Part design is critical for dimensional stability because warpage due to inadequate part design is the most difficult to overcome. Wall thickness, ribs, and bosses should be given particular attention. This chapter considers these part design elements in detail.

3.1 Wall Thickness

Figure 3.1 represents the general relationship between part-wall thickness and mold shrinkage. Increasing the wall thickness of a part has much the same effect as increasing the mold temperature. More time is required for cooling, so more stress relaxation occurs, and, if the material is semicrystalline, more and larger crystals develop, which also increases shrinkage. If the part is designed with two or more walls of different thickness, the wall with the greater thickness will experience the greater shrinkage and will tend to warp the part. This occurs because of orientation phenomena. Briefly, a thin, randomly oriented layer is formed against the cavity wall. Below that is a layer where molecular orientation occurs. Finally, in the center of the thickness, there is another random layer. The thicker wall may allow for greater shrinkage for the reasons discussed in Ch. 2

Nonuniform wall thickness in the design of a plastic part is probably the single largest cause of warpage. Sections of the same part having varying wall thickness tend to shrink at different rates. The thicker sections tend to retain the heat from the molding process longer than their thinner counterparts. As a result, the thicker sections continue to cool and contract long after the thinner sections have attained their final part dimensions. One or both of the following conditions result:

- The part distorts dimensionally when it is ejected from the mold (to accommodate the nonuniform contraction taking place within it).
- The part exhibits high levels of molded-in stress which, when relieved, will also lead to part warpage.

Uniform wall thickness consistent with the structural requirements of the part will minimize these adverse effects. Figure 3.2 shows a typical method for maintaining uniform wall thickness (top), and a functional design for screw-hole dimensioning to maintain uniform wall thickness (bottom).[7]

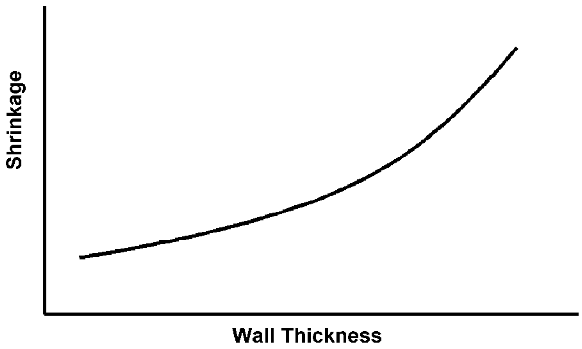

Figure 3.1 Graph showing the relationship between shrinkage and wall thickness.

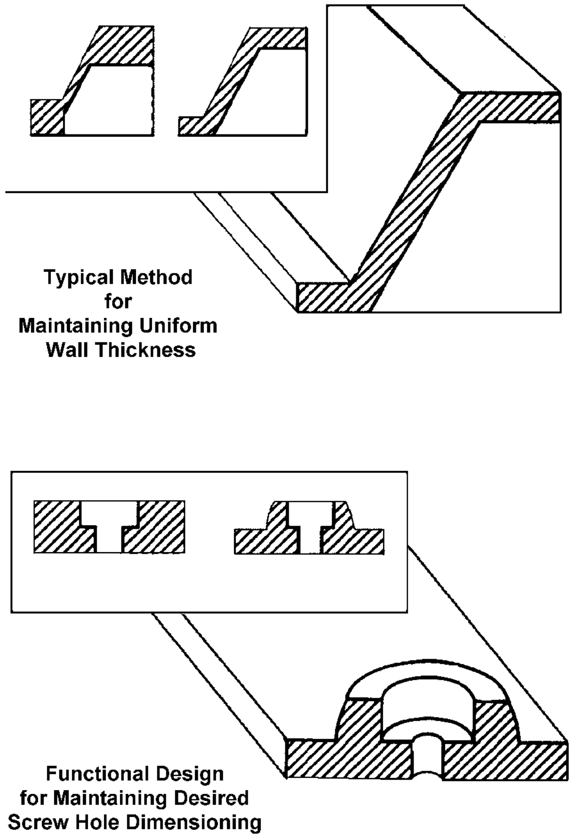

Figure 3.2 Wall and boss configurations to maintain more uniform wall thickness.[7] *(Courtesy of GE Plastics.)*

Often part designers add material where they think it is needed for strength and rigidity, without understanding that additional thickness causes molded-in stress and uneven shrinkage. In Fig. 3.2, the desired part design is shown on the top right. The design on the left was probably based on a perceived need to have a rigid bottom and rim to resist an anticipated load. If, in fact, more rigidity is needed in the flange, then a "U"-shaped flange would provide additional stiffness without increasing the wall thickness. A more uniform wall will resist the forces without introducing shrink and warp problems.

