Forging

Forging → cold – forging
→ requires higher forces
→ material must possess sufficient ductility @ room temperature
→ good finish + dimensional accuracy

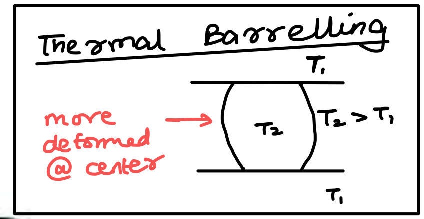
Forging → hot – forging
→ lower forces
→ surface finish may not be as good.

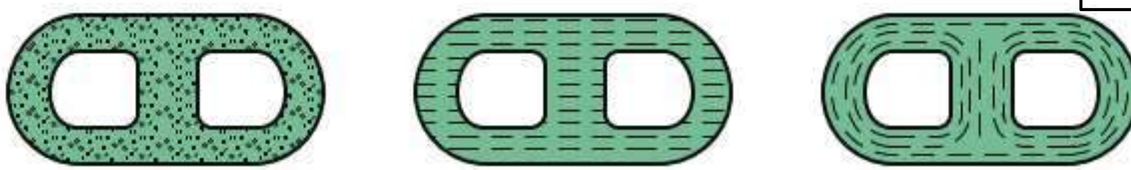
Steps to produce a knife by Forging

Forging is a basic process in which the workpiece is shaped by compressive forces applied through various dies and tooling to produce jewelry, coins, turbine rotors, gears, bolts, rivets, cutlery, hand tools, components for machinery, aircraft landing gear and railroads, and so on.

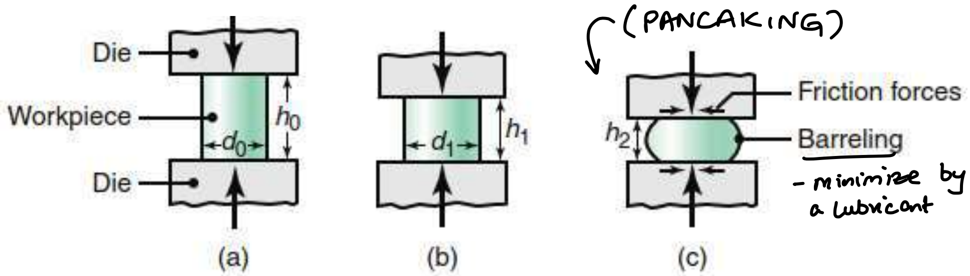
• Forging Force →
- Y_f: flow stress
- μ: coeff. of friction
- r, h: instant. dimensions

$$\boxed{F_y = Y_f \pi r^2 \left(1 + \frac{2\mu r}{3h}\right)}$$

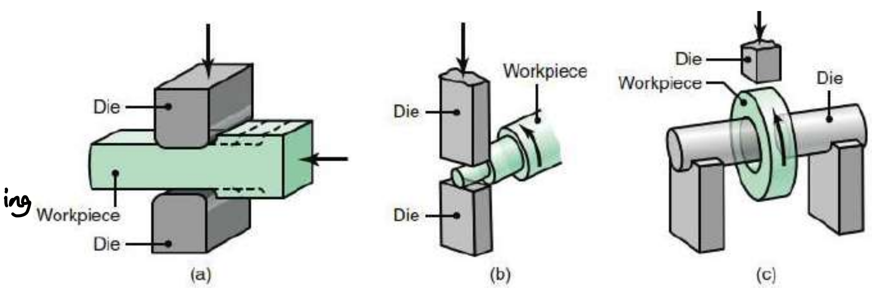




In Forging, metal flows in a die and the material's grain structure can be controlled. So, forged parts have good strength and toughness, and are very reliable for highly stressed and critical applications.



Open Die Forging with and w/o Friction
(Upsetting / Flat Die Forging)



Cogging (reducing thickness of a slab or diameter of a bar / disc) is an example of open die forging

aka "drawing out" : reducing thickness of bar by successive forging steps (bites) at specific intervals.

