

DRAWING AND STRETCHING OF METALS

Deep Drawing of a Cylindrical Cup

Figure 1 illustrates the forces involved in deep drawing of a metal cup. It is important to note that all of the force required for drawing is transmitted by the draw punch to the bottom of the cup.

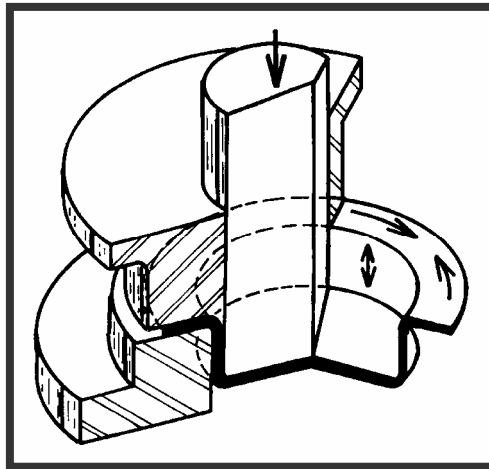


Figure 1. Sectional view of a simple draw-die illustrating the tensile forces and circumferential compressive forces involved in deep cup drawing. *Smith & Associates*

The cup drawing process starts with a flat round blank. The blank is subjected to both radial tension and circumferential compression. The metal thickens as it flows toward the draw radius. Deep drawing is unique because of the deformation state of the metal restrained by the blankholder.

Metal Flow in Cup Drawing

In general, the metal flow in deep cup drawing may be summarized as follows:

1. Little or no metal deformation takes place in the blank area that forms the bottom of the cup.
2. The metal flow occurring during the forming of the cup wall uniformly increases with cup depth.
3. The metal flow at the periphery of the blank involves an increase in metal thickness caused by circumferential compression (Figure 1).

Success Factors in Cup Drawing

The success of a drawing operation depends upon the several factors including:

1. The formability of the material being drawn.
2. Limiting the drawing punch force to a lower value than that which will fracture the shell wall.
3. Adjustment of the blankholder force to prevent wrinkles without excessively retarding metal flow.

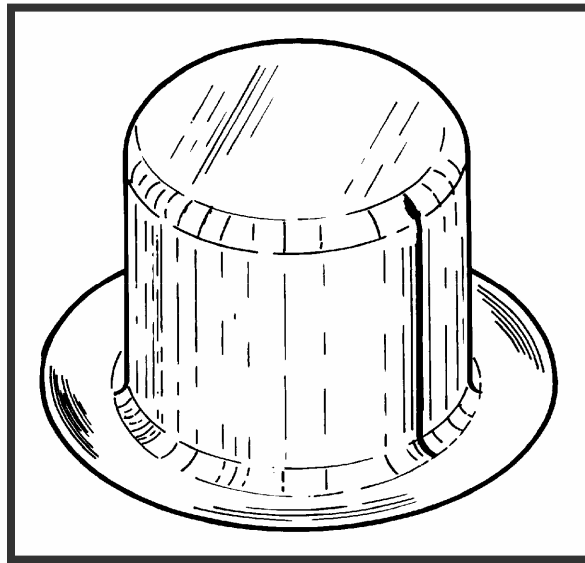


Figure 2. An example of a successfully drawn cup-shaped drawn shell. *Smith & Associates*

Why and How Deep Drawn Cup Shaped Shells Fail

Figure 2 is an example of deep cup drawing in which very little deformation occurs over the bottom of the punch. Nearly all deformation occurs in the metal restrained by the blankholder.

The maximum force requirement for the drawing process is limited by tensile failure of the material in the sidewall. As this limit is approached, the metal will neck or thin excessively in a localized area near the punch radius.

