

## 27 Polycarbonate

### 27.1 General

#### Altuglas International: Tuffak (form: sheet)

Table 27.1 shows an overall comparison of joining methods for Tuffak polycarbonate sheet.

**Reference:** *Tuffak Polycarbonate Sheet. Forming and Fabrication*, Supplier design guide (ADV980496/APL:ATG-16S/web/6-00), Altuglas International, 2000.

#### Dow Chemical: Calibre (features: transparent)

Assembly methods for parts made of Calibre polycarbonate are numerous, ranging from relatively simple mechanical fits to complex welding operations. Calibre polycarbonates provide for superior solvent and adhesive bonding; their rigidity permits ultrasonic and vibration welding.

Each of the assembly methods used for parts of Calibre polycarbonate has its advantages and disadvantages. The decision of which method is best suited for a particular application should be based on several factors: product requirements, technical expertise, production requirements, equipment availability, and costs. It is important to consider all these factors during the product design stage, so that the parts and tooling can be designed to meet the assembly needs.

Calibre polycarbonate is an ideal material for various welding techniques because of its amorphous structure. That structure results in a material that is rigid, and has a broad softening temperature range. Also, because it is noncrystallizing, polycarbonate is welded without acquiring thermal stresses. These properties qualify Calibre resins for both vibrational (frictional) and direct-heat welding.

**Table 27.1.** Overall Comparison of Joining Methods for Tuffak Polycarbonate Sheet

Method of Joining	Solvent Cement	Adhesive Bonding	Self-tapping Screws	Medium Screws	Rivets	Hot Gas Welding	Hot Blade/Plate Welding	Ultrasonic Welding	Vibration Welding	Spin Welding	Ratings Legends	
											10=	1=
Tensile strength	8	4	10	10	10	10	10	10	10	10	Parent material strength	Poor
Speed	3	2	2	1	3	2	7	10	6	6	Fast	Slow
Tooling	–	1	1	1	3	5	7	8	8	5	Costly	Inexpensive
Labor	1	2	2	1	3	2	9	10	9	10	High	Low
Capital investment	1	1	2	2	2	4	6	9	8	5	Highest	Lowest
Cosmetic appearance	10	3	5	5	5	2	8	9	9	8	Best	Worst
Setup preparation	1	2	3	3	3	6	8	8	7	5	Long	Short
Part size	10	10	10	10	10	8	6	2	4	6	Unlimited	Small
Dissimilar materials	Yes	Yes	Yes	Yes	Yes	?	No	No	Ok	No		
Part design	9	10	10	10	10	5	6	1	8	3	Simple	Limited complex
Cost of materials	9	6	4	1	3	10	10	10	10	10	Most expensive	Least expensive

**Reference:** *Calibre Engineering Thermoplastics Basic Design Manual*, Supplier design guide (301-1040-1288), Dow Chemical Company, 1988.

## 27.2 Heated Tool Welding

### Bayer: Apec, Makrolon

The recommended hot plate welding parameters for Apec polycarbonate are:

- Hot plate temperature: 280–410°C (536–770°F)
- Joining pressure: 0.1–0.9 N/mm<sup>2</sup> (14.5–130 psi)

The recommended hot plate welding parameters for Makrolon polycarbonate are:

- Hot plate temperature: 250–410°C (482–770°F)
- Joining pressure: 0.1–0.9 N/mm<sup>2</sup> (14.5–130 psi)

**Reference:** *Hot Plate Welding*, Supplier design guide, Bayer MaterialScience AG, 2007.

### GE Plastics: Lexan 141

The thickness of the HAZ was approximately 2.5 mm (1 inch) for hot plate welds made using the following welding parameters:

- Hot plate temperature: 516 K (469°F)
- Matching time: 10 seconds
- Matching pressure: 659.3 kPa (95.6 psi)
- Heating time: 35 seconds
- Change-over time: 1.5 seconds
- Forging time: 60 seconds
- Forging pressure: 741.7 kPa (107.6 psi)

**Reference:** Krishnan C, Toussant D, Benatar A: Comparison of weld morphology of polycarbonate and polypropylene for hot plate, vibration and ultrasonic welding. ANTEC 2004, Conference proceedings, Society of Plastics Engineers, Chicago, May 2004.

### Bayer: Makrolon

For polycarbonate sheet sealing, the surface temperature of the blade should be about 550–650°F (290–345°C). You need to regulate the speed of the heated element so that the surfaces to be joined reach a

temperature of about 450°F (230°C). Then they are immediately pressed together at a contact pressure of about 100 psi (690 kPa) and held together for a few seconds until the bond solidifies.

**Reference:** *Engineering Polymers. Joining Techniques. A Design Guide*, Supplier design guide (5241 (7.5M) 3/01), Bayer Corporation, 2001.

### Polycarbonate (form: 3 mm (0.118 inch) thick sheet)

With increasing melt layer thickness, hence an increasing hot plate temperature and/or heating time, there was an increase in the component's susceptibility to stress cracking. As far as process control is concerned, this means the lowest possible heating times and hot plate temperatures should be selected. This is not, however, in the interests of the cost efficiency of the process, and the additional costs incurred through increased cycle time must be set against the costs of heated component storage subsequent to the welding process.

**Reference:** Potente H, Schnieders J: Influence of process parameters on the phenomenon of stress cracking during hot plate welding. ANTEC 2000, Conference proceedings, Society of Plastics Engineers, Orlando, May 2000.

### GE Plastics: Lexan 9030 (form: extruded sheet)

Test specimens were cut from 3.0, 5.8, and 12.0 mm (0.12, 0.23, and 0.47 inch) thick extruded sheet. Welds were made using melt and weld penetrations of 0.13 and 0.66 mm (0.005 and 0.026 inches), respectively, a hot plate temperature of 245°C (473°F) and a seal time of 10 seconds.

Bubbles could be seen in all the welds, concentrated around the central weld plane. They were elongated by the squeeze flow and tended to be larger near the edges. For each thickness, the weld zone thickness increased with the melt time.

**Reference:** Stokes VK: Comparison of the morphologies of hot-tool and vibration welds of thermoplastics. ANTEC 1999, Conference proceedings, Society of Plastics Engineers, New York, May 1999.

### GE Plastics: Lexan 9030 (form: extruded sheet)

In this study, it was shown that high strengths can be attained in hot tool welds of both undried and dried specimens of polycarbonate. However, the hot tool temperature window for attaining high weld strengths

is very wide for dried specimens but quite narrow for the undried specimens. The thickness of the part does have a small effect—with increasing part thickness, the optimum temperature process window appears to shift to higher temperatures. A higher weld penetration appears to result in a higher weld strength. An increase in the heating time appears to reduce the hot tool temperature required for obtaining high weld strengths.

Within the weld parameters studied in the undried material, the highest weld strengths, equal to that of the base material, were obtained at the following conditions:

- For 3 mm (0.12 inch) thick specimens:
  - Hot tool temperature 260–290°C (500–554°F); heating time 10 seconds
  - Hot tool temperature 245–290°C (473–554°F); heating time 15 seconds
  - Hot tool temperature 230–275°C (446–527°F); heating time 20 seconds
- For 5.8 mm (0.23 inch) thick specimens:
  - Hot tool temperature 275–305°C (527–581°F); heating time 10 seconds
  - Hot tool temperature 275–290°C (527–554°F); heating time 15 seconds
  - Hot tool temperature 245°C (473°F); heating time 20 seconds
- For 12 mm (0.47 inch) thick specimens:
  - Hot tool temperature 260–275°C (500–527°F); heating time 10 seconds
  - Hot tool temperature 245–275°C (473–527°F); heating time 15 seconds
  - Hot tool temperature 245–275°C (473–527°F); heating time 20 seconds

Based on repeat tests, consistently high weld strengths were demonstrated in 5.8 mm (0.23 inch) thick specimens at a hot tool temperature of 275°C (527°F) and a heating time of 10 seconds, and a hot tool temperature of 245°C (473°F) and heating times of 15 and 20 seconds.

One interesting result was that very high weld strengths, equal to that of the base material, could be obtained in the presence of bubbles in the weld zone. A small number of large bubbles did not have much effect. However, a large number of small bubbles did result in reduced strength.

While hot tool welding can produce strong welds, it requires careful dimensional and temperature control, and a continuous cleaning of the hot-tool surface.

**Reference:** Stokes VK: A phenomenological study of the hot-tool welding of thermoplastics. Part 1: polycarbonate. *Polymer*, 40, p. 6235, 1999.

### GE Plastics: Lexan 9030 (form: sheet)

High strengths can be attained in hot tool welds between very dissimilar materials. In hot-tool welds of polycarbonate to the semicrystalline polyester PBT, weld strengths equal to that of PBT are obtainable. The use of different hot-tool temperatures is important for obtaining high strengths in welds between dissimilar materials. The hot-tool temperatures varied from 232–316°C (450–600°F) for polycarbonate and from 246–316°C (475–600°F) for PBT. In addition to the hot tool temperatures, the weld strength also depends on the melt time. The highest weld strengths were attained at the longer melt time of 20 seconds. The very high weld strengths obtained for hot tool welding are consistent with those obtained in vibration welds of these two materials.

Although the two immiscible, amorphous polymers polycarbonate and polyetherimide have glass transition temperatures of 150°C (302°F) and 215°C (419°F), respectively, weld strengths comparable to the strength of polycarbonate can be attained. The use of different hot-tool temperatures is important for obtaining high strengths in welds between dissimilar materials. In addition to the hot-tool temperatures, the weld strength also depends on the melt time.

High relative strengths are obtained for heated tool temperatures in the range of 575–625°F (302–329°C) for polycarbonate and 700–750°F (371–399°C) for polyetherimide. Relative strengths (weld strength/strength of polycarbonate) of 0.83 can be attained. This is lower than the 0.95 relative strength obtained in vibration welds. Relative strengths at a polyetherimide heated tool temperature of 800°F (427°C) appear to vary erratically. This could be due to degradation of polyetherimide at this high temperature and deposits on the hot plate surfaces affecting the cleanliness of the molten plastic layers.

**Reference:** Stokes VK: Experiments on the hot-tool welding of dissimilar thermoplastics. ANTEC 1993, Conference proceedings, Society of Plastics Engineers, New Orleans, May 1993.

### Bayer: Makrolon

Makrolon polycarbonate may be heat welded and sealed, following procedures similar to those used for other plastics.

Parts molded of Makrolon polycarbonate resin to be joined by heat welding or sealing must be predried at 250°F (121°C) if maximum bond strengths are to be obtained. Drying times at this temperature are dependent on part thickness.

**Reference:** *Makrolon Polycarbonate—A Guide for Joining Techniques*, Supplier design guide (55-A664(10)C), Bayer, 1987.

## 27.3 Ultrasonic Welding

### Bayer: Makrolon; Apec

At a frequency of 20 kHz, an amplitude of 25–40  $\mu\text{m}$  (0.0010–0.0016 inches) is recommended for ultrasonic welding of Makrolon and Apec polycarbonate.

**Reference:** *Ultrasonic Welding*, Supplier design guide, Bayer MaterialScience AG, 2007.

### GE Plastics: Lexan 141

The size of the HAZ was approximately 200  $\mu\text{m}$  (0.008 inches) for ultrasonic welds made using the following welding parameters:

- Weld time: 0.3 seconds
- Hold time: 2.0 seconds
- Booster: 2:1
- G-pressure: 275.8 kPa (40 psi)

Due to the rapid heating and cooling, very high stresses were developed during ultrasonic welding.

**Reference:** Krishnan C, Toussant D, Benatar A: Comparison of weld morphology of polycarbonate and polypropylene for hot plate, vibration and ultrasonic welding. ANTEC 2004, Conference proceedings, Society of Plastics Engineers, Chicago, May 2004.

### Bayer: Makrolon DP1-1456 (features: impact-modified, high-flow)

Injection-molded tensile bars with and without a 90° energy director were ultrasonically welded using four different welding modes: time, depth reference point numeric (RPN), energy, and absolute distance. Results showed that impact-modified, high-flow polycarbonate parts can be welded successfully under a variety of welding conditions.

**Reference:** Chung JYJ: Effects of ultrasonic welding conditions on weld strength of impact-modified, high-flow polycarbonate. ANTEC 1997, Conference proceedings, Society of Plastics Engineers, Toronto, May 1997.

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This study concluded that amplitude profiling promotes stronger ultrasonic welds in polycarbonate due to reduced residual stresses and increased molecular randomness. Amplitude profiling does not reduce polymer degradation. This was shown by comparing the molecular weights of welded material to those of the as molded material (unwelded sample).

The relationship of weld strength and weld/hold force for the materials was studied. It is seen that weld strength is generally inversely proportional to weld force. High weld force promotes strong molecular alignment and results in weaker welds. At the lower weld forces (<455 N; 102 lbf) this relationship does not hold true due to sample warpage. By varying the force during the weld cycle, it was found that both short cycle times and strong welds could be achieved simultaneously. Force profiling results in maximized weld strengths while the weld time was decreased by 43% for polycarbonate. In polycarbonate, the weld strength did not increase with force profiling since the final weld force is low and allows the polymer chains to solidify in a relaxed state.

When both amplitude and force profiling are used, increased strength and decreased weld time result compared to welds made without any profiling. The increased strength comes from the reduced molecular alignment. The reduced cycle time is a result of using high weld forces to initiate the weld. In summary, a relatively high amplitude and force is used to start the weld quickly and a relatively low amplitude and force is used to complete the weld with minimal molecular alignment.

**Reference:** Grewell DA: Amplitude and force profiling: studies in ultrasonic welding of thermoplastics. ANTEC 1996, Conference proceedings, Society of Plastics Engineers, Indianapolis, May 1996.