If additional strength is needed in the vicinity of a screw hole, then a boss should be provided, as shown on the right in the bottom of Fig. 3.2, rather than making the whole wall thicker.

Use of a uniform wall thickness may be impractical, sometimes because of differing part requirements. In such instances the designer should incorporate a smooth transition between thick and thin sections, as shown in Fig. 3.3.[7] The transition region should span a distance of at least three times the adjacent wall thickness of the part. Parts designed in this manner and gated in the thickest section will exhibit uninterrupted flow paths, and thereby achieve a reduction in the stresses induced during the molding process.

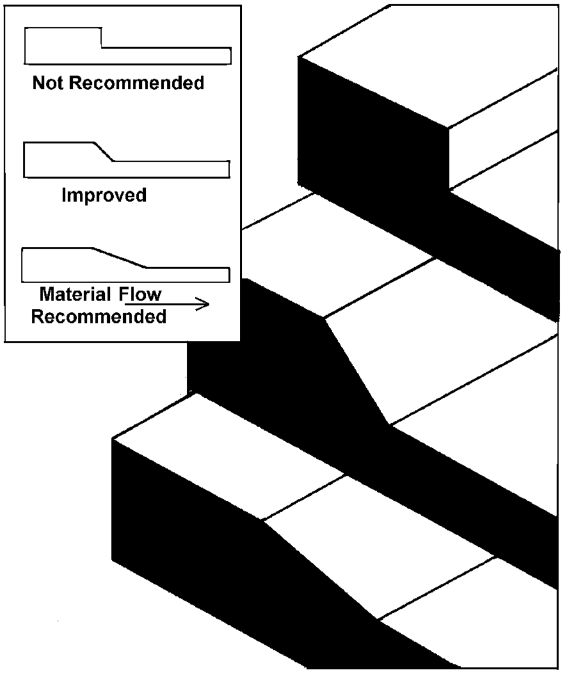

Figure 3.3 Wall transition for solid injection molding.[7] *(Courtesy of GE Plastics.)*

An abrupt change in thickness, also shown in Fig. 3.3, can cause shrinkage stresses at the cross-section change great enough, in some cases, to tear or break the part at the minimum thickness at the cross-section change. A more gradual change in thickness spreads the variation in shrinkage over a broader area, so that there is not so great a stress at a given point or along the edge of the cross-section change.

3.2 Ribs

When designing in plastics, incorporating ribs into the part design can help achieve the required structural rigidity. Added rigidity does not come without cost however, and in many cases the ribbing can contribute to warpage. Therefore, careful consideration should be given to any design that incorporates any type of projection. The following are two potential sources of problems with ribbing.

- The contours of the cavity change abruptly due to the ribs, disrupting the flow pattern as the plastic fills the cavity.
- The presence of the ribs may create significant variations in the thickness of the plastic part in the vicinity of the rib.

Both of these circumstances can adversely affect smooth filling of the mold. Rounding the corners at the base of the ribs to enhance smoother filling can help minimize problems resulting from abruptly changing contours. However, too large a radius at the intersection can cause problems of a different nature: sinks opposite the rib or bending of the part as a result of the thick section, and greater shrink at the intersection of the wall and the rib. In general, it is best to maintain the thickness at the base of the rib at not more than 50–70% of the intersecting wall. Ribs which are improperly located, or which violate this recommended dimensioning, may display shrinkage patterns that place the dimensional stability of the part in jeopardy.

Some plastic part and mold design CAE (computer-assisted engineering) software can predict the severity (depth) of sinks with a reasonable degree of accuracy. See Fig. 3.4.[8]

The relationship of pressure and rib width is shown in the following six figures.[8] Figure 3.5 shows the area analyzed. The abbreviation "nd" represents the width of the area analyzed in diameters of an inscribed circle at the intersection of the rib and the wall. In Figs. 3.6 through 3.10, "num" stands for numerical analysis data. The abbreviation "expt" stands for experimental data. The important thing to observe is that the sink mark increases in depth as the width of the rib increases and as the packing pressure decreases.

