

Polycarbonate

General Discussion of Joining Techniques

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. Because they are plastics, CALIBRE polycarbonates accommodate most assembly methods. They provide for superior solvent and adhesive bonding; their rigidity permits ultrasonic and vibrational welding.

Each of the assembly methods used for parts of CALIBRE polycarbonate has its advantages and disadvantages. The decision on 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 the parts and tooling can be designed to meet assembly needs.

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

Welding

Dow Chemical: Calibre (features: transparent)

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 melt temperature range. Also, because it is non-crystallizing, polycarbonate is welded without acquiring thermal stresses such as those that occur in PBT or PET when those plastics are welded. These properties qualify CALIBRE resins for both vibrational (frictional) and direct-heat welding.

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

Heated Tool Welding

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 upon part thickness.

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

Dow Chemical: Calibre (features: transparent)

CALIBRE polycarbonate is suitable for hot tool welding.

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

GE Plastics: Lexan 9030

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 (250 - 400°C) but quite narrow for the undried specimens (230 - 250°C). 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 seal penetration appears to result in a higher weld strength. An increase in the melt time appears to reduce the hot tool temperature required for obtaining high weld strengths.

Reference: Stokes, V.K., *Experiments on the Hot-Tool Welding of Polycarbonate*, ANTEC 1995, conference proceedings - Society of Plastics Engineers, 1995.

GE Plastics: Lexan 9030 (product 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.

Reference: Stokes, V.K., *Experiments on the Hot Tool Welding of Dissimilar Thermoplastics*, ANTEC 1993, conference proceedings - Society of Plastics Engineers, 1993.

GE Plastics: Lexan 9030 (product form: sheet)

High strengths can be attained in hot tool welds between very dissimilar materials. Although the two immiscible, amorphous polymers polycarbonate and polyetherimide have glass transition temperatures of 150°C and 215°C, 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 hot-tool temperatures in the range of 302-329°C (575-625°F) for polycarbonate and 371-427°C (700-750°F) 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 hot-tool temperature of 427°C (800°F) appear to vary erratically. This could be due to degradation of polyetherimide at this high temperature and deposits on the hot-tool surfaces affecting the cleanliness of the molten plastic layers.

Reference: Stokes, V.K., *Experiments on the Hot Tool Welding of Dissimilar Thermoplastics*, ANTEC 1993, conference proceedings - Society of Plastics Engineers, 1993.

Vibration Welding

Bayer: Makrolon

Vibration welding is a friction-welding technique which utilizes a vibration welding machine that operates at a frequency of either 120 or 240 Hz.

In this process, one part is fixed in a stationary head, and the other part is attached to a welding head that moves in the plane of the joint. 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.

Dow Chemical: Calibre (features: transparent)

Parts made of CALIBRE polycarbonate can be bonded by vibrational welding.

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

GE Plastics: Lexan 9030 (features: 5.8 mm thick; product 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 in), and penetrations greater than 0.25 mm (0.01 in). For an amplitude of $a = 0.95$ mm (0.0375 in), 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, V. K., *Cross-Thickness Vibration Welding of Thermoplastics*, ANTEC 1992, conference proceedings - Society of Plastics Engineers, 1992.

GE Plastics: Lexan 9030 (product form: sheet)

In the vibration welding of polycarbonate, the overall cycle time will increase with increasing part thickness for fixed weld parameters (frequency, n ; amplitude, a ; pressure, p_0), due to an increase in the times spanned by phases 2-4 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 $p_0 = 0.9$ MPa results in acceptable cycle times and threshold penetrations for part thicknesses below 5.8 mm, higher pressures are indicated for thicknesses equal to 12.3 mm. 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, V.K., *Thickness Effects in the Vibration Welding of Polycarbonate*, ANTEC 1989, conference proceedings - Society of Plastics Engineers, 1989.

GE Plastics: Lexan 9030 (features: 5.8 mm thick; manufacturing method: extrusion; product 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 of 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, V.K, Hobbs, S.Y., *Strength and Bonding Mechanisms in Vibration-Welded Polycarbonate to Polyetherimide Joints*, ANTEC 1989, conference proceedings - Society of Plastics Engineers, 1989.

