CHAPTER 3 : ANALYSIS ON CUP DRAWING

3.1 Drawing Process

The objective of this chapter is to provide the knowledge on cup draw operations. The complete cup drawing operations can be divided into 5 stages as stated below [5],[6] :

a. Bending

b. Straightening

c. Friction

d. Compression

e. Tension

The deep draw die was selected because the deep drawing operation is the most difficult and complex process as compared to other sheet metal stamping operations. Deep drawing is a multi-stage drawing which requires design calculations and estimations to plan for a successful draw and re-draw operations. Described below are the stages of drawing a flat bottomed cup. The sectional view in Figure 3.1 shows the punch at the instant of contact with the flat round blank.

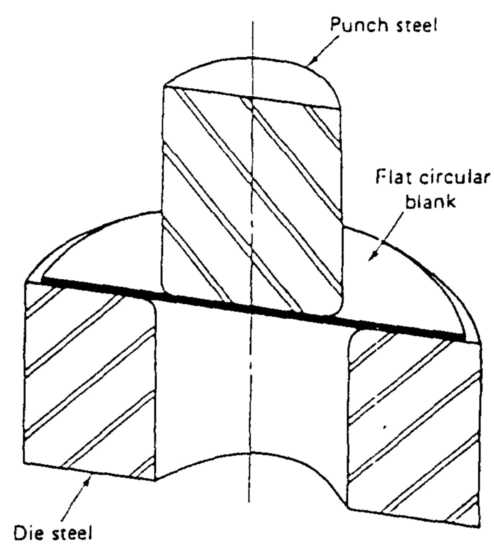


Figure 3.1 : Initial Contact With Blank

3.1.1 Bending Stage

As the punch lowers into the die opening, several distinct phenomena occurs [6] . At this first instant of the punch movement, sheet metal is bent to the punch radius as shown in Figure 3.1.

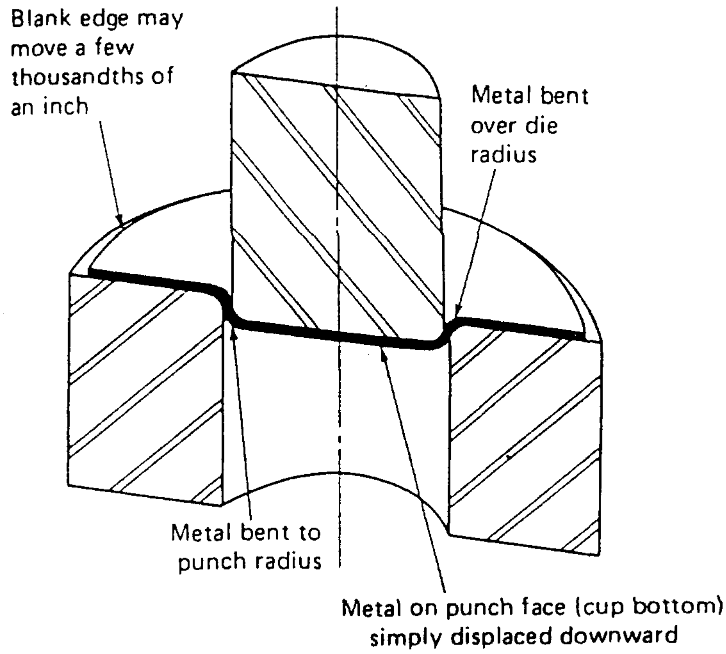


Figure 3.2 : Bending At Start Of Operation

Like wise , adjacent metal is bent over the die radius. The flat metal in contact with the punch face is moved downwards. Thus the bottom of the cup is in the final form. This flat bottom is not work hardened and the sheet metal retains its original thickness in this area. The edge of the blank may move in towards the punch very slightly but can be ignored at this time. At this stage of drawing, the operation is no more than simple bending or forming. The real draw action has not begun yet.

