THE SCIENCE OF FORMING | STUART KEELER

Cups and Boxes Are Different

Stuart Keeler (Keeler Technologies LLC) is best known worldwide for his discovery of forming limit diagrams, development of circle grid analysis, and implementation of other press shop analysis tools.

Stuart's sheetmetal forming experience includes 24 years at National Steel Corporation and 12 years at The Budd Company Technical Center, enabling him to bring a very diverse background to this column and the many seminars he teaches for PMA. Stuart's next seminar is "Amateur Metallurgy for the Professional Stamper" scheduled for February 19-20, in South Bend, IN.

Last month's column highlighted troubleshooting similarities between cylindrical cups and corners of square or rectangular boxes. When analyzing the deformation, the corners of the boxes are treated as one-quarter of the cylindrical cup. The size and shape of the blank in the corner areas are the most significant process variables controlling success or failure.

However, in spite of these similarities, a major difference exists between the cylindrical cup and the corners of a box. For a given corner radius, the height of the box can be several times greater than the height of a cup with the same plan view or corner radius.

Let's use a good grade of cold-rolled aluminum-killed drawing-quality steel to make a cylindrical cup with a width (diameter) of $2r_c$ (Fig. 1a). The maximum ratio of the cup height (depth) to corner radius (h/r_c) for the cylindrical cup is about two.

One of the problems limiting cup height is the circumferential compression of all the elements in the blank. Fig. 1a shows no possible relief for the compression of corner section one. The surrounding corner sections (shaded) also are compressing and their compressive forces balance the compressive forces in section one. The metal is forced to move along straight radial lines toward the die opening without relief in the circumferential direction.

This circumferential compression and the resulting radial elongation require a force. A greater cup height requires more blank volume, resulting in increased deformation and a greater force. When the maximum force capability of the cup wall is reached, the bottom of the cup tears out.

A box deforms differently. Before deformation begins, the corner sections (1) of the box (Fig. 1b) look identical to one-quarter (1) of the cylindrical cup (Fig. 1a). The corners are separated by a straight-line segment (2) of length *l*. As the blank begins to deform, the straight section of the box side (2) moves toward the die opening without any width compression, so compression of the corner section has almost no resistance on its boundary.

This combination of corner and straight segments of the box allows

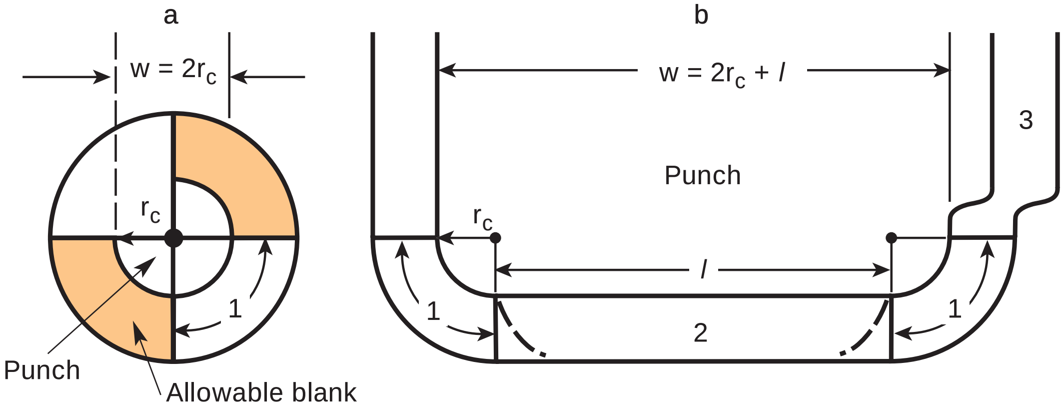

Fig. 1—a) The quarter section (1) of a cup is blocked on either side by other quarter sections. b) A corner section of a box (1) relieves some of the compression by flowing sideways into the straight wall section (2).

some of the excess material in the corner sections (1) to flow sideways into the straight section (2) of the blank as shown by the dashed lines in section two. The force required to deform the corner is reduced, allowing deformation of a bigger blank to create a greater box height without breakage.