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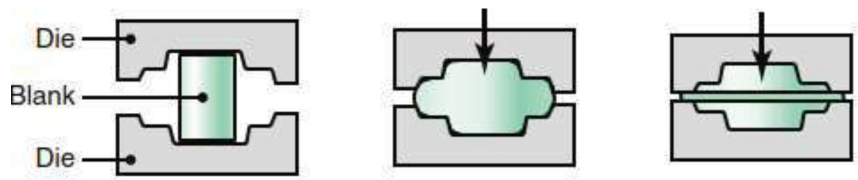
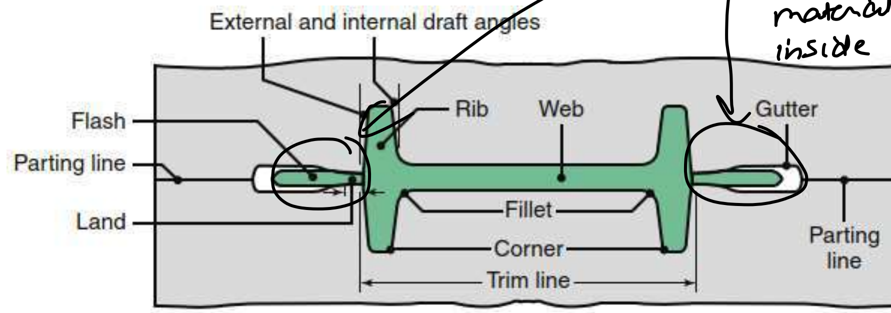
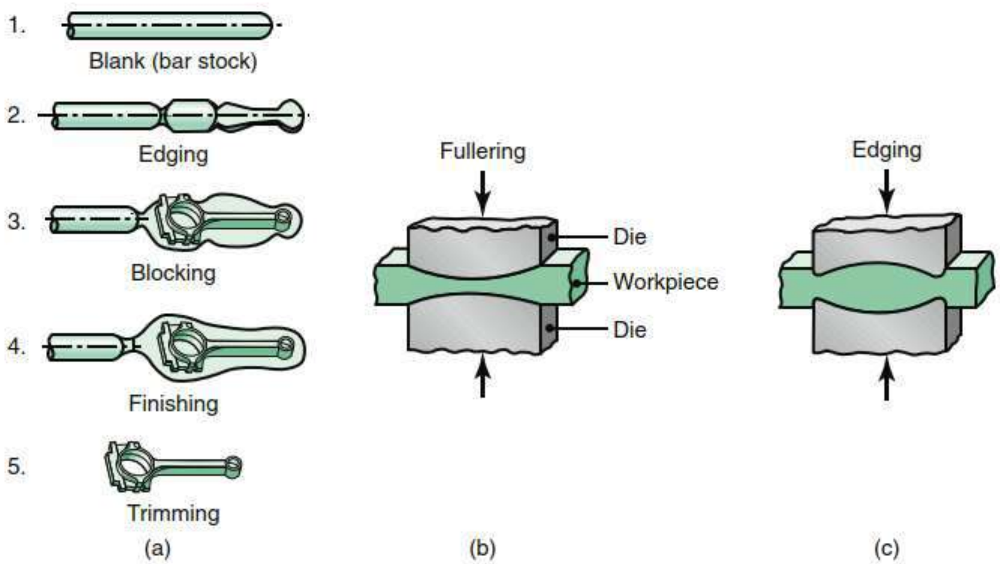
Impression Die Forging





flash
→ due to high pressure, it makes material flow inside cavity

In impression-die forging, the workpiece takes the shape of the die cavity as it is forged between two shaped dies. It is mostly carried out at elevated temperatures to lower the required forces and ensure good plastic flow of the workpiece. (ductility improves @ elevated temperature)



Forging of an automotive connecting rod is shown on the left. In fullering, material is distributed away from an area. In edging, it is gathered into a localized area. The part then is formed into the rough shape by blocking using blocker dies. The final operation is the finishing of the forging in impression dies that give the forging its final shape. The flash is removed later by a trimming operation.

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Impression Die Forging Force → $\boxed{F = k Y_f A}$

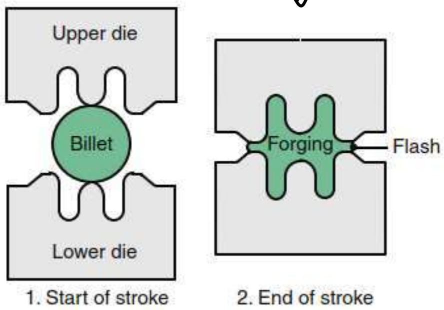
Y_f: flow stress

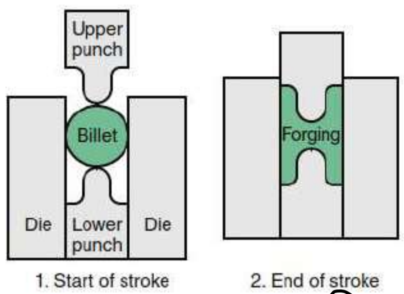
A: projected area

k: factor

Closed Die Forging (flashless forging)

