THE SCIENCE OF FORMING | STUART KEELER

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.

Keeler Technologies LLC
P.O. Box 283
Grosse Ile, MI 48138
Fax: 734/671-2271
E-mail: keeltech@comcast.net

By popular request, Stuart has created a new seminar on "Circle Grid Analysis and Forming Limit Diagrams" scheduled for June 22 in Chicago, IL. Check www.metalforming.com for this and other seminars.

Material Properties and Cup Drawing

The forming forces in cylindrical cup drawing were discussed in last month's column. The contribution of material properties in cup drawing will be discussed this month, and the results may surprise some readers.

The limiting draw ratio (D_b/D_p) is the maximum diameter blank that can be drawn into a cup with a specified punch diameter in one deep-drawing operation. The material property that can increase the LDR is the normal anisotropy (r_m) of the sheetmetal. Without getting complicated and deep into metallurgical theory, the normal anisotropy provides a measure of the resistance of the sheetmetal to change in thickness during deformation. A reference value of one for r_m means no influence on cup drawing.

An r_m value greater than 1 means the sheetmetal has increased resistance to deformation in the thickness direction. Therefore, the cup wall will resist thinning and will be capable of generating a greater force F_P to pull a larger blank into the wall (Fig. 1). In contrast, the primary binder deformation is pure shear when the sheetmetal compresses in the circumferential direction and elongates in the radial (flow) direction. Pure shear requires very little thickness deformation. Only the edge of the blank thickens significantly. Therefore, a higher r_m value can create a greater LDR and a slightly deeper cup with the same diameter punch. That sounds like an important material property for cup drawing.

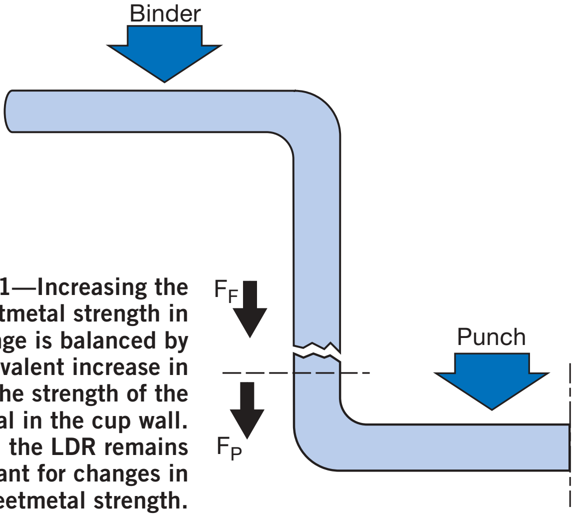

Fig. 1—Increasing the sheetmetal strength in the flange is balanced by an equivalent increase in the strength of the sheetmetal in the cup wall. Therefore, the LDR remains constant for changes in sheetmetal strength.

Perhaps this was true in the old days when the two common steels were rimmed and aluminum-killed draw-quality (AK-DQ). Today, the only two high-volume steels with r_m values greater than one are cold-rolled AK-DQ and vacuum-degassed, interstitial-free (VD-IF). All hot-rolled and the important higher-strength steels have r_m values of approximately 1. Likewise, nonferrous metals, such as aluminum, copper and brass, have r_m values around 1.

If r_m values for a great majority of sheetmetal are all around one and therefore do not affect the LDR, then the strength of the sheetmetal must certainly affect the LDR. When asked if the LDR will increase, stay the same or decrease when the as-received strength of the material increases, the almost unanimous answer is decrease. The reason given is that the blank is stronger and requires a larger force to pull the material toward the die opening against friction and then to bend/unbend it

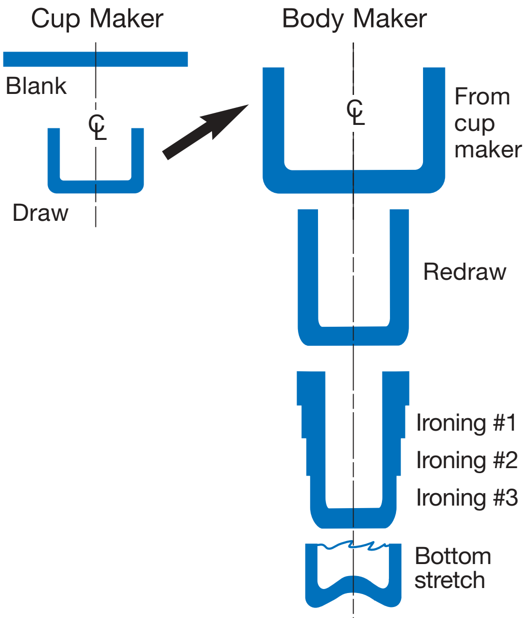

Fig. 2—Beverage can production begins with a full hard steel blank that undergoes six forming operations without an interstage anneal.

around the die radius.

However, both theoretical analyses of deep drawing in 1959 at M.I.T. and laboratory verification in England in 1972 showed no dependence of the LDR on the sheetmetal strength. Even though the flange is stronger and requires a greater force F_F in Fig. 1, the same sheetmetal in the cup wall transferring the punch load (F_P) also is increasing strength at the same rate. The two increased forces balance each other and the LDR remains the same.

This capability to form higher-strength cylindrical cups was utilized by the two-piece container industry (beverage and food) more than two decades ago when these cans were made from steel. Because these containers were considered pressure vessels, the highest wall strength possible was desired for the thinnest gauge for cost reduction. One primary steel grade used by the beverage industry was called DR-9. This grade was cold-rolled down to its thinnest gauge possible, given a full anneal, and then cold-rolled again to about a 35-percent reduction. The steel now was full hard. This was the starting steel for a multi-stage forming process (Fig. 2).

One manufacturing setup had a “cupper” at the head of the line. This press made six cups—or six-out—in one stroke from the DR-9 steel. Behind the cupping press was a line of six body makers. After each stroke of the cupping press, one cup would go to each body maker. In one continuous stroke, the body maker would redraw, complete three ironing stages, and then finally form the inward bottom dome—all without an interstage anneal. That one line would produce a half-million cans per day with a reject rate of less than 0.1 ppm.

In terms of cylindrical-cup draw designs, manufacturers have learned that the LDR represents the edge of the deformation cliff and tailor their designs to remain well back of the edge. Deeper cups or smaller-diameter cups are generated by redraw operations. For very severe designs, as many as 10 or 20 redraw operations may be required.

Two important concepts emerge from these cup-drawing studies. First, the statement that all sheetmetal formability decreases as yield strength increases is incorrect. Some forming modes are independent of yield strength. Second, sheetmetal will increase in strength and decrease in stretching capacity during deformation. However, except under extremely rare conditions, it does not become brittle. The fractures are still ductile.

A new PMA seminar will be presented in Chicago on June 22. Newcomers to sheetmetal forming will obtain complete in-depth information on the where, when, how and why of circle grids, forming-limit diagrams, ultrasonic thickness gauges and other related content. Old timers will benefit from understanding how these tools will help solve press-shop problems and learn many tricks to make the analyses faster and more informative. **MF**