Many complex interactions occur during the cup drawing process. The actual force required depend upon the cross sectional area of the cup wall and the yield strength of the material as it is worked. Should the process fail, some or all of the following factors may be the root causes:

1. The ductility or drawability of the stock may be too low.
2. The blankholder force may be too high.
3. Scoring or galling may be present on the die surfaces.
4. The blankholder geometry and draw radius may not provide for metal thickening and smooth flow into the die cavity.
5. Incorrect or insufficient drawing lubricant.
6. The depth of draw or percentage of blank reduction may be too great.
7. One or more redrawing operations may be necessary to obtain the desired depth of draw.

Annealing may be required between redrawing operations, especially when using materials that work harden rapidly.

Recommended Draw Radius

The blankholder draw radius should be approximately four to six times the metal thickness for most applications. The blankholder draw radius has a large effect on the punch force required to pull the metal into the draw cavity. As the metal passes over the radius it is bent and then straightened to form the sidewall of the drawn cup. Too small a radius can lead to fracture because more force is required to pull the metal over a small radius than a larger one. In addition, too small a radius will more severely strain the metal increasing work hardening. This in turn requires more force to draw the part.

There is little reduction of drawing force achieved by making the draw radius larger than six times metal thickness. Exceeding a draw radius of ten times metal thickness may result in puckering of the metal as it flows over the draw radius.

In cases where all of the metal on the blankholder is to be drawn into the cavity to form a straight walled shell without a flange, a large radius may result in folded metal as blankholder control ceases.

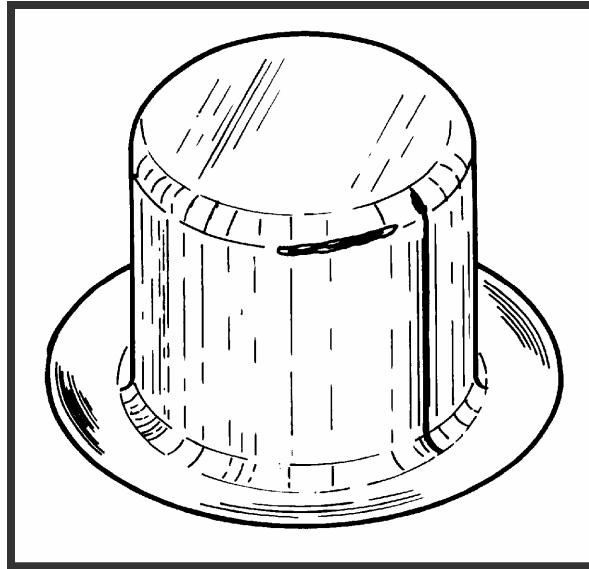


Figure 3. An example of a failure of the drawing process due to localized thinning (necking) at the punch radius. *Smith & Associates*

Necking Failures

Necking failures such as shown in Figure 3 are preceded by localized thinning that may not be visible in the part. However, the onset of a necking failure can be detected by measuring the metal thickness with an ultrasonic thickness-measuring device.



Figure 4. Photograph of a necking failure on the corner of a deep drawn box shaped stamping. *Smith & Associates*

Application of an Ultrasonic Thickness Gauge

The ultrasonic thickness gage is a modern stamping analysis tool that is very useful for on line process tracking, troubleshooting and control. It features a portable control box, which provides thickness readout and a probe having an ultrasonic transducer.

Principle of Operation

The principle of operation is much like that of the sonic or SONAR depth finders used as a navigational aid by boaters. In their simplest form, these Sonic depth finders measure the time between a sonic pulses being sent out by a transducer attached to the boat's hull and the arrival of the return echo.

The speed of sound in water is a known constant. The delay time between the sending of the sonic pulse and the return echo can be easily converted and displayed in units of depth such as feet, meters or fathoms.

Ultrasonic metal thickness gauges work in much the same way; an ultrasonic pulse is sent out by the handheld transducer, which attaches to the control unit. The return echo time is very short since the speed of sound in steel is in excess of 16,000 feet (4877 m) per second. For stamping thickness measurements, the operating frequency is approximately 15 MHZ. A plastic delay line is used between the transducer and the point of contact with the workpiece being measured so the faint return echo can be detected. Manufacturer supplied *compliant media* is placed between the transducer and plastic delay line. This media requires periodic renewal to assure accuracy.

