

Plasticity and Deformation Process

Drawing

Drawing is a group of plastic deformation processes that vary depending on the temperature and the shape of the material to be deformed

Cold drawing refers to two different operations:

1. If the starting stock is sheet metal it refers to forming of parts where plastic flow occurs over a curved axis
The parts have elongated, 3D shapes with a depth much more than the thickness of the metal
A wide range of shapes from small cups to large automobile body panels can be produced which makes cold drawing one of the most important cold-working operations
2. If the starting stock is wire, rod or tubing, cold drawing processes reduce the cross section of the material by pulling it through a die

The main difference between wire drawing and extrusion is that the applied forces are tensile in the former

Hot drawing of sheets is done for forming relatively thick-walled parts of simple geometries, usually cylinders because hot material undergoes thinning as it passes through the dies

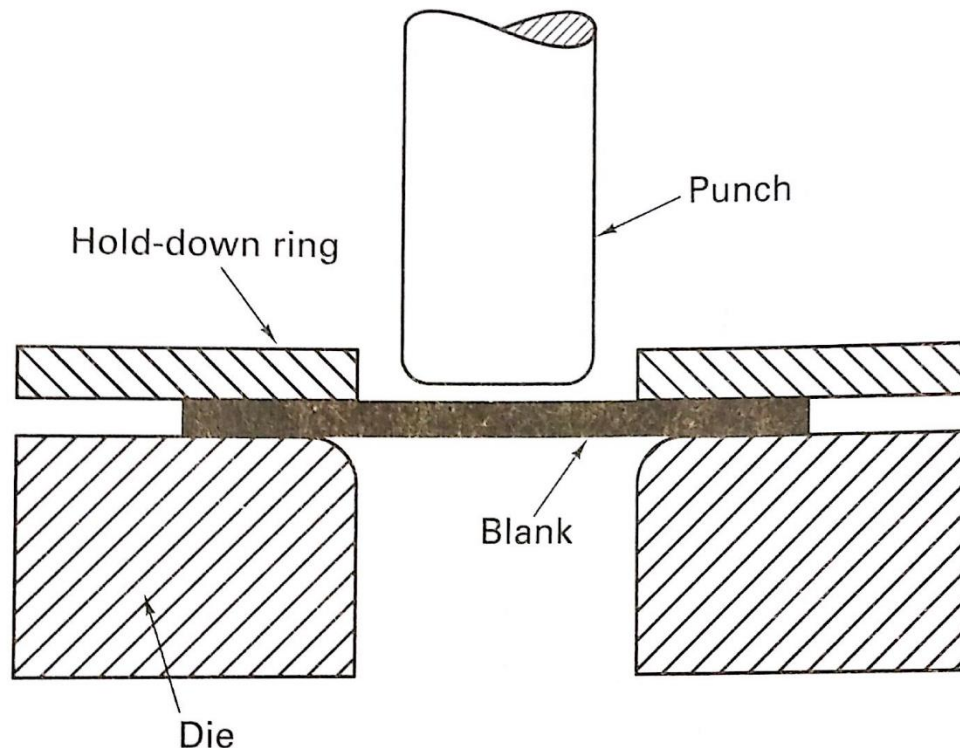
In contrast relatively thin metal is processed into complex shapes in cold (deep) drawing of sheets and the thickness changes very little

Hot drawing is done by the equipment setup shown in the figure according to the following steps:

- A heated sheet or plate is positioned over a female die
- A punch descends on the metal sheet, pushing the metal through the die
- Circular metal blank is converted to a cylindrical cup

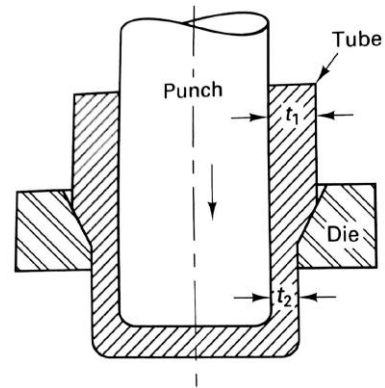
The height of the cup wall is determined by the difference between the diameter of the original blank sheet and the diameter of the punch

The height is limited by the occurrence of defects like wrinkles that form in the cup walls when the circumference is reduced, or tearing in the blank around the punch perimeter

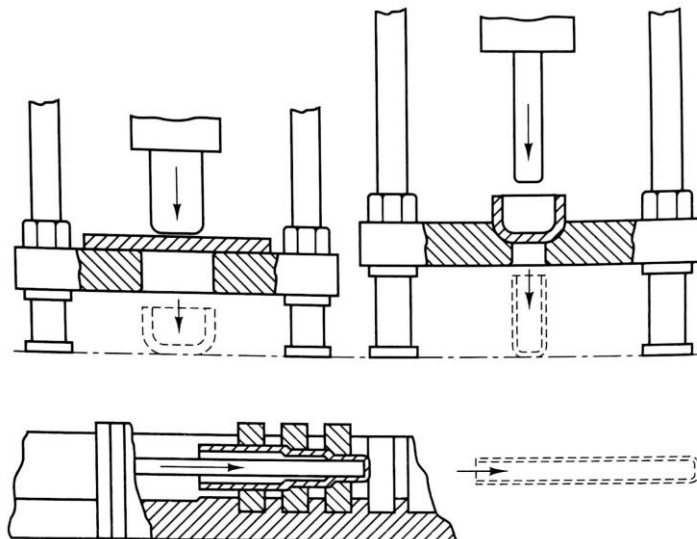


Cups with taller walls can be produced than by standard deep drawing:

- Ironing (thinning) and elongation of the walls occurs when the gap between the punch and the die is less than the thickness of the incoming material (thin-walled coke cans are the most common example)



- If thinning weakens the metal significantly, another subsequent drawing with a smaller punch and die can follow the initial drawing
- A series of dies with decreasing diameters can be used in combination with a single punch



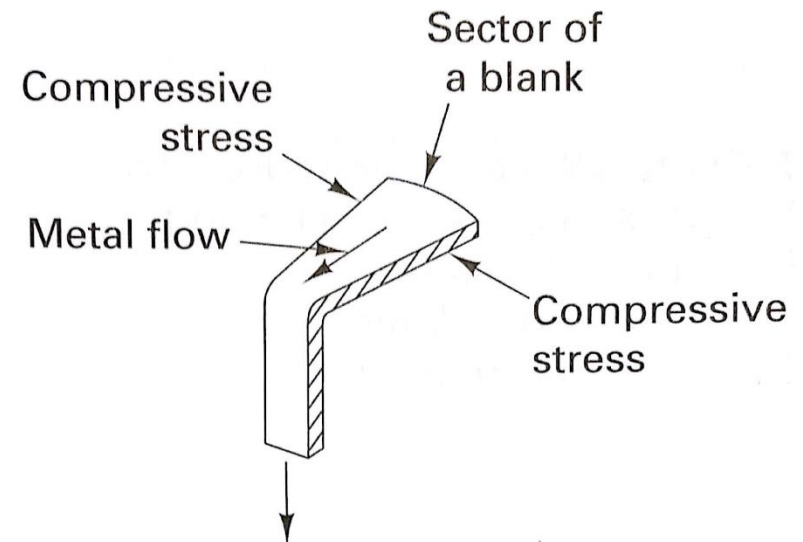
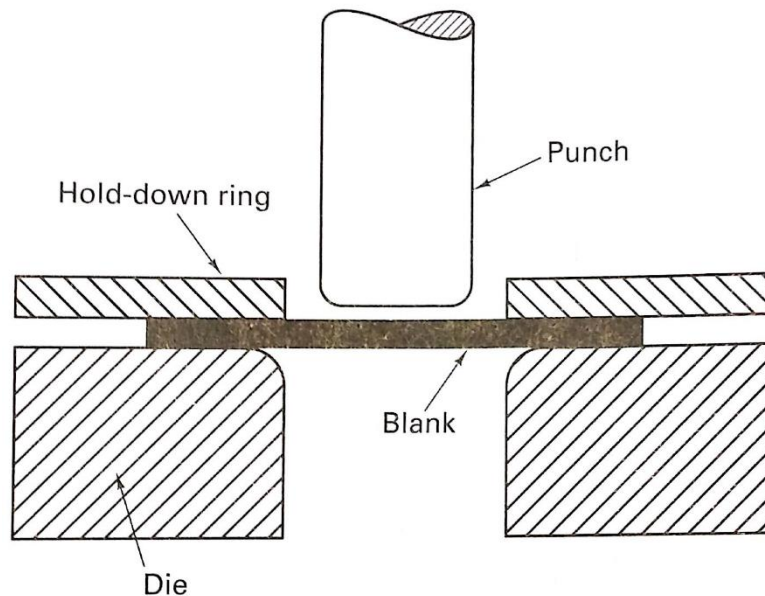
Cold drawing is similar to hot drawing except using higher deformation forces and thinner metal with limited ductility

