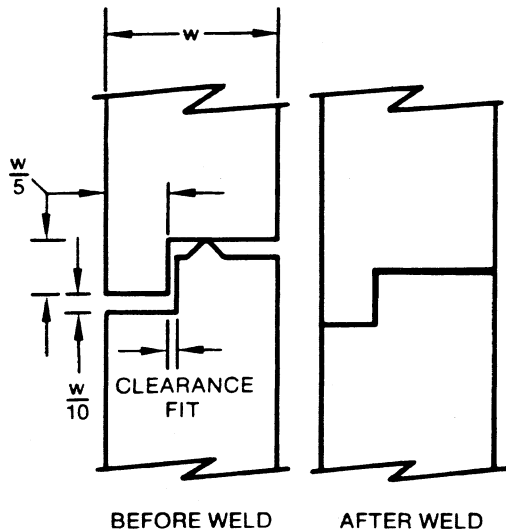


Fig. 24-16. Step joint with 90° energy director. (Courtesy Sonics and Materials, Inc.)

into the vertical clearance. The step joint provides good strength in shear as well as tension, and often is recommended where good cosmetic appearance is required. In work with crystalline materials, a 60° included angle energy director should be used instead of the 90° included angle energy director.

Figure 24-17 shows variations of the basic step joint design.

The tongue-and-groove joint with energy director is illustrated in Fig. 24-18. This joint is used primarily for scan welding, self-location of parts, and prevention of flash both internally

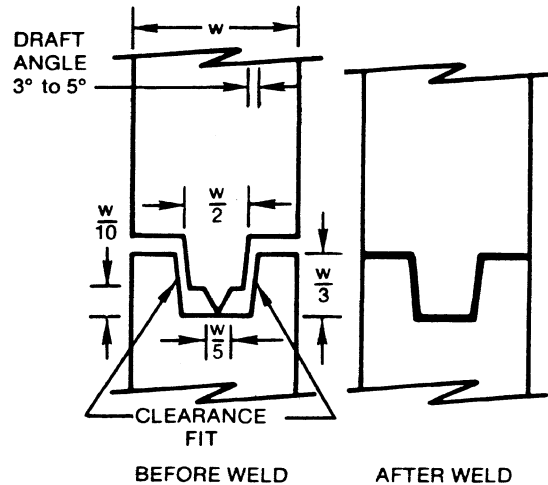


Fig. 24-18. Tongue-and-groove joint with energy director. (Courtesy Sonics and Materials, Inc.)

and externally. It provides the greatest bond strength of the three joints discussed so far.

The shear joint or interference joint shown in Fig. 24-19 is generally recommended for high-strength hermetic seals on parts with square corners or rectangular designs, especially with crystalline resins.

The initial contact is limited to a small area, which is usually a recess or step in either of the parts. The contacting surfaces melt first; then as the parts telescope together, they continue to melt along the vertical walls. The smearing action of the two melt surfaces eliminate leaks and voids, making this the best joint for strong hermetic seals.

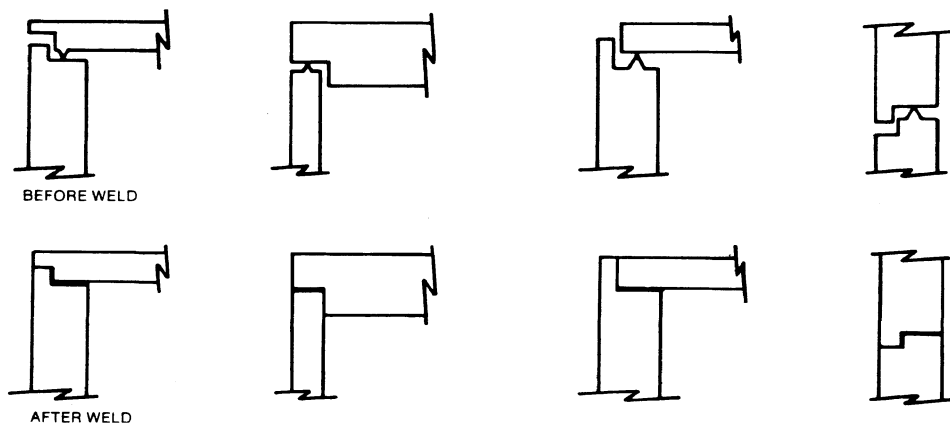


Fig. 24-17. Step joint variations. (Courtesy Sonics and Materials, Inc.)

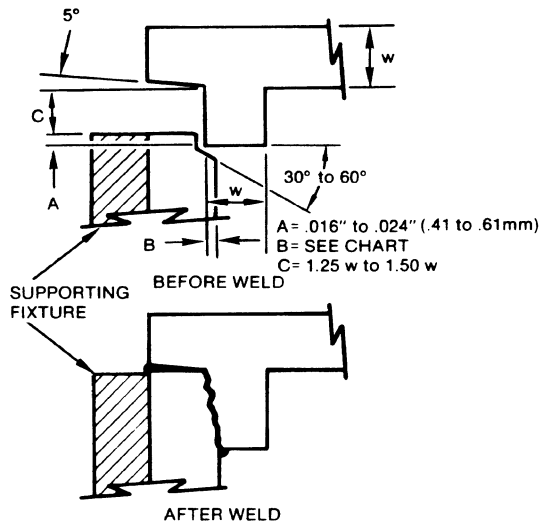


Fig. 24-19. Shear joint. (Courtesy Sonics and Materials, Inc.)

Several important aspects of the shear joint should be considered: (1) the top part should be as shallow as possible, (2) the outer walls should be well supported by a holding fixture, (3) the design should allow for a clearance fit, and (4) a lead-in (A) should be incorporated. The chart shows part and interference joint dimensions.

Maximum Part Dimension	Interference (B)
Less than 0.75" (19 mm)	0.008" to 0.012" (0.2 to 0.3 mm)
0.75" to 1.50" (19 to 38 mm)	0.012" to 0.016" (0.3 to 0.4 mm)
Greater than 1.50" (38 mm)	0.016" to 0.020" (0.4 to 0.5 mm)

The shear joint requires weld times in the range of three to four times that of other joint designs because larger amounts of resin are being melted. In addition, a certain amount of flash will be visible on the surface after welding.

When flash cannot be tolerated for aesthetic or functional reasons, a well similar to the ones shown in Fig. 24-20 should be incorporated.

Modified joints, such as those shown in Fig. 24-21, should be considered for large parts of parts where the top piece is deep and flexible.

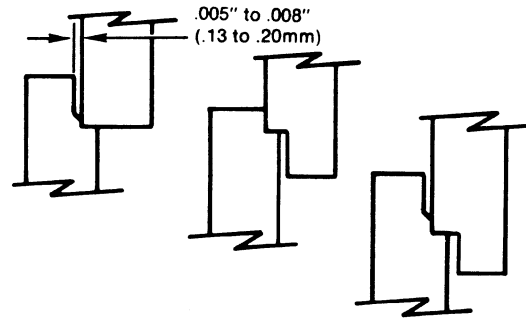


Fig. 24-20. Shear joints with flash wells. (Courtesy Sonics and Materials, Inc.)

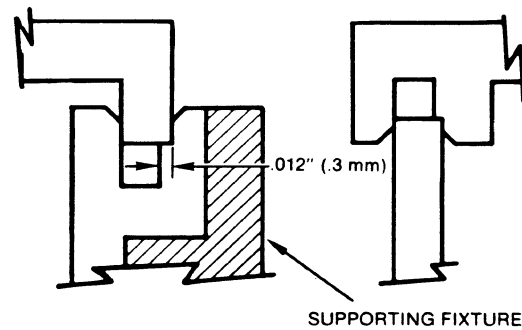


Fig. 24-21. Shear joint variations with large parts. (Courtesy Sonics and Materials, Inc.)

Ultrasonic Staking

In ultrasonic staking, also referred to as ultrasonic heading or riveting, the controlled flow of the molten plastic is used to capture or retain another component, usually of a different material, in place.

Ultrasonic staking provides an alternative to welding when the two parts consist of dissimilar materials that cannot be welded, or when simple mechanical retention of one part relative to another is adequate (i.e., as distinct from molecular bonding).

The most usual application involves the attachment of metal to plastic. A hole in the metal part receives a pre-molded plastic boss. The horn tip, vibrating at high frequency, contacts the boss and, through friction, creates localized heat. As the boss melts because of frictional heat, light pressure from the horn forms a head to a shape determined by the horn tip configuration.

ration. When the vibrations stop, the plastic material solidifies, and the dissimilar materials are fastened together.