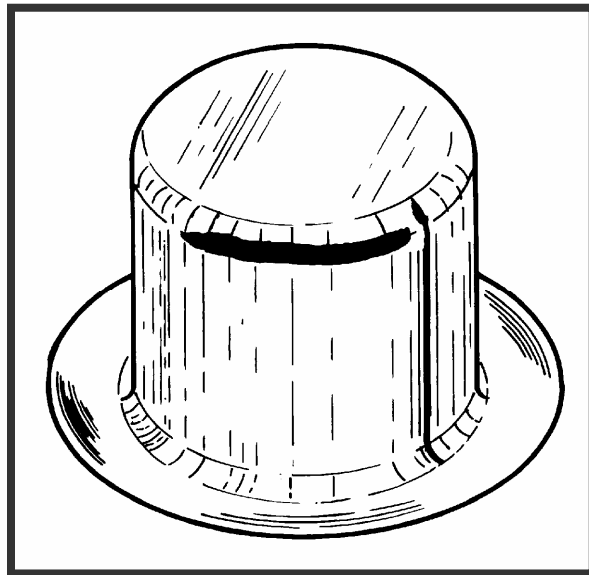


Figure 5. A severe failure of a drawn cup due to a pronounced fracture.
Smith & Associates

A 0.125-inch diameter transducer is considered better than larger sizes, e.g. 0.250 inch, especially for use on curved surfaces. A compliant media is needed between the transducer face and the metal workpiece. The best readily available material meeting this requirement is common Johnson & Johnson K-Y™ brand surgical jelly—a product made to strict quality requirements for uniformity and purity. Be sure to wipe this substance off the part after measurement because it can cause rusting problems.

Tracking Thinning with an Ultrasonic Thickness Gauge

Stampings that are severely drawn or formed usually have one or more areas where thinning is apt to occur. These areas are spots for regular thickness checks.

Determining the Areas to Check

The areas where a necking failure or fracture is apt to occur on a stamping can be predicted with circle grid analysis (CGA) during the development and die tryout period for new stampings. The failure locations on an existing stamping become well known to pressroom personnel.

Once the areas found to thin leading to failure are identified, regular checks should be made with an ultrasonic thickness gauge. It is helpful to trend chart the thinning in each area. This permits corrective action to be taken before a necking failure becomes visible. Causal factors for a pronounced increase in thinning include:

1. Excessive blankholder force.
2. Material problems such as a lack of ductility or drawability.
3. Material too thin.
4. Scored die surfaces.

Material Quality Issues

When drawing operations fail, often the material is immediately blamed. The logic is that if the vendor can supply some material that will run it should be possible to do so consistently. Material formability properties do vary from lot-to-lot, and even within the same coil.

It is poor economy to specify expensive deep-drawing quality material, when good die design and maintenance will permit the use of less costly commercial-grade stock. Formulas and charts giving recommended maximum reductions for various materials can be found in references.^{1 2}

If there is proper sidewall clearance in the die, the punch force will not exceed the ultimate tensile strength of the material cross section in the wall. Since some thinning occurs as the ultimate tensile strength is approached, using this figure for force requirement calculations usually provides a substantial safety factor.

The material yield strength should normally be used for drawing calculations. The results generally will produce results that correspond closely to measured values. It is to be noted that excessive blankholder forces can cause any cup drawing operation to fail.

¹ D. Smith, *Die Design Handbook*, Section 11, Product Development for Deep Drawing, The Society of Manufacturing Engineers, Dearborn, Michigan, © 1990.

² Arnold Miedema, Reference Guide for the videotape training course, *Progressive Dies*, The Society of Manufacturing Engineers, Dearborn, Michigan © 1988.