It is considered shallow drawing when the depth of the product is less than its diameter

When the depth is greater than the diameter, it is known as deep drawing

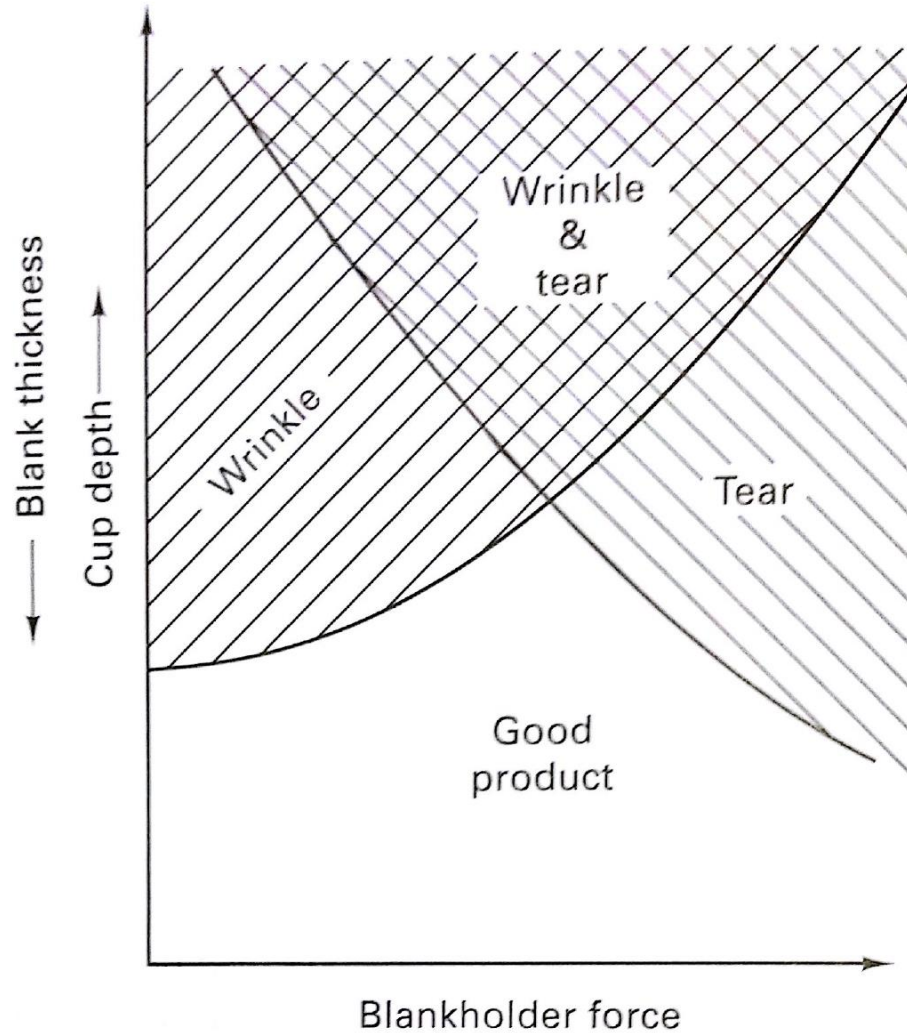
For a simple operation of converting a circular disk of sheet metal into a flat-bottom cylindrical cup,

- The material beneath the punch remains largely unaffected and becomes the bottom of the cup
- The cup wall is formed by pulling the remainder of the disk inward, over the radius of the die
- The circumference decreases as the material is pulled inward
- The decrease in circumferential dimension must be compensated by an increase in another dimension such as thickness since the volume is constant



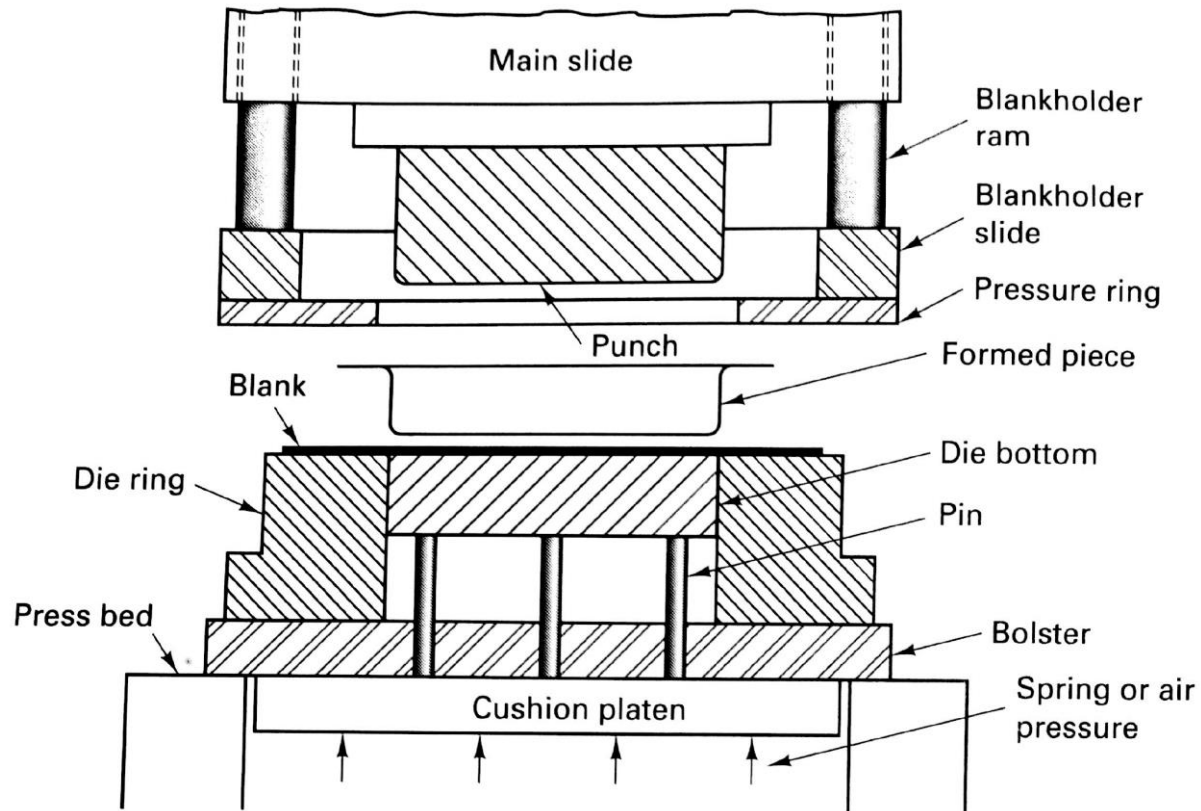
Wrinkling may occur to compensate for the decreased circumference since the material is thin

