Guide to forming polycarbonate sheet

by Elizabeth Grimes

Polycarbonate sheet may be thermoformed, cold formed and brake formed, resulting in one-piece shapes. The one-piece configurations are desirable to retain the original tough integrity of the material.

Thermoforming, including vacuum thermoforming, may take place at various temperature ranges, which require different sheet conditioning and handling. High-temperature thermoforming (370ºF to 415ºF) provides deep draws and sharp detail. Lower temperatures (350ºF to 370ºF) fit simple drape forming. Cold forming is possible when a retainer frame holds the polycarbonate sheet to a shape. Flex forming is cold forming performed at temperatures between 300ºF and 340ºF for a few hours — until the shape sets. Brake forming produces a straight bend and eliminates high-temperature strip heating, which can warp the sheet.

High-temperature thermoforming

Polycarbonate differs from most thermoplastics in three important ways:

• It rapidly loses its rigidity at forming temperatures above 370ºF.

• It has a narrow high-temperature forming range of 370ºF to 415ºF.

• It forms interior bubbles if entrained moisture is present.

These differences affect the type of heating used for forming, the characteristics of the machine needed to form it, and the amount of drying required.

• ***Sheet conditioning*** — In sheet less than 0.060-inch thick, entrained water usually escapes as vapor to the surface before it develops into a bubble in the hot sheet. In thicker sheet, as little as 0.04 percent moisture can create enough pressure inside the soft hot sheet to create a permanent bubble inside. Most polycarbonate sheets have absorbed excessive moisture by the time distributors receive them.

Drying the sheet in an oven ensures that bubbling does not occur during high temperature thermoforming. The drying time depends on sheet thickness, as indicated in Figure 1. After drying, the sheet can be held aside for a certain length of time before it picks up enough moisture to risk bubbling. The rate of reabsorption of moisture, a function of relative humidity and ambient temperature, determines how long the sheet can be stored before re-drying is necessary (see Figure 2). Dry sheet stored in a room with air having a dew point less than 20ºF will maintain a low moisture level indefinitely.

• ***Heating methods*** — Heating polycarbonate sheet in a hot air oven is impractical because the rapid stiffening rate demands fast action between heating and forming. For example, only six seconds are recommended for 0.118-inch sheet between heating and forming. The corresponding time for 0.236-inch sheet is about 10 seconds. An infrared oven (gas-fired or electric) is the accepted heating method. Electric heating is generally safer, more controllable, and less maintenance-prone than gas heating.

Single-sided heating suffices for sheet up to 0.080-inch thick, but double-sided heating of thicker sheet will minimize heating time. The forming temperature for attaining the best vacuum detail is 415ºF for polycarbonate sheet. An excellent way to monitor surface temperature is with a paper thermometer.

Sag, which is related to the modulus of the hot sheet, is also a good indication of temperature. In this case an electric eye set at the proper distance below the clamping frame automatically starts the machine when the center of the hot sheet sags into the light beam. Sag is relatively independent of thickness. Figure 3 shows the relationship of sag to sheet dimension at optimum forming temperature.

Some skylights take advantage of the natural sag of the sheet being heated. A cold air blast freezes the shape; otherwise the sag would deepen even when heat is removed.

Figure 1. Drying time of Tuffak® polycarbonate sheet vs. thickness in a 250°F oven. The time indicated is that required to achieve 0.04 percent moisture or less.

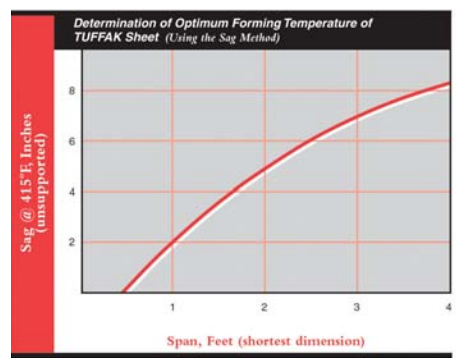

Figure 2. Moisture reabsorption of dry Tuffak® polycarbonate sheet under various ambient conditions. The parameters indicate longest exposure times before the sheet becomes too moist for proper high temperature forming.

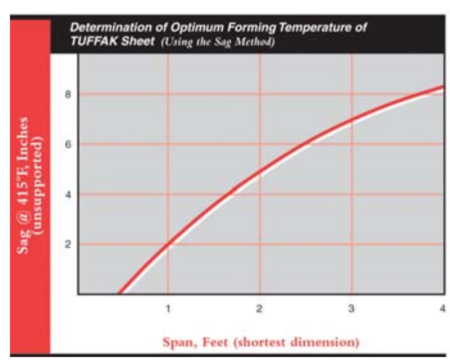

Figure 3. The amount of Tuffak® sheet sag, a function of sheet span, can be used to determine the optimum forming temperature.

• ***Forming machine*** — The thermoforming machine should have ample distance between clamping frame and mold to allow for a deep sag. It should also have infrared heaters on the top and bottom along with fast-operating platens to minimize cooling time.

• ***Tooling*** — The higher thermoforming temperatures needed for polycarbonate sheet influence selection of a mold material. Wood molds, particularly pine and sappy woods, should serve only for prototypes. Aluminum is the best material for permanent molds. Aluminum must be maintained at 200ºF to 210ºF with an oil heat exchanger to prevent chill lines and other distortions.