Example of Force and Energy Requirements

In another, section, the force and energy requirements for cutting a low-carbon blank 12-inch (304.9 mm) in diameter and 0.1875-inch (4.763 mm) thick were calculated. The required energy is surprisingly small. Only 1840.8 foot-pounds (2496 J) is required. At 60 strokes per minute (SPM), ignoring frictional losses, 3.347 horsepower will sustain the process.

Several arbitrary assumptions are made. This heavy 12-inch diameter 0.1875-inch thick blank is to be drawn into a flanged cup having a diameter of 6.000-inches (152.4 mm) and a depth of draw of 2.000-inches (50.8 mm). The yield strength of the material is 40,000 psi (275 MPa). Here we will assume that the force and energy required is based on working the cup wall at its yield strength. It should be noted that the yield strength is normally specified as a *minimum value*.

The total cross-sectional area of the wall is 3.534 square inches. Based on the yield strength of 40 KSI, 70.69 tons of punch force is required. While the force is much less than required to cut the blank, it must act through a distance of 2.000-inches (50.8 mm). The work or energy required per part is 141.37 inch-tons or 23,562 foot-pounds (31,950 J).

The energy input per part is 12.8 times greater to draw the part than that required cutting the blank. While the 60 strokes per minute rate may be too high for optimum formability, neglecting frictional losses, 42.84 horsepower would be required to restore energy to the flywheel.

In pressworking processes, the materials are worked in a plastic state. High internal friction is present. Nearly all of the energy required for the process is converted to heat.

Conversion of Energy to Heat Case Study

Studies conducted on drawing automotive suspension components at Ford Motor Company, by the author, confirmed that 80 to 90 percent of this energy often exits the die as latent heat in the stamping. Nearly all of the mechanical energy to heat conversion occurs within the stamping itself during deformation. The remainder results from surface friction at the part-to-die interface.

The most severely strained portions of the part exit the die at a higher temperature than the surface temperature of the corresponding die surfaces. The energy input was determined by calculations of force versus distance. Waveform signature analysis was used to aid in determining the energy input.

The temperature profile of the part and die was measured by a small thermistor probe. The temperature data was used to determine the heat energy in the part and the temperature gradient of the heat energy conducted through the die.

There is close agreement of theoretical versus measured values of mechanical to heat energy. In general, large dies function as effective heat sinks, when operated at press speeds from eight to 20 SPM.

In the dies studied, ion nitriding of the nodular-iron die surfaces essentially eliminated the metal pickup or galling problems that occurred as the die warmed during operation. However, cooling by chilled water piped through the die is useful for some severe drawing operations.

Water-based pressworking lubricants assist in cooling through evaporation. Their use is suggested wherever possible.

Stretch Forming

Figure 6 illustrates a stretch forming operation to produce a dome-shaped part. The edges of the blank are securely clamped with a *lock bead*.

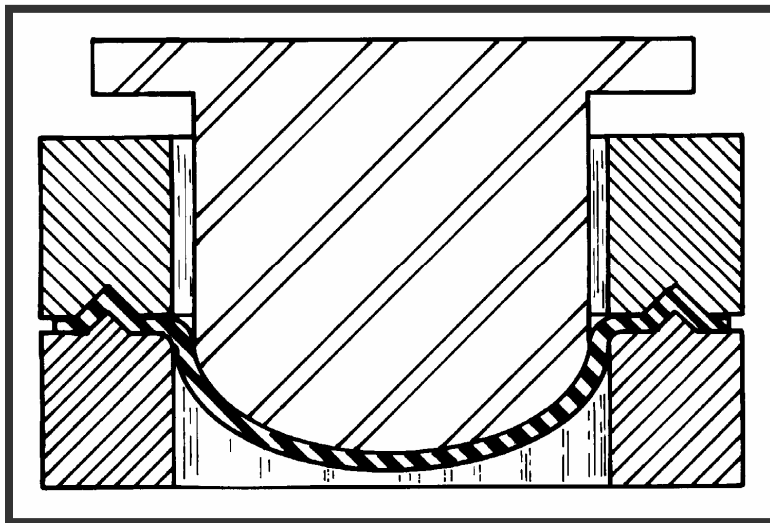


Figure 6. A section through a stretch-forming die producing a dome-shaped part: the edges of the blank are securely clamped with a lock-bead, and the metal in the punch area is deformed by biaxial stretch. *Smith & Associates.*

In the example shown in Figure 6, only the metal in the punch area is deformed. Both the width and length dimension of the metal are stretched. This type of forming is known as *biaxial stretch*.