Compressing the blank sheet between the die and the blankholder suppresses the wrinkles, causing an increase in radial length or thickness



In single action presses where there is only one movement that is available, springs or air pressure are used to compress the metal sheet between the die and pressure ram

The hold-down force can be applied independently of the punch position when multiple actions are available in the press



This compression force can be varied during the drawing operation

Multiple action presses are usually used for the drawing of complex parts where non-uniform strain distribution is possible

Key variables in design of deep drawing processes are the blank diameter and the punch diameter



These two variables determine the draw ratio, the die radius, the clearance between the punch and the die, the thickness of the blank, lubrication and the hold-down pressure

The process is designed and tooling is manufactured once these parameters are set

The primary variable during the deep drawing process is the hold-down pressure

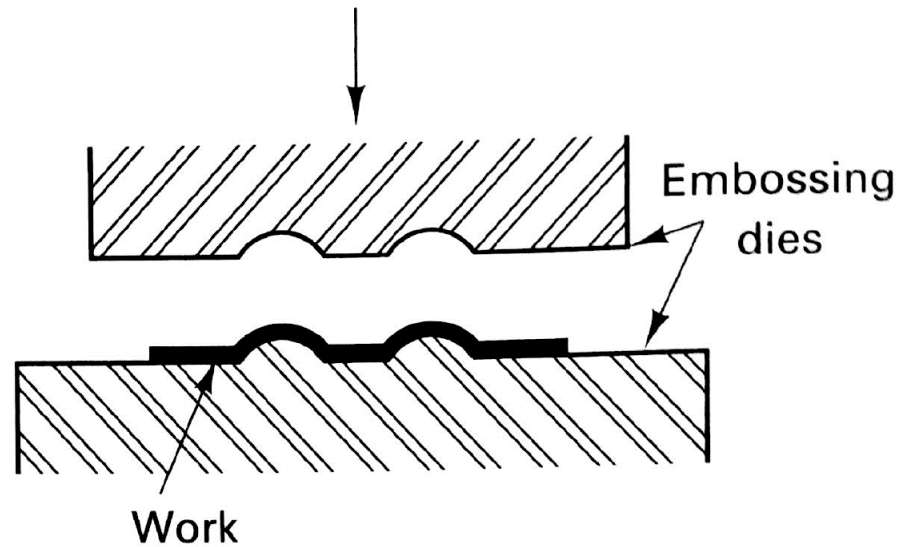
Wrinkling may occur at the start of the process if the compressive force is too low

If it is too high, there is too much restraint on the blank sheet and the descending punch may tear the disk or some portion of the formed cup wall

When drawing a shallow cup, there is little change in circumference and a small area is confined by the blankholder. So the tendency to wrinkle or tear is low

There is an increased tendency for forming both of the defects as the cup depth increases

Embossing is a similar pressing-cold drawing process in which shapes or letters with shallow depth are impressed in sheet metal



Generally the depth of the draw is limited to 1-3 times the thickness of the metal

The material thickness remains mostly unchanged



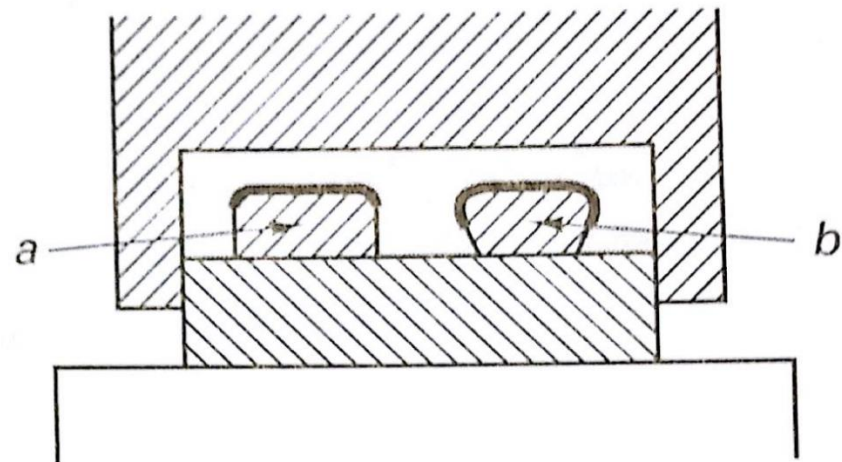
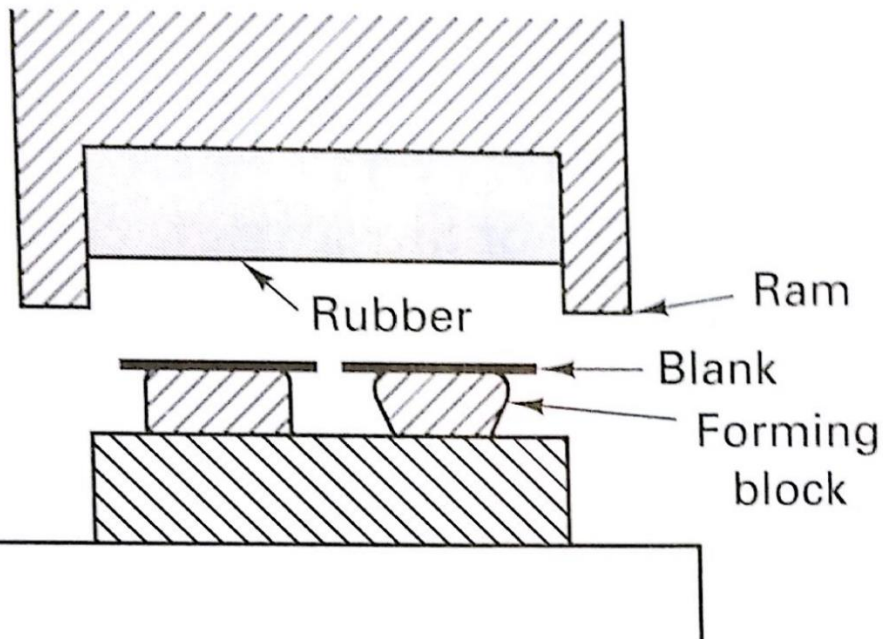
The cost of tooling in conventional drawing is high as upper and lower die sets of high precision are required

Numerous methods have been developed to reduce tooling cost

An efficient approach seeks to extend the amount of deformation that can be performed with a single set of tools, eliminating the need for multiple operations and associated tooling and anneals

One example is the Guerin process that replaces the female component of the die set with rubber

Guerin process (rubber-die forming) is based on the phenomenon that rubber acts as a fluid when totally confined and transmits pressure uniformly in all directions



Forming blocks are used in place of expensive male dies in the Guerin process which can be made of wood, bakelite, polyurethane, epoxy or low-melting metal

The upper ram contains a pad of rubber 20-25 cm thick mounted within a steel container

The rubber pad becomes confined as the ram descends, and transmits force to the metal, causing it to bend to the desired shape



The total tooling cost is quite low since no female die is used and inexpensive forming blocks replace the male die

Other advantages of the process are:

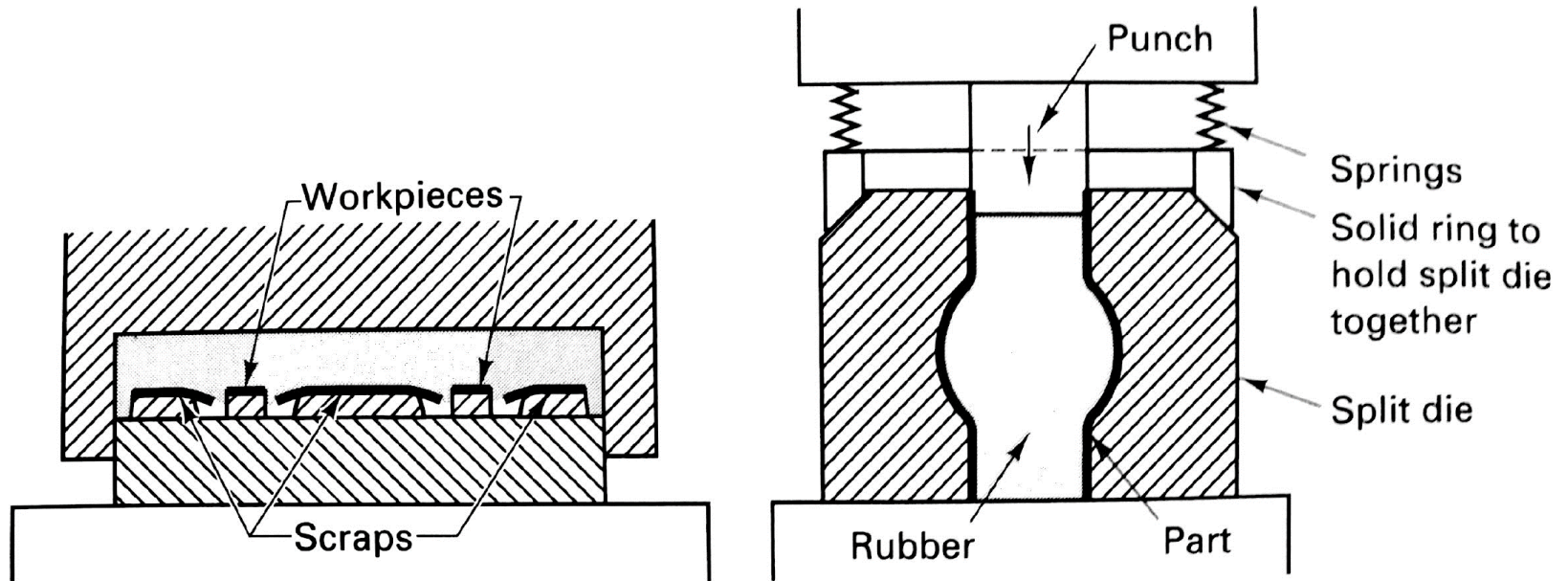
- No mating tools to align
- Different shapes can be formed at the same time
- Low wear on the material and tooling
- Surface quality of the workpiece is easily maintained
- Reentrant sections can be produced (it must be possible to slide the parts lengthwise from the blocks)

The Guerin process was developed by the aircraft industry where the production of small number of duplicate parts favors the low cost of tooling

Aluminum sheet up to 3mm thick and stainless steel up to 1.5 mm thick are commonly processed

Most of the forming done with the process is multiple-axis bending but some shallow drawing can be also performed

It can be used to prepare thin parts of aluminum using forming blocks of hardened steel face or edges

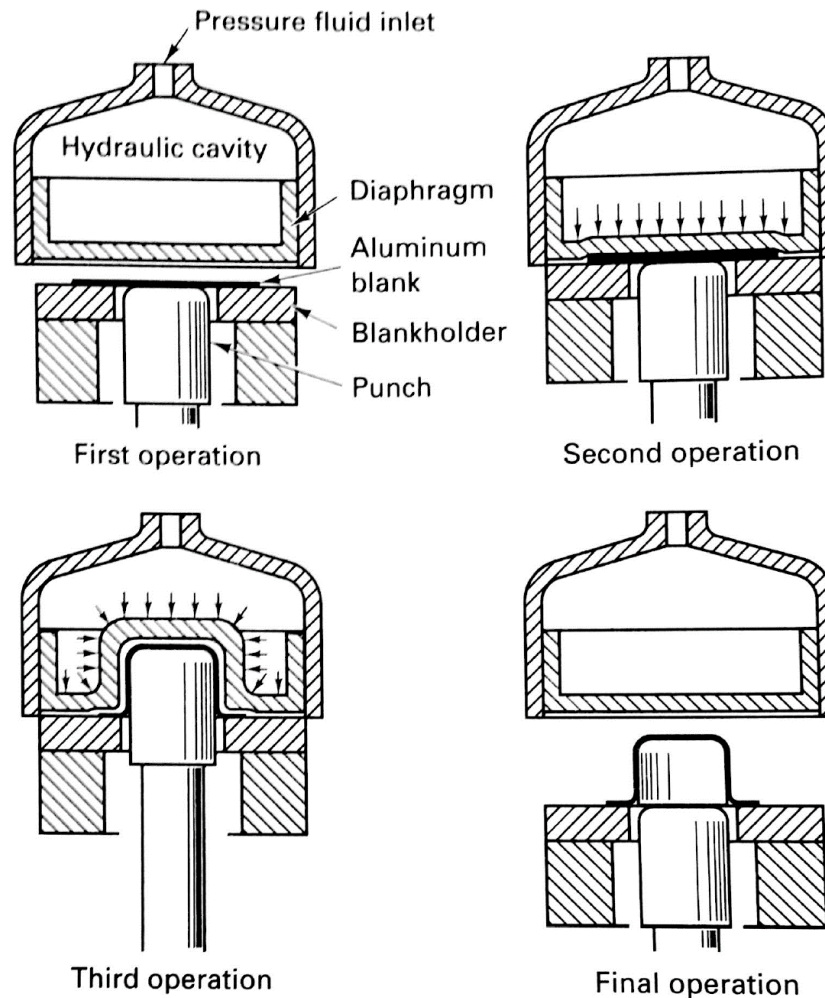


Bulging tubes is a variant of the process where rubber is used to transmit the pressure required to expand a metal blank or tube outward against a split female die

Rubber is used for simpler shapes (easy removal) while fluid pressure is used to form the bulge for more complicated shapes

In another variant of the Guerin process, the rubber pad is replaced by a flexible rubber diaphragm backed by controlled hydraulic pressure at values up to 200 MPa

High pressure flexible die forming is one of the processes in sheet hydroforming group

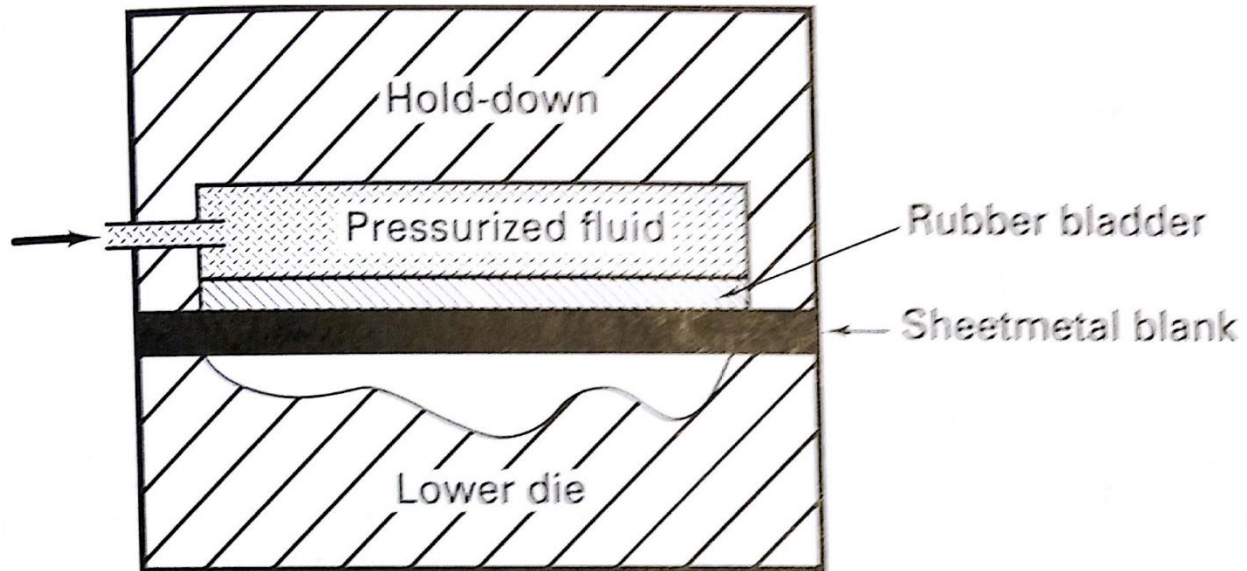


The solid punch presses the sheet against the resisting medium whose pressure is adjusted