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Ultrasonic welding is a very complex process that is difficult to control. Two approaches for improving the control of ultrasonic welding were investigated—power threshold control and closed-loop power tracking. Power threshold control relies on the rapid rise in power that is observed near the end of welding for triggering a shutoff of the ultrasonic vibration. For closed-loop power tracking of a preset power curve, the amplitude of vibration is varied in real time in order to impose a power curve that is known experimentally to produce good joints. For polycarbonate, these two approaches were equal to the energy mode and displacement mode in producing strong joints with low standard deviations. The time mode was less effective in producing strong joints for polycarbonate.

The effect of hold pressure on joint strength was also evaluated. As is the case for hot plate welding, decreasing the hold pressure prior to the end of welding improved the joint strength substantially while decreasing the standard deviation. Lower hold pressures result in reduced squeeze out of the molten polymer, thereby permitting more time for intermolecular diffusion.



Also, the lower pressure reduces the molecular orientation that develops parallel to the welds, thereby improving the joint strength.

**Reference:** He F: Effect of amplitude and pressure control on the strength of ultrasonically welded thermoplastics. ANTEC 1996, Conference proceedings, Society of Plastics Engineers, Indianapolis, May 1996.

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In this ultrasonic welding study, welding profiles used were a constant amplitude profile, and three amplitude profiles including: an inclining curve, a declining curve, and a pyramid curve. These profiles were used to weld a shear joint in a part made of polycarbonate. The responses that were used to evaluate each curve were flash, tensile strength, and tensile strength standard deviation. Since all of the curves provided tensile results that were both acceptable and comparable, the most important response was determined to be the amount of flash. This was the response that was used as the basis for evaluating how each curve affected the welding of a shear joint.

From the results obtained, the curve which leads to the least amount of flash was the decline curve. It can be theorized that the reason for this was that the high initial amplitude generated enough heat to create a good melt front. Then as amplitude tapered off, there was less energy being put into the part and consequently less flash was squeezed out. Since a good melt front was generated, the parts welded together very nicely. This led to a strong weld which had less flash. This theory can also be seen less dramatically in the results obtained from the pyramid curve. The pyramid curve had the second lowest amount of flash generated. Like the declining curve, the pyramid curve ended with a declining amplitude and, therefore generated less flash. But, since the amplitude was minimal at the beginning of the pyramid curve, there was not as good a melt front created and therefore, the tensile breaking force was a little less than the declining curve, but still relatively strong.

The opposite of this theory can be seen when investigating the results obtained from the inclining curve and the constant amplitude curve. These curves led to significantly higher amounts of flash than the declining or pyramid curves. The constant amplitude curve showed somewhat similar results to the inclining curve: excessive flashing, but the tensile strength was less affected.

From these results, a conclusion on how different amplitude profiles affect an ultrasonically welded shear joint in a part made of polycarbonate can be drawn. It can be concluded that when ultrasonically welding a

shear joint made from polycarbonate, a declining amplitude profile will lead to less flash and still provide a strong weld.

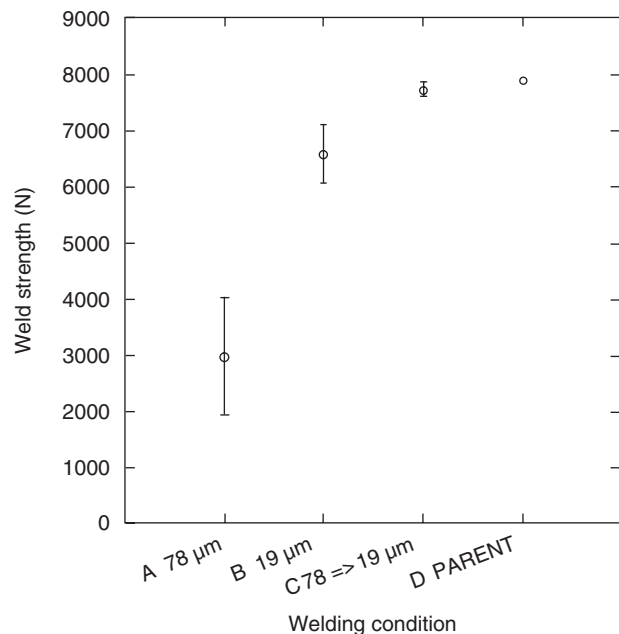
**Reference:** Ford RL, Driscoll SB: Ultrasonic welding with amplitude profiling. ANTEC 1995, Conference proceedings, Society of Plastics Engineers, Boston, May 1995.

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Using parameters indicative to industrial applications results in weld strengths of 2967 N (667 lbf) with a standard deviation of  $\pm 1041$  N (234 lbf). If the amplitude is varied, weld strengths as high as  $7735 \pm 138$  N ( $1739 \pm 31$  lbf) can be achieved, which nearly matched the parent material strength of 7850 N (1765 lbf) (Fig. 27.1). In fact, in these welds, failure usually occurred outside the weld zone when tested in tension.

It has been shown that varying the amplitude during the ultrasonic weld allows better control of the melting process. By reducing the amplitude during the welding cycle it is possible to:

- Maintain the melt within the bond line.
- Obtain stronger welds compared to welds made with a constant amplitude.
- Decrease part marking.
- Increase weld consistency.



**Figure 27.1.** Weld strength for polycarbonate test samples ultrasonically welded with various amplitude conditions. Tests with two numbers (i.e., 78  $\Rightarrow$  19  $\mu$ m) represent the use of amplitude profiling.

### *Ultrasonically Welded Hermetic Seal with No Flash Application Case Study*

The application consists of a polycarbonate tube containing a step joint. The requirements were for a hermetic seal with no flash outside the bond line. Using constant amplitude during the welding cycle, resonant modes of vibrations would develop within the parts. These modes of vibrations would result in some areas of the bond line being over-welded with flash extending outside the bond line, while other areas would not be welded. Attempts to modify the tooling to assure a uniform horn amplitude across the entire face of the horn did not improve weld consistency.

However, when the amplitude was modified, more uniform welds were obtained. Using a relatively high amplitude to initiate melting and reducing the amplitude during the cycle reduced the undesirable vibrations and allowed uniform welding. It is important to note the simultaneous change in power and velocity once the amplitude is reduced, which allows the parts to move more uniformly. The only disadvantage is a 40% increase in weld time (from 250 ms to 350 ms).

**Reference:** Grewell DA, Frantz JL: Amplitude control in ultrasonic welding of thermoplastics. ANTEC 1994, Conference proceedings, Society of Plastics Engineers, San Francisco, May 1994.

**Dow Chemical: Calibre 2061-15** (features: medical grade, transparent; melt flow index: 15 g/10 minutes); **Calibre 2080-15** (features: gamma radiation stabilized; note: high acrylonitrile content)

This study was designed to identify which resins could be effectively ultrasonically welded to themselves and other resins, and to identify the maximum bond integrity. Besides looking at the weld strength of various thermoplastic resins, this study explores the effects of gamma radiation and ethylene oxide (EtO) sterilization on the strength of these welds. A wide variety of resins used in the healthcare industry were evaluated, including: ABS, polycarbonate (PC), polycarbonate/ABS blends (PC/ABS), styrene acrylonitrile (SAN), thermoplastic polyurethanes (TPU), rigid TPUs (RTPU), high impact polystyrene (HIPS), and general purpose polystyrene (GPPS).

The strength of customized "I" beam test pieces was tested in the tensile mode to determine the original strength of each resin in the solid, nonbonded test piece configuration. Data from this base-line testing were used to determine the percent of original strength that was maintained after welding. Only amorphous resins

were used in this study. The most commonly used energy director for amorphous resins, a 90° butt joint, was used as the welding architecture.

Every attempt was made to make this a "real world" study. The aim during the welding process was to create a strong weld, while maintaining the aesthetics of the part. One of the most important factors in determining whether or not a good weld had been achieved was the amount of flash, or overrun noticed along both sides of the joint. Another characteristic of a good weld was a complete wetting of the cross-sectional weld area. The problem here, however, was that only clear polymers used as the top piece allowed the whole weld to be seen.

Almost all resins involved in the study could be welded together with some degree of success (except for thermoplastic urethanes which did not bond to the polystyrenes). Overall, it appeared that resin compatibility and the ability to transfer vibrational energy through a part, and not similar glass transition temperatures, were the overriding characteristics that lead to the best welds. Although not shown in this study, it should be noted that the ability of a resin to be welded is also a function of the architecture of the ultrasonic weld. Some resins which welded well in the architecture used for this study may not weld well with other architectures.

The PC resins bonded very well with themselves and the ABS resins. Limited success was achieved in bonding PC to the PC/ABS blend and the SAN, however, they bonded poorly or not at all with the urethanes and the polystyrenes. Statistically, the EtO and gamma sterilization did not weaken the bonds for the polymers tested in this short-term study.

**Reference:** Kingsbury RT: Ultrasonic weldability of a broad range of medical plastics. ANTEC 1991, Conference proceedings, Society of Plastics Engineers, Montreal, May 1991.

### **Dow Chemical: Calibre** (features: transparent)

Calibre polycarbonate is well-suited to ultrasonic welding. The only concerns on the use of ultrasonic welding with these resins are: high energy levels are required to melt the resin; and any contaminants on or in the resins, especially moisture and spray mold release, can result in a poor weld.

Calibre polycarbonate can be ultrasonically welded to itself or to polycarbonate/ABS alloys with excellent results. In some instances, it can be welded to acrylics, to polyphenylene-oxide based resins, and to polysulfones. Calibre polycarbonate is a good ultrasonic welding material, even when the induced vibration

must travel through a 0.25 inch (6.4 mm) thick wall to reach the joint site.

An important factor in the ultrasonic welding process is the design of the joint. Decision on the design must include the material, the part geometry, and the requirements of the product. Several standard joint designs are available to meet those needs. Calibre polycarbonate has been successfully welded using the most common “ultrasonic” joint designs, especially when an adequate energy director was used to initiate the melting process.

**Reference:** *Calibre Engineering Thermoplastics Basic Design Manual*, Supplier design guide (301-1040-1288), Dow Chemical Company, 1988.

### Bayer: Makrolon

Makrolon polycarbonate joined by ultrasonic welding can result in excellent, trouble-free bonds if done correctly. Makrolon polycarbonate may also be welded to some grades of ABS and to Bayblend polycarbonate/ABS blend.

In general, fillers such as glass do not inhibit welding. However, when glass content is 10% or higher, horn wear can occur. Poor bonding can result when glass content is 30% or more. Some external mold release agents, lubricants, and flame retardants also can adversely affect the quality of the welds.

The following points should be considered for optimum welding results:

- Be sure the horn, parts, nest, and so forth, are in true alignment to each other.
- When the joint design is a butt joint with an energy director, the energy director should be at least 0.018–0.020 inches (0.46–0.51 mm) high. The apex angle can be 60°–90°.
- A design that employs near-field welding is best.
- If a hermetic seal is required, a shear joint will give the best results.

**Reference:** *Makrolon Polycarbonate—A Guide for Joining Techniques*, Supplier design guide (55-A664(10)C), Bayer, 1987.

### GE Plastics: Lexan

Ultrasonic bonding can be utilized when Lexan resin is to be welded to itself, to some grades of ABS, and to some grades of polycarbonate alloys. The most important element in designing Lexan resin parts for ultrasonic welding is the joint design.

Weldability is dependent upon the concentration of the vibratory energy per unit area. Since Lexan resin has a higher melting point than many other thermoplastics, more energy is required to cause the material at the joint to flow. Therefore, the energy director for welding Lexan resin parts should be fairly tall with a minimum height of approximately 0.2 inches (5.1 mm) and a width of approximately 0.25 inches (6.4 mm).

Parts should be joined immediately after molding. If joined later, predrying may be necessary to provide maximum joint strength. This should be done in a hot air (250°F (121°C)) recirculating oven for one to two hours. Parts should be joined as soon as possible after removal from the oven.

**Reference:** *Lexan Design Guide*, Supplier design guide (CDC-536E), General Electric Company, 1986.

## 27.4 Vibration Welding

### Bayer: Apec, Makrolon

For linear vibration amplitudes between 0.6 and 0.9 mm (0.024–0.035 inches), and orbital vibration amplitudes between 0.4 and 0.7 mm (0.016–0.028 inches), the recommended welding pressure for Apec and Makrolon polycarbonate is between 1 and 2 N/mm<sup>2</sup> (150–300 psi).

**Reference:** *Vibration Welding*, Supplier design guide, Bayer MaterialScience AG, 2007.

### GE Plastics: Lexan 141

The size of the HAZ was approximately 260 μm (0.01 inches) for vibration welds made using the following welding parameters:

- Peak-to-peak amplitude: 0.76 mm (0.03 inches)
- Pressure: 206.84 kPa (30 psi)
- Weld time: 1 second

Much higher residual stresses were developed during vibration welding, compared to hot plate welding.

**Reference:** Krishnan C, Toussant D, Benatar A: Comparison of weld morphology of polycarbonate and polypropylene for hot plate, vibration and ultrasonic welding. ANTEC 2004, Conference proceedings, Society of Plastics Engineers, Chicago, May 2004.

### GE Plastics: Lexan 141 (form: injection-molded plaque)

This work compares the differences in weld quality between orbital and linear vibration welding of various thermoplastics. The control parameters were varied as follows:

- Amplitude: 0.76–1.8 mm (0.03–0.07 inches) peak-to-peak
- Clamping pressure: 1.0–6.9 MPa (145–1001 psi)
- Collapse: 0.76–1.8 mm (0.03–0.07 inches)

Results showed that there was little difference in the maximum weld strength between linear and orbital welding. Therefore, orbital welding enables a 30% or more reduction in cycle time without loss in maximum weld strength.

The weld strength increased rapidly with collapse and then levelled off once the steady-state phase was reached. Orbital welding required approximately 0.05 mm (0.002 inches) less collapse than linear vibration welding to achieve comparable weld strengths.