Stretch forming is a very common operation. The forming of automotive, appliance, and aircraft panels is a widespread application. Typically 3% to 10% strain is required to obtain the mechanical properties needed for proper stiffness.

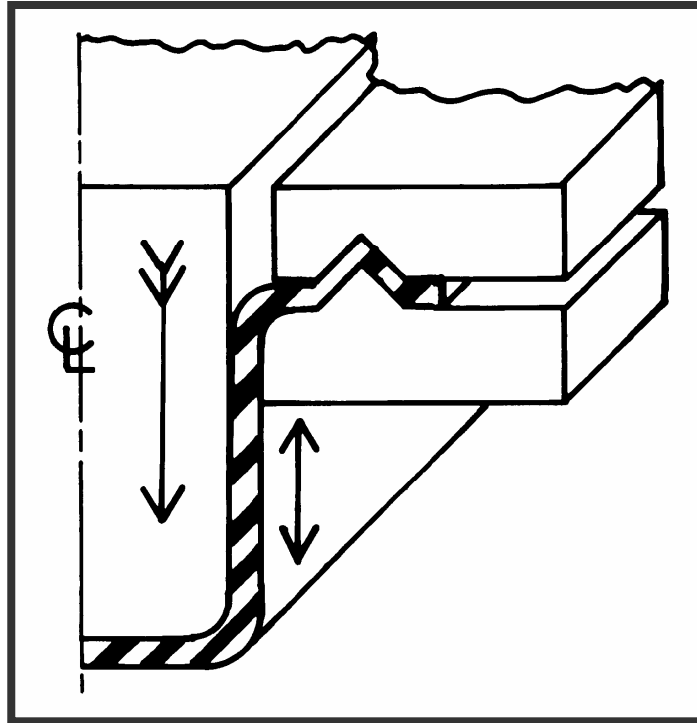


Figure 7. A plane strain condition in which the metal, restrained by a blankholder lock-bead, is stretched and thinned. *Smith & Associates*

Success Factors In Biaxial Stretch Forming

Like deep cup drawing, stretch forming involving severe deformation is dependent on good material properties, proper lubrication of the punch, and correct die maintenance. To obtain enough stretch to realize good part stiffness, it is important to maintain enough blankholder force to prevent metal slippage through the lock-bead. The blankholder force required throughout the press stroke is greater than the pressure required to form the lock-bead upon initial die closure.³

Excessive localized thinning or necking often leading to fracture is evidence of stretch forming process failure. Surface roughness of both the die and material should not be excessive. Smooth surfaces may also have high friction. Good lubrication is an important success factor in operations involving severe deformation. Both the die and stock may require an optimum roughness profile to facilitate holding lubricant.

Plane Strain

If the metal is formed by stretching in one direction only, the operation is called *plane strain* or simple stretching and thinning of the metal. When compared to biaxial stretch forming, this operation allows substantially less elongation to occur before a fracture occurs. The plane strain forming method is illustrated in Figure 7.

³ Michael R. Herderich, *Experimental Determination of the Blankholder Forces Needed for Stretch Draw Design*, SAE Paper 900281, Warrendale, Pennsylvania, © 1990.

Bending and Straightening Operations

Figure 8 illustrates a forming method in which the metal is bent and straightened as it passes over the blankholder radius. Bending and straightening operations permit large deformations with very little thickness change.