GE Plastics: Lexan

Dissimilar materials may be joined to Lexan resin by vibrational welding and a special dovetail/tongue-in-groove joint design (Figure). 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.

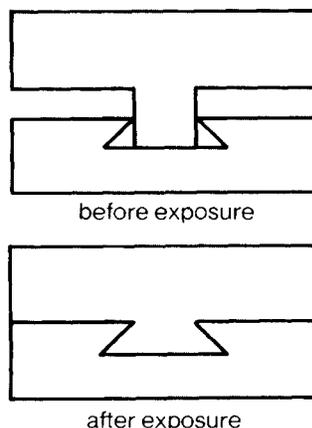


Figure 35.1: Joint design for vibration welding dissimilar materials to GE Plastics Lexan polycarbonate.

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

GE Plastics: Polycarbonate

Table 35.1: Achievable strengths of vibration welds of polycarbonate to itself and other thermoplastics.

Material Family	PC							
Tensile Strength ² , MPa (ksi)	68 (9.9)							
Elongation @ Break ² , %	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 ¹	ABS	M-PPO	M-PPO/PA	PC	PBT	PC/ABS	PC/PBT	PEI
Tensile Strength ² , 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 ² , %	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 ² , % (nominal)	1.7	0.4	0.75	6	1.7	1.8	4.9	2.75

¹ABS - 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
²strain rate of 10⁻²s⁻¹

Reference: Stokes, V.K., *Toward a Weld-Strength Data Base for Vibration Welding of Thermoplastics*, ANTEC 1995, conference proceedings - Society of Plastics Engineers, 1995.

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. Labour cost was cut by 70 percent and the total part cost was cut considerably.

Reference: White, P., *Vibration Welding*, Making It With Plastics, trade journal 1987.

Spin Welding

Bayer: Makrolon

Spin welding, sometimes called friction welding, is a method of joining parts made from Makrolon polycarbonate with heat. The parts to be joined, or at least their joint areas, must be circular for this method of joining to be used. A shallow matching groove (tongue and groove) is desirable to index the two parts and to provide a uniform bearing surface.

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.

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.

Ultrasonic Welding

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 (acrylonitrile-butadiene-styrene) and to Bayblend polycarbonate/ABS blend.

In general, fillers such as glass do not inhibit welding. However, when glass content is 10 percent or higher, horn wear can occur. Poor bonding can result when glass content is 30 percent 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 in (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.

Dow Chemical: Calibre 2061-15 (features: medical grade, transparent; melt flow index: 15 grams/10 min.); **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 TPU's (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 was 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 didn't 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 didn't weaken the bonds for the polymers tested in this short term study.

Reference: Kingsbury, R.T., *Ultrasonic Weldability of a Broad Range of Medical Plastics*, ANTEC 1991, conference proceedings - Society of Plastics Engineers, 1991.

Dow Chemical: Calibre (features: transparent)

Calibre polycarbonate is well suited to ultrasonic welding. The only concerns on 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 an 0.25 inch 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.

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 0.20 in. (5.1 mm) and a width of approximately 0.25 in. (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.

Polycarbonate

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) 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, D.A., *Amplitude and Force Profiling: Studies in Ultrasonic Welding of Thermoplastics*, ANTEC 1996, conference proceedings - Society of Plastics Engineers, 1996.

Polycarbonate

Ultrasonic welding is a very complex process that is difficult to control. Two approaches for improving control of ultrasonic welding were investigated -- power threshold control and closed-loop power tracking. Power threshold control relies on the rapid rise in power which 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, 1996.

Polycarbonate

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, D.A., Frantz, J.L., *Amplitude Control in Ultrasonic Welding of Thermoplastics*, ANTEC 1994, conference proceedings - Society of Plastics Engineers, 1994.

Polycarbonate

In the ultrasonic welding experiment with polycarbonate, the results were even more pronounced than with ABS. Using parameters indicative to industrial applications results in weld strengths of 2967 N with a standard deviation of ± 1041 . If the amplitude is varied, weld strengths as high as 7735 ± 138 N can be achieved, which nearly matched the parent material strength of 7850 N. In fact, in these welds, failure usually occurred outside the weld zone when tested in tension.