Taking these results into consideration, Fig. 3.11 illustrates a recommended rib design.[7] The tapered sides of the rib allow easy part removal. The tip of the rib may be radiused as shown or squared off. The radius at the tip will, in most cases, provide a more esthetically pleasing part but is likely to be more difficult to manufacture. The small radius at the base of the rib reduces the stress concentration at that intersection and will make the part more resistant to breakage. However, any radius at all increases the section thickness at the wall-rib intersection, which aggravates sinks and warpage.

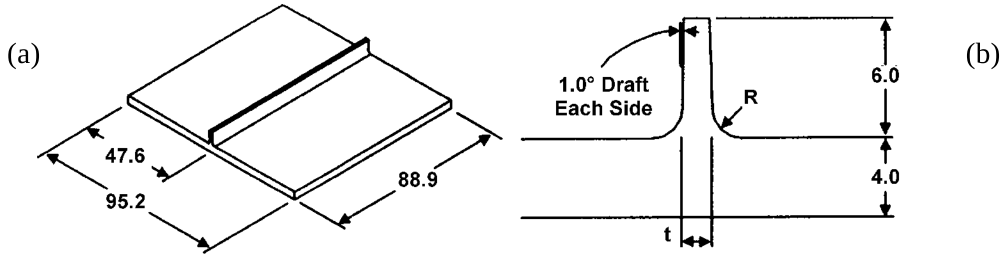

Figure 3.4 (*a*) The geometry of the part used in the analysis. (*b*) The dimensions of a cross-section near the rib. All the dimensions shown in the figures are in millimeters. [8] *(Courtesy of SPE.)*

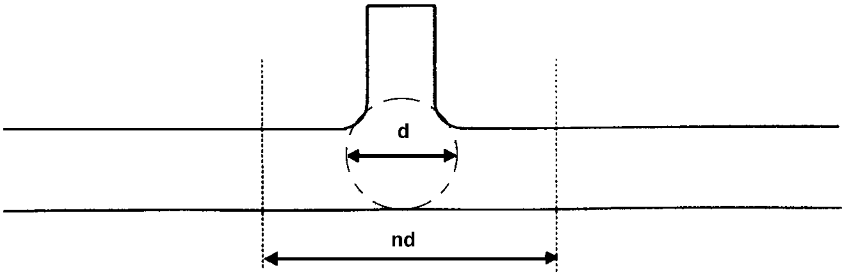

Figure 3.5 This diagram shows the area analyzed. The results of these analyses are shown in Figs. 3.6 through 3.10.[8] *(Courtesy of SPE.)*