It is logical to expect bending to occur first since the bending forces are very small compared to the force needed to compress the metal as it flows towards the die radius. As seen in Figure 3.2, further punch travel will cause tearing of the metal if the metal is not allowed to flow. In other words, the depth of the contour by forming alone is very limited. Greater depth is obtained by drawing or pulling the metal from the outer regions of the blank.

3.1.2 Straightening

Next consider that the punch has moved down another small portion of its total travel. At this stage, the flat cup is simply moved further down as may be seen in Figure 3.3.

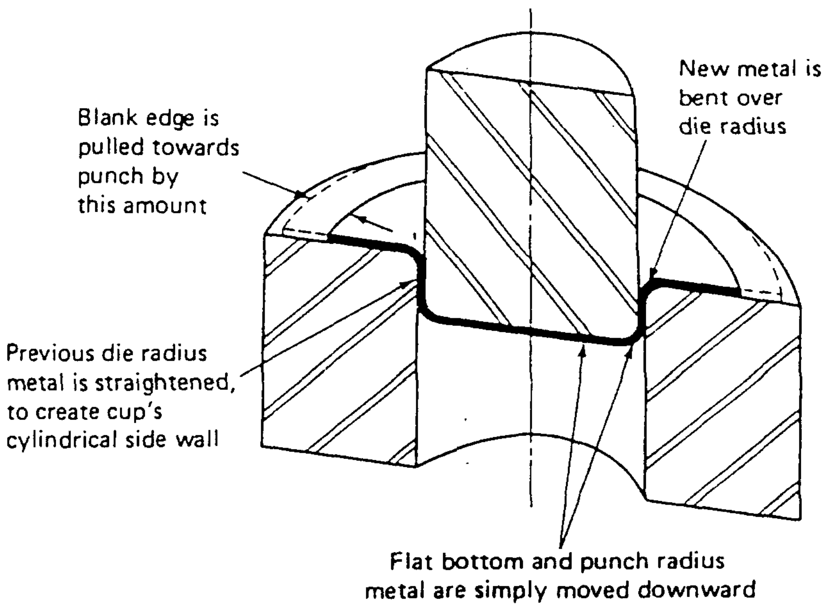


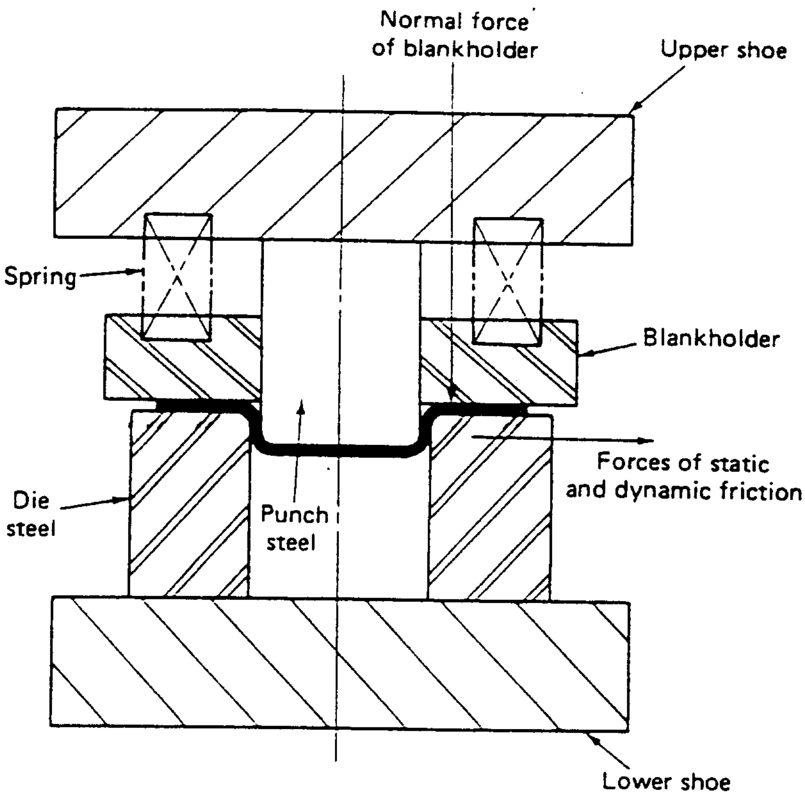
Figure 3.3 : Draw Action Begins with Straightening