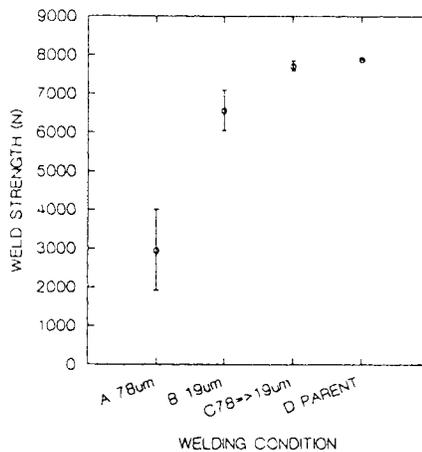


Figure 35.2: Weld strength for polycarbonate test samples ultrasonically welded with various amplitude conditions. Tests with two numbers (i.e. 78 ⇒ 19 µm) represent the use of amplitude profiling.

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.

Reference: Grewell, D.A., Frantz, J.L., *Amplitude Control in Ultrasonic Welding of Thermoplastics*, ANTEC 1994, conference proceedings - Society of Plastics Engineers, 1994.

Polycarbonate

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, R.L., Driscoll, S.B., *Ultrasonic Welding with Amplitude Profiling*, ANTEC 1995, conference proceedings - Society of Plastics Engineers, 1995.

Ultrasonic Inserts

Bayer: Makrolon

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 in (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 - 0.010 in (0.003 mm) - the top surface of the boss. If the insert is below this surface, jackout 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

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.

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

Induction Welding

Dow Chemical: Calibre (features: transparent)

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

Radio Frequency Sealing

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 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, 1992.

Electromagnetic Welding

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 (acrylonitrile-butadiene-styrene), acrylic, polysulfone, and SAN (styrene-acrylonitrile polymer).

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

Mechanical Fastening

Dow Chemical: Calibre (features: transparent)

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

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

Riveting

Bayer: Makrolon

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.

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

Dow Chemical: Calibre (features: transparent)

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.

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

GE Plastics: Lexan

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. 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 2-1/2 to 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 shouldn't be so great as to allow slippage of the joined parts.

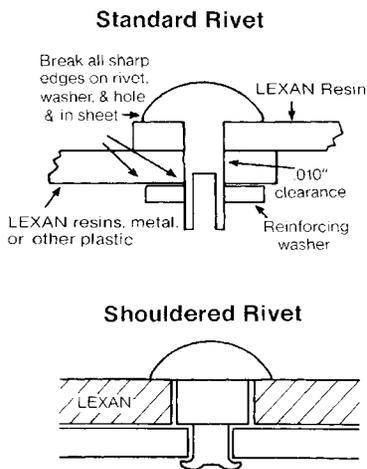


Figure 35.3: Standard rivet and shoulder rivet design for Lexan polycarbonate.

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

Snap Fit Assemblies

Bayer: Makrolon

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 percent. For repeated assembly, the maximum strain should be reduced to 2.4 percent.

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

Dow Chemical: Calibre (features: transparent)

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%.

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

Press Fit Assemblies

Bayer: Makrolon

Press fits are occasionally used in Makrolon polycarbonate applications. Because this procedure involves high stresses, the fit must be designed with care.

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.

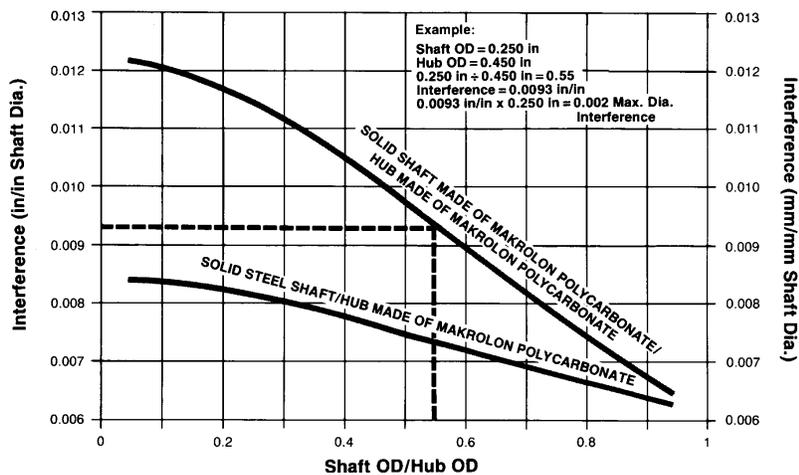


Figure 35.4: Maximum diametral interference for Makrolon polycarbonate and steel press fits (solid shafts).