impression die forging



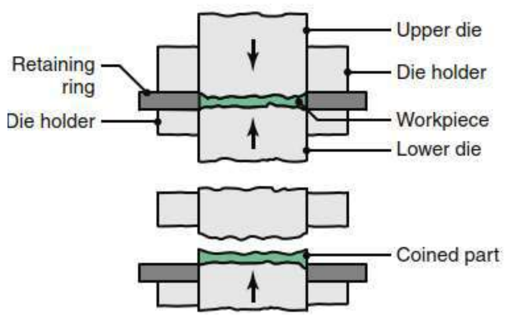


closed die forging

Closed-die forging is almost similar to impression die forging with very little or no flash. Closed-die forging is also referred to as flashless forging.

The workpiece completely fills the die cavity. The forging pressure is very high, and accurate control of the blank volume and proper die design are essential to producing a forging with the desired dimensional tolerances.

Undersized blanks prevent the complete filling of the die cavity and in contrast, oversized blanks generate excessive pressures and may cause dies to fail prematurely or the machine to jam.



Coining is a closed-die forging process that is used for minting of coins, medallions, and jewelry. The blank or slug is coined in a completely closed die cavity. In order to produce fine details (for example, the detail on newly minted coins), the pressures required can be as high as five or six times the strength of the material.

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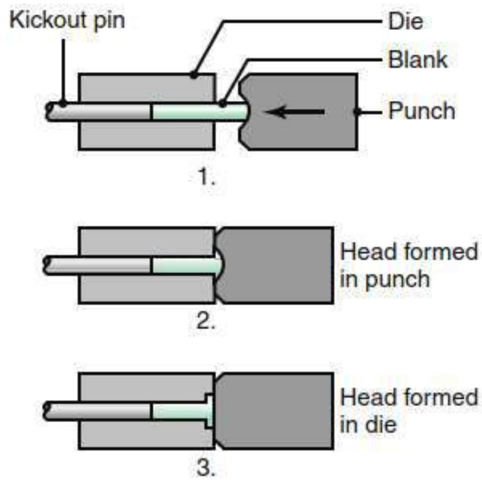
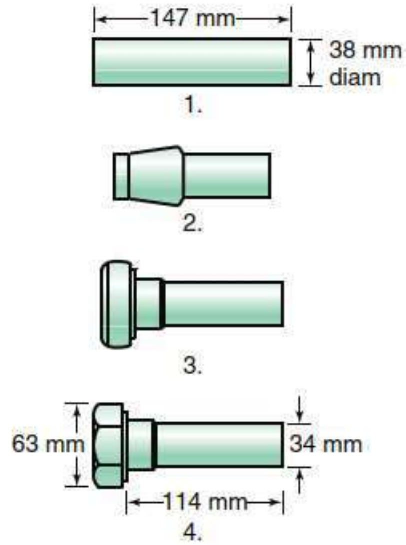
Closed Die Forging