**Reference:** Grewell DA, Benatar A: An application comparison of orbital and linear vibration welding of thermoplastics. ANTEC 1999, Conference proceedings, Society of Plastics Engineers, New York, May 1999.

### GE Plastics: Lexan 9030 (form: extruded sheet)

Test specimens were cut from 3.0, 5.8, and 12.0 mm (0.12, 0.23, and 0.47 inch) thick extruded sheet. Welds were made at a frequency of 120 Hz, a weld amplitude of 1.59 mm (0.063 inches), a nominal penetration of 0.5 mm (0.02 inches) and weld pressures between 0.52 and 13.79 MPa (75–2000 psi).

At the lowest weld pressure (0.52 MPa; 75 psi), gas bubbles could be seen in the central weld plane; the density of bubbles increased from the center to the edges. At 0.9 MPa (131 psi), the bubbles were confined to the outer edges of the specimen. At higher pressures, no bubbles could be seen in the weld zone. The thickness of the weld zone decreased with increasing weld pressure.

**Reference:** Stokes VK: Comparison of the morphologies of hot-tool and vibration welds of thermoplastics. ANTEC 1999, Conference proceedings, Society of Plastics Engineers, New York, May 1999.

### GE Plastics: Lexan 9030 (form: extruded sheet)

Under the right conditions, very high weld strengths can be achieved in 120 Hz cross-thickness welds of PC, with weld strengths equal to the base resin.

Cross-thickness welds do not necessarily attain the highest strengths at the process conditions under which normal-mode welds have high strengths. Therefore, optimum weld conditions for low frequency (120 Hz) welds must be based on cross-thickness weld data.

At a welding frequency of 120 Hz, the cross-thickness weld strength increases with the weld amplitude and the weld pressure. The strength appears to continue to increase with the penetration up to a threshold penetration, which is higher than the threshold for normal-mode vibration welding of PC. This can be explained by the fact that in cross-thickness welds, steady-state conditions are attained at larger penetrations—of the order of 0.3 mm (0.012 inches)—than for the normal mode welds. Under the right conditions, weld strengths equal to the strength of PC can be achieved. For a weld pressure of 3.45 MPa (500 psi), a penetration of 0.25 mm (0.01 inches) should result in very high strengths.

At the higher frequency of 250 Hz, excellent cross-thickness weld strength can be achieved in PC, and the optimum conditions are the same as for normal-mode welds.

**Reference:** Stokes VK: Cross-thickness vibration welding of polycarbonate, polyetherimide, poly(butylene terephthalate) and modified polyphenylene oxide. *Polymer Engineering and Science*, 37(4), p. 715, April 1997.

### GE Plastics: Polycarbonate

Achievable strengths of vibration welds of polycarbonate to itself and other thermoplastics are given in Table 27.2.

**Reference:** Stokes VK: Toward a weld-strength data base for vibration welding of thermoplastics. ANTEC 1995, Conference proceedings, Society of Plastics Engineers, Boston, May 1995.

### GE Plastics: Lexan 9030 (features: 5.8 mm (0.228 inches) thick; form: sheet)

Under the right conditions, the strengths of cross-thickness vibration welds of polycarbonate (PC) can equal the strength of PC. This is achieved for example, for 120 Hz welds at a weld pressure of 3.45 MPa (500 psi), amplitudes greater than 1.27 mm (0.05 inches), and penetrations greater than 0.25 mm (0.01 inches). For an amplitude of 0.95 mm (0.037 inches), all other conditions remaining the same, it may also be possible to achieve very high weld strengths at higher penetrations, but more data are required to confirm this.

**Reference:** Stokes VK: Cross-thickness vibration welding of thermoplastics. ANTEC 1992, Conference proceedings, Society of Plastics Engineers, Detroit, May 1992.



**Table 27.2.** Achievable Strengths of Vibration Welds of Polycarbonate to Itself and Other Thermoplastics

Material Family	PC							
Tensile strength <sup>b</sup> , MPa (ksi)	68 (9.9)							
Elongation @ break <sup>b</sup> , %	6							
Specimen thickness, mm (in.)	6.3 (0.25)	6.3 (0.25)	6.3 (0.25)	6.3 (0.25)	6.3 (0.25)	3.2 (0.125)	6.3 (0.25)	6.3 (0.25)
Mating Material								
Material family <sup>a</sup>	ABS	M-PPO	M-PPO/ PA	PC	PBT	PC/ABS	PC/ PBT	PEI
Tensile strength <sup>b</sup> , MPa (ksi)	44 (6.4)	45.5 (6.6)	58 (8.5)	68 (9.9)	65 (9.5)	60 (8.7)	50 (7.3)	119 (17.3)
Elongation @ break <sup>b</sup> , %	2.2	2.5	>18	6	3.5	4.5		6
Specimen thickness, mm (in.)	6.3 (0.25)	6.3 (0.25)	6.3 (0.25)	6.3 (0.25)	6.3 (0.25)	3.2 (0.125)	6.3 (0.25)	6.3 (0.25)
Process Parameters								
Process type	Vibration welding							
Weld frequency	120 Hz							
Welded Joint Properties								
Weld factor (weld strength/weaker virgin material strength)	0.83	0.24	0.29	1.0	1.0	0.7	1.0	0.95
Elongation @ Break <sup>b</sup> , % (nominal)	1.7	0.4	0.75	6	1.7	1.8	4.9	2.75

<sup>a</sup>ABS: acrylonitrile-butadiene-styrene copolymer; M-PPO: modified polyphenylene oxide; M-PPO/PA: modified polyphenylene oxide/polyamide alloy; PC: polycarbonate; PBT: polybutylene terephthalate polyester; PC/ABS: polycarbonate/ABS alloy; PC/PBT: polycarbonate/PBT alloy; PEI: polyetherimide.

<sup>b</sup>Strain rate of  $10^{-2} \text{ s}^{-1}$ .

### GE Plastics: Lexan 9030 (form: sheet)

In the vibration welding of polycarbonate, the overall cycle time will increase with increasing part thickness for fixed weld parameters (frequency, amplitude, and pressure), due to an increase in the times spanned by Phases II–IV of the welding process. The penetration at which steady-state conditions are attained (and hence the threshold penetration) increases with specimen thickness, but decreases with increasing weld pressure. Therefore, cycle times can be reduced by increasing the weld pressure.

Low weld pressures not only result in increased cycle times, but can result in unacceptably high threshold penetrations. For example, while a pressure of 0.9 MPa (130 psi) results in acceptable cycle times and threshold penetrations for part thicknesses below 5.8 mm (0.228 inches), higher pressures are indicated for thicknesses equal to 12.3 mm (0.484 inches). If penetration-based controls are used for terminating the weld cycle, then the threshold penetration must be adjusted to account for both the pressure and part thickness.

**Reference:** Stokes VK: Thickness effects in the vibration welding of polycarbonate. ANTEC 1989, Conference proceedings, Society of Plastics Engineers, New York, May 1989.

**GE Plastics: Lexan 9030** (features: 5.8 mm (0.228 inches) thick; manufacturing method: extrusion; form: sheet)

This study showed that under the right conditions, very high strengths and ductilities can be achieved in polycarbonate to polyetherimide vibration welded joints. These joints can attain the strength of PC, the weaker of the two materials.

However, the conditions for achieving high strengths are different from those for neat resins, and cannot be determined from penetration-time curves alone. In neat resins, high strengths are achieved once the penetration rate reaches a steady state, so that penetration-time curves can be used for determining optimum welding conditions. On the other hand, because of differences in “melt” temperatures and viscosities, the apparent steady-state conditions indicated by penetration-time curves for PC to PEI welds are deceptive. The process

is dominated by the high melting and flow rates of PC, which masks the still developing melt and flow conditions in PEI when an apparent steady state has been attained. As a result, weld strength continues to increase with penetration, even when this penetration falls in the steady-state regime. Because of this, additional information is required for optimizing PC to PEI welds.

Scanning electron microscopy studies have demonstrated that the dominant mechanism for bond strength during the early stages of welding is the mechanical interlocking at the weld interface produced by shear mixing of the two molten polymers. Process conditions affect the thickness and structure of the zone over which this mixing and interlocking occurs.

The fracture surfaces of PC to PEI welds are interesting. The high-strength welds have deep ridges on both halves of the fracture interface. The depth of the ridges, and the strength appear to increase with the weld pressure. There is a major difference between low-frequency and high-frequency welds. At 120 Hz, the ridges are perpendicular to the direction of the vibratory motion. Although nominally parallel, these ridges exhibit a “wavy” structure. On the other hand, at frequencies equal to 250 and 400 Hz, the ridges are parallel to the direction of motion. Also, the ridge structure is more parallel, and better defined. These well-defined ridges, which appear in the high-frequency (low-amplitude) welds are probably caused by flow instabilities.

**Reference:** Stokes VK, Hobbs SY: Strength and bonding mechanisms in vibration-welded polycarbonate to polyetherimide joints. ANTEC 1989, Conference proceedings, Society of Plastics Engineers, New York, May 1989.

### Bayer: Makrolon

Frictional heat is generated by pressing the surfaces of two parts made from Makrolon polycarbonate together at a pressure of 200–245 psi (1.4–1.7 MPa) and vibrating one against the other through a small displacement. When a molten state is reached at the joint interface, the vibrating action stops, parts are aligned, and a clamp pressure is briefly applied. Overall cycle times can be 4–15 seconds.

**Reference:** *Makrolon Polycarbonate—A Guide for Joining Techniques*, Supplier design guide (55-A664(10)C), Bayer, 1987.

### Polycarbonate

Aircraft air diffuser ducts made from polycarbonate were first assembled with epoxy, requiring sandblast

preparation and prebonding of parts. Also required were expensive fixturing devices with clamp arrangements and a 24-hour cure time.

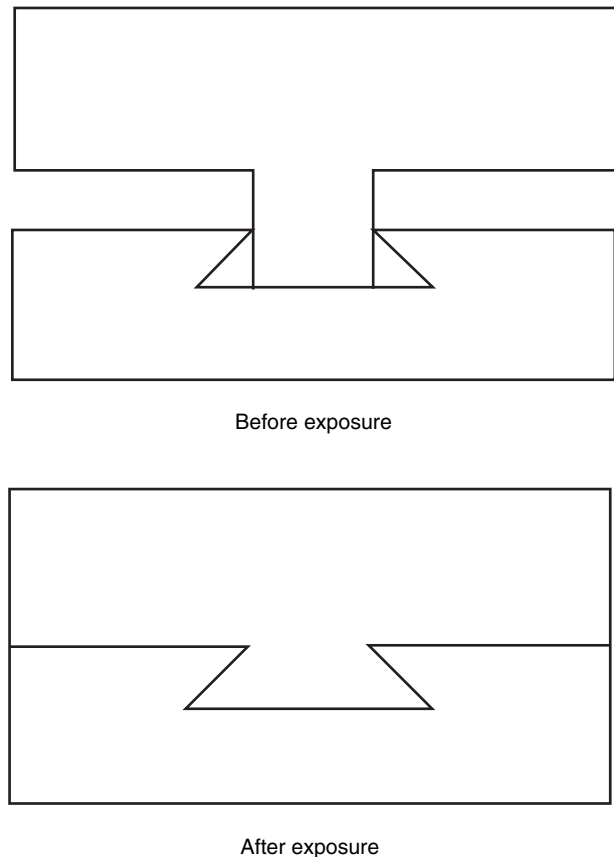
Vibration welded production is up from less than one part per minute to three parts per minute. Labor cost was cut by 70%, and the total part cost was cut considerably.

**Reference:** White P: Vibration welding. *Making It With Plastics*, Trade Journal, 1987.

### GE Plastics: Lexan

Dissimilar materials may be joined to Lexan resin by vibration welding, and a special dovetail/tongue-in-groove joint design (Fig. 27.2). Using this method, a mechanical bond is formed by melting the material with the lower melt viscosity into the material with the higher melt viscosity.

**Reference:** *Lexan Design Guide*, Supplier design guide (CDC-536E), General Electric Company, 1986.



**Figure 27.2.** Joint design for vibration welding dissimilar materials to GE Plastics Lexan polycarbonate.

## 27.5 Spin Welding

### Dow Chemical: Calibre (features: transparent)

Calibre polycarbonate is well-suited to spin welding.

Three variables affect the spin weld process: speed of rotation, duration of rotation, and pressure applied to the joint. Each of the variables depends on the material and the diameter of the joint. In most cases, the actual spin time should be approximately 0.5 seconds, with an overall weld time of 2.0 seconds. When assembly by spin welding is proposed, a prototype evaluation should be done to determine the rotation speed and time, pressure, and holding time that fit the application.

**Reference:** *Calibre Engineering Thermoplastics Basic Design Manual*, Supplier design guide (301-1040-1288), Dow Chemical Company, 1988.

### Bayer: Makrolon

With one part held stationary, the other is rotated at 300–500 rpm with enough pressure applied to keep the parts in contact with each other. The heat generated by the friction is used to bring the surfaces to a sealing temperature of about 425°F (218°C). When sufficient melt is obtained, the spinning stops and the pressure is increased to distribute the melt and also to squeeze out excessive melt, completing the bonding process.

In some cases, the stationary part can be made to rotate with the moving part when the driver stage of spinning is disengaged. This is to counteract the inertial forces incurred in stopping the rotating part.

**Reference:** *Makrolon Polycarbonate—A Guide for Joining Techniques*, Supplier design guide (55-A664(10)C), Bayer, 1987.

## 27.6 Radio Frequency Welding

### Polycarbonate

The glass transition temperature of polycarbonate is significantly higher than that of the other materials in this radio frequency welding study. Because of this, considerable difficulty was experienced in sample preparation. In the light of this, it was considered unlikely that sound bonds could be achieved between polycarbonate and other materials studied (flexible PVC, rigid PVC, polyurethane, styrenic TPE). There is not sufficient overlap in the temperature ranges in which these materials soften.