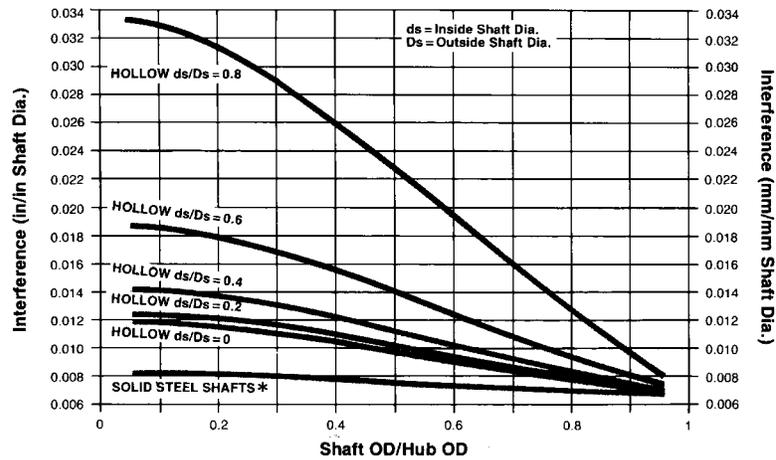


Figure 35.5: Maximum diametral interference for Makrolon polycarbonate and steel press fits (hollow shafts).

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

Dow Chemical: Calibre (features: transparent)

When designing a press-fit, make sure the design provides holding strength adequate to meet the assembly requirements without over-stressing 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.

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.

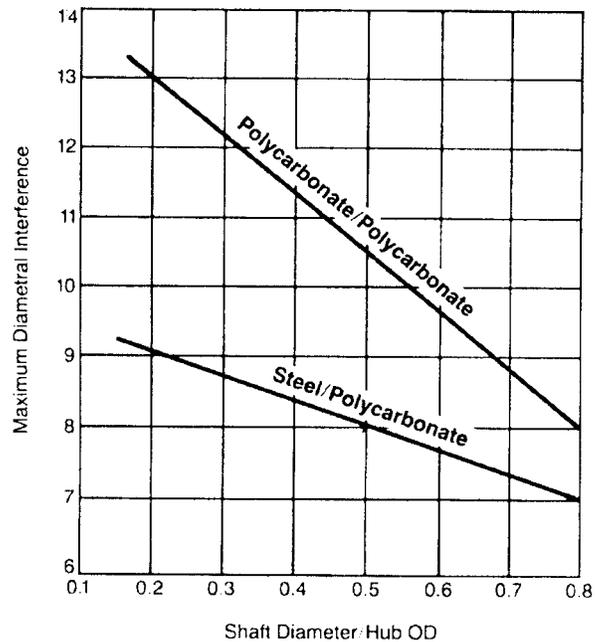


Figure 35.6: Recommended diametral interference @ 73°F (23°C), for interference fits in Dow Chemical Calibre polycarbonate resins.

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

GE Plastics: Lexan

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:

- 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 environment and other potential conditions to which the part may be exposed.

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

Staking

Dow Chemical: Calibre (features: transparent)

Because of the high degree of stiffness of Calibre polycarbonate, and because of the extremely high residual stresses of the staking process, cold staking generally is not an acceptable assembly method.

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

GE Plastics: Lexan

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.

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

Polycarbonate

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, D.A., Frantz, J.L., *Amplitude Control in Ultrasonic Welding of Thermoplastics*, ANTEC 1994, conference proceedings - Society of Plastics Engineers, 1994.

Screws

Dow Chemical: Calibre (features: transparent)

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.

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

GE Plastics: Lexan

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.

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

Tapping and Self-Tapping Screws

Bayer: Makrolon

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 destroy the cut-in thread or may even cause breakage of the boss.

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.

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

Bayer: Makrolon

A thread-forming screw displaces material as it is installed in the receiving hole. This type of screw induces high stress levels in the plastic part and is not recommended for parts of Makrolon polycarbonate.