In a variation of that process, the workpiece is held in place below the pressurized diaphragm and the punch is stationary

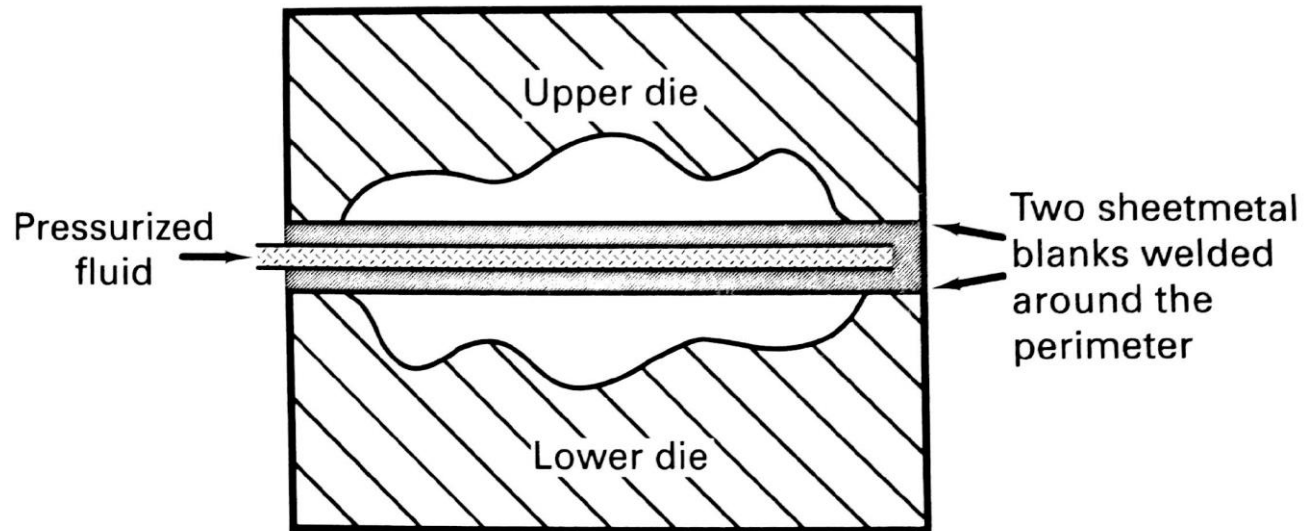
The fluid is pressurized causing the workpiece to balloon toward the punch

The sheet is uniformly stretched and thinned since the pressure is uniformly distributed by the fluid



Ballooning action causes the material to conform fully to the female die which may be made of epoxy or other low cost material

Parallel-plate hydroforming or pillow forming similarly enables simultaneous production of upper and lower contours



This is a more attractive way of producing complex sheet metal containers than forging since the manufacturer does not have to cope with the problem of aligning and welding two separately formed pieces

Other advantages of hydroforming

- Reduced tool cost
- Metals exhibit greater formability by producing a more uniform distribution of strain
- Drawing limits are about 1.5* those of conventional deep drawing (deeper parts can be formed without fracture)
- Complex shapes can be formed in single pressing
- Part dimensions are more accurate and consistent

Cycle times for sheet hydroforming are generally 1-3 minutes but the reduced costs make the process attractive for prototype manufacturing and low volume production (up to 10000 parts)

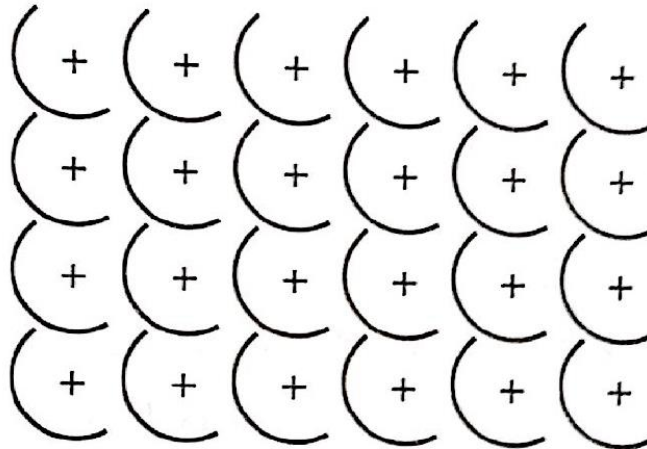
Process control

A majority of sheet metal failures occur due to thinning or fracture which are both the results of excessive deformation in a given region

Strain analysis is a quick and economical way of evaluating the severity of deformation in formed parts

A pattern or grid is placed on the surface of a sheet by scribing, printing or etching

Circle diameters between 2.5 to 5 mm are required to detect variations in strain distribution



When the sheet is deformed, the circles are converted to ellipses and the distorted pattern is then measured and evaluated

Regions where the enclosed area has expanded are locations of sheet thinning and possible failure

Regions where the area has contracted have undergone sheet thickening and may be sites of possible buckling or wrinkles

The major strains (strains in the direction of the largest diameter and the associated minor strains (strains 90 degrees from the major) are determined using the ellipses on the deformation grid for a variety of locations.

The major and minor strain values are plotted on a forming limit diagram

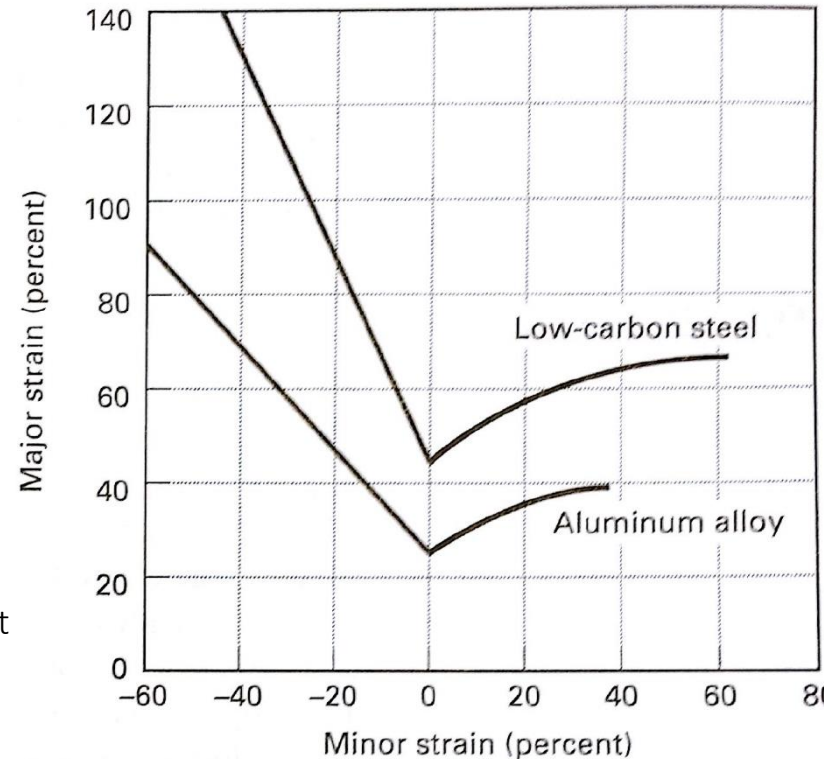
The deformation is stretching if both major and minor strains are positive and the sheet metal will decrease in thickness

If the major strain is positive and minor strain is negative, the contraction may partially or wholly compensate any positive stretching in the major direction