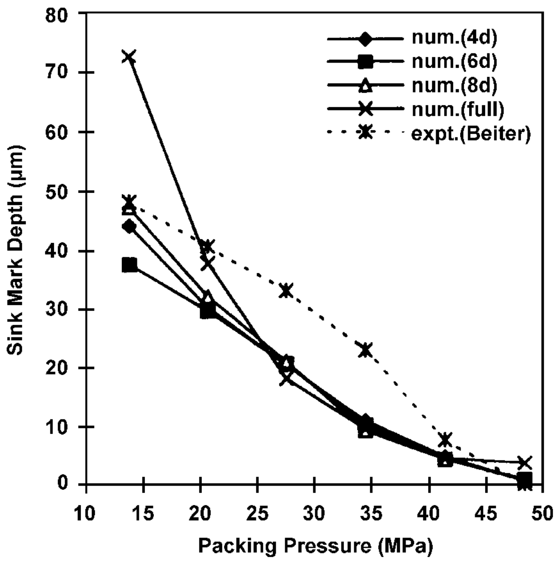

Figure 3.6 Sink-mark depth for a 1.000-mm thick rib.[8] *(Courtesy of SPE.)*

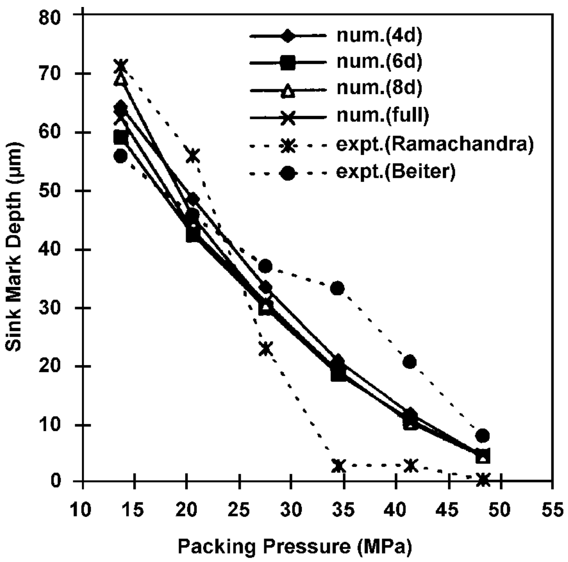

Figure 3.7 Sink-mark depth for a 1.524-mm thick rib.[8] *(Courtesy of SPE.)*

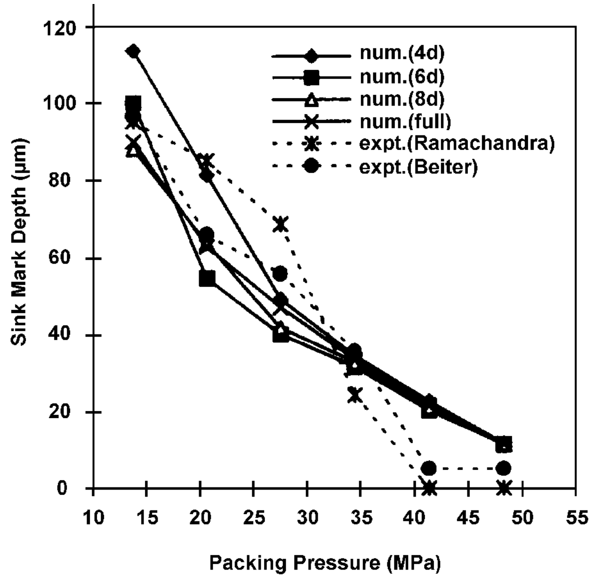

Figure 3.8 Sink-mark depth for a 2.286-mm thick rib.[8] *(Courtesy of SPE.)*

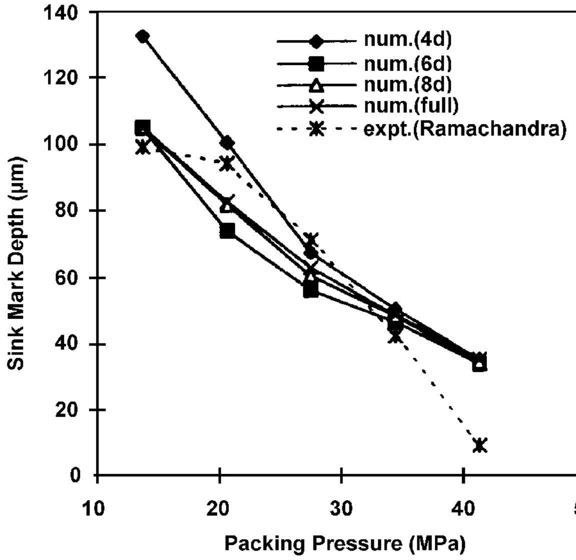

Figure 3.9 Sink-mark depth for a 2.946-mm thick rib.[8] *(Courtesy of SPE.)*

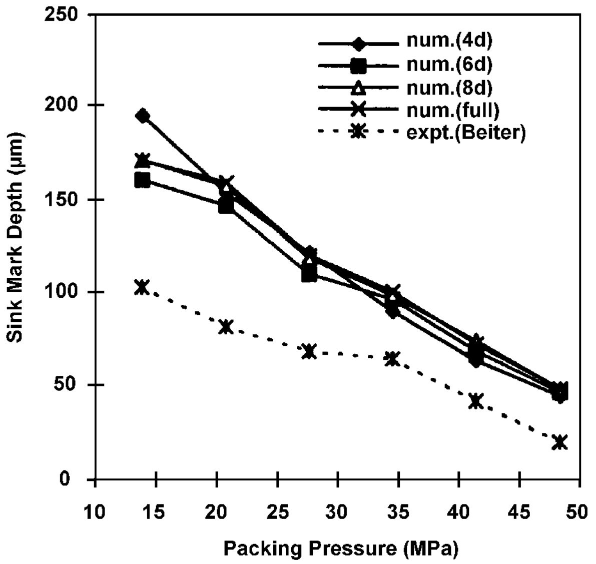

Figure 3.10 Sink-mark depth for 3.988-mm thick rib.[8] *(Courtesy of SPE.)*

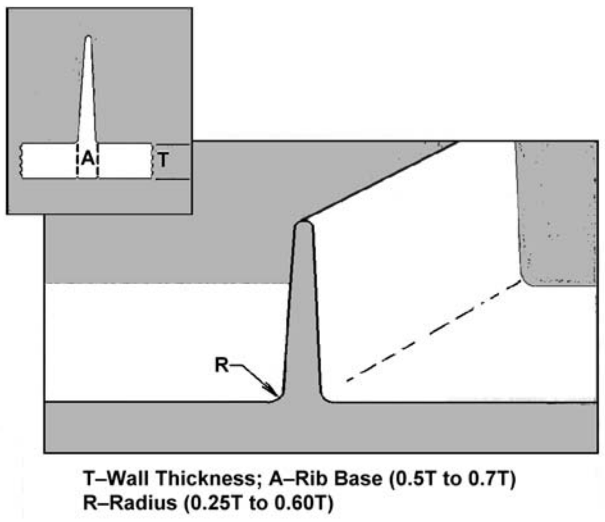

Figure 3.11 Recommended rib design.[7] *(Courtesy of GE Plastics.)*

3.3 Bosses

Designing bosses presents many of the same concerns as designing ribs. A boss design with an outside diameter that is two or three times the inside diameter is sufficiently strong for most applications. However, this may result in a boss-wall thickness equal to or exceeding the wall thickness to which it is attached. This increased material mass will often result in high molded-in stresses. Bosses connected directly to the sidewall of a part usually will cause problems because of the additional