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 buildup. 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.

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

Dow Chemical: Calibre (features: transparent)

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:

- 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 to 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.
- 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.

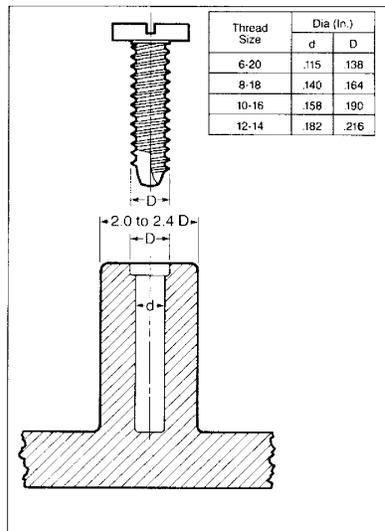


Figure 35.7: Recommended boss design for self threading screws in Dow Chemical Calibre polycarbonate.

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

GE Plastics: Lexan

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 (O.D.) should be strong enough to withstand possible hoop stresses developed by screw insertion. Usually, a boss O.D. 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 which 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.

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

Screws with Nuts

Dow Chemical: Calibre (features: transparent)

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:

- 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.

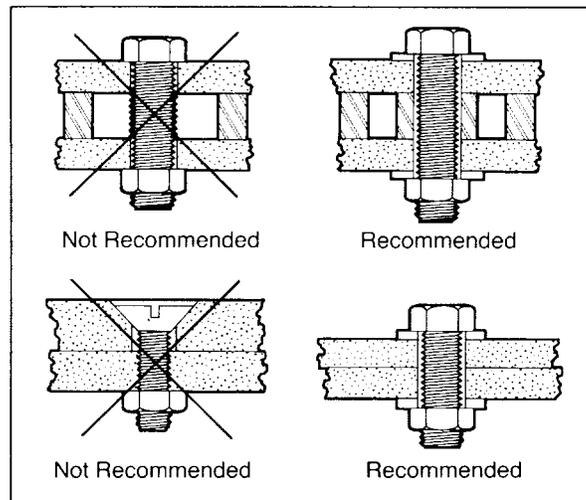


Figure 35.8: Assembly design for screws with nuts using Dow Chemical Calibre polycarbonate.

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

Molded-in Inserts

Bayer: Makrolon

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 in (6.36 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.

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.

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

GE Plastics: Lexan

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.

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

Molded-in Threads

Bayer: Makrolon

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 hole 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

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), that 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.

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

Dow Chemical: Calibre (features: transparent)

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 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:

- Avoid running threads out to the edge of the screw base. Leave a gap of approximately 0.030 inch.
- Minimum active thread length should be 1.5 times the pitch diameter of the thread.
- 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.

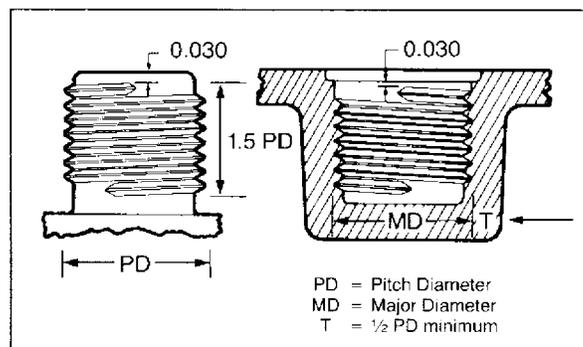


Figure 35.9: Recommended design for molded-in threads, Calibre polycarbonate.

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

Self-Tapping Inserts

GE Plastics: Lexan

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 percent of the outer radius of the insert.

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

Threaded Inserts

Dow Chemical: Calibre (features: transparent)

Threaded inserts, commonly made of non-ferrous 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 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.

Adhesive and Solvent Bonding

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

Cyrolon AR polycarbonate sheets are available with either one or two sides coated from protection against abrasion. When cementing to a non-coated 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 which 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, 1989.

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

Bond strength after sterilization is an area of interest in the medical market. The table below contains the results of a bonding study conducted to determine the effects of gamma radiation on adhesive and solvent bond strength. Based on the results of this study, solvent bonding and 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.