**Reference:** Leighton J, Brantley T, Szabo E: RF welding of PVC and other thermoplastic compounds. ANTEC 1992, Conference proceedings, Society of Plastics Engineers, Detroit, May 1992.

## 27.7 Laser Welding

### Sheffield Plastics: Hyzod GP (form: sheet)

The objective of this study was to determine the effect of welding parameters (power, focal spot size, and travel speed) on weld size and weld quality in terms of hermetic seal and strength. Two focal spot sizes were used (25 and 50  $\mu\text{m}$ ; 0.001 and 0.002 inches). A transparent bladder was used to applied weld pressure. The pressure in the bladder was varied from 0.02 to 0.45 MPa (3–65 psi).

The results showed that, in general, the weld strength was proportional to the weld width (which was between 50 and 300  $\mu\text{m}$ ; 0.002 and 0.012 inches), and that maximum weld strength was seen with a heat input of 0.025 J/mm. It was also seen that the weld strength is relatively independent of bladder pressure. It is believed that this is due to the fact that the true pressure developed within the weld is a function of thermal expansion of the material.

**Reference:** Grewell D, Benatar A: Experiments in micro-welding of polycarbonate with laser diodes. ANTEC 2003, Conference proceedings, Society of Plastics Engineers, Nashville, May 2003.

### PC

Transmittance and reflectance of PC were measured for various thicknesses and incident angles of the laser beam (from a 50 W diode laser with a wavelength of 810  $\pm 10$  nm). The optical properties of PC did not depend on the thickness. Transmittance of PC was high, making it well-suited for through transmission laser welding (TTLW). Reflectance increased and transmittance decreased with increasing incident angle. However, even for an incidence angle of 75° the transmittance was still at 40%, making it acceptable for TTLW.

**Reference:** Rhew M, Mokhtarzadeh A, Benatar A: Diode laser characterization and measurement of optical properties of polycarbonate and high-density polyethylene. ANTEC 2003, Conference proceedings, Society of Plastics Engineers, Nashville, May 2003.

### PC (form: injection-molded AWS G1 ultrasonic weld test sample)

The AWS standard G1 samples were cut to reduce the length from 50.8 mm (2 inches) to 10 or

20 mm (0.39 or 0.79 inches) because of the laser equipment limitations. PC with 0.5% carbon black was used for the absorbent part. Since PC is hygroscopic, all samples were dried prior to welding in a vacuum oven at 121°C (250°F) for 6 hours.

A maximum weld factor of 95% was obtained for a welding power of 4.06 W at the weld interface, a heating time of 20 seconds, and welding pressure of 0.427 MPa (62 psi).

**Reference:** Rhew M, Mokhtarzadeh A, Benatar A: Through transmission laser welding of polycarbonate and high-density polyethylene. ANTEC 2003, Conference proceedings, Society of Plastics Engineers, Nashville, May 2003.

#### **PC (form: 2.9 mm (0.114 inch) thick injection-molded plaque)**

In these experiments, welds were made between 3.2 mm (0.126 inches) thick clear PC (top) and 6.4 mm (0.252 inches) thick black PC (bottom) using a diode laser with an 828 nm wavelength. The pressure was set to 69 kPa (10 psi). The power was varied from 50 to 1000 mW, the travel speed was varied between 30 and 140 mm/s (1.2–5.5 inches/s) and the focal spot size was varied between 25 and 50  $\mu\text{m}$  (0.001–0.002 inches).

Results showed that the weld width was directly proportional to power level.

**Reference:** Grewell D, Jerew T, Benatar A: Diode laser microwelding of polycarbonate and polystyrene. ANTEC 2002, Conference proceedings, Society of Plastics Engineers, San Francisco, May 2002.

#### **PC (form: 2.9 mm (0.114 inch) thick injection-molded plaque)**

Quasi-simultaneous welding involves a laser beam being guided over the length of the weld by means of a mirror system and scanning the joining surface several times over a relatively high speed (up to 10 m/s; 33 ft/s). This ensures a (quasi-) simultaneous and homogeneous heating and plasticization of the adherent surface, and makes it possible to press warped parts to be welded together during welding.

The joining surface was  $69 \times 2.9$  mm ( $2.72 \times 0.114$  inches). The applied carbon black content for the absorbing part was 0.1 wt.%. The laser employed was a solid-state (Nd:YAG) laser with a wavelength of 1064 nm. The maximum power output of the laser in continuous-wave operation was approximately 250 W.

For the T-joint geometry, the highest weld strength was 23 N/mm<sup>2</sup> (3300 psi) and was predicted for an

intensity of 35 W/cm<sup>2</sup> (4600 psi) and a joining displacement of 1.00 mm (0.039 inches). For the butt joint geometry, the maximum weld strength was established at 32 N/mm<sup>2</sup> (4600 psi) for an intensity of 30 W/cm<sup>2</sup> and a melting displacement of 1.00 mm (0.039 inches).

**Reference:** Potente H, Fiegler G, Becker F, Korte J: Comparative investigations on quasi-simultaneous welding on the basis of the materials PEEK and PC. ANTEC 2002, Conference proceedings, Society of Plastics Engineers, San Francisco, May 2002.

#### **Polycarbonate (form: sheet)**

Experiments showed that PC can be laser-welded with a 150 W diode laser, operating at a wavelength of 808 nm. 8.5 W of laser power was sufficient to weld PC to carbon black pigmented PC at welding speeds of 50 mm/s (2 inches/s), resulting in 1.2 mm (0.047 inch) wide welds. These welds were strong and flexible. Tensile tests showed that a yield strength close to the parent material can be achieved.

PC was also welded with a smaller beam cross-section to produce 0.4 mm (0.016 inch) wide welds at powers <8 W.

**Reference:** Nilsson T, Lampa C: Diode laser welding of plastics. 7th NOLAMP Conference proceedings, Lappeenranta, Finland, August 1999.

## **27.8 Induction Welding**

#### **GE Plastics: Lexan 9030 (features: extruded sheet)**

A commercial high-frequency generator (Emabond Systems HD500) was used for making all the induction welds. Pressure applied by an air cylinder was used to control the weld interface pressure; two weld pressures of 0.21 MPa (30 psi) and 0.41 MPa (60 psi) were used.

Relative weld strengths as high as 48% were demonstrated, although it should be remembered that, while this study focused on the tensile strengths of welds, in induction welding, the weld joints are mainly subjected to shear stresses.

**Reference:** Stokes VK: Experiments on the induction welding of thermoplastics. ANTEC 2001, Conference proceedings, Society of Plastics Engineers, Dallas, May 2001.

#### **Dow Chemical: Calibre (features: transparent)**

Calibre polycarbonate is suitable for induction welding. It can be welded to itself, to polycarbonate/ABS



alloy, acrylics, and to polysulfones. A tongue-and-groove joint design that incorporates a shear-type weld is recommended. This type of joint produces a fast, strong bond.

**Reference:** *Calibre Engineering Thermoplastics Basic Design Manual*, Supplier design guide (301-1040-1288), Dow Chemical Company, 1988.

### Bayer: Makrolon

Makrolon polycarbonate can be electromagnetically welded into strong, clean, structural, hermetic, or high-pressure seals utilizing this process. Besides bonding to itself, Makrolon polycarbonate can be bonded to some grades of ABS, acrylic, polysulfone, and SAN.

**Reference:** *Makrolon Polycarbonate—A Guide for Joining Techniques*, Supplier design guide (55-A664(10)C), Bayer, 1987.

## 27.9 Heat Sealing

### GE Plastics: Lexan

This work describes experiments in impulse welding of thin polycarbonate films on a carbon-filled polycarbonate substrate, similar to the sealing of microchannels on a microfluidic device. Pressure burst testing was carried out in order to measure the weld strength. The effects of power and heating time on weld width and weld strength were studied. The weld width was found to increase with power and welding time. Weld strength was found to increase with power and time, until a point beyond which the strength dropped due to possible degradation.

Kapton films were placed on either side of the nichrome wire to avoid sticking. Nichrome wires with diameters of 203.3, 101.6, 50.8 and 35.56  $\mu\text{m}$  (0.008, 0.004, 0.002 and 0.0014 inches) were used. A clamping force of 0.29–0.32 MPa (42–46 psi) was used.

The strongest weld that was produced was 150  $\mu\text{m}$  (0.006 inches) wide with an average weld strength of 26.73 MPa (3877 psi), corresponding to a burst pressure of 0.27 MPa (39 psi). Welds that were as small as 80  $\mu\text{m}$  (0.003 inches) could be made with this process but the strengths were extremely low (<1 MPa; 145 psi).

**Reference:** Krishnan C, Benatar A: Experiments in impulse welding a thin film lid for sealing micro-channels in microfluidic applications. ANTEC 2005, Conference proceedings, Society of Plastics Engineers, Boston, May 2005.

### Bayer: Makrolon

Makrolon polycarbonate films up to 0.25 mm (0.010 inches) thick can be bar sealed. Do not seal thicker sheets in this manner, because bond dimensions may distort. For bar sealing polycarbonate film, the surface temperature of the heater elements should be between 450 and 500°F (230–260°C). Typically, you will need a contact pressure of approximately 100 psi (690 kPa), which usually results in a cycle time of 0.5–2 seconds, depending upon the thickness of the film to be sealed.

**Reference:** *Engineering Polymers. Joining Techniques. A Design Guide*, Supplier design guide (5241 (7.5M) 3/01), Bayer Corporation, 2001.

## 27.10 Solvent Welding

### Bayer: Makrolon

You can bond parts made of Makrolon polycarbonate using methylene chloride or ethylene dichloride. Methylene chloride's fast evaporation rate helps to prevent solvent–vapor entrapment for simple assemblies. For complex assemblies that require more curing time, use ethylene dichloride because it has a slower evaporation rate, allowing for longer assembly times. Mixing methylene chloride and ethylene dichloride in a 60:40 solution, a commonly used mixture, will give you a longer time to assemble parts than pure methylene chloride because of the reduced evaporation rate.

When using solvent welding techniques with polycarbonate, some embrittlement may occur. The parts can lose some of their excellent impact strength at the weld joint.

A 5–10% solution of polycarbonate in methylene chloride helps to produce a smooth, filled joint, when the mating parts made of Makrolon resin do not fit perfectly. Do not use this mixture to compensate for severely mismatched joints. Increasing the concentration can result in bubbles at the joint.

Tests carried out indicate that methylene chloride-bonded parts had 80–90% of the ultimate bond strength after curing for 1 to 2 days. When working with polycarbonate resins, curing parts for elevated-service use and maximum bond strength is much more complicated. You may have to use a complicated treatment schedule of gradually increasing temperatures for these applications (see Table 27.3).

**Reference:** *Engineering Polymers. Joining Techniques. A Design Guide*, Supplier design guide (5241 (7.5M) 3/01), Bayer Corporation, 2001.

**Table 27.3.** Solvent Bond Curing Schedule for Makrolon Resins

Sequential Holding Time, hrs	Part or Bond Temperature, °C (°F)
8	23 (73)
12	40 (100)
12	65 (150)
12	93 (200)
12	110 (225)

**Altuglas International: Tuffak** (form: sheet)

Solvent welding is the simplest method of joining Tuffak sheet to itself. The solvent type can be (a) pure solvent, (b) a polymerizable monomer/solvent or (c) a thickened solvent. Welded joints have low impact and are not recommended if high impact resistance is necessary.

Pure solvents are water-thin. The most common methods for application of pure solvents are by needle applicator capillary action and edge dipping.

Polymerizable monomer cements will give a better-looking joint than the pure solvent, since voids can be eliminated. However, these joints are more brittle, and they will blush more than a pure solvent joint.

Thickened cements, with 10–15% of the parent material dissolved in a solvent, can be used when mating joint parts that do not fit together. The strength is not as high as a solvent joint.

A good solvent joint should have a tensile strength of 2500 psi (17 MPa). The clearest joint is obtained by putting pressure on the joint using a press while the solvent is drying.

**Reference:** *Tuffak Polycarbonate Sheet. Forming and Fabrication*, Supplier design guide (ADV980496/APL:ATG-16S/web/6-00), Altuglas International, 2000.

**GE Plastics: Lexan 9034** (form: 5.5 mm (0.22 inch) thick sheet)

The relationship of joint strength of solvent-welded joints of polycarbonate to their microstructure was investigated. Three solvents were used: butanone, acetone, and cyclohexanone, together with mixtures of cyclohexanone with ethanol. The effect of welding temperature was also investigated.

Results showed that butanone gave the highest joint strengths, followed by acetone and cyclohexanone.

When the concentration of cyclohexanone in ethanol was less than 60 vol%, no welding was observed; polycarbonate treated with cyclohexanone at 78 vol% had the maximum joint strength. Also, the joint strength of polycarbonate treated with cyclohexanone increased with the welding temperature.

**Reference:** Chang KC, Sanboh L: Strength and microstructure of solvent welded joints of polycarbonate. *Journal of Adhesion*, 56, p. 135, 1996.

**Cyrolon AR** (features: transparent, abrasion resistant coating, 3.2 mm (0.126 inches) thick; manufacturing method: continuous cast; form: sheet)

Cyrolon AR polycarbonate sheets are available with either one or two sides coated from protection against abrasion. When cementing to a noncoated sheet surface, use the same solvent or polymerizing cements commonly used for Cyrolon sheet products. The most critical factor is the edge of the part to be cemented. The edge must first be properly prepared with low stresses. Scraping, wet sanding, and buffing are acceptable methods to prepare a finished edge. Flame polishing is not recommended. Overspray from the flame may cause the surface coating to crack or craze. This may lead to delamination of the coating and a loss of abrasion resistance. Annealing of the part prior to cementing is recommended.