Unlike ultrasonic plastics welding, staking requires that out-of-phase vibrations be generated between the horn and the plastic surfaces. Light, initial contact pressure thus is a requirement for out-of-phase vibratory activity within the limited contact area. It is the progressive melting of the plastic boss under continuous, but light, pressure that forms the head. In staking, low pressure rather than high pressure usually is recommended.

With staking, tight assemblies are possible because mating parts are clamped under the pressure of the horn until the rivet head solidifies. There is no elastic recovery as occurs with heat staking or cold forming.

Ultrasonic staking should be considered when the parts to be assembled are still in the design stage. Several configurations for boss/cavity design are available, each with specific features and advantages. Their selection is determined by such factors as type of plastic, part geometry, assembly requirements, machining and molding capabilities, and cosmetic appearance. The principle of staking is the same for each: the area of initial contact between the horn and the boss is kept to a minimum, in or-

der to concentrate the energy and produce a rapid melt.

The integrity of an ultrasonically staked assembly depends greatly upon the geometric relationship between the boss and the horn cavity. Proper design will produce optimum strength with minimum flash.

Whenever possible, the bosses should be designed with an undercut radius at the base to prevent fracturing or melting. Holes in the mating parts should be radiused or at least deburred. Long bosses should be avoided, and tapered from the base to the top.

The boss should be properly located and rigidly supported from below to ensure that the energy will be dissipated at the horn/boss interface rather than exciting the entire plastic assembly and fixture.

Best staking results are obtained when the ultrasonic vibrations are started before the horn contacts the boss. This prevents cold forming and allows for the gradual reforming of the boss. The pretriggering of the ultrasonic vibrations normally is accomplished by using a pre-trigger switch.

To obtain repeatable results when staking, the distance that the horn travels should be consistent and limited by the positive stop adjustment. (See Figs. 24-22 through 24-26.)

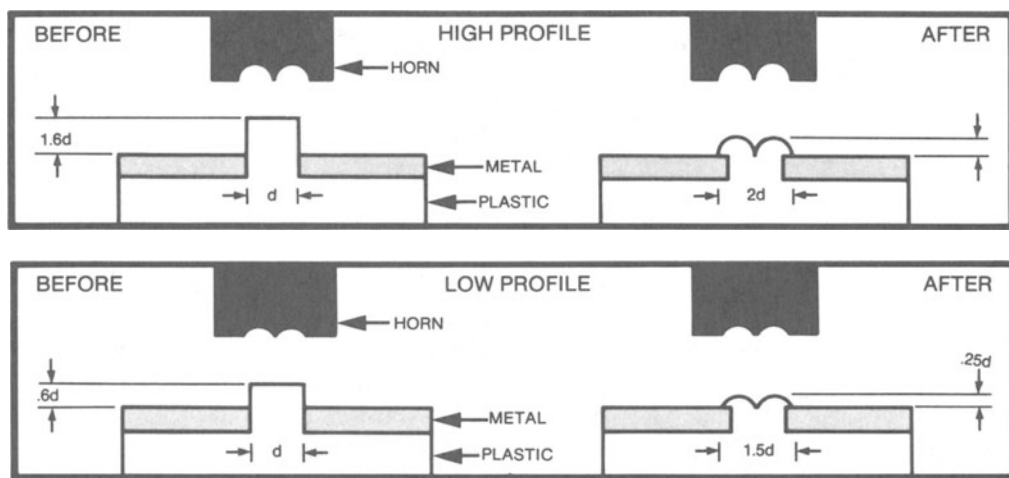


Fig. 24-22. Standard flared stake: The standard flared stake satisfies the requirements of most applications. This stake is recommended for bosses with an O.D. of $\frac{1}{16}$ inch (1.6 mm) or larger, and is ideally suited for low-density, nonabrasive amorphous plastics. (Courtesy Sonics and Materials, Inc.)

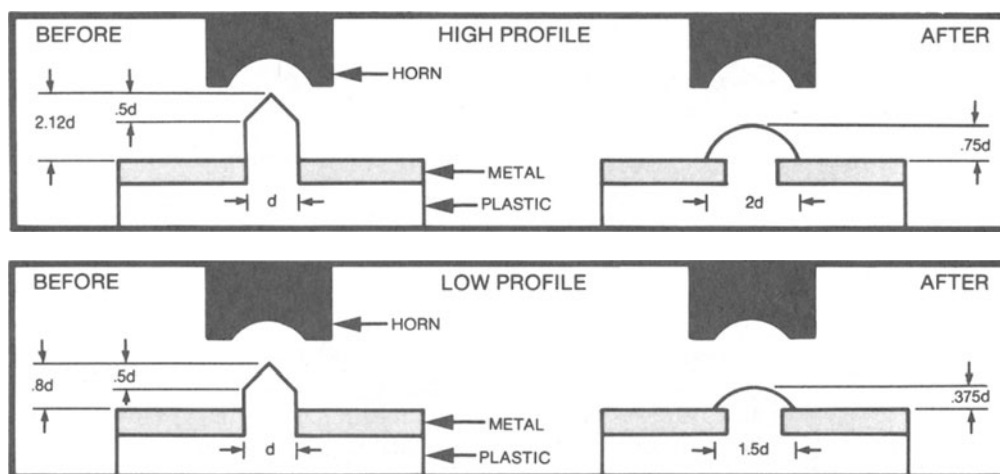


Fig. 24-23. Spherical stake: The spherical stake is preferred for bosses with an O.D. less than $\frac{1}{16}$ inch, and is recommended for rigid crystalline plastics with sharp, highly defined melting temperatures, for plastics with abrasive fillers, and for materials that degrade easily. (*Courtesy Sonics and Materials, Inc.*)

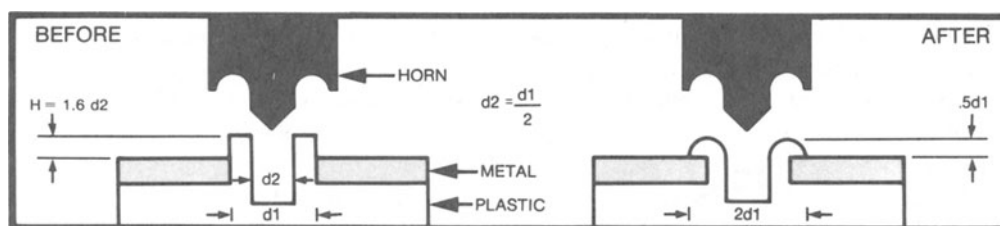


Fig. 24-24. Hollow stake: Bosses with an O.D. in excess of $\frac{5}{32}$ inch (4 mm) should be made hollow. Staking a hollow boss produces a large, strong head with no need to melt a large amount of material. Also, the hollow stake avoids a sink mark on the opposite side of the component, and enables the parts to be reassembled with self-tapping screws should repair and disassembly be necessary. (*Courtesy Sonics and Materials, Inc.*)

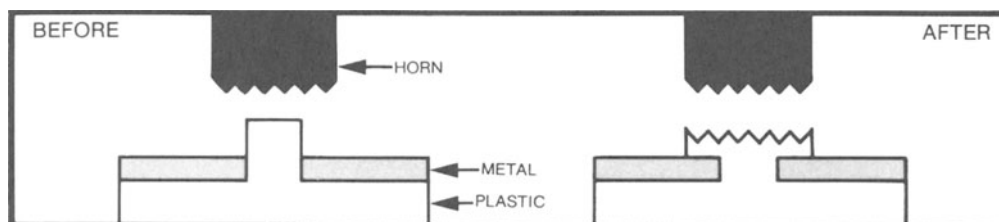


Fig. 24-25. Knurled stake: The knurled stake is used in applications where appearance and strength are not critical. Because alignment is not an important consideration, the knurled stake is ideally suited for high-volume production, and is often recommended for use with a hand-held ultrasonic spot welder. Knurled tips are available in a variety of fine, medium, and coarse configurations. (*Courtesy Sonics and Materials, Inc.*)

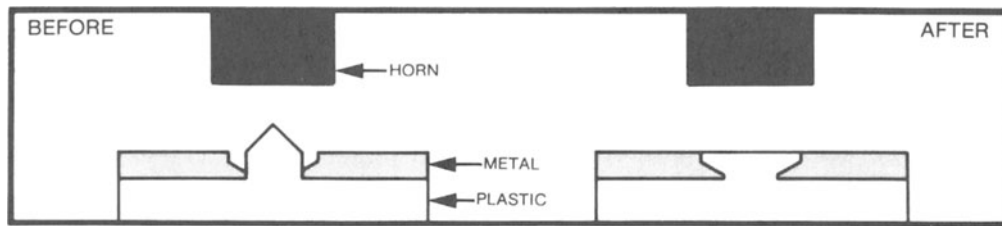


Fig. 24-26. Flush stake: The flush stake is used for applications requiring a flush surface. The flush stake requires that the retained piece have sufficient thickness for a chamfer or counterbore. (Courtesy Sonics and Materials, Inc.)