mass of material at the juncture of the boss and the wall. A better design separates the boss from the wall and ties it to the wall with a relatively thin rib, as shown in Fig. 3.12.[7]

3.4 Example of Proper Part Design

Since molded-part shrinkage and warpage are facts of life, we must continue to learn new ways to counteract them, keeping in mind the established principles. For example, consider the relatively common problem encountered in molding snap-closure lids like those shown in Fig. 3.13.[3]

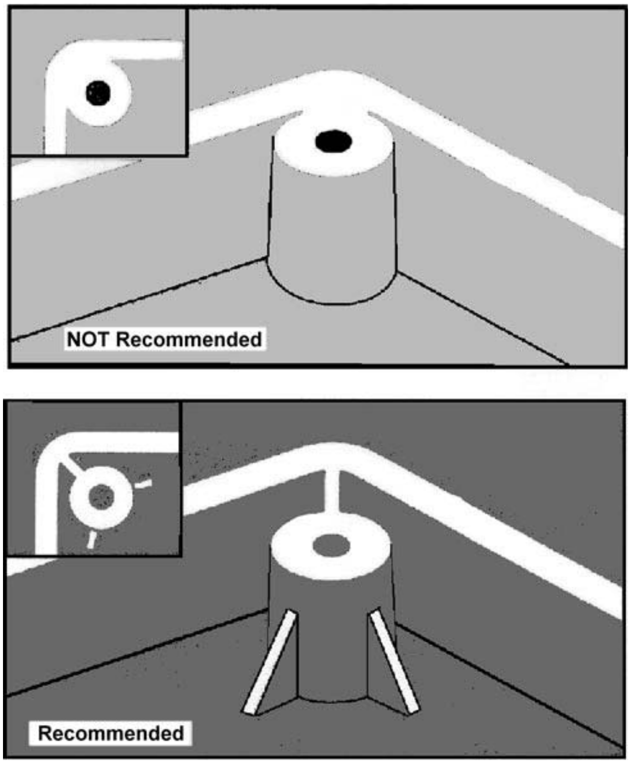

Figure 3.12 Recommended boss design shown at bottom.[7] *(Courtesy of GE Plastics.)*

When these parts are filled from a center gate, the mold pressure varies. The greatest pressure is at the center, near the gate. The least pressure is at the outer diameter. As a result, the shrinkage around the outer perimeter is greater than the shrinkage near the gate. If the part were molded absolutely flat, in a disk shape, it would shrink into a shape somewhat similar to a potato chip. The outer perimeter shrinking more than the center makes the disk ripple or fold to allow for the shorter resultant perimeter, while the center, shrinking less, tries to remain flat.