A 1974 bulletin from BHP Steel Co. reported research conducted by Robert Hobbs on deep-drawn boxes. His data are reworked into a different format and shown in Fig. 2. The solid line shows the approximate safe ratio of height to corner radius of the box that can be formed in one operation as a function of the ratio of box width to corner radius. As the width of the box (which is defined as the longest box dimension) increases, the height of the box for a given corner radius (r_c) increases.

The solid curve in Fig. 2 starts at a minimum w/r_c ratio of two, which is the ratio for a cylindrical cup because the cup width (diameter) for all cylindrical cups is equal to $2r_c$. Using the solid line in Fig. 2, this w/r_c ratio of two converts to an h/r_c ratio of two for forming without problems. This relates back to the previous statement that the generally accepted maximum height of a cylindrical cup formed in one operation is about equal to its diameter.

The dashed line in Fig. 2 represents the ratio of box height to corner radius above which two forming operations must be used. Ratios between the dashed line and solid line can generate successful cups or boxes if everything about the forming operation is favorable. Areas of concern include material properties, lubrication, blankholder force, die radii, blank spotting, die temperature and all the other forming-process variables.

The analysis above assumes that the sidewalls of the box are straight. Features such as the sidewall jog (section three in Fig. 1b) will restrict the flow of excess material past that portion of the sidewall. For that corner of the box, the active width and the allowable corner height will be greatly reduced.

Additional work by Hobbs showed that nonvertical walls (tapered) are more susceptible to wall wrinkling or buckling. If wrinkling is not acceptable, then the blankholder force must be increased and the allowable box height decreased. For example, for a wall taper of 20 deg. from vertical (included angle of 110 deg.) the calculated box height allowable in one operation must be decreased by more than 25 percent. **MF**

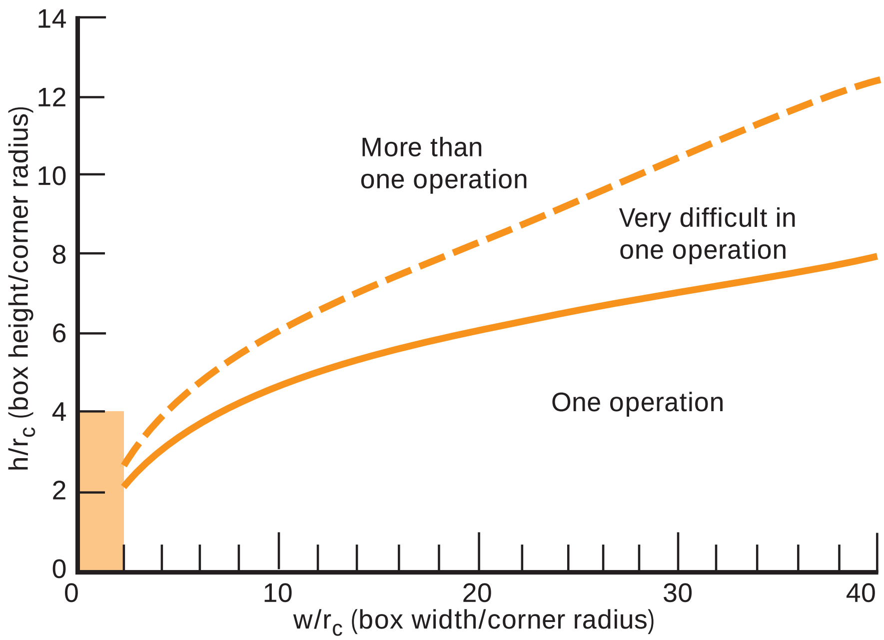

Fig. 2—The allowable height of a box increases as the width (longest side) of the box increases.