Inserting

In ultrasonic insertion, a metal insert is placed in a cored or drilled hole that is slightly smaller than the insert. This hole provides a certain degree of interference and also serves to guide the insert into place. The vibrating ultrasonic horn contacts the insert, and the ultrasonic vibrations travel through the insert to the interface of the metal and plastic. Heat, generated by the insert vibrating against the plastic, causes the plastic to melt, and as the horn advances, the insert is embedded in the component. The molten plastic flows into the serrations, flutes, or undercuts of the insert, and, when the vibrations terminate, the plastic resolidifies, and the insert is securely encapsulated in place. In ultrasonic insertion, a slow horn approach, allowing the horn to develop a homogeneous melt phase, is preferable to “pressing” the insert.

Ultrasonic insertion provides the high-performance-strength values of a molded-in insert while retaining all of the advantages of post-molded installation. Inserts can be ultrasonically installed in most thermoplastics. Some of the advantages of ultrasonic inserting over other methods include rapid installation, minimal residual stresses in the component following insertion, elimination of potential mold damage, reduced mold fabrication costs, and increased productivity as a result of reduced mold cycle times.

In some applications, multiple inserts can be embedded simultaneously with special horns, increasing productivity and further reducing assembly and manufacturing costs.

Ultrasonic insertion is not restricted to standard-type threaded inserts. Inserts that can be

installed ultrasonically include a variety of bushings, terminals, ferrules, hubs, pivots, retainers, feed-through fittings, fasteners, hinge plates, binding posts, handle-locating pins, and decorative attachments.

Typically, the plastic component is fixtured and the insert driven in place by the horn (Method 1, Fig. 24-27). However, in some cases, the part configuration might prohibit insert contact by the horn, and the horn is made to contact the plastic component instead of the insert (Method 2, Fig. 24-27).

The functional characteristics or requirements of an application usually determine the insert and hold configuration. In all cases, a sufficient volume of plastic must be displaced to fill the undercuts, flutes, knurls, threads, and/or contoured areas of the insert. Care should be exercised in selecting the proper insert. Inserts are designed for maximum pullout strengths, torque retention, or some combination of both. Inserts with horizontal protrusion, grooves, or indents usually are recommended for high-pullout-strength requirements, whereas inserts with vertical grooves, or knurls are usually recommended for high torque retention. In regard to the hole configuration or insert selection, the recommendations provided by the insert manufacturer should always be observed.

Because the horn contacts the metallic insert, it is subjected to some wear, and horns used for insertion usually are made of hardened steel or titanium. For low-volume applications, titanium horns with replaceable tips can be utilized.

Ideally the diameter of the horn should be twice the diameter of the insert.

To prevent a “jack-out” condition, the top

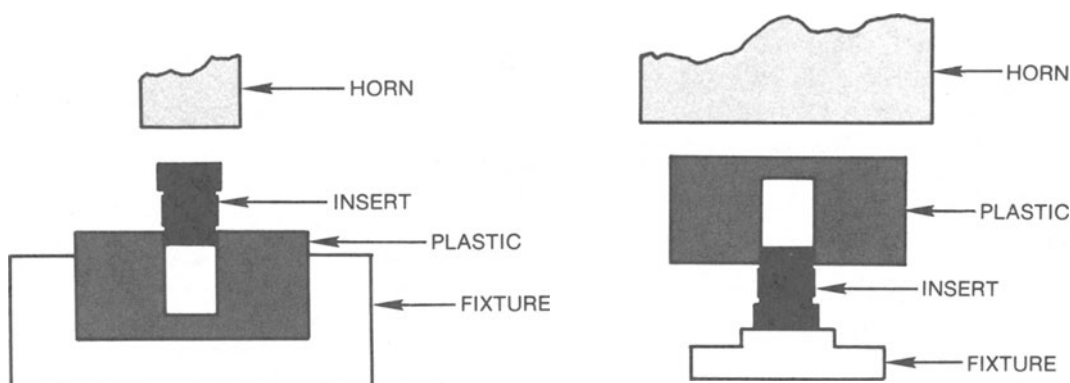


Fig. 24-27. Inserting. Typically, the insert is driven in place by the horn (Method 1). However, in some cases, the horn is made to contact the plastic component instead of the insert (Method 2). (Courtesy Sonics and Materials, Inc.)

of the seated insert should be flush or slightly above the surface of the part. Rigid fixturing should be placed directly under the insert.

In most instances, it is necessary to initiate ultrasonic vibrations prior to horn contact with the insert.

To maintain an accurate depth of insertion, the total distance the horn travels should be limited, either mechanically by a positive stop or electrically by a lower-limit switch, or both.

Spot Welding

Using an ultrasonic spot welder and standard replaceable tips, large thermoplastic parts and those with hard-to-reach joining surfaces can easily be welded together.

Vibrating ultrasonically, the pilot of the tip penetrates the top sheet and enters the bottom sheet to a depth of one-half the top sheet thickness. The molten plastic displaced is shaped by

a radial cavity in the tip to form an annular formation around the weld. Simultaneously, the molten plastic displaced from the second sheet flows into the preheated area and forms a permanent molecular bond (Fig. 24-28).

Film and Fabric Welding and Cutting

Film and fabric sealing is done on a continuous-feed basis with the material being pulled under the horn. The horn usually has a radiused face, and the anvil can be a rotating wheel or stationary block. A stitch pattern can be engraved into the rotary anvil to produce ultrasonically "sewn" fabrics.

Applications include the sealing of polypropylene and polyester films and woven and nonwoven fabrics. Ultrasonics is the preferred way to join Mylar film. There also are other applications where ultrasonics is used to cut and seal the edges of woven and nonwoven materials.

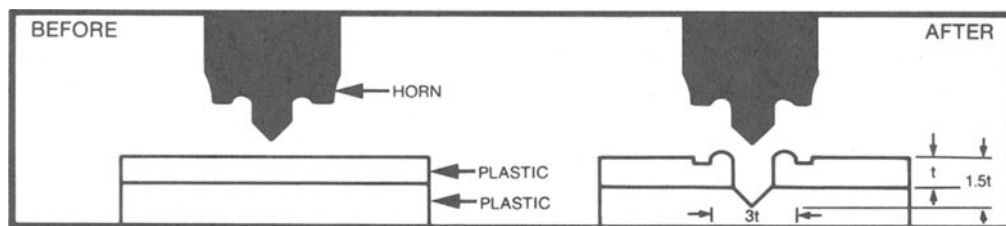


Fig. 24-28. Spot welding. (See text for description.) (Courtesy Sonics and Materials, Inc.)

Vibration Welding

Vibration welding is a form of friction welding. Frequencies used for this technique are typically 120 to 300 Hz, as compared to 20,000 Hz for ultrasonic welding.

The principle of this technique is that vibrations are imparted into the clamped plastic parts in a plane parallel to the joint. When melting occurs at the joint interface, the vibrations are stopped, and the clamping pressure is briefly solidified.

Vibration welding permits the welding of parts having a cross section as large as 22 inches by 16 inches. Crystalline resins such as nylon, acetal, polyethylene, polypropylene, and thermoplastic polyesters are excellent candidates, along with many filled resins, for this technique. All the plastics that can be welded ultrasonically can also be assembled with vibration welding.

Typical applications for this technique include automobile bumpers, fuel tanks, pump impellers, expansion tanks, and emission canisters.

MECHANICAL JOINTS

There are a variety of methods of providing mechanical fastenings and various types of joints in all kinds of plastics. This subsection covers: (1) fasteners, both in metal and in plastics; (2) such techniques as swaging, press-fitting, cold-heading, and so on, which represent mechanical means of fastening; and (3) unique plastic fastening concepts such as the integral or "living" hinge.

