

Technology of THERMO FORMING

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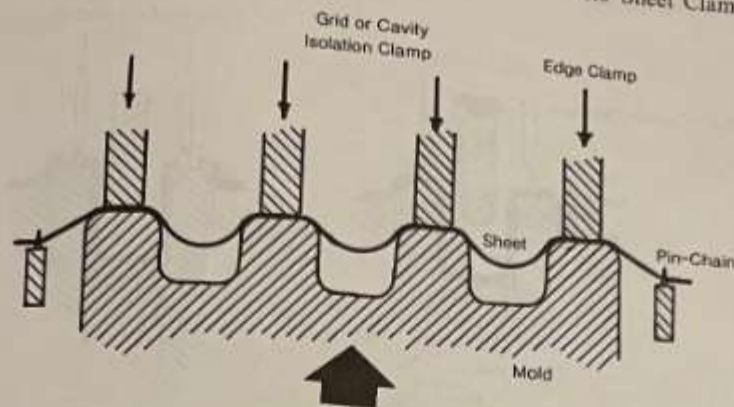


Figure 6.42 Schematic of individual cavity isolation or grid in combination with peripheral clamping

polymers such as ABS and PC. The secondary or perimeter clamp presses the sheet against the mold surface after the mold has passed the clamp plane (Fig. 6.41). This ensures a positive sheet seal against the mold surface. For prestretching with a vacuum or draw box, the edge of the vacuum box acts as the secondary sheet clamp as the mold enters the billow. In pressure forming, the edge of the pressure bell serves as the secondary sheet clamp.

For roll-fed forming, the sheet is only held along two edges. If secondary sheet clamping is not used during multicavity mold travel and forming, the sheet is pulled into the leading and trailing edges of the mold. The result is nonuniform part weight, warping and distortion. The full perimeter clamp is the most common secondary sheet clamp (Fig. 6.42). This clamp engages the sheet just prior to the time the mold touches the sheet and before the mold has reached its final position. The clamp resides above the sheet for forming presses where the mold is situated below the sheet. Individual cavity clamps, cages or grids are used for products that have stringent wall thickness requirements. Individual cavity clamping ensures that polymer from one cavity region will not be preferentially pulled into another. The cavity clamp framework is also positioned above the sheet for forming presses where the mold is situated below the sheet. The cavity clamp framework may also contain the perimeter clamp or it may be on a separate framework and may be sequenced to engage the sheet after the mold has reached its final position but before the plugs and vacuum sequences have begun. In certain cases, the cavity clamp may provide other functions, for example:

- The clamp may contain steel rule dies for trimming. The dies may partially cut through the polymer during the initial phase of the clamp. The die then acts as the clamp. When the part is formed and cool, the die resumes its travel, cutting through the sheet as a trim-in-place die (Fig. 6.43) [36].
- The clamp may contain a forming ring that compresses the rim region. This is called "coining" and is used whenever the formed part must have a molded-to-tolerance rim thickness. Deli container rims are sometimes coined. Coining may also

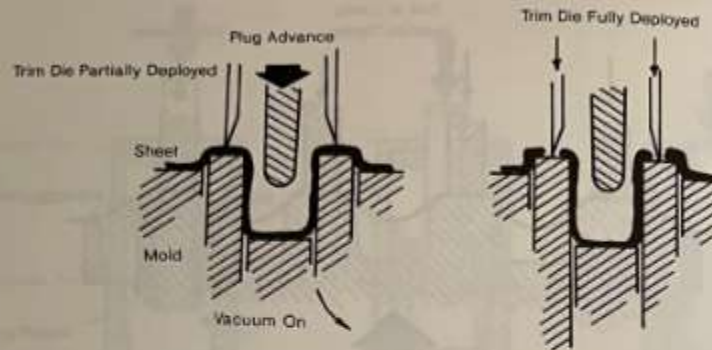


Figure 6.43 (Left) Example of in-mold trim die acting as cavity isolator followed by (right) trimming after forming