The designs in Fig. 3.14,[3] showing two different compensating shrink sections, address the differential shrink problem. The offset surfaces of the circular rib flex somewhat allowing the center and the outer rim to shrink at slightly different rates without objectionable distortion. These modifications also allow for greater latitude in molding conditions and material selection. Note that since the open edge of the lid is furthest from the gate, that edge will exhibit the greatest shrink, and the diameter at the open edge will shrink more than the diameter at the intersection of the cylindrical and disk portions of the lid.

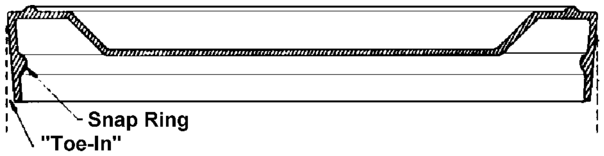

Figure 3.13 A typical polyethylene lid. A snap closure lid with a depressed center to allow for variations in shrink between the center and the outside portions of the lid.[3] *(Reprinted with permission of Voridian, Division of Eastman Chemical Company.)*

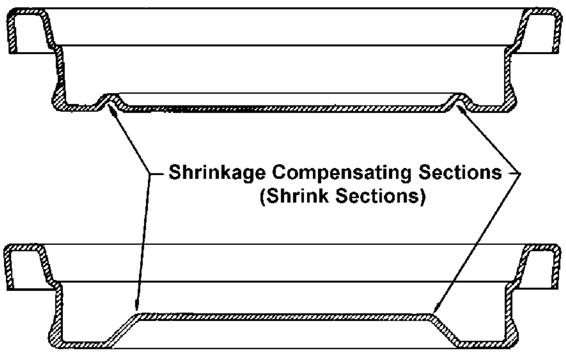

Figure 3.14 Two lids with different compensating shrink sections.[3] *(Reprinted with permission of Voridian, Division of Eastman Chemical Company.)*

3.5 Other Design Considerations

Product designs have become increasingly complex, demanding closer part tolerances to ensure that the finished and assembled products function properly. For example, critical dimensioning is necessary for a part that supports internal electrical components because proper alignment is essential for the product's operation. Dimensional stability, an important aspect of ensuring that part tolerances are maintained, is therefore an important consideration when designing parts in plastic. If a plastic part carrying a circuit board changes size with age, the size change can cause one or more circuits on the board to crack, causing intermittent or complete failure.

Virtually all properties of plastics—electrical, mechanical, physical, and chemical—are temperature dependent. For this reason, designers need to consider the recommended processing temperature range, as well as the continuous service and heat distortion temperatures of plastic material to determine its suitability for applications where elevated temperatures are a concern. In many instances, heat stability (as related to warpage) becomes the key design parameter when a material must perform over a wide temperature range.

Also, and critically, the shape of the part can contribute to warpage, in that extra or unnecessary detail can contribute to nonuniform cooling or contraction of the part. In processing, the concentration of fiber reinforcement can be reduced significantly as the material flows around relatively sharp corners. This reduction in reinforcement can cause a significant increase in shrinkage, requiring remanufacture of portions of the mold.

Parts designed in reinforced thermoplastics benefit greatly from the use of generous radii at intersecting part surfaces. Extremely high stress loads may develop at sharp part corners during part ejection, handling, and/or application. Employing generous radii can significantly reduce these loads. Another function of part radii is to facilitate uniform material flow during cavity filling. Properties and surface finish benefit from uniform cavity filling. Inside radii should be as large as appearance and part-function requirements permit. A radius of at least 1.6 mm (0.0625 inch) is necessary if part strength is to be maintained at surface intersections. Outside radii should be sized to maintain uniform part-wall thickness and minimize material stagnation during mold fill.