Mechanical Fasteners

The type of fasteners that can be used with plastics covers a wide range: clips, nails, screws, assorted inserts, bolts, rivets, hinges, and pins, to name a few. However, it is important when working with plastics to consider the special characteristics of the material, as compared to those involved in joining metals.

For example, the coefficient of thermal expansion is one of the more important considerations in selecting a fastener or designing a

product that will use mechanical fasteners. Although a phenolic or other thermoset with a coefficient of thermal expansion similar to metal may not be severely affected, a real problem can be encountered with such thermoplastics as polystyrene with a coefficient of thermal expansion some six to seven times greater than that of steel. This problem is especially magnified in using molded-in inserts, and some suppliers recommend using these inserts only with filled materials, which have less expansion.

Plastics also vary in their ability to sustain loading (e.g., some are high in compression, others in tension), and plastics deflect more than metals under the same loading (so metal and plastic should not share loads in parallel).

The following discussion contains specific guidelines relating to the various types of mechanical fasteners. However, because of the many variables among different plastic materials, it is suggested that users contact materials manufacturers for precise assembly data. Also, for a complete catalog of mechanical fasteners, a useful reference is the *Fasteners Handbook*, by J. Soled (Van Nostrand Reinhold Co., 1957).

Among the advantages offered by mechanical fasteners are these: (1) ultimate bond strength is attained immediately; (2) a movable joint can be attained, if desired; (3) disassembly is possible, with some types of fasteners; and (4) capital equipment costs are low.

It should also be noted that mechanical fasteners are available in plastics as well as in metals. Fasteners made of plastic are particularly useful in problems of fastening involving (1) corrosion resistance, (2) color matching, (3) sealing, (4) protection of painted or porcelain finishes, and (5) electrical insulation. They should not normally be considered where service temperatures are high, joints are subjected to high tensile or shear stresses, or the cost of the fastener itself is critical. Plastic fasteners are discussed later in this section.

Inserts. In using some of the mechanical fasteners described in this section, many applications will use threaded metal inserts to provide threaded holes in the plastic parts. These in-

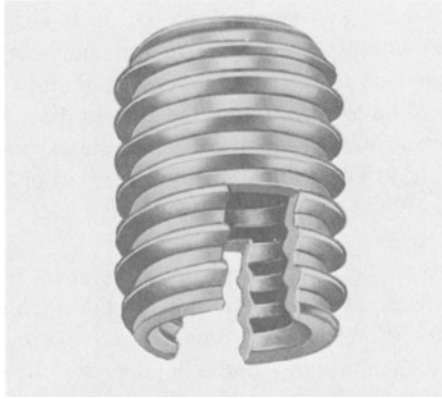


Fig. 24-29. Coarse external thread brass insert is ideal for both thermoplastics and thermoset materials. The wider thread spacing reduces the installation torque and provides stronger threads in weak or brittle plastics. Regular slotted case-hardened steel inserts are recommended if the plastic contains highly abrasive fillers. (Courtesy Groov-Pin Corp.)

serts are discussed in greater detail in Chapter 25. Basically, the major types of inserts include (1) molded-in inserts and (2) post-molding inserts.

Post-molding inserts may be subdivided into:

- *Self-tapping inserts:* There are two types of such inserts—thread-cutting and thread-forming. Thread-cutting inserts cut their own mating threads in the plastic material. They can be used in both thermoplastic and thermosetting materials. For most applications in plastics, the slotted type can be used. These inserts have coarse external threads that reduce installation torque and provide strong threads even in brittle plastics (Fig. 24-29).

In very hard plastics, or those with abrasive fillers, a case-hardened steel insert is used. This is the same type that is used in many metal applications and is available with internal locking features.

Thread-cutting inserts also are available with male threads. This self-tapping stud or male insert is useful where alignment or ease of assembly is a consideration.

Installation of thread-cutting inserts consists of two steps: drilling or coring the holes and driving the insert. Because only

two steps are needed and tapping is not required, thread-cutting inserts can be economically installed. Equipment available in most shops can be readily adapted for volume production.

Thread-forming inserts create threads by mechanically displacing material as the insert is driven.

- *Press-fit inserts* (generally knurled).
- *Expansion inserts:* These inserts are placed in predrilled or premolded holes and expanded against the walls by insertion of a screw. Torsion resistance and pullout retention are obtained by embedding the knurls into the material.
- *Inserts installed ultrasonically:* Friction caused by ultrasonic vibrations melts a thin film of resin at the metal-plastic interface. Pressure from the ultrasonic tool directs the insert into the cored or machined hole.

Standard Machine Screws. For applications where assembly and disassembly are expected to be frequent, it is generally recommended that the part design incorporate metal threaded inserts (as described above) to accept a mating threaded screw.

Where the application involves infrequent assembly (less than six times), a hole in the plastic part with machined or molded-in threads to receive the mating threaded screws can be used. Most thermoplastics can be readily machined after molding with standard metal-working tools, and this procedure is generally recommended for achieving threads below $\frac{1}{4}$ inch in diameter.

Larger internal threads may be formed by a threaded core pin that is unscrewed either manually or automatically. External threads may be formed in the mold by splitting the thread along its axis or by unscrewing the part from the mold. When a parting line or the slightest flash on the threads cannot be tolerated, the second method (unscrewing the part from the mold) must be used. Mold designs with automatic unscrewing operations are feasible.

Coarse threads can be molded more easily than fine threads and thus are preferable. Threads finer than 28 pitch or closer than class 2 should not be specified. The roots and crests

of all threads should be rounded with a 0.005 to 0.010 inch radius to reduce stress concentration and provide increased strength.

For inserting a screw-type fastener, a hand-held or automatic drill is preferred, although it can be a simple hand insertion. Many screw insertions make use of commonly available hand-held drills.

Standard taps can be used with phenolic parts. The predrilled or premolded hole should be chamfered to the maximum diameter of the thread. For threading or tapping a thermoplastic to receive a metal fastener, a slight increase over normal metal clearance is required for the difference in thermal expansion coefficients.

Self-Tapping Screws. These screws are available only in metal and are designed to produce their own mating threads when driven into a material. The unthreaded hole for a self-tapping screw can be either molded or drilled into the molding. The entering edge usually is suitably chamfered to prevent spalling.

Self-tapping screws provide a substantial cost savings by simplifying the molding operation and reducing assembly costs (molding or machining threads into the part is not necessary because the self-tapping screw forms its own). They are not recommended, however, when frequent disassembly is required. Reassembly is generally limited to about five or six times.

There are two types of such screws: thread-cutting and thread-forming. Thread-cutting screws tap or cut a mating thread as the screw is driven. They are slotted to provide a channel for disposal of chips; therefore, the depth of the hole should be slightly deeper than the screw (generally around $\frac{1}{32}$ inch) to provide a depository or reservoir for chips. Thread-cutting screws usually are suggested for use with plastics with higher flexural modulus (over 2×10^5 psi). They are used with thermosets and various high-performance engineering plastics, such as the acetals, nylon, ABS, and so on. The stress factor with thread-cutting screws is relatively low.

Thread-forming screws create threads by mechanically displacing material as the screw is driven. They are used with the more ductile thermoplastics.

In using self-tapping screws, it is best to check with the screw manufacturer and the resin supplier as to installation specifications (i.e., how close to the edge of the part to place the fastener, how wide and how deep a hole should be, etc.). These specifications vary according to the type of fasteners and the plastic involved.

Overall, the optimum hole diameter for self-tapping screws in plastic parts is the pitch diameter of the screw. Smaller hole sizes increase the stripping torque but decrease the ratio of stripping to driving torque. Both the stripping torque and the strip-drive ratio are important factors in fastener design. Larger holes reduce drive torque, strip torque, and vibration resistance.

In general, the number of screw threads engaged in the plastic is determined by the depth of the hole. The threads on the taper of a self-tapping screw provide little, if any, holding power. Therefore, the strength of a self-tapping screw is dependent upon the length of the cylinder of plastic that extends from the lowest full thread engaged in the plastic up to the top of the hole.

In designing for a self-tapping screw in thermoplastics, the taper length and the length tolerance of the screw must be subtracted from the depth of penetration available in the plastic. As a rule, the hole should be deep enough to provide a minimum of two or three full threads of engagement. The practical upper limit of hole depth is a hole deep enough to provide a stripping torque equal to the torsional strength of the screw. For fine-pitch threads, this is approximately eight to twelve threads. For coarse threads, three to eight full threads are required.