Bend and Straighten Operation

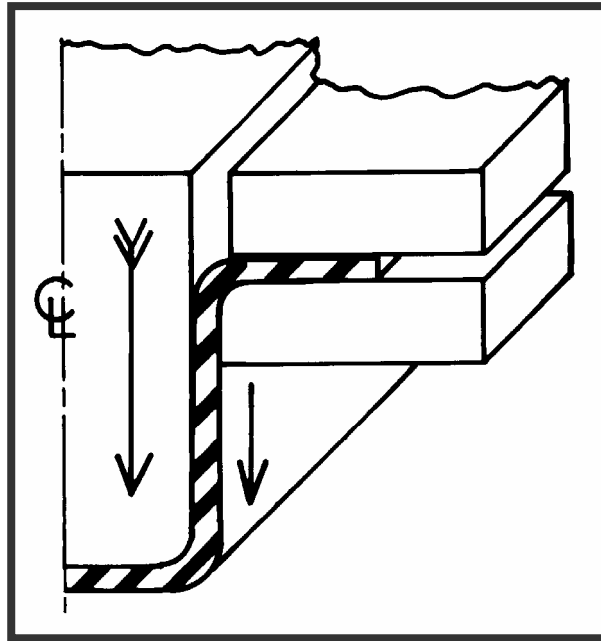


Figure 8. A bend and straighten operation in which the metal is bent and straightened in the die permitting very large deformations and little thickness change. *Smith & Associates*

Bending and Straightening Applications

A simple type of die employing bending and straightening is used to make U-shaped cross-sections with right angle flanges. Parts of this type are used as stiffeners attached to flat panels in many applications. Examples are automotive body frame rails and cross members, which are assembled by welding.

Bending and straightening operations are employed in conjunction with processes such as drawing, plane strain in the production of complex stampings. A simple example is the stamping of rectangular shells.

Combined Drawing and Bending

The stamping of a rectangular shell involves both cup drawing and simple bending and straightening. True drawing occurs at the corners only. The metal movement at the sides and ends involves bending and unbending. Figure 8 illustrates a section through a portion of a die where bending and straightening occurs as the metal passes over the radius.

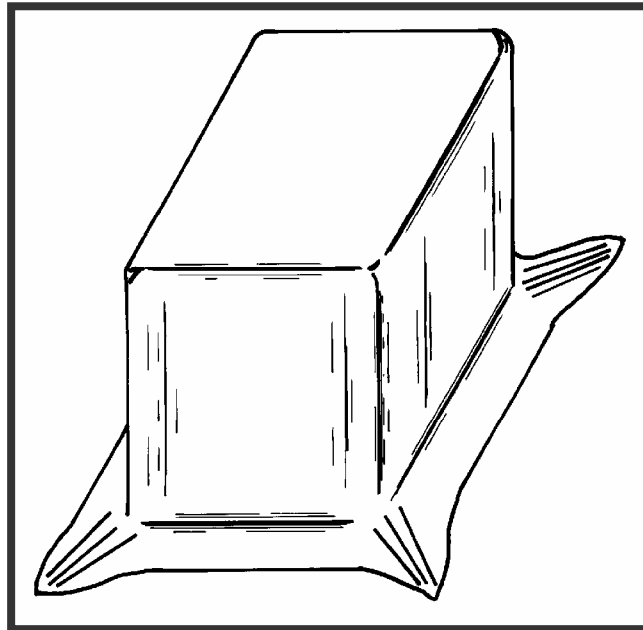


Figure 9. A typical rectangular drawn shell showing how metal thickens and tends to wrinkle at the corners. *Smith & Associates*

The stresses at the corner of the shell are compressive, and result in a thickening of the metal moving toward the die radius. After the metal has been drawn over the radius, the forces are tensile. The metal between the corners is in tension on both the sidewall and where restrained by the blankholder. This portion of the operation involves deep cup drawing illustrated in Figure 1.