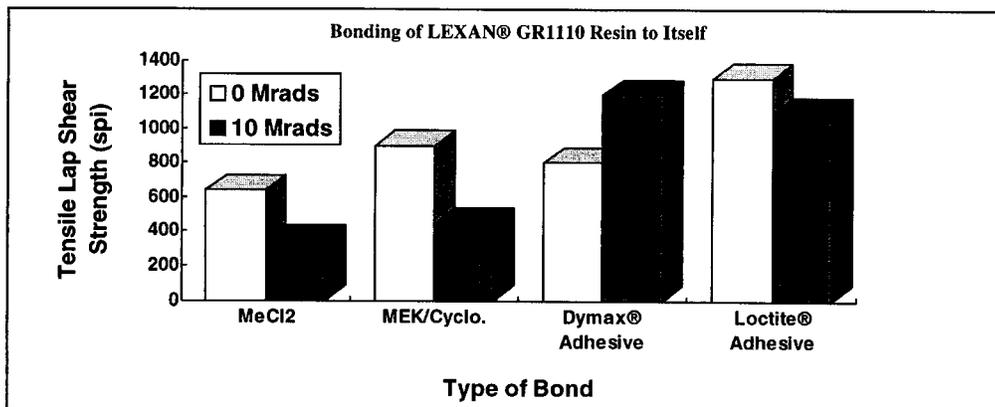


Figure 35.10: Effect of gamma radiation on adhesive and solvent bond strengths of General Electric Lexan GR1110 polycarbonate resin bonded to itself. (Solvents: MeCL₂ = methylene chloride; MEK = methy ethyl ketone; cyclo = cyclohexanone; UV Curable Adhesives: Dymax is a registered trademark of Dymax Corporation, Loctite is a registered trademark of Loctite Corporation.)

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

GE Plastics: Lexan GR1310 (features: gamma radiation stabilized)

The figure below provides a representative sample of the bond strength that can be achieved with GE Plastics Lexan 1310 polycarbonate resin adhered to flexible polyvinyl choride (PVC). Of the solvents, the methylene chloride/ cyclohexanone combination typically yielded the highest results when bonding Lexan resins to PVC. The UV curable adhesives tended to produce an even stronger bond joint, causing the PVC to yield before the adhesive.

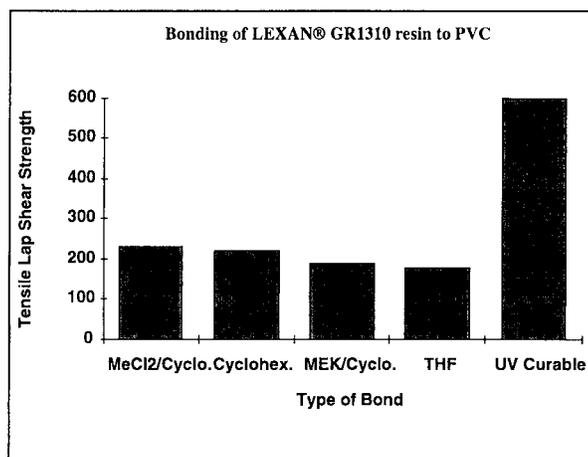


Figure 35.11: Adhesive and solvent bond strengths of General Electric Lexan 1310 polycarbonate resin adhered to Alpha Chemical PVC 2235L85 flexible polyvinyl chloride (PVC). (Solvents: MeCL₂ = methylene chloride; MEK = methy ethyl ketone; cyclo = cyclohexanone; THF = tetrahydrofuran. note: solvent combinations are 50:50 solutions.)

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

Adhesive Bonding

Bayer: Makrolon

Makrolon polycarbonate can be bonded to itself and to other substrates with a variety of adhesives. However, solvent-based adhesives can be harmful to Makrolon polycarbonate if the molded part is subject to stress greater than 1,300 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. Also, the equipment for dispensing it is 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.