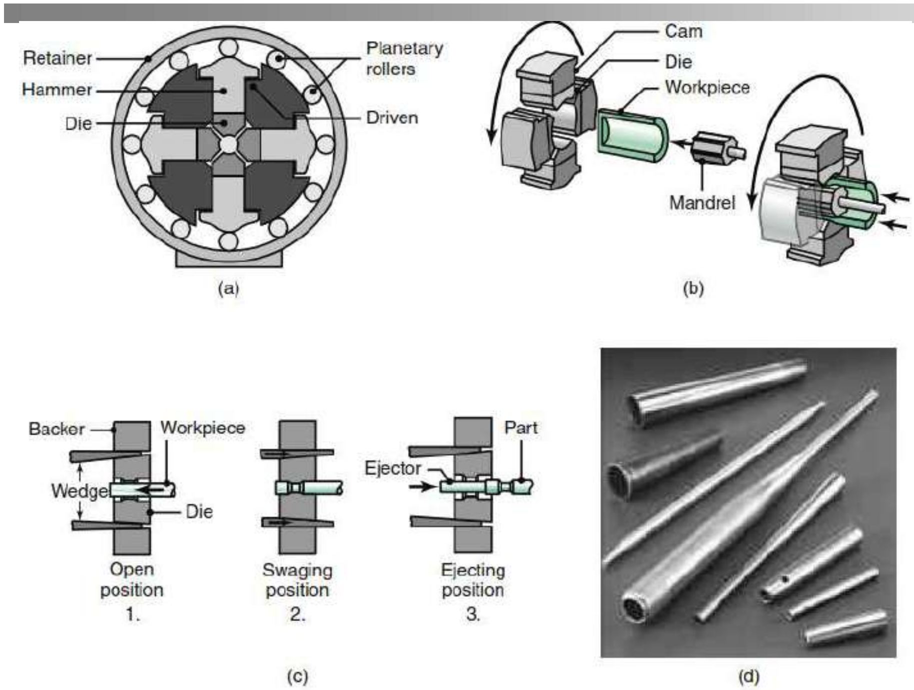


Heading is a closed-die forging that is performed on the end of a round rod or wire in order to increase the cross-section. Typical products are nails, bolt heads, screws, rivets, and various other fasteners. It is also known as upset forging. (To produce hexagonal bolts)

Piercing is a closed-die forging process that is used for indenting (but not breaking through) the surface of a workpiece with a punch in order to produce a cavity or an impression. A common example of piercing is the indentation of the hexagonal cavity in bolt heads.

The piercing force depends on (a) the cross-sectional area and the tip geometry of the punch, (b) the strength of the material, and (c) the magnitude of friction at the sliding interfaces. The pressure may range from three to five times the strength of the material

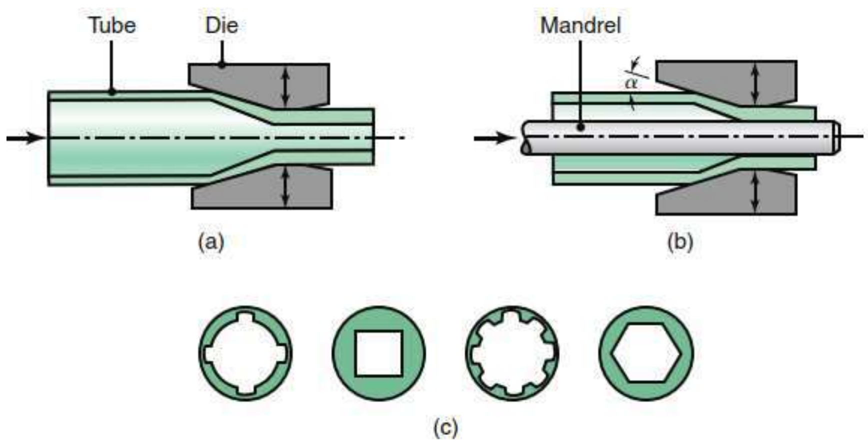
Rotary Swaging (Radial forging)



Rotary Swaging is a process in which a solid rod or tube is subjected to radial impact forces by a set of reciprocating dies of the machine.

The workpiece is stationary and the dies rotate (while moving radially in their slots), striking the workpiece at rates as high as 20 strokes per second.

Rotary Swaging is also used for operations such as pointing (tapering the tip of a cylindrical part) and sizing (finalizing the dimensions of a part).



Tube Swaging is a process in which the internal diameter and / or the thickness of the tube is reduced with or without the use of internal mandrels.

For small-diameter tubing, high-strength wire is used as a mandrel. Mandrels can have longitudinal grooves, to allow swaging of internally shaped tubes (e.g. the rifling in gun barrels requires internal spiral grooves to give gyroscopic effect to bullets and can be produced by swaging a tube over a mandrel with spiral grooves).

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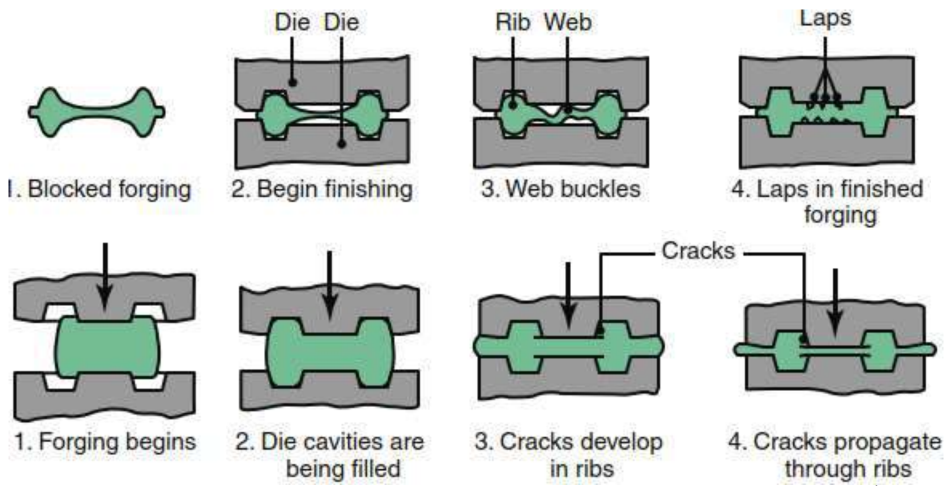
Defects in Forging, Die Design