The combination of tension and compression is drawing and the thickness may decrease, increase or stay the same

Regions where both strains are negative (compressive) do not appear on the diagram since fractures occur only in tensile environment

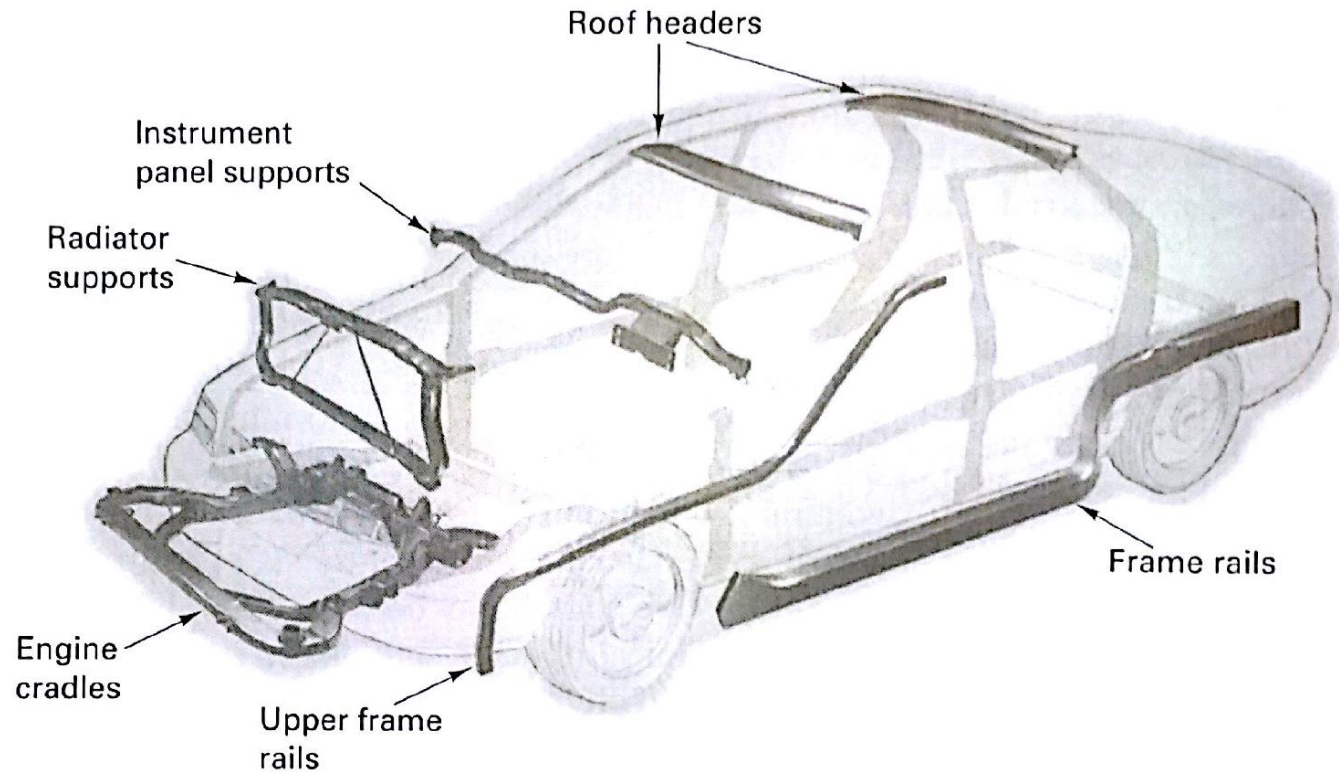
The strains that fall above the forming limit line indicate regions of probable fracture. They can be corrected by modification of the lubricant, change in the die design and varying the hold-down pressure



Tube hydroforming was developed for manufacturing strong, lightweight, one-piece automotive components which replaced an assembly of welded stampings

Typical parts include engine cradles, frame rails, roof headers, radiator supports, exhaust components

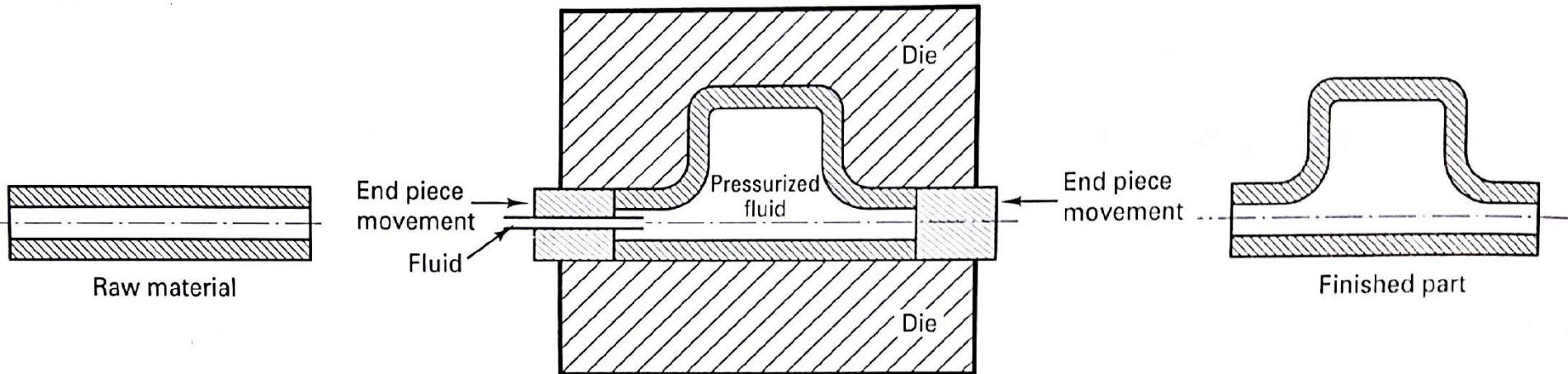
FIGURE 19-79 Use of hydroformed tubes in automotive applications. (Courtesy of MetalForming, a publication of PMA Services, Inc., for the Precision Metalforming Association, Independence, OH.)



A tubular straight or preshaped blank is placed in an encapsulating die with sealed ends

A fluid is introduced through one of the end plugs, achieving sufficient pressure to expand the material to the shape of the die

The end closures may move inward at the same time to help compensate or overcome the thinning due to radial expansion



The process may use combinations of internal pressure and axial motion to control the flow and final thickness of the material:

In low pressure tube hydroforming, the tube is first filled with fluid and then the dies are closed around the tube. The primary function of the fluid is to act as liquid mandrel that prevents collapsing as the tube is bent to the contour of the die. The cross section shapes should be simple, corner radii should be large and there must be minimal expansion of the tube diameter

In high pressure tube hydroforming an internal pressure between 100 and 700 MPa is used to expand the diameter of the tube, forming tight corner radii and significantly altered cross sections