Bosses. The use of bosses may be desirable in many applications and they are quite commonly used in plastics. Bosses are protruding studs or pads used for the reinforcement of holes or for mounting and assembly. In general, when working with thermoplastics, the boss diameter is usually from two to three times the outside diameter of the screw (the average is $2\frac{1}{2}$ times). This is generally sufficient to take the possible hoop stresses developed due to screw insertion (see Fig. 24-30).

Troubleshooting Tips. The three most com-

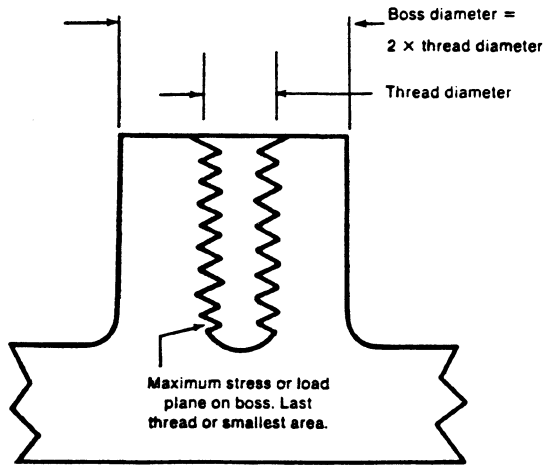


Fig. 24-30. In applications requiring the use of a metal screw and a threaded polycarbonate boss, the boss diameter must be equal to twice the thread diameter. This recommendation should generally be followed for screws up to $\frac{3}{8}$ inch. (Courtesy GE Plastics)

mon problems associated with the use of self-tapping screws in plastic parts are: (1) fracture of the part as the screw is inserted, (2) stripping of the plastic threads as the screw is inserted, and (3) loosening of the screw after a period of time.

- **Part fracture:** The basic cause of this problem is a high stress as the screw is inserted. The user should determine whether he or she is employing the right type of screw (e.g., thread-forming screws, as noted above, develop more stresses in the plastic than thread-cutting screws).

A second major cause of part fracture is the use of small-diameter holes. With a small hole, the tap of the screw takes a deeper bite into the plastic material, and this may again produce excessive stress in the boss.

- **Stripped threads in the plastic:** Often, the cause of this problem is an insufficient strip-drive ratio. The initial step in correcting this difficulty is to determine the hole size in the plastic. Larger-diameter holes yield a lower value of stripping torque but increase the strip-drive ratio.

If the hole depth in the plastic is too shallow, the screw may bottom out before the screw head seats. The hole should be deep enough to allow for the length tolerance of the screw.

If the screws are inserted with a power-driven screwdriver, the high driver speed may cause failure of the plastic thread. Slowing down the driver tends to increase the accuracy of torque setting and decrease the rate of loading of the threads in the plastic.

For some applications, a finer pitch screw may correct thread stripping, as the finer pitch is less efficient in converting applied torque to compressive loadings of the threads in the plastic. The hole size should be checked when the screw pitch is changed.

If all of the above have failed to correct the problem, redesign may be necessary. The shear area in the plastic can be increased with a larger-diameter screw, a longer screw with a deeper hole, or a larger-diameter head on the screw.

- **Screw loosening:** The common cause of this problem is insufficient thread engagement. The area of thread engagement may be increased by any or all of the following: smaller-diameter holes; longer screws and deeper holes; or screws with finer pitch. Also, a careful re-evaluation of the application environment should be made to determine that estimates of temperature and moisture conditions are valid.

Drive Screws. These screws are designed to be driven into place with an impact and are used for permanent fastening. A distinct advantage with this type of screw is alignment. Drive screws are ideal for conduit installation or other operations where installation space or alignment may be a problem. They also can be used to join thin-gauge materials (Fig. 24-31).

Bolts and Nuts. Bolts and nuts of standard configuration, made of metal or of plastic, can be used where mechanical requirements of the joined area permit.

Rivets. Rivets, made of metal or of plastic, can be used to hold parts together securely, or to hold two or more parts together and permit motion between them.

Rivets are noted for their low cost and simple mechanical installation that lends itself to automation. High clamp load or tension load is limited, and accuracy of location is not as good as with other mechanical fasteners. Rivets can

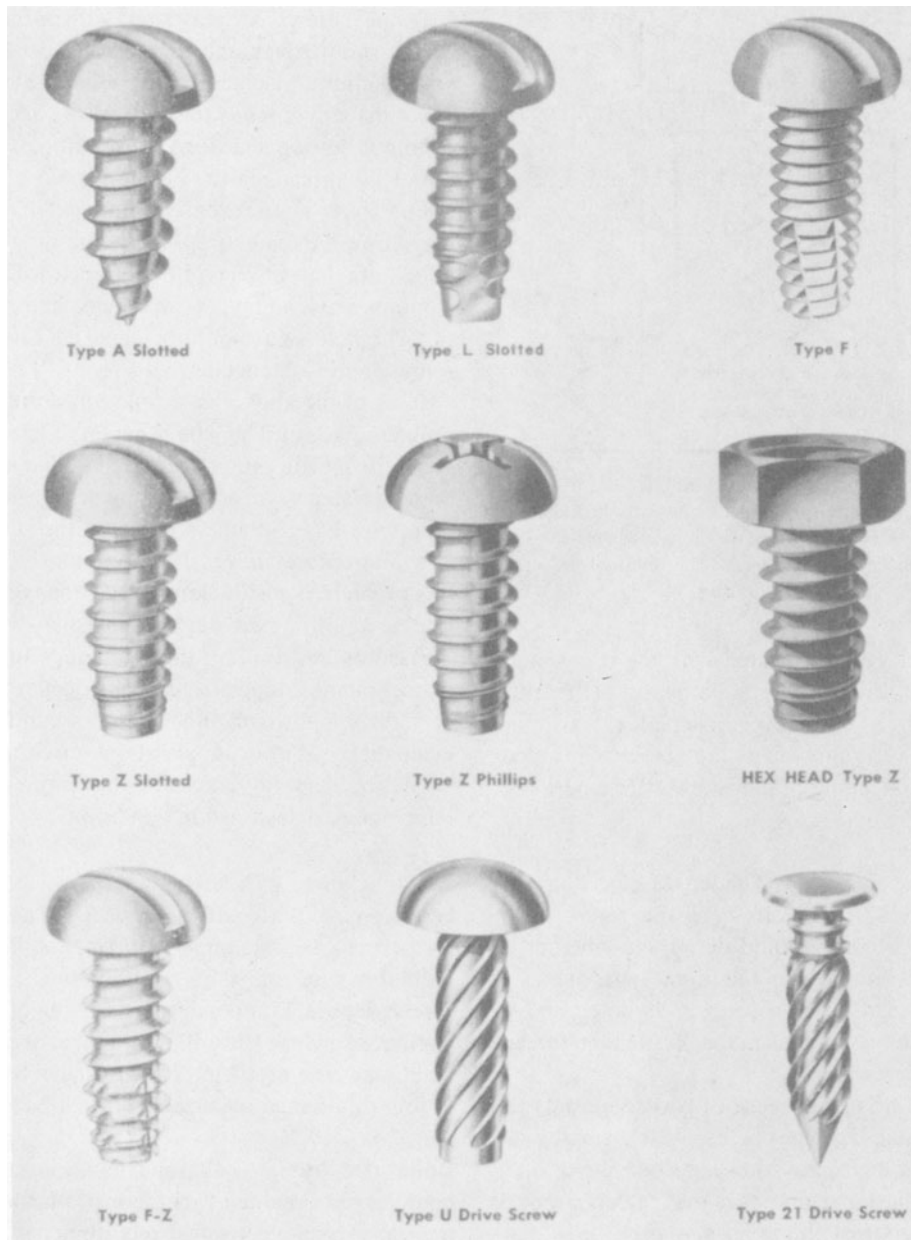


Fig. 24-31. Some typical self-tapping and drive screws. (Courtesy Parker-Kalon)

be installed to allow for dimensional change with temperature. Rivets are particularly applicable for use with plastics of high impact strength. To join very thin sections of plastics, metallic eyelets may be used instead of commercial rivets. Eyelets are particularly advantageous in providing a bushing for a rivet, or

metal shaft that must rotate in service. The eyelet minimizes wear of the plastic.

Of the rivets used in joining plastics, the blind rivet is probably the most common. Blind rivets are available in both metal and plastics, and are designed for installation from one side only. Though there are a variety of proprietary

designs for such rivets, essentially they consist of a hollow body and a solid pin. The setting of the rivet is accomplished by driving or pulling (depending on the specific rivet being considered) the solid pin through the hollow shank and thus flaring the shank on the blind side of the rivet, to effect a positive locking action (Fig. 24-32).