Solvent cementing to a hard-coated surface cannot be readily accomplished due to the chemical resistance of the coating. To solvent cement on or to a coated surface, the coating first must be removed by sanding or routing. When removing the coating, insure that the bonding surface is flat, clean, and free of stress. Annealing the piece will insure a stress-free surface.

**Reference:** *Physical Properties Acrylite AR Acrylic Sheet and Cyrolon AR Polycarbonate Sheet*, Supplier design guide (1632B-0193-10BP), Cyro Industries, 1993.

**Dow Chemical: Calibre 2060-15** (features: transparent); **Calibre Megarad 2080-15** (features: transparent)

In tests conducted to evaluate the bondability/compatibility of plasticized PVC tubing to rigid, transparent thermoplastics, this study presents results for two types of polycarbonate: a general purpose grade and a radiation-stabilized grade. The latter is not to be confused with polycarbonate that has been merely

color-compensated to adjust for the characteristic color shift upon exposure to gamma radiation. The distinction refers instead to a specific additive package, which reduces the color shift. Any differences in the bond strength performance and overall bond integrity may be explained by the plasticization effect of the additive, resulting in luers with lower molded-in stress and slight differences in the surface properties.

Straight methylene chloride and acetone were the only solvents which brought about short-term signs of crazing or other solvent attack in the polycarbonate. Cocktails made of 50:50 blends of methylene chloride in cyclohexanone or MEK in cyclohexanone displayed satisfactory bond strengths. Bonds made with THF, cyclohexanone, MEK, or an 80:20 blend of MEK in cyclohexanone were all bordering between marginal and satisfactory ratings based on bond strength. The 1,2-dichloroethane resulted in high bond strengths, though the ease of insertion was marginal for the radiation stabilized version. Insertion was also marginal or unsatisfactory for blends rich in methylene chloride and for acetone. In fact, tubing could not be completely inserted into the radiation stabilized luers using acetone as a solvent, so no accurate tests could be performed. The 50:50 blend of MEK in cyclohexanone is suggested for polycarbonate as the best solvent without any short-term, adverse effects.

**Reference:** Haskell A: Bondability/compatibility of plasticized PVC to rigid, transparent thermoplastics. ANTEC 1989, Conference proceedings, Society of Plastics Engineers, New York, May 1989.

#### **Dow Chemical: Calibre** (features: transparent)

Calibre polycarbonate is well-suited to solvent bonding because of its amorphous nature. The most common solvent used is methylene chloride at varying concentrations. The main limitation of this technique is in the handling of the solvent.

In solvent welding, methylene chloride (or a combination of methylene chloride and ethylene dichloride) is applied to the joint area of one or both components, and the two components are then held together in a fixture. While the parts are held together, and after being subjected to a pressure of 250–500 psi (2–3 MPa), the bond cures to form a joint in 1–5 minutes, depending on the size and shape of the joint area.

Environmental conditions, such as elevated temperatures can cause stress crazing. Therefore, the bond

should be dried for 24–48 hours at a temperature just below the maximum anticipated operating temperature. This often eliminates crazing, which can be caused by entrapped solvent.

**Reference:** *Calibre Engineering Thermoplastics Basic Design Manual*, Supplier design guide (301-1040-1288), Dow Chemical Company, 1988.

#### **Bayer: Makrolon**

Solvent welding is a practical method of joining Makrolon polycarbonate to itself or to another plastic soluble in the same solvent. It involves treating the weld area with a minimum amount of solvent to soften the surfaces, then clamping the parts together until the weld takes place.

**Welding Procedure:** The most common mistake made in making solvent welds is the use of too much solvent. Only the minimum amount required to wet the surface area should be used. Excessive solvent can result in bubbling and squeeze-out, which decreases the strength of the bond.

Before applying solvents, the mating surfaces should be cleaned of any grease, dirt, or foreign matter. Well-mated parts are essential for optimum welds. They should mate with no strain, so that contact pressure may be uniformly distributed over the entire weld area.

In solvent welding, it is best to apply a thin film of the solvent in a quick and efficient manner. With Makrolon polycarbonate, only one of the mating surfaces should be treated with the solvent, and the parts should be clamped together in a pressure fixture within a few seconds. Pressures between 100 and 500 psi (0.7 and 3.4 MPa) should be used for best results.

The ultimate weld strength is primarily a function of solvent concentration on mated surfaces. Therefore, the elapsed time between solvent application and clamping must be carefully controlled because, if too much evaporation occurs, a poor weld will result. The amount of clamp time is not as important, but a minimum of 60 seconds is recommended.

**Curing Solvent-welded Parts:** Parts solvent welded with methylene chloride which are intended to function at room temperature should be cured for 24–48 hours at room temperature. Adequate air circulation should be provided for efficient solvent vapor removal. Air-tight enclosures where solvent vapors may be trapped should be avoided, since the solvent vapors not removed can lead to embrittlement of the material. Using ethylene

dichloride, laboratory tests conducted by Mobay indicated 80–90% of the ultimate weld strength was reached within 1–2 days.

Smaller weld areas might be successfully cured in shorter times, while large areas might require still longer times or narrower temperature intervals to avoid the tell-tale appearance of bubbles in the weld. Uncured parts that are suddenly exposed to service at elevated temperatures may suffer complete joint failure. If exposed to service in hot water, a cloudy, weak weld will result. In general, the highest cure temperature should be equal to, or slightly higher than the highest expected service temperature.

**Reference:** *Makrolon Polycarbonate—A Guide for Joining Techniques*, Supplier design guide (55-A664(10)C), Bayer, 1987.

### GE Plastics: Lexan

Solvent welding is one of several alternatives for joining Lexan resin parts. The joint area for Lexan resin parts that are to be welded with this technique should be designed such that the two parts fit precisely, without pressure, when they leave the mold. Locating pins or tongue-and-groove shapes may be used to align the bonding area and promote rapid part matching after the application of solvent. These devices should be kept shallow to avoid solvent entrapment in the mating surface. Parts to be welded must be molded well, dimensionally, and possess low residual stresses.

The following solvent systems are recommended for parts molded of Lexan resin:

- Methylene chloride, which has a low boiling point of 40.1°C (104.2°F) and an extremely fast evaporation rate.
- A 1–5% solution of Lexan resin in methylene chloride can be used in extreme cases to obtain smooth, completely filled joints when perfectly mated bonding areas are impossible to obtain. This solution 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.

When solvent welding parts molded of Lexan resin, 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 of time. Solvent should be applied to only one of the

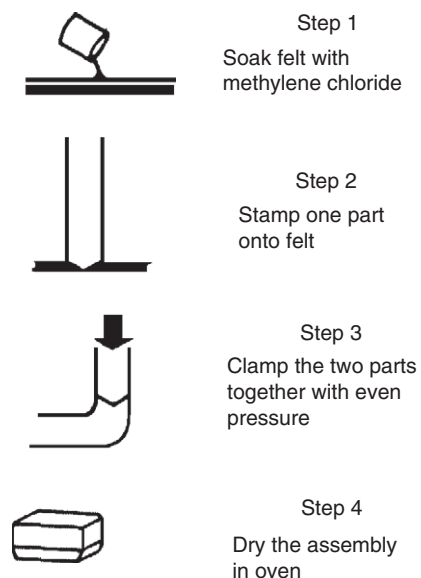
Lexan resin joint surfaces. The other half should remain dry and ready in the clamping fixture. Surfaces to be welded should be free of dirt, grease, and mold release.

The following two methods of applying methylene chloride enable the minimum amount of solvent to be used to weld Lexan resin parts:

- (1) Saturate a piece of felt, sponge, or other absorbent material with solvent. The Lexan resin part to receive the methylene chloride should then be stamped onto the solvent-saturated material and clamped to the mating part with an even pressure distribution (Fig. 27.3).
- (2) Make fitting counterparts from wood or metal. Dip the counterparts into the solvent and press against the Lexan resin part surfaces, applying a thin film of solvent. Allow a few seconds for drying and then assemble the parts for welding, applying pressure evenly in a jig or fixture (Fig. 27.4).

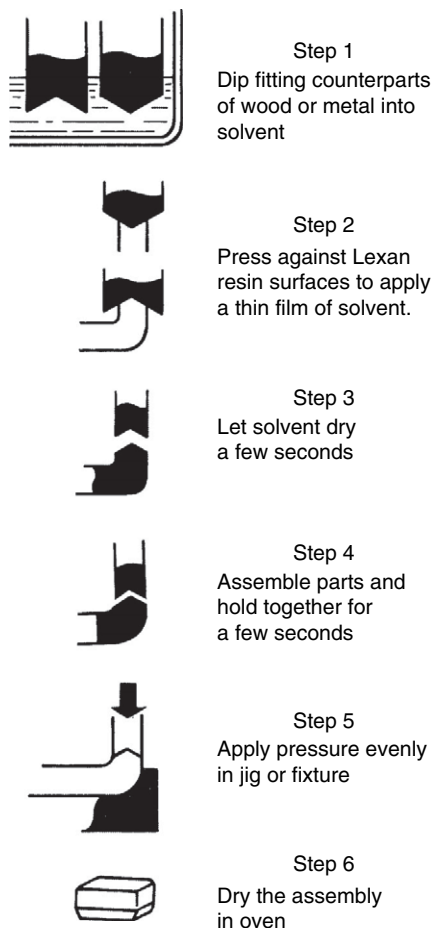
Pressure should be applied as soon as the two parts have been put together. Pressure between 200 and 600 psi (1.4–4.1 MPa) is suggested for best results. Holding time in the fixture should be approximately one to five minutes, depending on the size of the bonding area.

The welded joint should be clear and bubble-free. The presence of bubbles indicates either excess solvent and/or insufficient pressure, or too short a pressure hold. Squeeze-out is a sign of excessive pressure. Crystallizing at the weld area indicates excessive solvent



**Figure 27.3.** Solvent welding Procedure 1 for Lexan polycarbonate.





**Figure 27.4.** Solvent welding Procedure 2 for Lexan polycarbonate.

and too much elapsed time between solvent application and mating of the parts in the pressure fixture.

Although the welded parts may be handled without damage after the holding time in the pressure fixture, sufficient weld strength for room temperature use is normally achieved by drying the welded parts for 24–48 hours at room temperature. If the solvent-welded part is to be used at high temperatures, a longer solvent removal program is necessary. Otherwise, bubbles and a weakened weld result when the temperature is raised. Generally, the solvent removal schedule should ultimately reach a temperature which is equal to or slightly lower than the maximum service temperature. This can be done by raising the temperature 5–10°F (2.8–5.6°C) per hour, depending on the bond size, until the desired temperature is reached.

A typical schedule for a part used at 200°F (93°C) is:

1 hour @ 77°F (25°C)  
24 hours @ 100°F (38°C)

24 hours @ 160°F (71°C)

24 hours @ 185°F (85°C)

**Reference:** *Lexan Design Guide*, Supplier design guide (CDC-536E), General Electric Company, 1986.

### GE Plastics: Lexan GR1110 (features: gamma radiation stabilized)

Based on the results of a study to determine the effects of gamma radiation on solvent weld strength, it was found that solvent welding was effective in securing Lexan GR1110 resin. After extremely high dosages of gamma radiation, 10 Mrads, the bond strength was not compromised. In all cases, the mode of failure was within the substrate, indicating that the material broke, not the welded joint. Therefore, the weld strength is greater than, or equal to the values reported.

Methylene chloride/cyclohexanone combination typically yielded the highest results when bonding Lexan resins to PVC.

**Reference:** *Guide to Engineering Thermoplastics for the Medical Industry*, Supplier design guide (MED-114), General Electric Company.

## 27.11 Adhesive Bonding

### Dow Chemical: Calibre 300-4

A study was conducted to determine the bond strength of a representative matrix of plastics and the adhesives best suited to them. The block-shear (ASTM D 4501) test was used because it places the load on a thicker section of the test specimen; the specimen can therefore withstand higher loads before experiencing substrate failure. In addition, due to the geometry of the test specimens and the block shear fixture, peel and cleavage forces in the joint are minimized.

The substrates were cut into 1" × 1" × 0.125" (25.4 × 25.4 × 3.175 mm) block shear test specimens. All bonding surfaces were cleaned with isopropyl alcohol. The test specimens were manually abraded using a 3 M heavy-duty stripping pad. The surface roughness was determined using a Surfanalyzer 4000 with a traverse distance of 0.03 inches (0.76 mm) and a traverse speed of 0.01 inches per second (0.25 mm/s).

While the bond strengths in Table 27.4 give a good indication of the typical bond strengths that can be achieved, as well as the effect of many fillers and additives, they also face several limitations. For example, while the additives and fillers were selected because

**Table 27.4.** Shear Strengths of Calibre 300-4 PC to PC Adhesive Bonds Made Using Adhesives Available from Loctite Corporation<sup>b</sup>

Material Composition		Loctite Adhesive					
		<b>Black Max 380</b> (Instant Adhesive, Rubber Toughened)	<b>Prism 401</b> (Instant Adhesive, Surface Insensitive)	<b>Prism 401/ Prism Primer 770</b>	<b>Super Bonder 414</b> (Instant Adhesive, General Purpose)	<b>Depend 330</b> (Two-Part, No-Mix Acrylic)	<b>Loctite 3105</b> (Light Cure Adhesive)
Unfilled resin	4 rms	750 (5.2)	3850 (26.6)	2000 (13.8)	1600 (11.0)	1100 (7.6)	3700 (25.5)
Roughened	18 rms	1600 (11.0)	4500 (31.0)	3400 (23.5)	3950 (27.2)	1100 (7.6)	4550 (31.4)
Antioxidant	0.1% Irgafos 168 0.1% Irganox 1076	750 (5.2)	3850 (26.6)	2000 (13.8)	3950 (27.2)	550 (3.8)	3700 (25.5)
UV stabilizer	0.4% Tinuvin 234	750 (5.2)	3850 (26.6)	2000 (13.8)	1600 (11.0)	450 (3.1)	3700 (25.5)
Flame retardant	2% BT-93 1% Anti-mony oxide	1300 (9.0)	>4100 <sup>a</sup> (>28.3) <sup>a</sup>	>3800 <sup>a</sup> (>26.2) <sup>a</sup>	>3400 <sup>a</sup> (>23.5) <sup>a</sup>	300 (2.1)	3700 (25.5)
Impact modifier	5% Paraloid EXL3607	1000 (6.9)	3850 (26.6)	2000 (13.8)	>4500 <sup>a</sup> (>31.0) <sup>a</sup>	500 (3.5)	3700 (25.5)
Lubricant	0.3% Mold Wiz INT-33UDK	1300 (9.0)	3850 (26.6)	2000 (13.8)	3850 (26.6)	1100 (7.6)	3700 (25.5)
Glass filler	23% Type 3090 glass fiber	1150 (7.9)	3850 (26.6)	600 (4.1)	2700 (18.8)	1100 (7.6)	4850 (33.5)
Colorant	4% CPC07327	1650 (11.4)	3850 (26.6)	500 (3.5)	3950 (27.2)	1100 (7.6)	3700 (25.5)

<sup>a</sup>The force applied to the test specimens exceeded the strength of the material, resulting in substrate failure before the actual bond strength achieved by the adhesive could be determined.