① Upsetting Test: cylindrical specimen is compressed till it cracks and changes are noted down. The greater the deformation before cracking, the greater the forgeability.

② Hot-Twist Test: round specimen is twisted continuously until it fails. Temperature @ which maximum turns occur is the temperature for maximum forgeability.

Forgeability is defined as the capability of a material to undergo deformation without cracking. In general, alloys are tested using an "upsetting test" and / or "hot twist test" to realize its forgeability at room temperature and elevated temperatures.

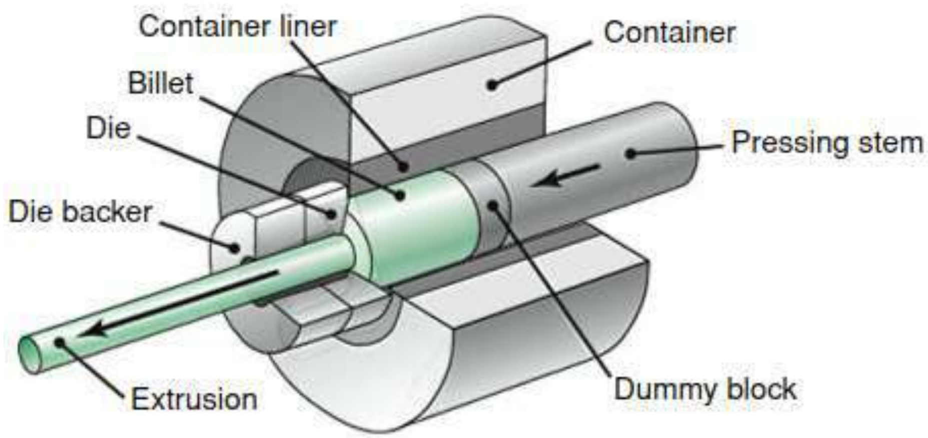
Defects in forging occurs primarily due to improper material flow. There can be surface cracks. If there is insufficient volume of material to completely fill the die cavity, the web may buckle and develop laps. If the web is too thick, the excess material flows past the already formed portions of the forging and develops internal cracks.

Most forging operations are carried out at elevated temperatures. So, die materials must have

(a) strength and toughness at elevated temperatures
(b) hardenability and ability to harden uniformly
(c) resistance to mechanical and thermal shock
(d) resistance to abrasive wear, because of the presence of scale in hot forging.

Common die materials are tool and die steels containing chromium, nickel, molybdenum, and vanadium.