The metal bent to the punch radius is also being moved with the flat bottom. An entirely new situation has been created at this point [6]. The metal previously bent over the die radius has been straightened. Additional sheet metal is being bent over the die radius. During a draw operation, metal bent over the die radius must be straightened to create the cylindrical side wall of the cup. Since this metal has already been work hardened by bending, a much greater force will be needed for the straightening action.

3.1.3 Friction

At this same stage, the blank edge has been pulled in towards the punch in a very noticeable amount. The draw operations gets its name from this pulling or drawing of metal towards the punch. In order for the blank edge to move in this manner, several conditions must be met [6] . First the force of the static friction between the blank and die surface must be overcome. Usually in draw dies, a blankholder or die ring will surround the punch. Friction also occurs between the blankholder and the surface of the blank. The normal force created by the blankholder adds significantly to the force of static friction.

This is verified by the basic formula as shown in Figure 3.4. After static friction has been overcome to start the blank movement, continuos force must be exerted to overcome dynamic friction. The force required to overcome dynamic friction would be less than that needed for static friction. The blankholder force must not be too large, however, or metal flow would be prevented. Lubricants or drawing compounds are usually required to reduce frictional forces.



Coefficient of static friction (μ)
Normal force (NF)
Force due to friction (F)

$$\mu = \frac{F}{NF}$$

<u>**Figure 3.4 : Overcoming Forces Due To Friction**</u>

3.1.4 Compression

Another condition required for the pulling in the blank edge is that the sheet metal must be compressed [6] . As the blank edge is moved inwards, it must be reduced to a smaller circumference or perimeter. Likewise , all the metal between the blank edge and die radius must be squeezed to various degrees. Metal in the flat blank close to the die radius at the start of the drawing would require little squeezing. The amount of squeezing required increases for the metal nearer to the blank edge as illustrated in Figure 3.5, the metal must be compressed so that it may move inward and flow over the die radius. The compression for this relatively thin sheet metal usually causes the formation of wrinkles during drawing. The blankholder is added to the draw die to prevent wrinkling when it is expected. Some thicker metals can be drawn without tendency to wrinkle.

Further movement of the punch is a continuation of the metal shaping conditions already described. In fact, the same conditions occur even to the point of drawing the flange completely off the cup. As more and more squeezing occurs, the flange and the top edge of the side wall becomes thicker than the original blank. The final stage of the drawing is shown in Figure 3.6. All compression loads cease in the metal after it flows over the die radius. The metal, after straightening, stays at the same diameter and is simply displaced downwards. The primary objective of drawing is to compress metal so that deep shapes can be produced without the presence of wrinkles.