Chemically expanded rivets have hollow shanks in which a chemical charge is reacted to expand the hollow shank. Heat is applied to the rivet head with an approved soldering gun.

Chemically expanded metal rivets can be used for joining plastics as well as the light metals. In joining materials of relatively low

elastic moduli, such as polyethylene and polytetrafluoroethylene resin, applications are limited to those where joints of low strength are permissible because the expansion of the exploding rivet shank distorts most soft plastics.

Spring Clips and Nuts. A wide variety of proprietary metallic spring clips and nuts provides inexpensive methods of rapidly fastening plastics. They range from simple spring-type fasteners, which are forced over a molded stud, to multi-perforated rings, tubular devices, and irregular shapes. These fasteners can be applied unattached, or attached to one of the parts to be joined. If the spring device is attached to

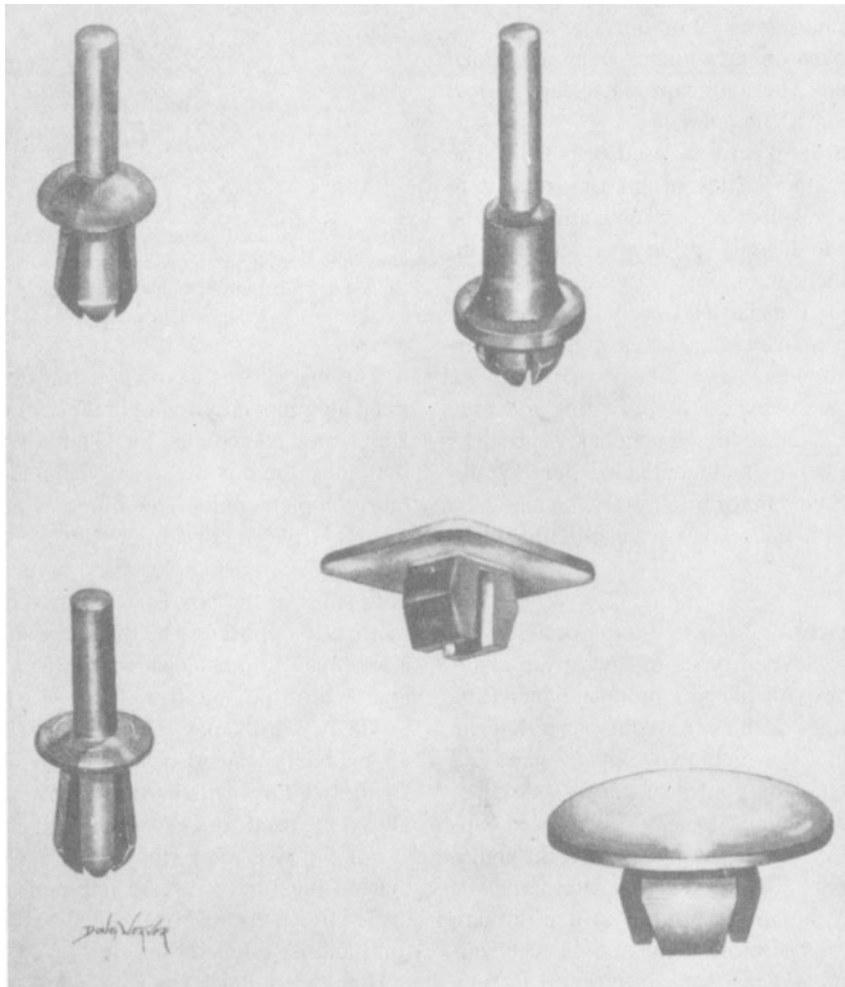


Fig. 24-32. Blind rivets. (Courtesy Shakeproof, Div. of Illinois Tool Workers)

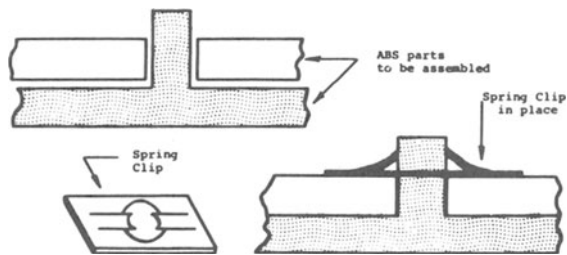


Fig. 24-33. Tinnerman spring clips to lock ABS parts together. (Courtesy GE Plastics)

one of the parts, rapid assembly can later be completed from one side only. (See Fig. 24-33.)

Speed nut stampings are used in combination with screws. The mating screw is usually of the coarse-thread sheet-metal variety. The speed nut acts to provide reinforcement and load distribution, and resists vibration. The speed clip provides push-on attachment over a molded boss or stud. The load capacity usually is low and reassembly limited.

Pins can be effectively used in plastic. The physical characteristics of plastics related to loading and residual stress propagation must be considered in design. Spring pins with their inherent resilience combine well with most plastic materials. Pins have a variety of usages such as locating and locking devices, bearing surfaces, and hinges.

A number of means of providing movable assemblies, such as hinges, latches, snap locks and bead-chain attachments, are largely derived from standard or proprietary devices used with common materials of construction other than plastics.

Other Devices.

Hinges. Several types of hinges are available for use with plastics products, including integral hinges such as those described later in this section (in which two plastics parts are joined together by a strip of plastic). Another type of integral hinge consists of a molded ball-and-socket type of hinge assembled through a snap-fit (Fig. 24-34). As an alternative, a socket may be molded for a drilled-through hole. In terms of more conventional mechanical fasteners, hinges that can be used include lug-and-pin and conventional hinge assemblies such as piano hinges.

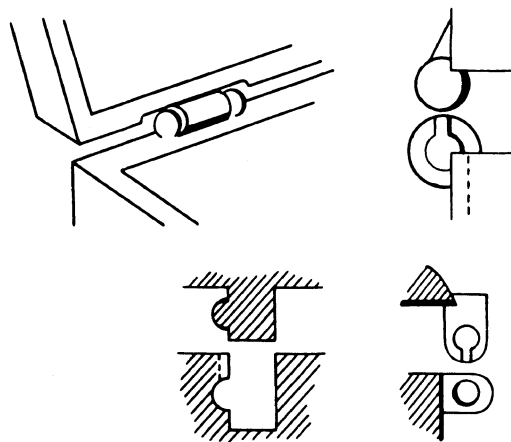


Fig. 24-34. Molded ball-and-socket type hinge assembled through a snap-fit. As an alternative, a socket may be a molded or drilled-through hole. (Courtesy Monsanto)

The lug-pin-rivet type consists of a molded male lug (generally found in the cover of a box) and a molded female slot. The cover and the bottom of the box are assembled and drilled as one complete unit. The hinge is formed by using a drive-pin or a hinge-pin.

To reduce cost, holes may be drilled from both sides of the box by using two drills, diametrically opposed. The drill unit should have a kinematic linkage, which controls the depth and feed of the hole.

The two drills may also be operated by small air cylinders instead of a mechanical linkage. Drilling fixtures with hardened bushings should always be used for best quality.

For the rivet type, the design may be such that no lugs and slots are required. A hole is drilled in the vertical wall of the cover and bottom, and is fastened by a rivet.

Hinge assemblies can be divided into hinges and snap-hinges. In some cases the usual hinge is a piano hinge screwed to the plastic cover

with drive screws or swaged to molded plastic lugs. In designing the box, however, adequate wall thickness must be allowed around the molded or drilled hole. Otherwise, assemblies may crack when the drive screws are forced into the plastic.

In addition to the piano hinge, there are shorter-type hinges assembled by riveting; also certain specialty designs are available whereby molded undercuts hold the hinge assembly to the plastic component.

Nails. As plastics continue to show up in applications originally intended for wood (e.g., furniture, shoe heels, etc.), there has been an increasing use of conventional nails as an assembly device. Many styrene structural forms used in furniture, for example, have been specially formulated to accept and hold nails. For ABS plastics used in heels, conventional wood-working equipment (i.e., a nailing machine) has been successfully used to attach the heels to the shoe. It is recommended in this latter case, however, that nails be located at least five diameters from an edge so that strains may be readily distributed.

Before using nails, however, one preferably should check first with the resin supplier. The stresses involved and the nail-holding ability of the plastic must be taken into consideration.