<sup>b</sup>All testing was done according to the block shear method (ASTM D4501). Values are given in psi and MPa (within parentheses).

they were believed to be representative of the most commonly used additives and fillers, there are many types of each additive and filler produced by many different companies, and different types of the same additive or filler may not have the same effect on the bondability of a material. In addition, the additives and fillers were tested individually in Table 27.4, so the effect of interactions between these different fillers and additives on the bondability of materials could not be gauged.

Another consideration that must be kept in mind when using this data to select an adhesive/plastic combination is how well the block shear test method will reflect the stresses that an adhesively bonded joint will see in “real world” applications. Adhesively bonded joints are designed to maximize tensile and compressive stresses, and to minimize peel and cleavage stresses, so the magnitude of the former two are generally much larger than the latter two. Thus, the shear strength of an adhesive is generally most critical

to adhesive joint performance, but since all joints experience some peel and cleavage stresses, their effects should not be disregarded.

Finally, selecting the best adhesive for a given application involves more than selecting the adhesive that provides the highest bond strength. Other factors such as speed of cure, environmental resistance, thermal resistance, suitability for automation, and price will play a large role in determining the optimum adhesive system for a given application.

*Adhesive Performance:* Flashcure 4305 light cure adhesive achieved bond strengths that were higher than the grade of unfilled polycarbonate tested. Prism 401 and Super Bonder 414, both cyanoacrylate adhesives, Loctite 3105, a light curing acrylic adhesive, and Hysol E30-CL epoxy adhesive, Hysol 3631 hot melt adhesive and Fixmaster high performance epoxy all achieved very high bond strengths on PC. Hysol 3651 and 7804 hot melt adhesives achieved the lowest bond strengths.

**Surface Treatments:** Surface roughening either caused no effect, or a statistically significant increase in the bondability of PC. The use of Prism Primer 770, in conjunction with Prism 401 instant adhesive, or Prism 4011 medical device instant adhesive with Prism Primer 7701, caused a statistically significant decrease in the bond strengths achieved on PC for most of the formulations evaluated.

**Other Information:** Polycarbonate is generally compatible with acrylic and cyanoacrylate adhesives, but there is a potential for stress cracking. In addition, polycarbonate can be attacked by the activators for two-part no-mix acrylic adhesives before the adhesive has cured. Any excess activator should be removed from the surface of the polycarbonate immediately. Polycarbonate is incompatible with anaerobic adhesives. Recommended surface cleaners are isopropyl alcohol and Loctite ODC Free Cleaner & Degreaser.

**Reference:** *The Loctite Design Guide for Bonding Plastics Vol. 4*, Supplier design guide, Loctite Corporation, 2006.

### Bayer: Makrolon

UV-cured adhesives, excellent for transparent materials such as Makrolon polycarbonate, cure in seconds and typically have high bond strength. Two-part acrylic adhesives usually show high bond strength. Use care in selecting these adhesives, as some of their accelerators can be very aggressive to Makrolon polycarbonate resins.

**Reference:** *Engineering Polymers. Joining Techniques. A Design Guide*, Supplier design guide (5241 (7.5M) 3/01), Bayer Corporation, 2001.

### Altuglas International: Tuffak (form: sheet)

Adhesive bonding creates the weakest type of joints. It must be used when other methods are not applicable, such as joining two different materials (e.g., Tuffak polycarbonate to metal).

A list of suitable thermosetting adhesive types is given in Table 27.5. Thermoplastic adhesives are not recommended for Tuffak polycarbonates.

**Reference:** *Tuffak Polycarbonate Sheet. Forming and Fabrication*, Supplier design guide (ADV980496/APL:ATG-16S/web/6-00), Altuglas International, 2000.

### Bayer: Makrolon

Makrolon polycarbonate can be bonded to itself and to other substrates with a variety of adhesives including Scotch-Weld 2216 B/A, a two-component epoxy adhesive from 3M Corporation. However, solvent-based adhesives can be harmful to Makrolon polycarbonate if the molded part is subject to stress greater than 1300 psi (9 MPa).

When selecting an adhesive for parts molded of Makrolon polycarbonate resin, consider the following:

- Requirements as to flexibility or rigidity of the assembled parts
- Environmental temperature requirements
- General appearance requirements

An adhesive that can be gravity-fed is easier to handle and to apply. The equipment for dispensing it is also less costly.

When using adhesives, part cleanliness is very important. Make sure that the bonding surfaces are free of all dirt, grease, and other contamination.

**Reference:** *Makrolon Polycarbonate—A Guide for Joining Techniques*, Supplier design guide (55-A664(10)C), Bayer, 1987.

### GE Plastics: Lexan

Parts molded of Lexan resin can be bonded to other plastics, glass, metal, and other materials using a variety of adhesives. Generally, best results are obtained with solventless (100% reactive) materials, such as epoxies, urethanes, and high performance adhesives.

**Table 27.5.** Thermosetting Adhesives Suitable for Bonding Tuffak Polycarbonate

Adhesive Type	Use
Acrylic	When high strength is important, but cosmetic (clarity) is not (brown in color)
Urethane	Useful with jewel trim on sign cans. Is clear, tough, and has good strength; is fast-reacting so special applicator may be necessary
Clear silicone rubber	Useful for sign tie-back; not as strong as urethane, but affects paint less. Used with a primer
Epoxy	Do not use amine-hardened or other rigid systems

Avoid adhesives containing incompatible constituents or curing agents that are incompatible with Lexan resin. Use curing temperatures below 250°F (121°C) and high (low) temperature adhesives for high (low) temperature applications.

Parts should be thoroughly cleaned before adhesive bonding. All oil, grease, paint, mold releases, rust, and oxides must be removed by washing with compatible solvents such as isopropyl alcohol, petroleum ether, 65°C (149°F) boiling point heptane, VM & P naphtha, white kerosene, or a mild solution of soap. Bond strength may be improved by mild surface abrasion (sanding) as is customary with other materials.

*Epoxies:* Epoxy adhesives offer an extremely wide range of resistance to moisture, chemicals, and heat. Consulting an appropriate handbook regarding these properties, as well as shear and peel strength, is recommended. Parts molded of Lexan resin can be joined using epoxy systems containing room temperature (RT) curing agents such as diethylene triamine, and polyamides, or with systems containing elevated temperature hardeners such as anhydrides, or Lewis acids. When bonding Lexan resin parts to metal parts, several considerations need to be taken into account. A room temperature cure will reduce the strains created in an adhesive caused by the difference in coefficients of thermal expansion. This thermal expansion difference can cause adhesive cracking and considerably decreases expected bond strength.

However, RT cures tend to form weaker bonds than high temperature cures. To minimize bond strain when using a high temperature adhesive, the grade of Lexan resin and the metal to be joined should be closely matched from a thermal expansion standpoint. Curing temperatures should not exceed 250°F (121°C), the heat distortion temperatures of standard Lexan resin grades. Sulfide modifiers increase elasticity, although at the expense of generally lower bond strength and increased odor. These impact or elastomer modified epoxies permit a fairly thick glue line.

Amine-cured or polyamide-cured epoxies are not generally recommended for hot water or steam environments above 250°F (121°C). Anhydride-cured epoxies usually require a high temperature cure. Before applying epoxy cement, parts should be predried for 2–3 hours at 250°F (121°C) in an air-circulating oven to drive out residual moisture.

*RTV Silicone Adhesives:* RTV silicone adhesives are recommended for applications requiring moderate bond strength, a high service temperature, and thermal expandability. Silicone rubber adhesives may be used with all standard Lexan resins including glass-reinforced grades.

For optimum performance the following procedure is recommended:

- Lightly abrade mating surfaces with fine emery
- Clean surfaces of grease or foreign material with isopropyl alcohol
- Treat abraded surfaces with recommended primer and follow procedure recommended by manufacturer
- Apply silicone adhesive in desired thickness. Final bond thickness may range from 0.005 to 0.030 inches (0.13–0.76 mm) depending on joint design
- Assemble

*Polyurethane Adhesives:* Polyurethane adhesives are recommended for bonding Lexan resin to metal, glass, ceramics, and other plastics. These two-part adhesives are characterized by bonds which have excellent shear and lap strength, high impact resistance and excellent low-temperature performance. However, polyurethane adhesives are generally limited to service temperatures under 200°F (93°C). At temperatures above 200°F (93°C), tensile lap shear values may decline dramatically due to their low degree of cross-linking. They suffer somewhat from creep at room temperature and may exhibit undesirable changes in properties with aging. As such, they are not particularly suited to outdoor applications.

*Other Adhesives:* There are a number of one-part adhesive systems recommended for use with Lexan resin. One-part elastomers are available in a wide range of formulations. They provide quick tack and moderate to high shear strength.

Hot melts are easy-to-apply compositions which solidify rapidly, producing good adhesion. These adhesives are not recommended for joints under heavy loading or where use temperature exceeds 200°F (93°C). However, they are characterized by good water resistance. A likely application would be a water-resistant label.

**Reference:** *Lexan Design Guide*, Supplier design guide (CDC-536E), General Electric Company, 1986.

#### **GE Plastics: Lexan GR1110** (features: gamma radiation stabilized)

Based on the results of a study to determine the effects of gamma radiation on adhesive bond strength, it was found that UV-curable adhesives were effective in securing Lexan GR1110 resin. After extremely



high dosages of gamma radiation, 10 Mrads, the bond strength was not compromised. In all cases, the mode of failure was within the substrate, indicating that the material broke, not the bond joint. Therefore, the bond strength is greater than, or equal to the values reported.

**Reference:** *Guide to Engineering Thermoplastics for the Medical Industry*, Supplier design guide (MED-114), General Electric Company.

## 27.12 Mechanical Fastening

### Bayer: Makrolon

*Tapping and Self-Tapping Screws:* Thread-forming screws do not have a cutting tip. They displace material in the plastic boss to create a mating thread. Because this process generates high levels of radial and hoop stress, avoid using these screws with less-compliant materials, such as Makrolon polycarbonate resins or polycarbonate blends. As an alternative, use thread-cutting screws for these materials.

Table 27.6 lists some average pull-out forces and various torque data for thread-cutting screws tested in Makrolon PC. For this data, the screws were installed in the manufacturer's suggested hole diameters. The screw boss outer diameter was approximately twice the screw's outer diameter.

**Reference:** *Engineering Polymers. Joining Techniques. A Design Guide*, Supplier design guide (5241 (7.5M) 3/01), Bayer Corporation, 2001.

### Altuglas International: Tuffak (form: sheet)

Mechanical fastening is best for all high-impact situations. All fasteners must be clean of any cutting oil, which could cause crazing after assembly in a hole.

*Threaded Fasteners:* Threaded fasteners can use a predrilled hole, and the fastener cuts its own threads, or has a nut, such as through bolts. The hole may be pre-threaded for machine screws or a threaded insert may be press-fitted or welded into a predrilled hole. Predrilled holes for self-tapping screws would have a diameter half-way between the root and outside diameter of the screw. Use a coarse thread, Type-25, for both screws and inserts. Inserts are chosen when frequent disassembly is anticipated, and cross-threading is likely. The material thickness must be great enough to allow at least four threads to be engaged. Vibrational service may rule out self-tapping screws, because high stresses can lead to cracks emanating from the hole. Fasteners hold better in holes pretapped in Tuffak, compared to threaded inserts. The joint, however, is not as strong, since plastic threads are susceptible to breaking and chipping and can be cross-threaded more easily. Metal inserts give the strongest joint, and the press-fit types hold well. Expansion-type inserts are stronger than press-fit. When predrilling for bolts, drill oversize to allow for ample clearance, since the hole will shrink more than the fastener under thermal contraction. A tight fit might crack the hole.

*Permanent Fasteners:* Tuffak polycarbonate permanent fasteners include some that cannot be used on other, more brittle materials and plastics. These include rivets, pins, staples, clinching fasteners, stitching, grommets, and eyelets. Because Tuffak polycarbonate is a notch-sensitive material, fasteners should not have sharp edges.

Speed rivets have two heads which fit inside each other to provide a longer-lasting joint. One-sided, blind rivets must have a washer on one side to prevent digging into the Tuffak polycarbonate surface. Rivets should be aluminum, or must use a soft washer to protect the soft Tuffak sheet surface. Snap-fits, if designed properly, can work well with Tuffak polycarbonate.