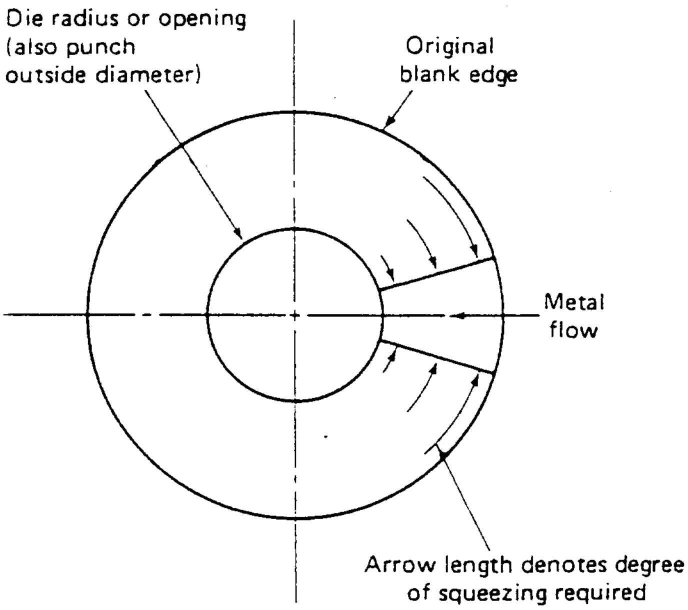


Figure 3.5 : Squeezing or Compression During Drawing

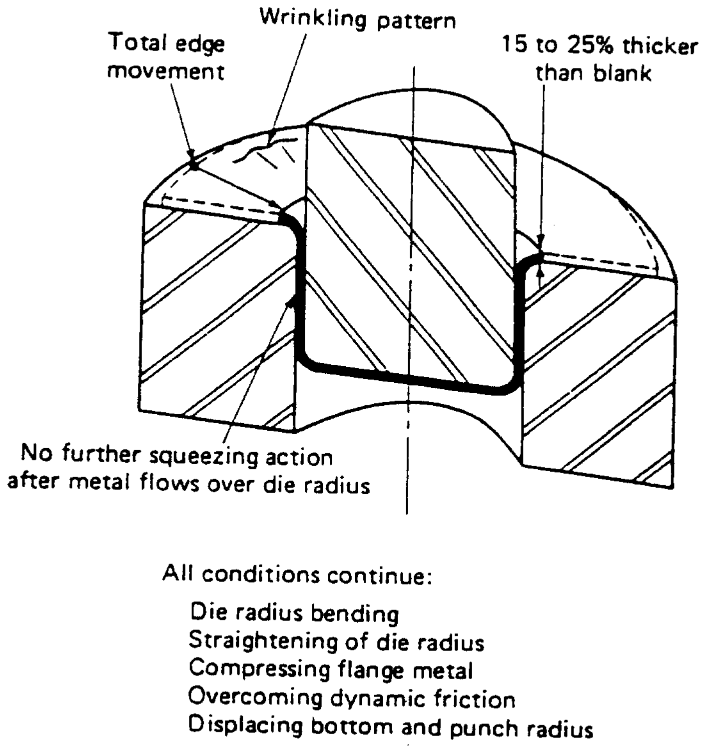


Figure 3.6 : Final Stage Of Drawing

3.1.5 Tension

All the drawing action is created by the punch exerting a force or pushing on the flat cup bottom. The point of punch force application is somewhat remote from the points where metal shaping and friction occurs. In fact, the points become more widely separated as the cup gets deeper during drawing. The cup side wall acts to transmit the punch force to the area of bending, straightening, friction and compression. The result is a high state of tension in the side wall as shown in Figure 3.7 [6] . The side wall near the punch radius is stressed highest and becomes much thinner than the original blank. Tears will often occur at this region. Thus drawing involves a high degree of tension or stretching due to the die design used.