Swaging or Peening

Swaging or peening is commonly used to fasten or connect molded pieces or metal parts to molded thermoplastics. It can also be used to provide an upset-type head (like a common nail) on a molded shaft, pin, or vee-slot.

Swaging is useful to assemble metal to plastic, or plastic to plastic, where motion between the parts is required. This operation is best performed when the plastic is heated to a softening temperature and formed under high pressure. If the temperature is high, less pressure is needed, but the quality of the swage is reduced.

The simplest form of tool used to swage is a soldering iron. For greatest production, automation can be employed by using a kick-press or air-operated cylinder.

In addition, an air-operated indexing table can be used to feed the work and position it under the heated tips. The use of air will pro-

vide the necessary pressure and minimize operator fatigue.

The most commonly used soldering iron tips are $\frac{1}{4}$ to $\frac{5}{16}$ -inch-diameter copper. However, they are often soft and deform or bend under continued usage. Hardened brass, which has been nickel-plated and then flash-chrome-plated, is most satisfactory. The brass is easy to machine into a concave tip to control the flow. Chrome improves the life and mold release.

During swaging operations a thin film of polymer may stick to the tip. This can be removed by a wire brush or a solvent.

Standard-type mold release agents on the heated tips will minimize sticking.

Press or Shrink Fitting

These techniques are universally applicable to joining similar and dissimilar thermoplastics, and require no foreign elements such as cement or metal inserts in the finished joints. Properly applied, they produce serviceable joints with good strength at a minimum cost.

Plastics are press-fitted in the same manner as metals and other materials, but interfaces are generally increased to compensate for the relatively low elastic modulus of most plastics. For maximum joint strength, interferences should be made as large as possible without restricting assembly or stressing a piece beyond its yield point. Theoretical relationships of interference and stress level are based on geometry and the properties of the materials. Interferences can be calculated by standard stress-analysis procedures.

The relationships of maximum stress, caused by press-fitting a shaft or insert in a plastic hub, to diametral interference (ΔD) is expressed as:

$$\Delta D = \frac{S_d D_s}{L} \left[\frac{L + \mu_h}{E_h} + \frac{L - \mu_s}{E_s} \right]$$

and:

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

where:

- D = Diametral interference, inches
- S_d = Design stress, psi. Refer to AWS under "Design Parameters"
- D_h = Outside diameter of hub, inches
- D_s = Diameter of shaft, inches
- E_h = Tensile modulus of elasticity of hub, psi
- E = Modulus of elasticity of shaft, psi
- μ_h = Poisson's ratio of hub material
- μ_s = Poisson's ratio of shaft material
- L = Geometry factor

Where large interferences are not required, shrink fitting may be suitable. Interferences for shrink fitting are determined by adding shrinkage of the hub to expansion of the shaft. In some applications it may be practicable to shrink-fit immediately after molding, while the article is still hot, to eliminate the necessity for reheating the hub.

Residual joint strengths in press- or shrink-fitted articles are affected by complex variables such as apparent modulus and coefficient of friction. For most thermoplastics, variation in apparent modulus becomes negligible after a year, so that joint strength becomes constant. Because the coefficient of friction is affected by variables such as lubrication, moisture, temperature, and stress level, the coefficient under each of these conditions must be known in order to calculate accurately the strength of the joints. Axial strength and torsional strength of joints then can be calculated by standard equations. When torsional strength is critical, a ribbed shaft should be used; when axial strength is critical, rings or threads should be used. When both torsional and axial strength are critical, a knurled shaft or combinations of rings and ribs provide a good balance of properties.

When pieces are to be press-fitted for maximum holding power immediately after molding, they should be free from internal stresses, which can be reduced by annealing. Also in designing such joints, environmental conditions should be carefully considered. Expansion by heat and moisture can be compensated by designing for expected growth at the worst conditions, by considering expected expansion as

an addition to the interferences selected for the desired joint strength. In plastics, a press-fitted assembly experiences its highest level of stress immediately after fittings; subsequent environmental dimensional shrinkage usually is more than compensated by creep, and thus generally can be neglected.

Internal stresses in a press-fitted article may tend to promote crazing in some plastics such as acrylics and polystyrenes, and may reduce impact strength. Where a pressed article is expected to withstand impact it should be tested under actual conditions to determine the feasibility of this type of joint.

The force required to press-fit two parts may be approximated by using the following equation;

$$F = \pi f P D_s T$$

and:

$$P = \frac{S_d}{L}$$

where:

- F = Assembly force, lb
- f = Coefficient of friction
- P = Joint pressure, psi
- D_s = Diameter of shaft, inches
- T = Length of press-fit surfaces, inches
- S_d = Design stress, psi
- L = Geometry factor

Snap Fitting

Snap fitting is a simple and rapid means of assembly, as all the elements for assembly (i.e., undercuts and corresponding lips on the mating part) are molded directly into the products so that they are ready to be joined together as they come out of the mold. Basically, snap fits involve an undercut on one part engaging a molded lip on the other to retain the assembly.

Joints of this type are strong, but are usually not pressure-right unless other features such as an O-ring are incorporated in the joint design. The critical factor in any snap fit is the amount of undercut that can be molded or machined

into the part. Generally, undercuts can be snapped out of the mold by a standard ejection system; the critical depth of the undercut will depend upon the material chosen, the wall thickness, part configuration, and so on. Where undercuts are too deep to be ejected conventionally, collapsible cores sometimes can be used. It is also possible to machine a deep undercut into a part.

In terms of design, undercuts and mating lips on snap-fit parts may be fully cylindrical or consist of flexible cantilevered lugs. Cylindrical snap-fits are generally stronger but require greater assembly force than cantilevered-lug snap-fits. For complex parts, the use of cantilevered lugs may simplify molding the parts.

The two general types of snap fits are the snap-on and the snap-in. The snap-on is accomplished by molding an undercut on one part and a corresponding lip on the mating part (Fig. 24-35). The snap-in fittings generally incorporate molded-in prongs on one part that are pressed through holes in the mating part.

The force required to assemble parts by snap fitting depends upon part geometry and on the coefficient of friction between the materials. This force may be divided arbitrarily into two elements—the force required initially to expand the hub, and the force required to overcome friction during the press-fit stage. As the beveled edges slide past each other, the maximum force for the expansion occurs at the point of maximum hub expansion and is approximated by:

$$F_e = \frac{(1 + f) \tan(\alpha) S_d \pi D_s L_h}{W}$$

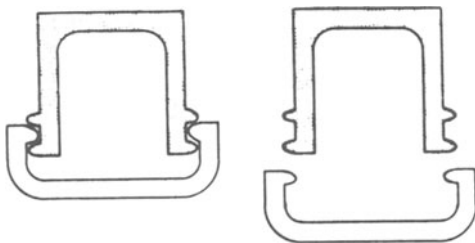


Fig. 24-35. Snap-on fit is accomplished by molding an undercut on one part and a corresponding lip in the mating part. (Courtesy GE Plastics)

where:

F_e = Expansion force, lb (kg)

f = Coefficient of friction

α = Angle of beveled surfaces

S_d = Stress due to interference, psi
(kg/cm²)

D_s = Shaft diameter, inches (cm)

L_h = Length of hub expanded, inches (cm)

W = Geometry factor

For blind hubs, the length of hub expanded, L_h , may be approximated by twice the shaft diameter. For short open hubs such as in pulleys, the length of hub expanded will equal the axial hub length. For other part geometries or where greater accuracy is required, tests on actual parts are recommended. The force required to overcome friction during the press-fit stage is approximated by:

$$F_f = \frac{f S_d L_s}{W}$$

where:

F_f = Friction force, lb (kg)

f = Coefficient of friction

S_d = Stress due to interference, psi
(kg/cm²)

D_s = Shaft diameter, inches (cm)

L_s = Length of interference sliding surface,
inches (cm)

W = Geometry factor

Generally, the friction force is less than the force for hub expansion for most assemblies.

Integral Hinges

Integral hinges offer a great potential for savings. Because they are molded into the item, they cost almost nothing to produce and eliminate much of the assembly cost with standard hinges.

Many approaches can be used. One basic style is the knuckle-and-pin design, in which the set of knuckles that make up the hinge pivot on an axial pin. The knuckles can be either hooks or eyes or a combination of the two. The

hook-and-eye combination does not require a pin, but the hinge can disengage if the cover is swung back too far.

A popular hinge, widely used on small boxes, is the ball-grip design. One half of the hinge consists of two balls, which snap into depressions in a projection molded into the mating part.