System	Description	Supplier
RP-5500/5511	Two-component urethane system. 100% solids. Pot life is 5-20 minutes. Exhibits high shear strength at low temperature.	REN Plastics Tooling Department, Lansing, MI 48909
Versilok 506 & 202, and Acceleratore #5	Both systems are two-component acrylic structural adhesive. They are semi-flexible with good impact strength and fast cure at room temperature.	Hughson Chemicals, Erie, PA 16512
Scotch-Weld 2216 B/A	Two-component epoxy adhesive. Pot life is about 90 minutes. Cures at room temperature in about 12 hours. Full bond takes several days.	3M Corporation, St. Paul, MN 55101
E-Pox-E-Glue	Two-component epoxy system. Cures at room temperature in 24 hours. Maximum bond strength takes several days.	Woodhill Chemicals, Cleveland, OH 44128
Thermogrip 6323	Hot melt adhesive having a high, bond strength after three weeks' cure time.	Bostik, Division of USM Corporation, Middleton, MA 01949

Table 35.2: Adhesive systems suitable for bonding Makrolon polycarbonate.

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

Dow Chemical: Calibre 300-4

A study was conducted to test for bond strength on a representative matrix of commonly used plastics and the adhesives best suited to them. For many of the plastics evaluated, the effect of polymer composition on bond strength was evaluated by compounding plastic formulations with each of the most commonly used additives and fillers for that plastic; common grades were used for the remaining resins. The effect of each additive and filler was determined by comparing the bond strength achieved with the specially compounded formulations to that of the neat plastic. In addition, the effect of surface roughening and chemical treatment of the plastic surface on bond strength was examined.

The block-shear (ASTM D 4501) test was chosen as the test method because it places the load on a thicker section of the test specimen that can withstand higher loads before experiencing substrate failure. In addition, the geometry of the test specimens and the block-shear fixture helps minimize peel and cleavage forces in the joint. How well the block-shear test method reflects the stresses that an adhesively bonded joint will experience in real world applications should be considered. Also, limitations on the data due to the variety of additives and fillers used by different companies should not be ignored.

Prism 401 and Super Bonder 414, both cyanoacrylate adhesives, and Loctite 3105, a light curing acrylic adhesive, achieved the highest bond strengths on PC, although there was no set trend in the magnitude of the bond strengths achieved by the three adhesives. Black Max 380, a rubber toughened cyanoacrylate adhesive, and Depend 330, a two-part no-mix acrylic adhesive, achieved the lowest bond strengths on PC.

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, 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 7070.

Table 35.3: Shear strengths of PC to PC adhesive bonds made using adhesives available from Loctite Corporation. Values are given in psi and (MPa).^{b,c}

Plastic Material Composition (Dow Chemical Calibre 300-4)	Loctite Adhesive					
	Black Max 380 rubber toughened cyanoacrylate (200 cP)	Prism 401 surface insensitive ethyl cyanoacrylate (100 cP)	Prism 401/ Prism Primer 770 polyolefin primer for cyanoacrylate	Super Bonder 414 general purpose cyanoacrylate (110 cP)	Depend 330 two-part no-mix acrylic	Loctite 3105 light cure acrylic (300 cP)
Unfilled resin 3 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% Antimony oxide	1300 (9.0)	>4100 ^a (>28.3) ^a	>3800 ^a (>26.2) ^a	>3400 ^a (>23.5) ^a	300 (2.1)	3700 (25.5)
Impact modifier 5% Paraloid EXL3607	1000 (6.9)	3850 (26.6)	2000 (13.0)	>4500 ^a (>31.0) ^a	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 (18.6)	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)

^a 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.

^b All testing was done according to the block shear method (ASTM D4501).

^c For more information on data presented in this table, contact Loctite Corporation at 800-562-8483 (1-800-LOCTITE). Request the "Design Guide for Bonding Plastics."

Reference: *The Loctite Design Guide for Bonding Plastics*, supplier design guide (LT-2197) - Loctite Corporation.

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. Avoid adhesives containing incompatible constituents or curing agents which 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, (149°F (65°C) 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 in. (0.13 to 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 crosslinking. 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.

Solvent Bonding

Bayer: Makrolon

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

The common solvents used in this process are methylene chloride and ethylene dichloride. The fast evaporation rate of methylene chloride can help to prevent solvent vapor entrapment while the slower evaporation rate of ethylene dichloride allows for more assembly time.