Extrusion

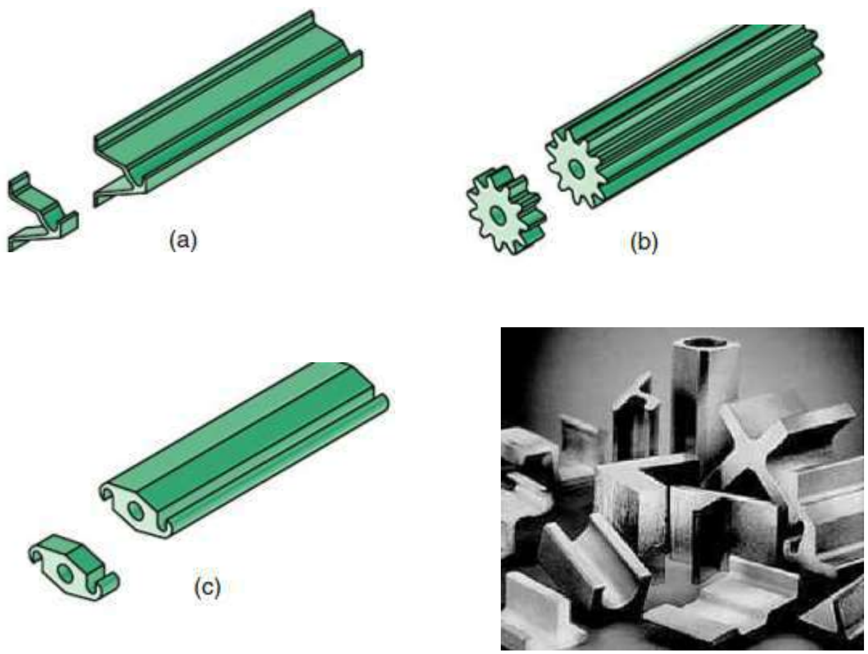


Extrusion involves forcing a cylindrical billet through a die (similar to squeezing toothpaste from a tube or extruding play-doh thru' various cross-sections in a toy press). These produce semi-finished parts.

A typical characteristics of extrusion is that large deformation can take place without fracture because the material is under high triaxial compression.

As the die geometry remains unchanged throughout the operation, extruded products typically havea constant cross-section.

Extruded products include sliding doors, window frames, tubing of various cross-sections, ladder frames and numerous structural and architectural shapes.



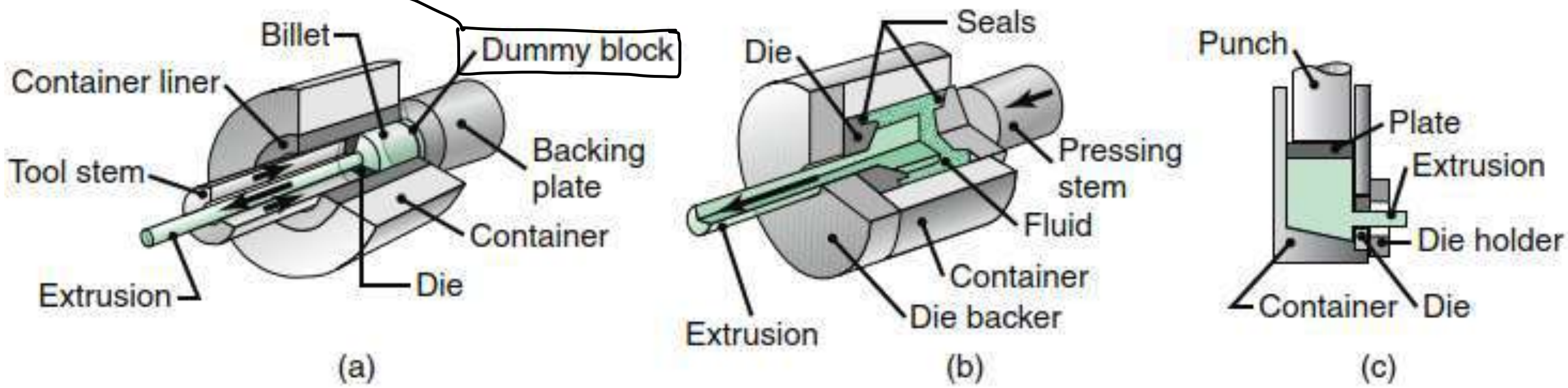
Depending on the ductility of the material, extrusion is carried out at room temperature (cold extrusion) or at elevated temperature (hot extrusion) → for metals with low ductility @ room temp.

Because extrusion involves a chamber, it is a type of a "batch" process. It is semi-continuos.

protects the tip of the punching stem (punch), particularly during hot extrusion.

Extrusion

① direct (forward) extrusion
② indirect extrusion
③ hydrostatic extrusion
④ lateral extrusion



① Extrusion are of three basic types. In direct extrusion (or forward extrusion), a billet is placed in a chamber (container) and forced through a die opening by a hydraulically driven ram (punch). The die opening may be round or of different shapes depending on the desired profile. This is the most common type of extrusion.

② In indirect extrusion (or reverse / backward extrusion), the die moves towards the unextruded billet. Indirect extrusion has the advantage of having no billet-container friction, since there is no relative motion. So, indirect extrusion is used on materials with very high friction, e.g. high-strength steel.