Still another approach is the integral strap hinge. The top and base are molded simultaneously, connected by straps spaced along one edge. A typical strap is about 0.25 inch wide and 0.35 inch thick.

The living hinge, made possible by polypropylene, has become extremely popular. This design is much neater in appearance than the strap hinge and is much longer-lived. Properly designed, a living hinge will flex over 300,000 times without failure.

Techniques used to fabricate integral hinges include: molded-in, cold-worked, extruded, and coined, as described below.*

Molded-In. The integral hinge can be injection molded by conventional techniques, provided that certain factors are kept in mind.

The desirable molecular orientation is transverse to the hinge axis. This can be best achieved by fast flow through the hinge section using high melt temperatures. Because these requirements are consistent with good molding practices, optimum production rates can be maintained.

The main concern in integral-hinge molding is to avoid conditions that can lead to delamination of the hinge section. These include filling too slowly; too low a melt temperature; a nonuniform flow-front through the hinge section; material contamination such as pigment agglomerates; and excessively high mold temperatures near the hinge area.

The integral hinge also can be produced by post-mold flexing. The hinge section is molded, then subjected to stresses beyond the yield point immediately after molding by closing the hinge, which creates a "necking-down" effect. Stretching the oriented polymer molecules on the outer surface of the hinge radius provides

the remarkable flex strength of the thinned-down hinge section.

Flexing of the molded hinge must be done while it is still hot, through an angle sufficient to stress its outer fibers. This post-molding step provides maximum and uniform orientation in the hinge area with a minimum of applied stresses. The thinness of the hinge area requires that pigments be well dispersed so that agglomerates will not provide focal points of weakness in the hinge structure.

Cold-Worked. Where parts are heavy or complex, it may be impractical to force the necessary quantity of resin through the hinge sections. In these cases, integral hinges can be obtained by cold-working the molded parts. With this process, the molecules are properly oriented during forming; so the direction of polymer flow in molding is not critical.

A press, home-made toggle job, or hot-stamping machine can be used to perform the cold-working operation. The male forming die should be at about 270 to 280°F. Pressure is maintained for about 10 seconds although the time can be reduced if the part still retains residual molding heat or is preheated. The recommended preheating temperature is from 175 to 230°F.

Die backings may be either hard or flexible. With a hard backing such as steel, the softened polypropylene is die-formed into the desired hinge contour. Thinner hinges usually are made by using flexible backing such as a stiff rubber. The deformation of this type of backing produces the hinge contour by stretching the softened plastic, and it generally results in thinner cross sections.

Extruded. Formation of the hinge cross section by use of an extruder die results in a hinge with a poor flex-life. Because hinges are formed in the direction of polymer flow, they cannot be sufficiently oriented when flexed. However, if the extruded hinge is formed by the takeoff mechanism while the polypropylene retains internal heat, the hinge will have properties approaching those of cold working.

Cold-Forming or Coining Hinges. It is possible to create hinges in some of the tougher

*Information supplied by Exxon Chemical Co.

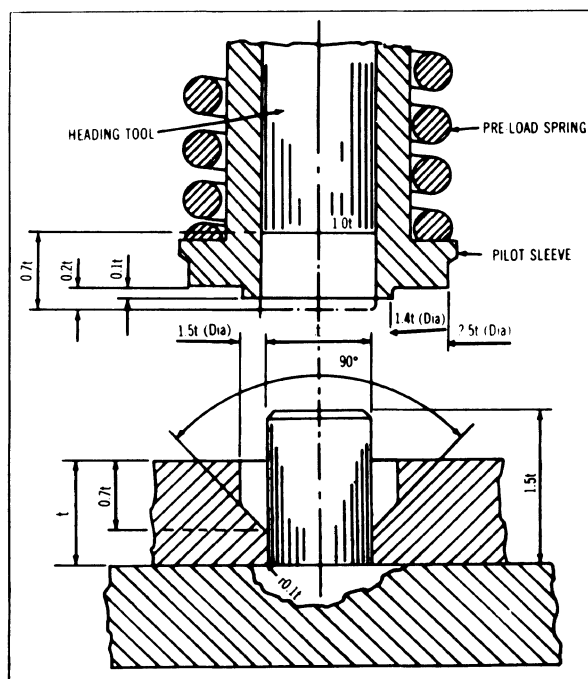


Fig. 24-36. Cold heading of acetal. (Courtesy E. I. du Pont de Nemours & Co., Inc.)

engineering thermoplastics by coining techniques. A molded or extruded part is placed in a fixture between two coining bars. Pressure is applied to the bars, and the part is compressed to the desired thickness, elongating the plastic. Coining is effective only when the material is elongated beyond the tensile yield point. The process usually is used for such materials as acetal and nylon, which cannot normally be molded in a sufficiently thin section for a strong, durable hinge.

Cold or Hot Heading

This technique is useful for joining thermoplastics to similar or dissimilar materials.

In cold heading or staking, a compression load is applied to the end of a plastic shaft (while holding and containing the shaft body). As the load exceeds the shaft's yield strength, the shaft (or stake) will cold-flow, forming a rivet-like head. The shaft, of course, can be molded right onto the part itself to facilitate assembly, or a separate shaft can be used to join two components together. In this case, double heading of the shaft (at each end) is required.

Cold staking is normally done at room temperature (73°F). However, if a head is formed at a higher temperature than is expected in use, it will not recover unless the temperature at which it was formed is exceeded.

Cold staking may be accomplished by using equipment ranging from a simple arbor press and hand vise to rivet-setting machines (Fig. 24-36).

Hot staking is similar to the cold staking method. It is accomplished by using a heated (400–500°F) flaring tool. This tool is frequently concave in shape, and will effectively form a rivet-like head.

AUTOMATION

As is evidenced by the coverage of secondary processing operations (machining, finishing, joining, decorating) in this handbook, automated procedures are of considerable importance. It is appropriate, then, to conclude this chapter with a few words on the subject.

In each of the chapters on secondary processing, we note the availability of automatic equipment to mark, decorate, seal, join, drill,

and so on. To automate these operations, it is necessary to devise automatic systems for removing parts from the mold, orienting them so that they will be in the proper physical position to be fed to the machine, mounting the parts appropriately, and then feeding or transferring them to the automatic secondary processing unit.

Robots

One way to keep parts under control as they are taken from the mold is to use either an automatic extractor or a robot (if parts are allowed to fall free or are otherwise ejected, some means must be added to unscramble and orient them for proper feeding). Robots are expected to influence many segments of the plastics industry. Thus far, the main functions of robots have been in loading and unloading molding machines, in orienting the molded parts for secondary operations, in applying paints and coatings, and even in spraying up fibrous glass for reinforced plastic parts.

Using hydraulically controlled "hands" or grippers, a robot can perform most of the highly repetitive simple operations that humans can. Some of the more advanced types can handle a number of different articulations or movements. For a more complete discussion of robotic parts handling, the reader is referred to Chapter 21 of this handbook.

Feeding Parts

If parts are not assembled immediately after being removed from the molding machine by a robot, they will have to be fed into position by other mechanical means. If orientation is required, the parts must have a molded-in device that can be sensed by the feeder and used to

position the article correctly. The device can be a projection, a flat, or a slot on the part.

Parts can be fed through tracks to an assembly unit end to end or side by side, using gravity or a vibratory feeder, depending on the shape of the piece. The tracks can be as simple as rods (for parts with holes in the center) or hollow tubes (for cylindrical items). For parts with heads or flanges, the track may have rails to allow them to travel in a hanging position. When several different parts are assembled, each will require its own feeding device, including hopper or vibratory feed bowl, track, and placement tooling.

Indexing Units

Although constantly moving conveyors or rotating table sometimes are used for parts assembly, most operations require intermittent motion. One of the most widely used assembly methods is the rotary indexing table, which revolves 360° in a number of steps, depending on how many stations are required. For example, a six-station table will rotate 60° at a time. The first and last stations are usually for loading and unloading, and the remainder are for the various assembly steps.

Rotary tables can be powered pneumatically or mechanically. Air-powered units are lower in cost, but their abrupt start-and-stop motion may not be suitable for all jobs. Mechanically driven tables use cams to regulate acceleration and deceleration for smooth operation.

Where more working room is required, linear indexing units can be used. The number of stations and the space allotted to each are limited only by the length of the belt. As with the rotaries, the drive system can range from simple (ratchet) to sophisticated (servo), depending on the need for accuracy in positioning.