While epoxy and polyester molds last longer than wood molds, their heat transference is much poorer than aluminum, and they require long cooling cycles. Epoxy and polyester molds must be cooled to prevent high temperatures from destroying the surface. A 5º draft angle is recommended on all vertical surfaces to allow easy removal. Oversized tooling should be designed to compensate for the 1/8-inch per-foot shrinkage for female molds, and 3/32-inch shrinkage per foot for male molds.

Polycarbonate sheet must be clamped on all four sides during heating to control the blank size. Some thermoforming techniques rely on the plastic memory of the sheet. These techniques, which include vacuum snap back and bellow forming, are not appropriate for polycarbonate. Also, free-blown domes are difficult to form. Sag forming often yields better parts.

TROUBLESHOOTING GUIDE FOR POLYCARBONATE FORMING PROBLEMS

Webbing — Webbing is a common thermoforming problem caused by excess material. An air pillow is sometimes used to prevent sagging of the sheet during heating, which minimizes pre-stretching. However, this technique will not allow the sag method of determining sheet temperature and limits the heating source to one-sided heating, which takes longer. Take-up blocks and pushers are more effective methods of taking up excess material around the web.

Mark-off — Use a temperature below 350°F, if possible. If this is not possible, apply a soft rubber coating to the mold surface or form the part out of material having a matte finish, keeping the matte side next to the mold.

Bubbling — Since polycarbonate seldom degrades at thermoforming temperatures, bubbling is almost always caused by moisture in the sheet. When this condition is borderline, bubbling can sometimes be eliminated by heating the sheet faster, rather than pre-drying it. A lower forming temperature also eliminates bubbling.

Mold hang-up — Because polycarbonate plastic forms to such fine detail, imperfections in the mold (such as undercuts) can lock the part to the mold. Use generous radii with adequate draft, smooth all surfaces, and do not use a mold (such as wood) that can easily chip out during thermal cycling at high temperatures. Also, remove the part from the mold as it cools.

Tearing — Tearing at the mold edge is sometimes caused by inadequate clearance between the frame and the mold. Hot sheet may stretch too much without a 1/2 to 1-inch clearance.

Sheet pullout — Sheet pulling out of the frame is usually caused by trying to form a sheet that has cooled below its forming temperature. After locking on clamping devices and the frames, heat the sheet to a higher temperature. The sheet will then form faster. If you are using a thicker sheet, the sheet will hold the heat longer.

Warpage — Do not cool the part over a long time on the mold. When the part cools to 250°F, remove it so that air can be directed to both surfaces at the same time to even the cooling process. Heated frames should also be used. To ensure a flat flange, frames should be heated to at least 250°F.

Uneven detail — Non-uniform sheet temperature causes uneven forming detail. Check the temperature of the heaters and the spacing of the heaters from each other vs. the spacing from the sheet. Do not bring the sheet closer than the heater spacing. Any air drafts originating from open doors can chill the sheet before it can be formed. Screen areas that are too hot and stretch too much.

Low-temperature thermoforming

Low temperatures in the range of 350ºF to 370ºF are sufficient to form single draped polycarbonate shapes and optical parts that require minimal shape change. At these lower temperatures, polycarbonate sheet loses its rubbery nature, so it will not stretch. While polycarbonate will not stretch at these low temperatures, it can be formed to any shape a piece of paper can be formed to, such as a cylinder or cone. At these temperatures, the high modulus of polycarbonate eliminates mark-off problems as long as the mold surface is softened with felt and sharp corners are avoided.

Remember that 2 to 5 percent shrinkage takes place above the glass transition temperature of polycarbonate sheet (which is below 300ºF). Pre-drilled holes may be out of register after the forming operation. Air ovens are recommended for low-temperature heating and forming, because closer temperature control prevents mark-off on optical parts.

Cold forming

Cold forming is any forming performed below 300ºF. A permanent frame is necessary to hold cold-formed edges in shape. Cold forming is feasible as long as stresses do not cause crazing. The minimum radius of curvature is 100t, where t = sheet thickness. For example, a 0.1-inch thick face shield cannot have a radius tighter than 10 inches — unless it is first heated to 300ºF for about 10 minutes in an air oven.

Brake forming and strip heating

Strip heating requires pre-drying the sheet (as needed for thermoforming). It frequently results in warped bends due to differential shrinkage.

For polycarbonate, a combination of brake forming and strip heating reduces warpage. In this case, the temperature of the strip heating element is reduced to produce a sheet surface temperature of about 500ºF.

Although cold brake forming is common with thin sheet, thick sheet may crack. Thus, the combination of strip heating the sheet to 300ºF to 350ºF and hand braking the material along the heated edge gives highly satisfactory bends. Sheet that is 3/16-inch thick can be heated single-sided, but thicker sheet should be flipped at mid-heating time, or use two-sided heating. ■

Elizabeth Grimes is technical services specialist for Atoglas, King of Prussia, PA. For more information on Tuffak® sheet, contact Atoglas, 2000 Market Street, Philadelphia, PA 19103; (800) 523-0762, fax (800) 217-1486, www.atoglas.com.