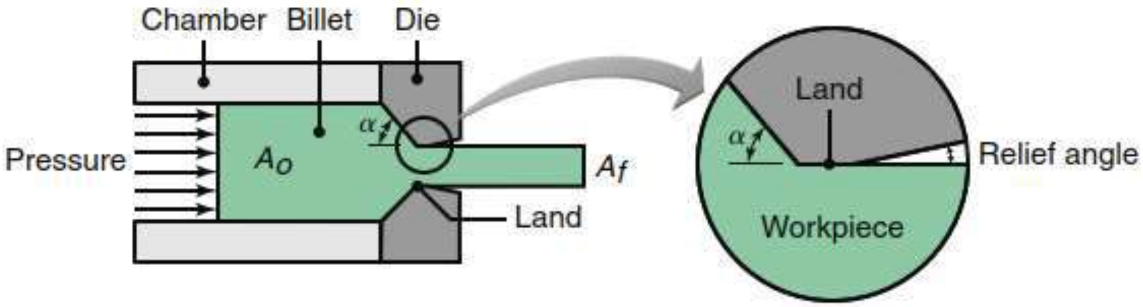
③ In hydrostatic extrusion, the billet is smaller in diameter than the chamber, which is filled with a fluid. The pressure is transmitted to the fluid by a ram. The fluid pressure results in a triaxial compressive stress on the workpiece and thus, improved formability. Workpiece-container friction is also reduced.

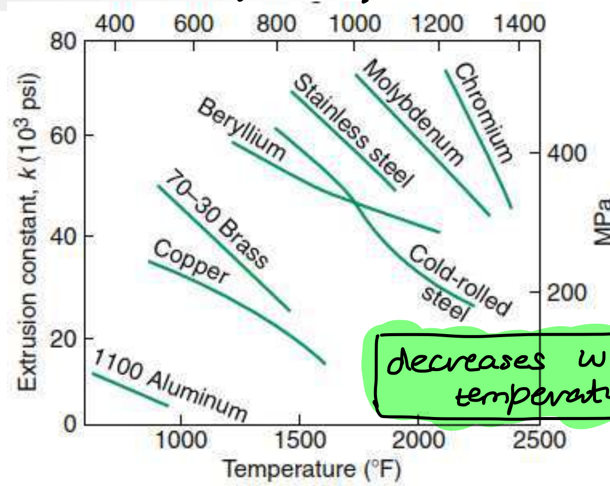
④ Lateral extrusion is relatively uncommon.

High Strength Steels: use indirect extrusion because of low frictional force due to no relative motion.

Extrusion

Variables → ① die angle
② extrusion ratio $= \frac{A_o}{A_f}$
③ type of lubricant
④ billet temperature
⑤ speed of ram
⑥ friction b/w billet and chamber





Important variables in extrusion are the die angle and the extrusion ratio i.e. the cross-section area of the billet to that of the extruded product. Other variables are the temperature of the billet, the travelling speed of the ram and the type of lubricants.

The extrusion force depends primarily on the – (a) strength of the billet material, (b) the extrusion ratio, (c) the friction between the billet and the chamber and the die surfaces, and (d) process variables, e.g. billet temperature and ram speed (or extrusion speed).

The extrusion force F is usually estimated as:

$$F = A_o k \ln\left(\frac{A_o}{A_f}\right)$$

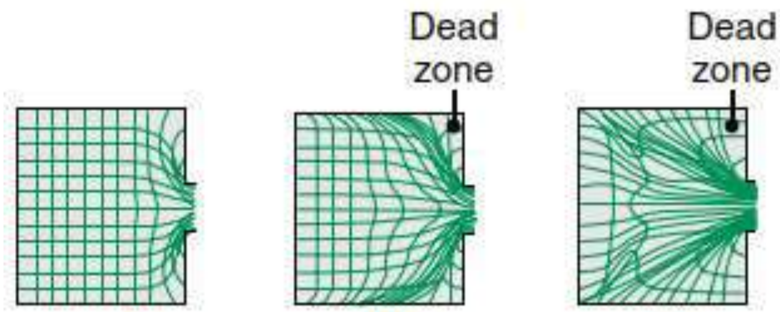
where, k is an extrusion constant (determined by experiments), and A_0 and A_f are the cross-sectional areas of te the billet and the extruded part, respectively.

k : measure of strength of material being extruded and frictional conditions.

COAXIAL EXTRUSION : aka cladding
→ coaxial billets are extruded together, provided that the strength and ductility of the two metals are compatible.
ex : (copper clad with silver)

Extrusion

produces elongated grain structure due to longitudinal material flow.



(a) (b) (c)

The above figure shows typical metal flow in extruding with square dies.