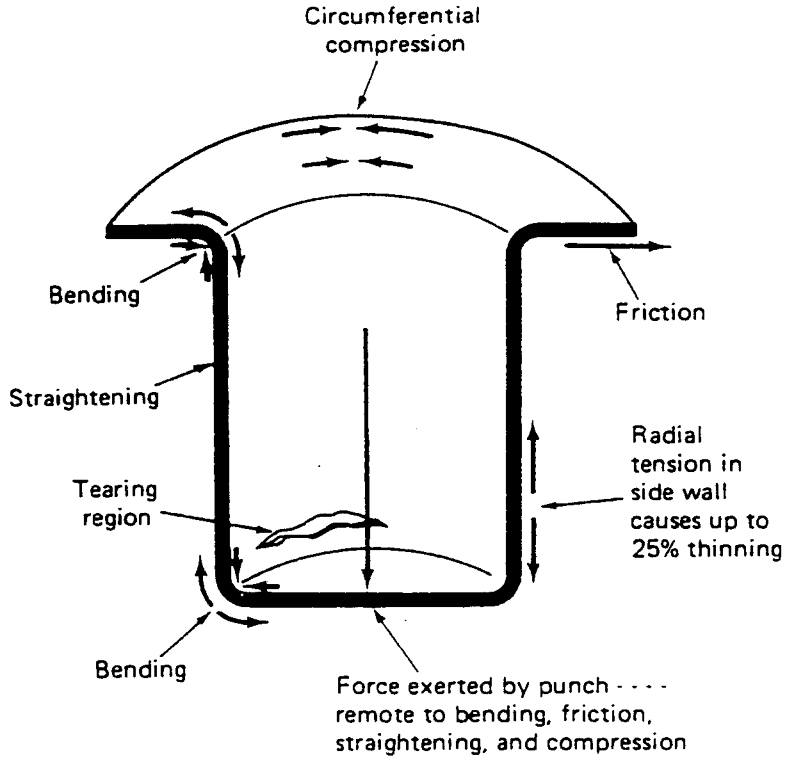


Figure 3.7 : Resulting Tension in Cup Side Wall

3.2 Blank Development

3.2.1 Introduction

The first calculation in preparing for a cupping operations is to find the blank diameter required [5],[6]. The surface area of the cup produced is nearly the same as the surface area of the blank. After redrawing, the surface area of the new cup is nearly the same as that of the first cup and blank. Therefore, if the surface area of the cup shown on the part print including trim allowance is found, the surface area of the blank is known. Without trim allowance the production of a circular flange within the specified limits would nearly be impossible. For various reasons, the flange edge on a drawn cup does not have a perfect circular shape. The reason for irregular flange or cup edges is non uniform metal flow during drawing.

Some reasons for non-uniform metal flow are :

1. Variation in friction due to a dry spot on the blank or an excess of drawing compound in one area. Heavy compounds may allow the blank to move horizontally just as the die closes.

2. Variation in friction due to un-equal blank holder force around the punch. This could be caused by one pressure pin being either too long or too short compared to others. Other causes could be dirt on the pins or the blankholder being off the horizontal position due to a poor guiding system or die construction.

3. Blank location is a common cause since the blank centerline is seldom located perfectly on the die centerline. Off center blanks cause an un-balance in the amount of compression needed during metal flow. A slightly off center blank may produce no flange on one side.

4. Variations in the sheet metal can have noticeable effects. Rolled out impurities called fibres cause earing of the edges. Fibres cause changes in the metal strength at different angles in the sheet.

3.2.2 Trim Allowance

The recommended trim allowance are as stated below [6] :

Cup or Flange Diameter	Trim Allowance Per Side
Up to 25.4 mm	1.52 mm
25.4 to 50.80 mm	3.18 mm
50.8 to 101.6 mm	6.35 mm
101.6 to 152.4 mm	12.70 mm
Larger than 152.4 mm	25.40 mm

Trimming operations are performed after the last redraw operations.

As mentioned earlier, the area of the cup is equal to the area of the blank. The relationship between the drawn cup and blank can be used to determine the diameter of the blank.

The dimensions and specifications of the desired cup is shown in Figure 1.1.

First, the surface area of the cup is determined [6].

Area of the cup = Bottom area + Flange area + Wall area

$$\text{Bottom area} + \text{Flange area} = (\pi \times d^2)/4$$
$$= 3.142 \times (101.6 \times 101.6)/4$$
$$= 8{,}108 \text{ mm}^2$$

where d = 88.90 mm (flange diameter) + 12.70 mm(trim allowance on both sides)

$$\text{Wall area} = \pi \times d \times h$$
$$= 3.142 \times 50.80 \times 177.80$$
$$= 28{,}379 \text{ mm}^2$$
$$\text{As such, area of the cup} = 8{,}108 \text{ mm}^2 + 28{,}379 \text{ mm}^2$$
$$= 36{,}487 \text{ mm}^2$$
$$\text{Area of the blank} = \text{Area of the cup}$$
$$= 36{,}487 \text{ mm}^2$$
$$(\pi \times D^2)/4 = 36{,}487 \text{ mm}^2$$
$$D = 215.5 \text{ mm}$$

The diameter of the required blank is 215.50 mm. For this study, a blank with the diameter of 216 mm will be used.