Blank Thickening at the Corners

Unlike circular shells in which pressure is uniform on all diameters, some areas of rectangular and irregular shells may require differing pressures. The metal at the corners of the blank compresses and will thicken. Both thickening and some wrinkling of the metal at the corners are normal. Figure 9 illustrates the appearance of a box-shaped drawn shell made from a rectangular blank. The metal at the corners often increases in thickness up to 25% or more.

Providing Clearance in the Blankholder

A common error in the construction and maintenance of rectangular shell drawing dies is to machine the blankholder surfaces perfectly flat. Clearance provided in the blankholder allows the metal to thicken. You can do this with a pneumatic hand grinder when the die is tried out.

Die Tryout Procedure

A skilled die tryout technician will optimize the metal flow by making a series of trial parts and reworking the blankholder as needed. In some cases, it is necessary to increase draw ring and punch radii with the approval of the product designer.

Benefit of Minor Product Changes

Minor product changes are often highly beneficial to reduce or eliminate the occurrence of fractures. The corner is the usual location of a fracture in a rectangular drawn shell. The localized thinning or necking, which can lead to a fracture, is the same failure mode that limits the severity of round deep cup drawing.

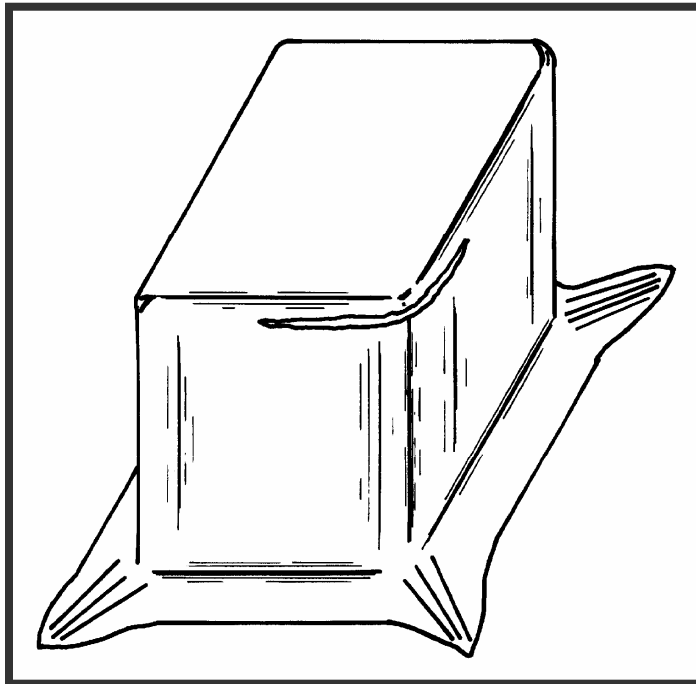


Figure 10. A rectangular drawn shell having a corner fracture. A typical fracture caused by the metal flow at the corners locking due to circumferential compression is shown.
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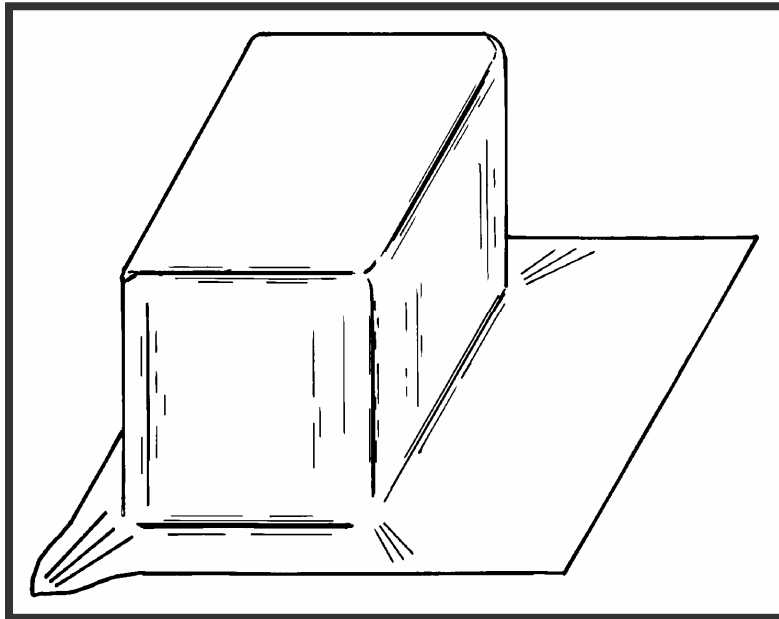