be used if the container rim must be rolled to provide rim stiffness, as discussed below. The force required to coin a lip is a function of the compressive strength of the polymer at its instant temperature. Consider a polymer with the following temperature-dependent compressive stress-strain relationship:

$$\sigma_c = C(T) \cdot \epsilon^n \quad (6.43)$$

where σ_c is the applied compressive stress, being the compressive force per unit area of the lip, $C(T)$ is the temperature-dependent compressive modulus of the polymer, ϵ is the compressive strain, with $0 < \epsilon < 1$, and n is an empirical shape factor for the stress-strain relationship. The amount of force required to compress the polymer in the lip a specific amount is given as:

$$F = \sigma_c \cdot 2\pi R w = C(T) \cdot 2\pi R w \cdot \epsilon^n \quad (6.44)$$

where R is the radius of the lip and w is its width. Example 6.16 illustrates the application of this expression to the forming of a cup lip.

Example 6.16 Coining Force for PP Lid

Consider a 4-in diameter PP deli cup having a lip width of 0.100 in. Determine the force required to coin the lip from a thickness of 0.055 in to 0.050 in. The value for $C(T)$ is $800 \text{ lb}_f/\text{in}^2$ and the compressive stress-strain relationship for PP is Hookean, or $n = 1$. If 24 cups are coined simultaneously, what is the force the mold must resist.

The force is given by Equation 6.44 as:

$$F = 800 \frac{\text{lb}_f}{\text{in}^2} \cdot 2\pi \cdot 2 \cdot 0.1 \text{ in}^2 \cdot \frac{(0.055 - 0.050)}{0.050} = 100.5 \text{ lb}_f$$

For 24 cups, the mold resistance is:

$$24F = 2412 \text{ lb}_f = 1.2\text{T}$$

- The clamp may combine with an ejection ring on the cavity to allow separation of the part from the trim. The formed part is held momentarily stationary between the ring and the clamp while the mold moves away and the trim is pulled downward. Then the clamp retracts, leaving the part on the ejection ring. The trim moves once the part and ring assembly have cleared the trim plane.

6.9 Sag Bands and Sheet Supports

Sheet sag is one of the most vexing problems in thermoforming. All polymers sag to some degree when heated. Certain polymers are quite weak when heated to forming temperatures¹. As a class, crystalline polymers are more problematic than amorphous ones. HDPE, PP and PA or nylon sag greatly when heated. Certain amorphous polymers such as cellulose acetate and toughened FPVC sag when heated to their upper forming temperatures. Sheet supports or sag bands are used in roll-fed forming to minimize catastrophic drooping during the final stages of heating. There are two common types of sheet supports. Stationary PTFE-coated hollow rods are placed parallel to the rails in the last section of the oven. PTFE-coated steel wires are also used. These wires may be stationary but are sometimes driven at the speed of the chain rail. Sag bands sometimes extend into the mold area and beyond. Provision for them must be included in the overall mold design layout. The presence of sag band slots in the mold structure can seriously restrict the arrangement of parts of unequal size in family mold designs. Early consideration must be given to their presence if forming of sagging polymers is ever to be considered.

Sheet supports are not used in heavy-gage forming with single cavity molds. Pneumatic lifting methods are preferred.

6.10 Other Aspects of Mold Design

Often, seemingly impossible designs are achieved through thoughtful, mature mold design. Mold designs that are impossible with high pressure applied against sticky fluids such as injection molding are quite feasible with thermoforming. This is because thermoforming is a process that uses only modest pressure applied against a rubbery solid sheet. So long as a portion of the sheet remains rubbery, in theory it can be stretched. As a result, secondary in-mold forming steps are frequently used. One technique moves male plugs against the sheet that is already formed in a female mold. This technique allows bosses and ribs to be formed of polymer having a thickness different from that of the main surface [37].

¹ Sag is also discussed in some detail in Chapter 5.