Assumptions :

The above calculation ignores the radius of the cup and assumes sharp corners. The result is suitable providing good trim allowance are added or when the radius are small compared to the cup size.

3.3 Draw and Redraw Design Calculations

3.3.1 Introduction

A frequent difficulty encountered is the natural tendency for the sheet metal to wrinkle as it is compressed to the die radius. In a few instances, wrinkling may be so severe that wrinkle free cups cannot be drawn.

Compressive loads and wrinkling problem can be reduced by the use of redraw operations. Drawing of the flat blank into a cup is called a drawing operation. Converting a drawn cup into a smaller diameter and deeper cup is called a redraw operation [5],[6].

3.3.2 Thickness to Diameter Ratio

Before the draw and redraw sequence can be planned for trouble free and economical production, the wrinkling difficulties must be estimated. Wrinkling can be best described by analyzing a small section of the blank near the edge as shown below in Figure 3.8 [6].

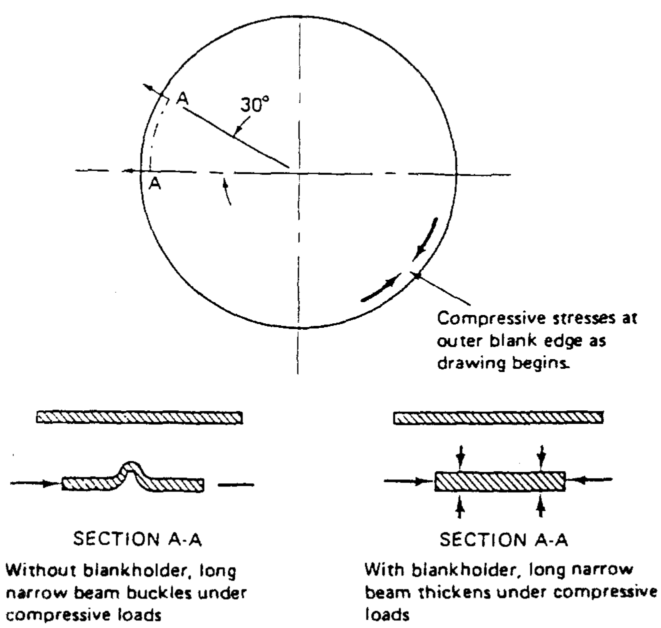


Figure 3.8 : Buckling Under Compressive Loads

Section A-A represents a small beam of sheet metal that is under high compressive loads as the blank is drawn towards the die radius. The width of the beam is the original blank thickness, the length of the beam is proportional to the blank size or diameter. The larger the blank diameter, the longer will be the beam length.

Wrinkling of the sheet metal is nothing more than the buckling of the unstable beam. The unstable beam is a long narrow beam loaded on the end in compression. thicker than the blanks.

Since thinner sheet metals are desired for weight or economical reasons , the general solution is to prevent wrinkling by supporting the beam with a blankholder. The sheet metal thickens under compressive load and thus the cups have flanges or tops that are thicker than the blanks.

Greater beam stability or sheet metal resistance to wrinkling can be improved in three ways as shown below in Figure 3.9.