**Table 27.6.** Thread-cutting Screw Data for Makrolon 3200 Polycarbonate Resin

Screw Size & Type	Screw length, in. (mm)	Hole Diameter, in. (mm)	Drive Torque, lb in. (Nm)	Recommended Tightening Torque, lb in. (Nm)	Stripping Torque, lb in (Nm)	Screw Pull-Out, lb (N)
#6, Type-23	0.375 (9.5)	0.120 (3.0)	8 (0.9)	14 (1.6)	25 (2.8)	360 (1600)
#6, Type-25	0.500 (12.7)	0.120 (3.0)	6 (0.68)	16 (1.8)	30 (3.4)	568 (2528)
#6, Hi-Lo	0.750 (19.0)	0.115 (2.9)	5 (0.56)	14 (1.6)	30 (3.4)	668 (2973)
#8, Type-23	0.500 (12.7)	0.146 (3.7)	9 (1.0)	21 (2.4)	38 (4.3)	556 (2474)
#8, Type-25	0.562 (14.3)	0.146 (3.7)	18 (2.0)	28 (3.0)	50 (5.6)	884 (3934)

They have low creep characteristics compared to other plastics, and maintain the required interference over a long time.

**Reference:** Tuffak Polycarbonate Sheet. *Forming and Fabrication*, Supplier design guide (ADV980496/APL:ATG-16S/web/6-00), Altuglas International, 2000.

## Polycarbonate

**Staking:** Staking is a common application for ultrasonic assembly. The process works well with soft or amorphous materials with relatively low melt flows. These materials allow the head of the rivet to be formed by both mechanical and thermal mechanisms. If materials with high melt flows or materials that require relatively high vibrational amplitudes are used, the melt tends to flow so rapidly and uncontrollably that material is ejected out of the horn contour. The loss of material results in an incomplete rivet head.

Amplitude modification was used to improve the control of the melt flow. High amplitude was used to initiate the melt of the plastic, then reduced to limit the flow while maintaining the heat.

**Reference:** Grewell DA, Frantz JL: Amplitude control in ultrasonic welding of thermoplastics. ANTEC 1994, Conference proceedings, Society of Plastics Engineers, San Francisco, May 1994.

## Dow Chemical: Calibre (features: transparent)

With some considerations, parts made of Calibre polycarbonate lend themselves to all mechanical assembly methods.

**Rivets:** Rivets can be used to assemble Calibre polycarbonate to itself, to metals, or to other plastics. Use rivets made of aluminum, because of this metal's ability to deform under load (which limits the compressive forces imparted during the riveting process) and because the coefficients of thermal expansion of aluminum and polycarbonate are similar. As with most mechanical assemblies, incorporating a washer to distribute the loading over a larger area is advisable.

**Snap-fit Assemblies:** Calibre polycarbonate is especially well-suited for cantilever snaps because of its consistent, low mold shrinkage, its high resistance to creep, and its overall dimensional stability. The permissible strain for Calibre polycarbonate during a single, brief snap-fit is 4%. If frequent assembly and disassembly are anticipated, the strain level should be reduced to about 60% of that value, or 2.4%.

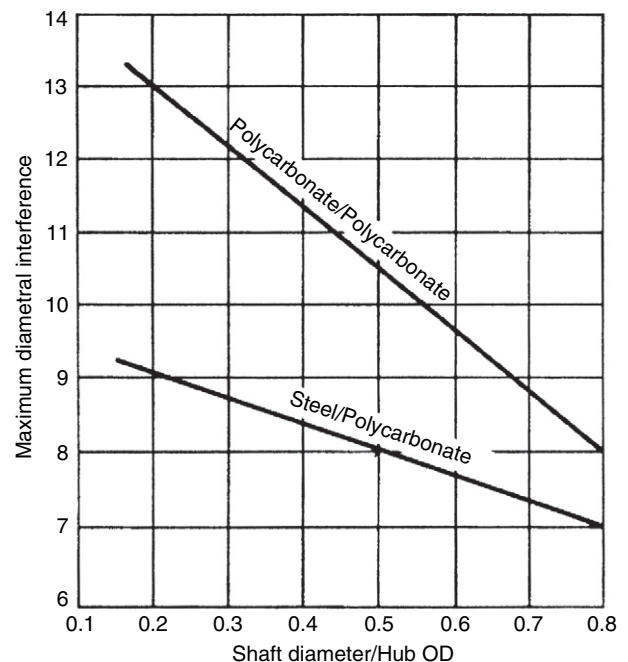
**Press-fit Assemblies:** When designing a press-fit, make sure the design provides holding strength adequate to meet the assembly requirements without overstressing the assembly. This potential problem is complicated by three factors:

- Press-fit designs require close manufacturing tolerances
- Calibre polycarbonate is a rigid material
- Part dimensions will change with time due to creep and relaxation

In designing a press-fit between two parts made of rigid materials, minimize the interference between the two parts to keep the assembly stresses at acceptable levels (Fig. 27.5).

Creep is the change in dimensions of a molded part resulting from cold flow incurred under continued loading. Creep can cause a press-fit that was considered satisfactory at the time of assembly to loosen to an unacceptable condition or even to failure. A standard method of overcoming this problem is to incorporate grooves on the shaft. This reduces the assembly stresses, and thereby the degree of creep. After assembly, and over time, the plastic will cold-flow into the grooves and retain the desired holding strength of the fit.

**Staking:** Because of the high degree of stiffness of Calibre polycarbonate, and because of the extremely



**Figure 27.5.** Recommended diametral interference @ 23°C (73°F), for interference fits in Calibre polycarbonate resins.

high residual stresses of the staking process, cold staking generally is not an acceptable assembly method.

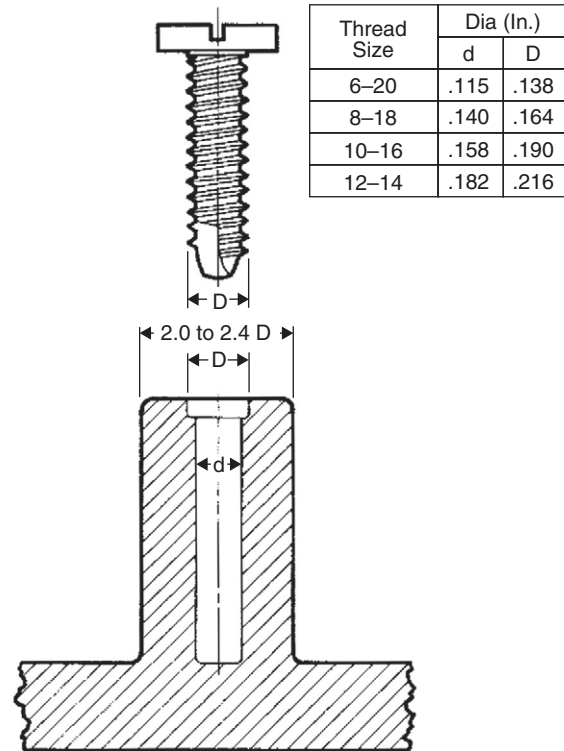
**Screws:** Like metals and many other plastics, Calibre polycarbonate accommodates many types of screw assemblies. The four major methods are: to screw directly into the Calibre polycarbonate part, using self-threading screws; to screw into a threaded insert that is incorporated within the part; to pass the screw through the part and secure it with an external nut or clip; and to mold threads into or onto the Calibre polycarbonate.

**Tapping and Self-tapping Screws:** There are two types of self-threading screws—thread-forming and thread-cutting. Thread-forming screws are not recommended for use with Calibre polycarbonate because they induce high stresses into the plastic as the thread is formed. Thread-cutting screws (such as Type-23 or -25) are recommended because they form threads by actually cutting away the plastic material, inducing minimal deformation and reducing hoop stress. Flat head screws should be avoided because the wedging action causes high hoop stress.

If the unit is to be repeatedly assembled and disassembled, use Type-23 screws. If a self-tapping screw is removed from an assembly, always replace it with a standard-pitch machine screw for reassembly. Otherwise, the self-tapping screw may cut a new thread over the original thread, resulting in a stripped thread. This assembly method allows for only a minimum number of disassemblies and reassemblies; repeated removal and return of the screw decreases the strength of the material. For applications requiring frequent reassembly, ultrasonically applied metal inserts are suggested.

The following comments are applicable to boss design for self-threading screws in Calibre polycarbonate (Fig. 27.6):

- Entry counterbore diameter should be equal to the major diameter (D) of the screw thread and approximately equal to a depth of one pitch length.
- Inside diameter of the boss (d) should be equal to the pitch diameter of the screw thread.
- Outside diameter of the boss should be 2.0–2.5 times the major diameter (D) of the screw thread.
- Minimum thread engagement should be 2.5 times the pitch diameter.
- Boss height must result in an assembly that supplies direct, flush, continuous support to the screw. The design may include a washer and/or spacer to accomplish this.



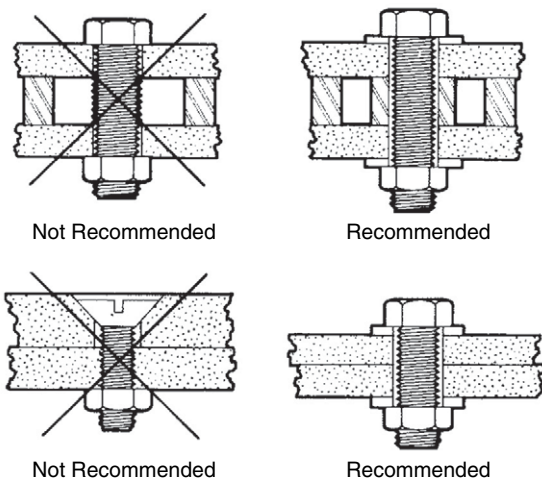
**Figure 27.6.** Recommended boss design for self-threading screws in Calibre polycarbonate.

- Either a through hole or blind hole in the boss will provide adequate melt flow. Bottom thickness of a blind hole should be equal to nominal wall thickness.

**Screws with Nuts:** Screws that pass through the plastic part and are retained by an external nut or clip provide a simple, convenient assembly method. This method lends itself to multiple reassemblies and is unaffected by the amount of torque that is applied to the plastic. Good design for this assembly method requires attention to the following (Fig. 27.7):

- Design the joint area to eliminate any space between the two plastic surfaces being assembled. This puts the assembly in compressive loading instead of tensile loading, reducing tensile stresses that can cause failure. A spacer may be needed to accomplish this.
- Use a washer to distribute the high torque loading over a greater surface area.

**Molded-in Threads:** Most standard thread designs can be molded into Calibre polycarbonate. There are only three limitations. First, avoid extra fine threads. These are difficult to fill, and usually are not strong



**Figure 27.7.** Assembly design for screws with nuts using Calibre polycarbonate.

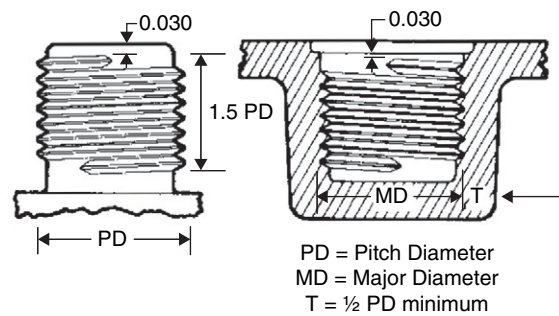
enough to withstand torque requirements. Second, threads should not have sharp corners. These can form notches and decrease the screw-retention values. Third, threads should always have a radius at the root to avoid stress concentrators.

The following dimension guidelines should be helpful in designing molded-in threads (Fig. 27.8):

- Avoid running threads out to the edge of the screw base. Leave a gap of approximately 0.030 inches (0.76 mm).
- The minimum active thread length should be 1.5 times the pitch diameter of the thread.
- The minimum wall thickness around the internal thread should be 0.5 times the major diameter of the thread.
- Avoid the use of tapered pipe threads. As the threaded article is increasingly tapered, the hoop stress increases.

**Threaded Inserts:** Threaded inserts, commonly made of nonferrous metal, are utilized in several designs. They can be built into the plastic part as molded-in inserts, heat or pressure inserts, ultrasonic inserts, or expansion inserts. The preferred method for embedding the insert into Calibre polycarbonate is ultrasonic insertion, because it imparts low residual stresses, and is inexpensive. The least preferred method, because of the high residual stresses that result, is expansion insertion.

For good design, inserts should not have sharp corners or edges that could act as notches or stress concentrators. An undercut with a flat or smooth knurl



**Figure 27.8.** Recommended design for molded-in threads, Calibre polycarbonate.

minimizes notch sensitivity and still provides acceptable pull-out and torque levels.

**Reference:** *Calibre Engineering Thermoplastics Basic Design Manual*, Supplier design guide (301-1040-1288), Dow Chemical Company, 1988.

### Bayer: Makrolon

**Tapping and Self-tapping Screws:** Any part mounted to another by means of a self-tapping screw must be located flush with the top of the boss. Eventually, a spacer must be used. Otherwise, the screw will be pulled out and the cut-in thread destroyed or even breakage of the boss may occur.

Data concerning the holding load or the stripping force for self-tapping screws, which can be found in the literature, are often irrelevant. They are results from short-term testing, but do not consider the long-term behavior of the material and its creep. The respective load would lead to failure, generally by breakage of the boss within a short period of time.

**Molded-in Threads:** Unified and American Standard screw threads, injection molded, must be judged very carefully. The threads, forming a number of pronounced notches, reduce the impact strength and the ultimate elongation under tensile stress significantly. Trapezoidal and knuckle threads are better to a certain degree. Preferably, screw and nut, or threaded holes should be of polycarbonate, and no higher load applied. The used length of the thread must be more than 1.5 times the diameter; the section thickness around the hole more than 0.6 times the diameter.

Avoid feather edges, and limit the tightening with a shoulder of the bolt.