Figure 11. Rectangular box draw with large outboard tab. The tab may severely restrict metal movement into the draw cavity and result in a fracture. *Smith & Associates*

Final Tool and Die Work on a Forming or Draw Die

After the die tryout work is complete, the die is oil-stoned and polished. If long service life is required in severe applications, ion-nitriding, hard chromium plating, or other processes to reduce surface wear and friction may be beneficial.

Example of Fractured Deep Drawn Part

Figure 13 is a photograph of a fractured drawn part similar to the design shown in Figures 11 and 12. Note the very tight coined area on the blankholder in the corner where the metal locked leading to the fracture. The metal movement restraining action of the large outboard tab is also a cause of the fracture occurring.

Fractures in Secondary Operations Due to Extreme Residual Stresses

Parts that emerge from the first operation without fractures in spite of being severely worked may have so much residual stress that they will fail in subsequent operations. A much more serious difficulty is to have such stampings fail in service.

Figure 14 is a photograph of a drawn shell sidewall. When asked to identify a defect, most observers note the ding or blemish as the fault. However, there is a much more serious problem.

Figure 15 is a photograph taken with a powerful quartz halogen lamp inside the rectangular drawn shell. The intense light reveals a hairline crack that is a serious defect.

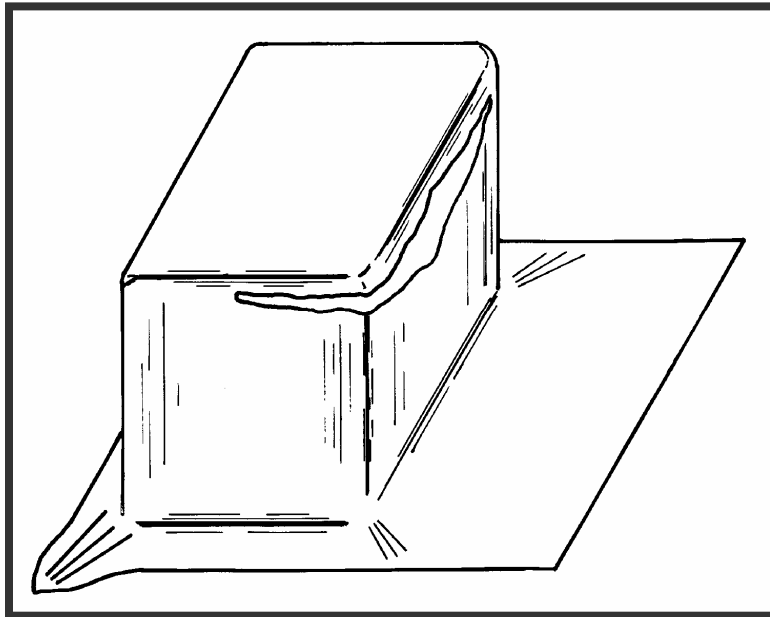


Figure 12. Fractured rectangular box draw with large outboard tab. *Smith & Associates*



Figure 13. A photograph of the type of failure illustrated in figure 12.
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Photograph of a Drawn Shell Sidewall



Figure 14. Photograph of a drawn shell sidewall. When asked to identify a defect, most observers note the ding or blemish as the fault. However, there is a much more serious problem. *Smith & Associates*

Photograph of a Drawn Shell Sidewall Hairline Crack



Figure 15. This photograph is taken with a powerful quartz halogen lamp inside a rectangular drawn shell. The intense light reveals a hairline crack—a serious defect. The crack occurs when a joggle to the left of the crack is formed. *Smith & Associates*

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