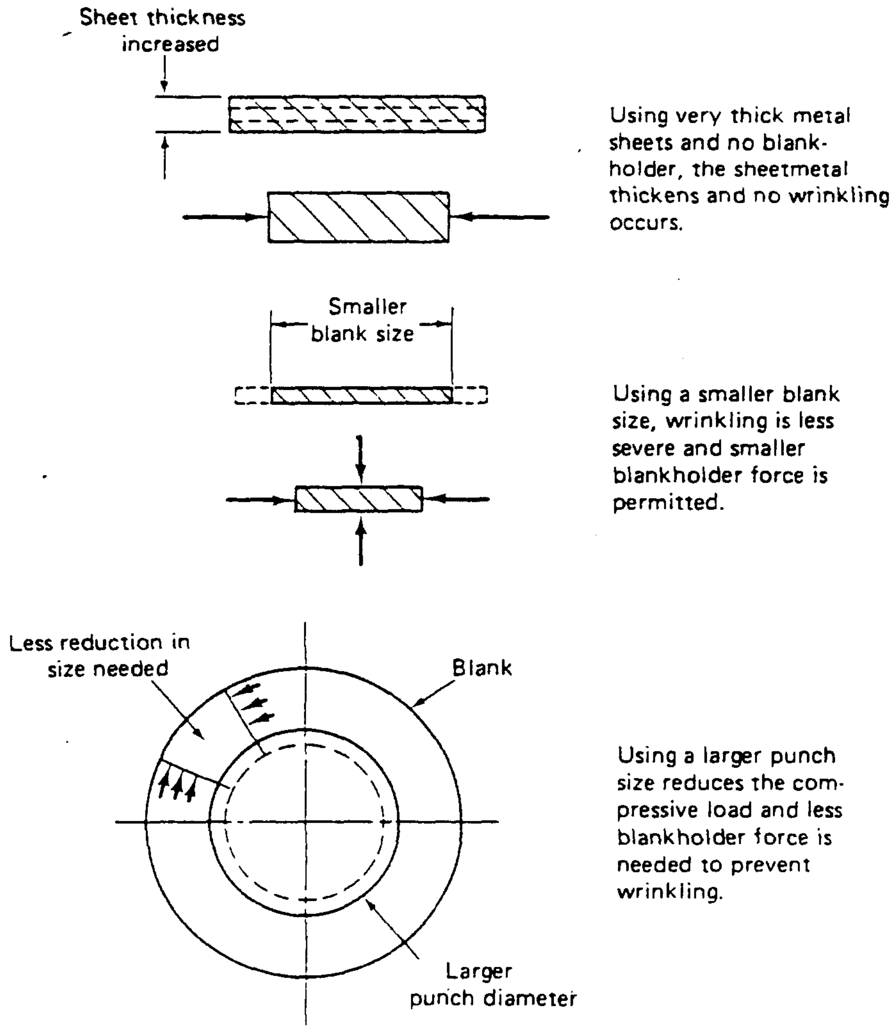


Figure 3.9 : Reducing Wrinkling Severity

Although not generally economical if the sheet metal thickness is increased to a certain amount, the beam is then wide relative to its length and no buckling occurs. Single action drawing is possible. Another possible approach is to shorten the beam length leaving the sheet thickness the same. Again a more stable beam is achieved. The beam length is in effect shortened by reducing the blank diameter. This blank size reduction reduces the cup size that can be drawn. However, often the product designer cannot reduce the cup height or flange diameter.

When the part print cannot be altered, the only alternative left is reduce the compressive or squeezing load applied to the beam. For a given blank diameter, lower compressive loads occur if a larger diameter draw punch and die ring is used. This is because the sheet metal compresses lesser in order to flow over the die radius. Wrinkling problems are greatly reduced but a larger diameter cup than part print must be drawn. This in fact is the reason why redraws must be used to reduce the larger cup diameter to that specified on the part print.

All cups would be made in a single draw if possible to limit costs. The wrinkling problem forces redrawing from oversized cups by the use of more dies at a greater expense.

Since the sheet metal thickens and blank diameter are the beam length and width in a buckling study, it is logical that these sizes be used to predict the severity of wrinkling.

t/D ratio is used for this purpose where t is the sheet metal thickness and D is the blank diameter [6].

Results have indicated that wrinkling severity can be described in 4 categories [6],

When the t/D percentage is 0.50 or less :

Wrinkling is severe and compressive loads must be reduced. A blankholder must be used so double action drawing is required.