**Reference:** *Makrolon Polycarbonate Design Guide*, Supplier design guide (55-A840(10)L), Bayer, 1988.



### Bayer: Makrolon

**Riveting:** With Makrolon polycarbonate, care must be exercised to minimize stresses induced during the fastening operation. To distribute the load, rivets with large heads (three times the shank diameter) should be used with washers under the flared end of the rivet. The rivet setting tool should be calibrated to the correct length to control the compressive stress applied to the joint area.

**Snap-fit Assemblies:** Snap-fits are a simple, economical, and rapid way of joining components manufactured from Makrolon polycarbonate. Many different designs and configurations can be utilized with this joining technique. The permissible strain for a one-time snap-fit assembly in Makrolon polycarbonate is 4%. For repeated assembly, the maximum strain should be reduced to 2.4%.

**Press-fit Assemblies:** Press-fits are occasionally used in Makrolon polycarbonate applications. Because this procedure involves high stresses, the fit must be designed with care (Figs. 27.9 and 27.10). Following are some points to keep in mind with press-fits:

- Be sure all parts are clean and free of any foreign substance.
- Press-fits of unlike materials should be avoided if they are subject to thermal cycling.
- Avoid press-fits if the assembly is subject to a harsh environment.

**Tapping and Self-Tapping Screws:** Thread-cutting screws like the Type-23, Type-25, and the Hi-Lo (with a cutting edge on the point) actually remove material as they are installed, avoiding high stress build-up.

Thread-cutting screws can cause problems if they are removed and reinstalled repeatedly, because each time they are reinstalled new threads can easily be cut. If repeated assembly is required, Type-23 screws should be replaced with a standard machine screw to avoid recutting of threads. This cannot be done with a Type-25 screw because it has a nonstandard thread pitch.

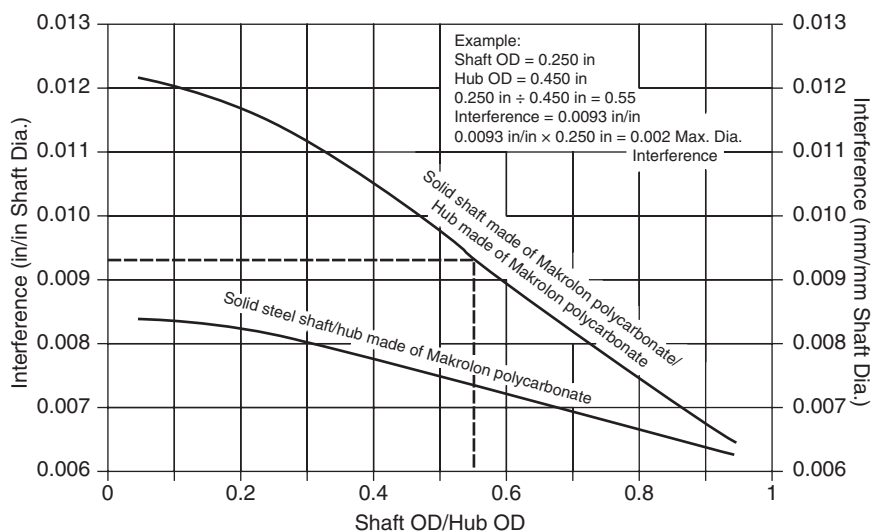
As with common threaded fasteners, flat-head screws should be avoided.

Screw bosses should be designed very carefully. While small boss diameters reduce the tendency for sinks and/or voids, they might not provide sufficient structural integrity to withstand assembly hoop stress.

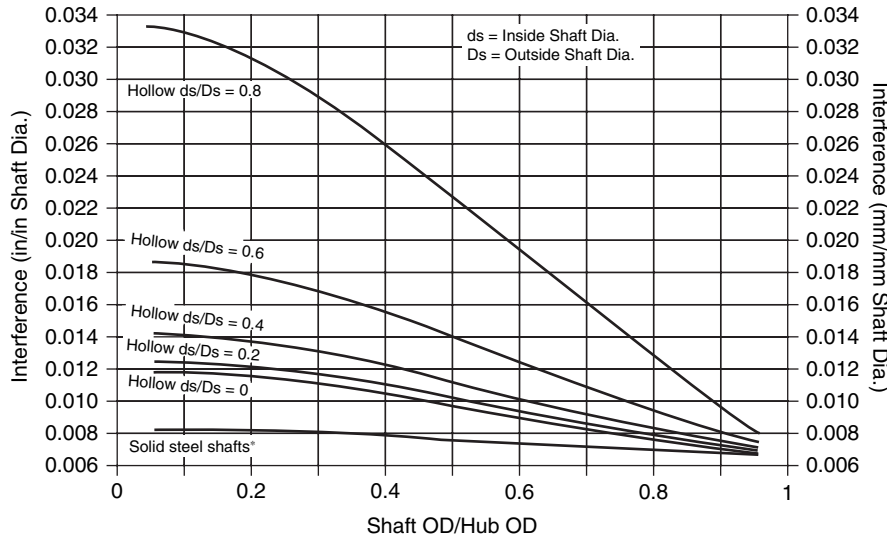
**Molded-in Inserts:** Metal inserts can be molded in Makrolon polycarbonate, but problems can result with this technique. Because Makrolon polycarbonate has a much higher coefficient of thermal expansion than metal, molded-in inserts should be avoided for applications subject to thermal cycling. Glass-reinforced grades of Makrolon polycarbonate that have thermal coefficients closer to metals are less likely to cause problems.

Inserts that weigh more than 0.05 oz (1.5 g), or are 0.250 inches (6.35 mm) in diameter or larger, should be preheated to about 350–400°F (177–204°C) prior to insertion in the mold. This will help to reduce thermal stresses caused by the hot melt contacting the cold metal insert.

Before inserts are placed in the mold, they should be free of all foreign matter. Care must be exercised to see that the insert seats securely to prevent floating which can cause extensive mold damage.



**Figure 27.9.** Maximum diametral interference for Makrolon polycarbonate and steel press-fits (solid shafts).



**Figure 27.10.** Maximum diametral interference for Makrolon polycarbonate and steel press-fits (hollow shafts).

Inserts with sharp knurls or protrusions can have high pullout values, but they can also reduce impact values because the sharp points cause a notch effect.

**Molded-in Threads:** When the application involves infrequent assembly, molded-in threads can be used. Coarse threads can be molded in Makrolon polycarbonate more easily than fine threads. Threads of 32 or finer pitch should be avoided, along with tapered threads (e.g., pipe threads), which are not recommended because they can cause excessive stress.

The following factors also should be considered:

- If the mating part is metal, over torquing will result in part failure.
- Feather edges on thread runouts should be avoided to prevent cross threading or thread damage.
- The roots and crests of threads should be rounded to reduce stress concentrations as well as to help mold filling.
- Internal threads can be formed by collapsible cores or unscrewing cores. External threads are formed by split cores or unscrewing devices. All of these increase mold costs.

**Threaded Inserts:** Inserts ultrasonically installed in Makrolon polycarbonate provide an excellent base for threaded fasteners. When done correctly, a problem-free joint can be expected.

In general, optimum insert performance may be achieved when the boss OD is two times the insert diameter. The receiving hole, which can be straight or have an 8° taper, as some inserts require, is usually

0.015–0.020 inches (0.38–0.51 mm) smaller than the insert OD. The hole should be deeper than the insert length so that the insert will not bottom out and to provide a well for any excess plastic melt.

When installed, the top of the insert should be flush or slightly above—0.0003 inches (0.01 mm)—the top surface of the boss. If the insert is below this surface, jacking out of the insert can occur.

**Reference:** *Makrolon Polycarbonate—A Guide for Joining Techniques*, Supplier design guide (55-A664(10)C), Bayer, 1987.

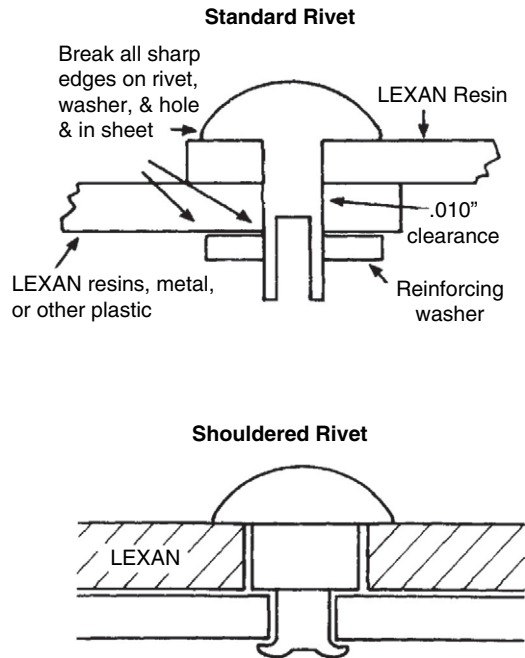
### GE Plastics: Lexan

**Riveting:** Care should be taken when riveting Lexan resin to avoid the high stresses inherent in most riveting techniques. Using a shouldered rivet limits the amount of stress imposed on the part (Fig. 27.11). Aluminum rivets also limit the force that can be applied, since the aluminum will deform under high stress.

In general, the rivet head should be 2.5–3 times the shank diameter, and the flared end of the rivet should have a washer to avoid high, localized stresses. Clearance around the shaft should allow easy insertion, but should not be so great as to allow slippage of the joined parts.

**Press-fit Assemblies:** Press-fit inserts can be used with Lexan resin to fasten two parts together. However, since this is a very high stress fastening technique, care must be taken to remain under the creep limit, and it should be remembered that high stresses leave the part more susceptible to chemical and thermal attack.

The following precautions must be observed in order to avoid over-stressed conditions:



**Figure 27.11.** Standard rivet and shoulder rivet design for Lexan polycarbonate.

- Design press-fit equal to or less than the creep limit.
- Use smooth, rounded inserts because of the possible stress concentration created by a knurl.
- Avoid locating a knit line on the area to be inserted.
- Remove all incompatible chemicals from the insert.

A change in operating temperature and dissimilar coefficients of thermal expansion can affect the amount of stress around the shaft. Press-fits should be designed for anticipated operating conditions, while keeping in mind the environment and other potential conditions to which the part may be exposed.

**Staking:** In ultrasonic staking, tip configuration of the horn will depend upon the application, the grade of resin, and the stud configuration. Rigid support of the Lexan resin part is necessary during the staking operation.

**Screws:** Machine screws are commonly used to assemble components made of Lexan resin. When machine screws are engaging Lexan resin threads, torque specification is a function of:

- Bearing force of the screw head or washer
- Thread shear stress
- Boss tensile stress

**Tapping and Self-tapping Screws:** Self-tapping screws of the thread-cutting variety perform satisfactorily in parts molded from Lexan resin, with Type-25 or -23 recommended because they cut a clean thread with negligible material deformation. Thread-forming screws should be avoided because of the high induced stress developed by the forming operation of the thread.

Generally, the designer should follow these recommendations in planning for self-tapping screws:

- The receiving hole diameter should be equal to the screw pitch diameter.
- The boss outside diameter (OD) should be strong enough to withstand possible hoop stresses developed by screw insertion. Usually, a boss OD equal to twice the screw major diameter is sufficient.
- A length at least twice the screw major diameter should be provided for thread engagement.
- Repeated assembly operations should be avoided.
- Use the minimum torque possible to keep screw assembly stress within the design limit of Lexan resin.

Self-tapping screws should not be used when repeated disassembly may occur. Unless extreme care is taken, a second insertion can result in the cutting of a second set of threads. This greatly weakens the structure, and may reduce torque retention to near-failure levels. If repeated removal and insertion is unavoidable, a Type-23 screw should be used initially, then replaced with a standard machine screw; an insert is best when repeated assembly is anticipated.

The amount of torque that can be placed on a screw depends on both the cross-sectional area of the boss and the total number of threads. Since sufficient threads can usually be provided, allowable torque is most often dependent on boss cross-section.

**Molded-in Inserts:** Molded-in inserts are not recommended for use with unreinforced Lexan resins (particularly in applications exposed to thermal cycling). They may perform adequately with glass-reinforced grades of Lexan resin, because of the lower coefficient of thermal expansion and high design stress limit. Although ultrasonic inserts are better alternatives than molded-in inserts, lack of facilities and experience result in many molders preferring molded-in inserts.

A simple pull-out or torque retention groove, or a flat surface on one or two sides of an insert may prove to provide sufficient torque and pull-out strength. Knurled inserts should be avoided because they can produce a notch effect in the material. Since molded-in inserts will cause stresses in the Lexan resin around

them, parts should be tested under the end-use environment to evaluate the strength of the inserts.

*Ultrasonic Inserts:* Ultrasonic insertion is a fast, economical method of embedding metal inserts into parts molded from Lexan resin. This technique offers a high degree of mechanical reliability with excellent pull-out strength and torque retention, combined with savings resulting from rapid production cycles. If the assembly is properly designed, ultrasonic insertion results in a lower residual stress compared to molded-in or pressed-in techniques. This is because a thin film of homogeneous melt occurs around the insert.

For most applications, the ultrasonic energy should be transferred through the metal insert. Due to the wear on the horn as metal touches metal during the insertion process, steel horns are usually recommended. Since steel horns cannot be driven at high amplitudes, a low

amplitude is usually used for insertion. In some cases, the horn can make contact with the Lexan resin. Experimentation will quickly determine the preferred medium for energy transfer in a specific application. A part must be rigidly supported during the insertion operation.

*Self-tapping Inserts:* As with self-tapping screws, self-tapping inserts with self-cutting Type-25 threads are recommended for use with Lexan resin parts. These inserts are able to withstand the same amount of longitudinal loading as a screw of the same outer diameter, since loading is a function of the shear area present around the insert. Generally, material thickness around the insert should be at least 90% of the outer radius of the insert.

**Reference:** *Lexan Design Guide*, Supplier design guide (CDC-536E), General Electric Company, 1986.