The advantages of tube hydroforming in tube manufacturing are

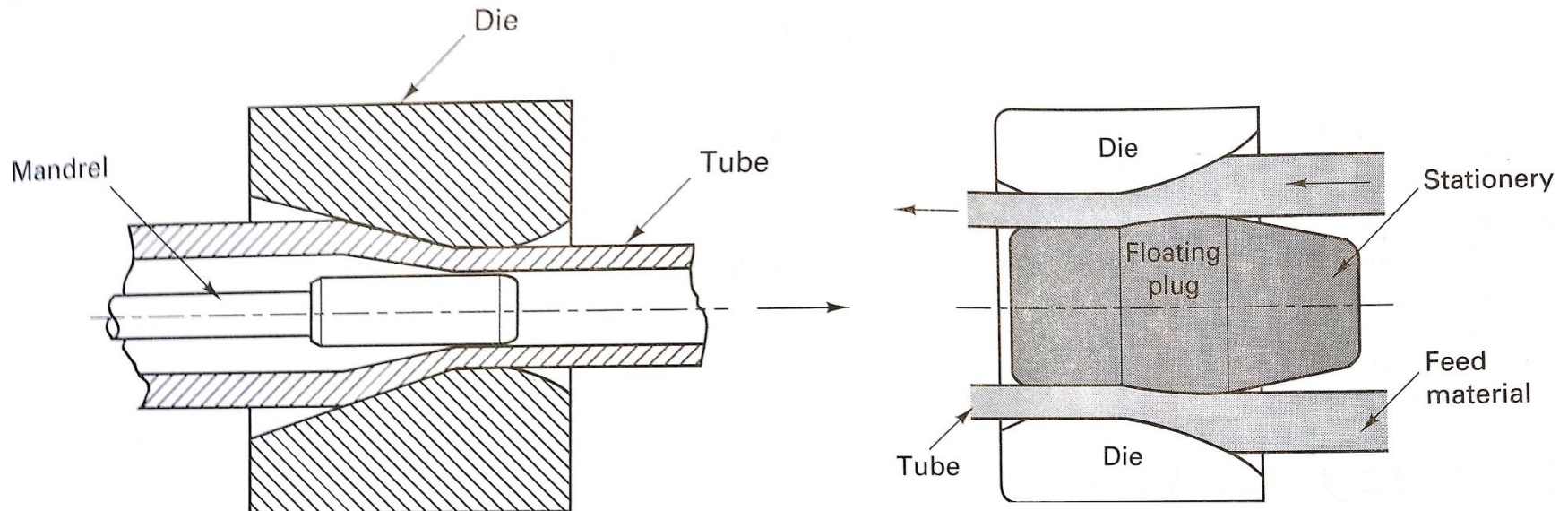
- Ability to use lightweight, high-strength material
- Increase in strength resulting from strain hardening
- Ability to utilize designs with varying thickness or varying cross section

The disadvantages are long cycle time (low production rate) and high cost of tooling and equipment

Tube drawing can be used to produce high-quality tubing where the product requires the smooth surfaces, thin walls, accurate dimensions and added strength due to cold working

Internal mandrels are often used to control the inside diameter of the tubes up to 25 cm in diameter

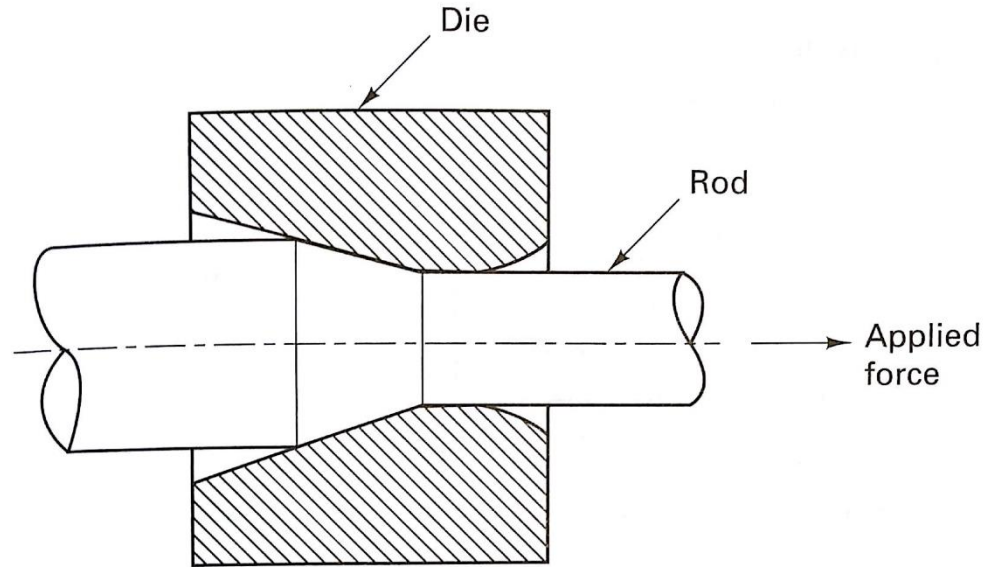
They are inserted through the incoming hollow stock and held in place during the drawing operation



Thick walled tubes and those less than 12 mm in diameter are often drawn without a mandrel in tube sinking process

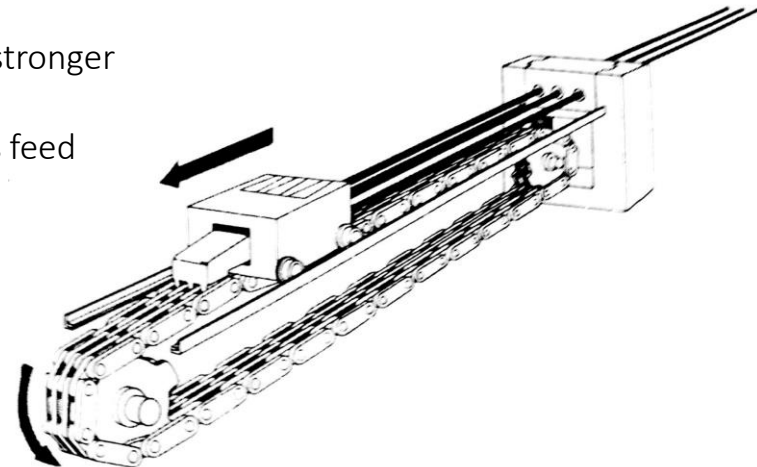
Precise control of the inner diameter is sacrificed in exchange for process simplicity and the ability to draw long lengths of product

Rod drawing is one of the simplest cold drawing operations



- One end of a rod is reduced or pointed so that it can pass through a die of somewhat smaller cross section
- The end is then gripped and pulled in tension, drawing the remainder of the rod through the die
- As a result the rods reduce in section, elongate and become stronger

Straight-pull draw benches are generally used with discontinuous feed
Chain drives can be used to draw products up to 30 m in length



The reduction in area is usually restricted to 20-50% since higher pulling forces are required (more risk of excess deformation) for more reductions

Multiple draws may be required to produce a desired size or shape, through a series of progressively smaller dies.

Intermediate anneals may be required to restore ductility

The drawing of bars can also be used to make products with shaped cross sections

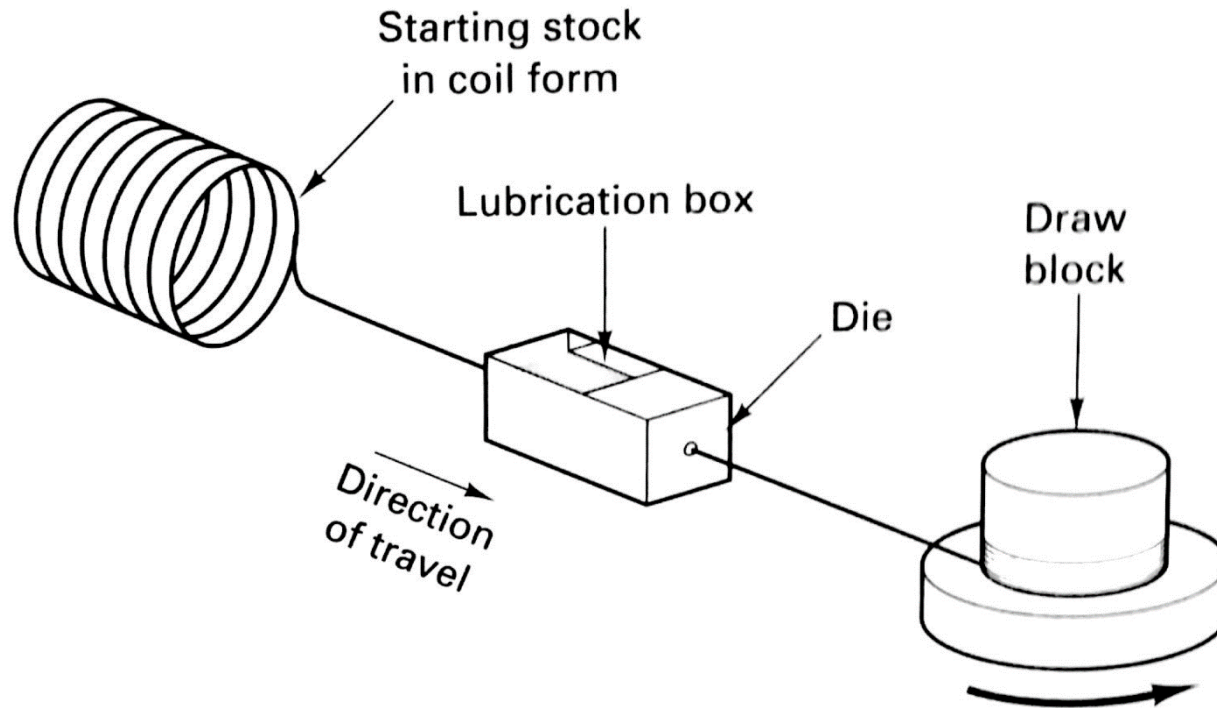
By using cold drawing instead of hot extrusion, the material emerges with precise dimensions and excellent surface finish