A mixture of methylene chloride and ethylene dichloride (60-40 percent) may be used when it is difficult to join both halves fast enough and a reduced evaporation rate is required.

A 5-10 percent solution of polycarbonate in methylene chloride can be used to obtain smooth, filled joints when the mating parts to be bonded do not have a perfect interface. However, this mixture should not be used to compensate for poorly matched joints. A higher concentration of this solution can result in the formation of bubbles at the joint.

Some embrittlement in the bond area might occur when using a solvent system. The excellent impact strength of Makrolon polycarbonate resin is largely lost at the weld joint when using solvent bonds.

Bonding procedure

The most common mistake made in making solvent bonds 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 decrease 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 bonds. They should mate with no strain so that contact pressure may be uniformly distributed over the entire bond area.

In solvent bonding, 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. Pressure between 100 and 500 psi (0.7 and 3.44 MPa) should be used for best results.

The ultimate bond 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 bond will result. The amount of clamp time is not as important, but a minimum of 60 seconds is recommended.

Curing solvent-bonded parts

Parts solvent-bonded with methylene chloride which are intended to function at room temperature should be cured for 24 to 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 percent of the ultimate bond strength was reached within 1-2 days.

If the bonded assembly is to function at elevated temperatures, and the maximum attainable bond strength is required, then a long and tedious cure of the solvent bond is required.

Smaller bond 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 bond. Uncured parts which are suddenly exposed to service at elevated temperatures may suffer complete joint failure. If exposed to service in hot water, a cloudy, weak bond 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.

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 bonding, 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 to 500 psi, the bond cures to form a joint in one to five 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 to 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.

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 and an extremely fast evaporation rate.
- A one to five percent 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 cementing 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 bonding surfaces. The other half should remain dry and ready in the clamping fixture. Surfaces to be bonded 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.

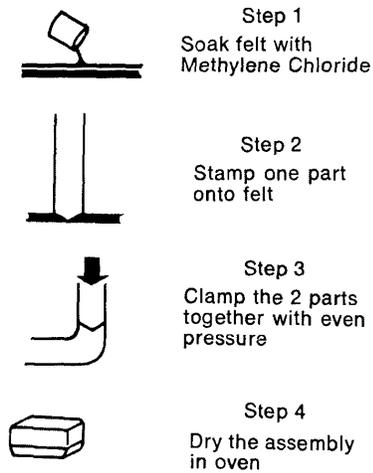


Figure 35.12: Solvent cementing procedure 1 for GE Plastics Lexan polycarbonate.

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.

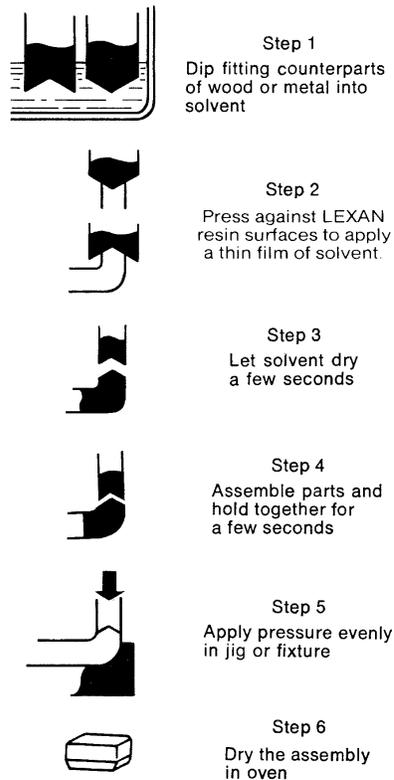


Figure 35.13: Solvent cementing procedure 2 for GE Plastics Lexan polycarbonate.

Pressure should be applied as soon as the two parts have been put together. Pressure between 200 and 600 psi (1.4 and 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 cemented 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 bond area indicates excessive solvent and too much elapsed time between solvent application and mating of the parts in the pressure fixture.

Although the cemented parts may be handled without damage after the holding time in the pressure fixture, sufficient bond strength for room temperature use is normally achieved by drying the cemented parts for 24 to 48 hours at room temperature. If the solvent-cemented part is to be used at high temperatures, a longer solvent removal program is necessary. Otherwise, bubbles and a weakened bond 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 to 10°F 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.