When the t/D percentage is from 0.5 to 1.50 :

Wrinkling is moderate and low blank holder force is required. Fewer redraws are needed since the compressive loads need not be reduced.

When the t/D percentage is from 1.5 to 2.5 :

Wrinkling is very slight and single action dies are permitted if the compressive loads are reduced by having larger punches.

When t/D percentage is over 2.50 :

No wrinkling is expected . As such, a blankholder is unnecessary even with high compressive loads.

Calculations for draws and redraws are made with the aid of Compressive Load Reduction for Severe Draws Chart as shown below in Figure 3.10. It shows the relationship between t/D percentage and percentage of reduction for both the first draw and three redraws [6].

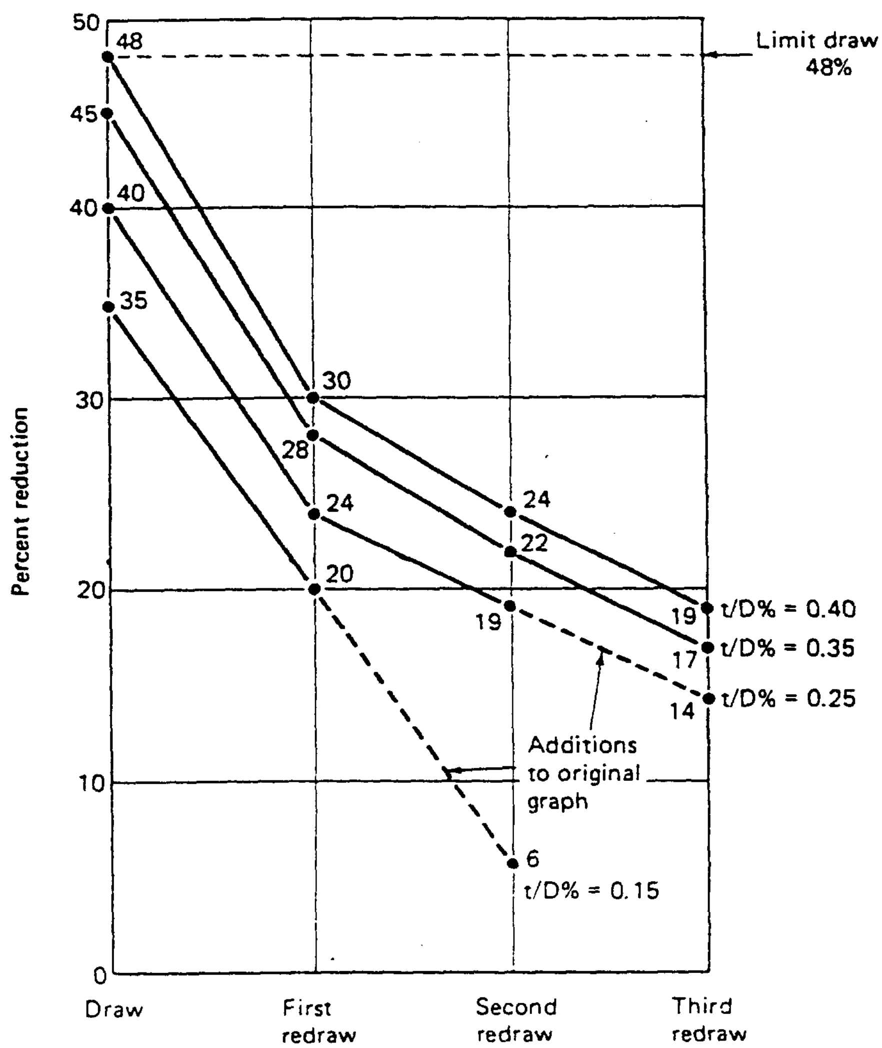


Figure 3.10 : Compressive Load Reduction for Severe Draw in 3003 - 03 Aluminium