Inexpensive materials strengthened by strain hardening can often replace stronger alloys or alloys that require additional heat treatment

Small parts with complex but constant cross section can be economically made by sectioning long lengths of cold-drawn, shaped bars of steels, copper alloys and aluminum alloys

The same operating procedure is applied to smaller diameter metal rods (9 mm) in wire drawing

Since the thin rod and wire can be coiled, the process can be conducted continuously on rotating draw blocks



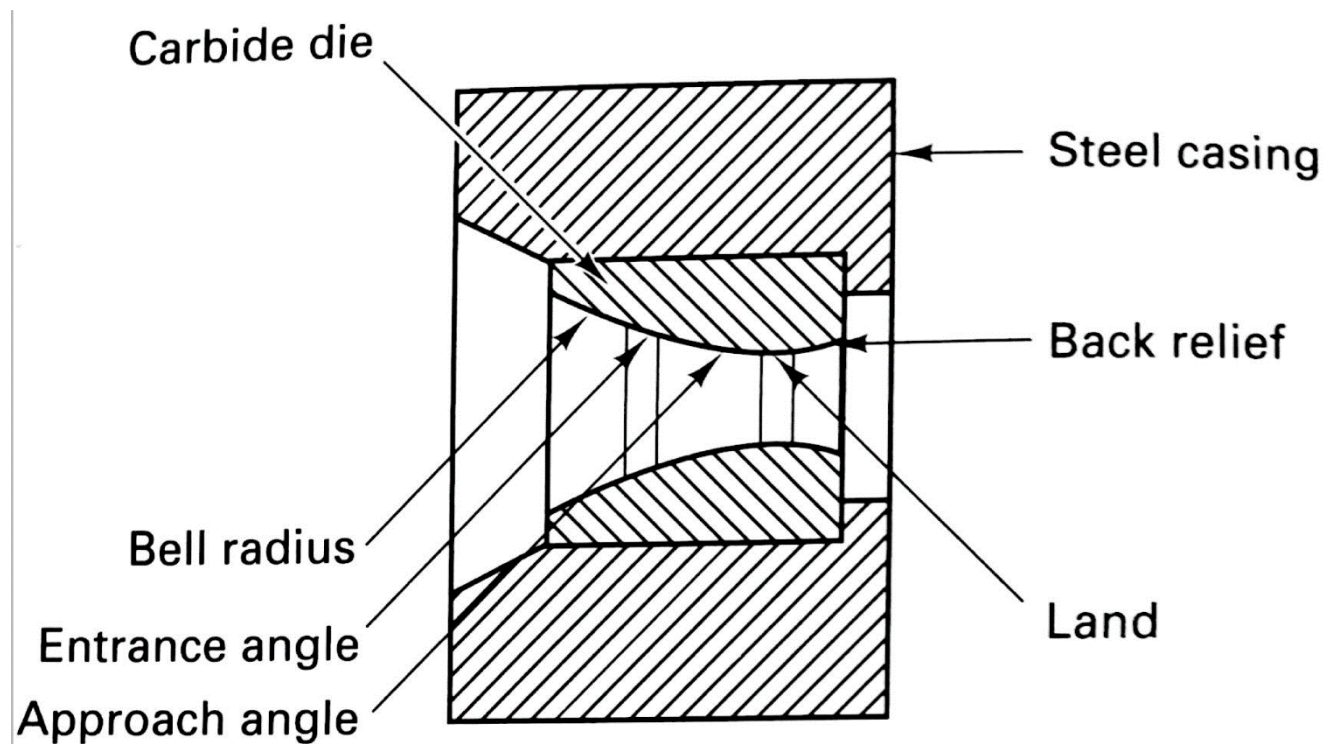
Commonly hot rolled rod is descaled, washed, and fed through a die to draw wires

Lubrication boxes often precede the individual dies to help reduce friction drag and prevent wear of the dies

The contact regions of wire drawing dies are usually made of wear-resistant tungsten carbide or polycrystalline diamond

Single crystal diamonds can be used for the drawing of very fine wire

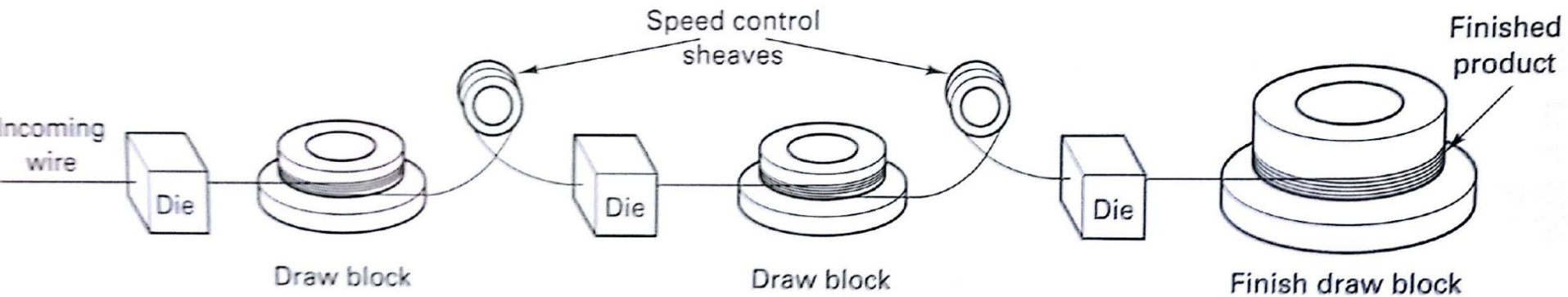
Wear-resistant and low-friction coatings can also be applied to the various die material substrates



The amount of reduction in a single wire drawing process is severely limited

A significant change in size can be produced by only multiple draws

For example copper wires used in telephone lines are drawn from hot-rolled rods through up to 30 individual dies
These operations are usually performed on tandem machines to minimize handling and labor



Wires that pass through all dies in a tandem machine usually requires an intermediate annealing before any further deformation

Wires can be made with a wide range of strengths by controlling the placement of last anneal to induce a selected amount of cold-working in the microstructure

Process analysis

Mechanical analysis of rod or wire drawing is the same as extrusion of a rod or wire except only the stress is tensile initially

Consider sheet drawing of an aluminum disc. In the presence of sufficient blankholder pressure no wrinkling or tear takes place and the only deformation occurs through the elongation of wall due to the downward stress
The effective stress is calculated from this stress in the z direction only

Deformation when ironing happens due to smaller gap than thickness (similar to extrusion)