(a) Flow pattern obtained at low friction or in indirect extrusion.
(b) Pattern obtained with high friction at the billet–chamber interfaces.
(c) Pattern obtained at high friction or with cooling of the outer regions of the billet in the chamber. This is observed in metals whose strength increases rapidly with decreasing temperature resulting a pipe defect (extrusion defect)

Metal flow in extrusion is important because it influences the quality and mechanical property of the extruded part. The material flows longitudinally (as an incompressible fluid flows in a channel). The extruded products usually show elongated grain structure (preferred orientation).

Because of HIGH DUCTILITY

Wrought aluminum, copper, and magnesium and their alloys, as well as steels and stainless steels, are extruded with relative ease into numerous shapes.

Other metals (such as titanium and refractory metals) also can be extruded, but only with some difficulty and considerable die wear.

Ram Speeds

① Lower ⟶ Al, Mg, Cu
② Higher ⟶ Steels, Titanium, Refractory Alloys

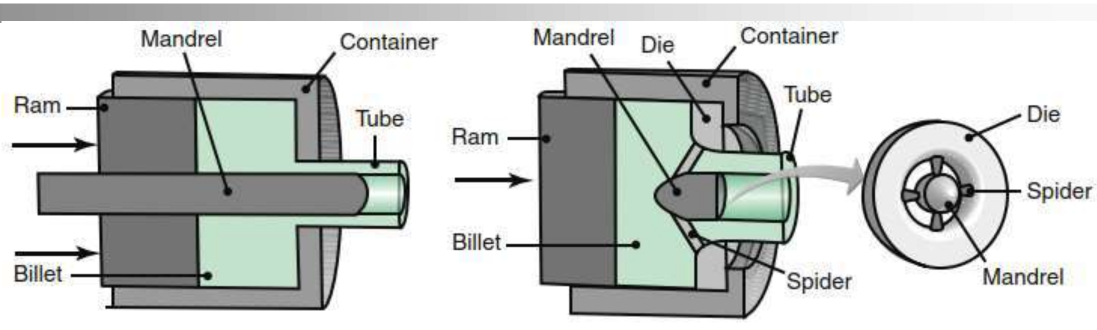
Most extrusion products require "straightening" and "twisting".

SCRAP / Butt end: due to die angle (α), small portion of end of billet remains in the chamber after operation has been completed. This is removed by cutting at die exit or using graphite billet extension @ the end.

Hot Extrusion

- Carried out for metals with low ductility @ room temperature.
- It has special requirements due to high working temperatures. For example, dies may undergo excessive wear and tear. Cooling of surfaces of hot billet and die may result in non-uniform deformation. To reduce these, dies may be preheated similar to hot-forging operations.
- Oxide film formation due to high temperature may cause abrasive surface affecting the flow pattern of the material. Their presence may also result in unacceptable surface finish. To avoid this, the dummy block placed ahead of ram is made of smaller diameter than the container. As a result, thin shell (skull) consisting mainly of the outer oxidized layer of the billet is left in the container. The skull is later removed from the chamber.

Extrusion Dies



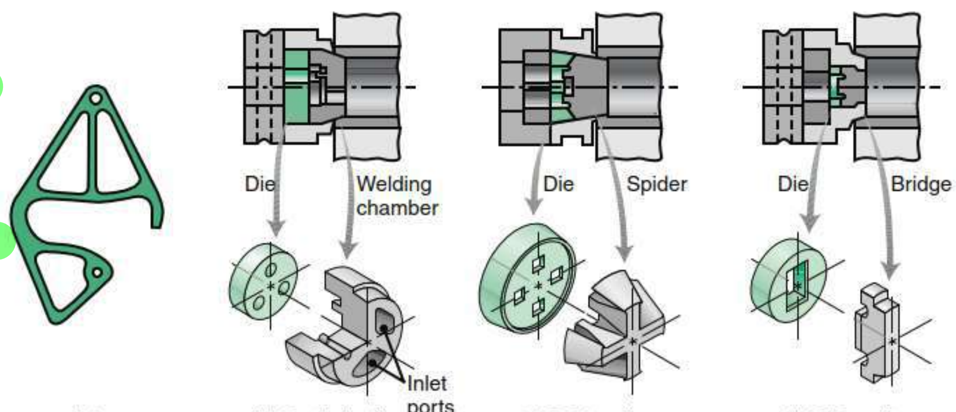
(a) (b)

Die design is extremely important in extrusion. Square dies are commonly used in extruding nonferrous metals, especially aluminum and the control of the dead-metal zones, which form a "die angle" along which the material flows in the deformation zone, becomes very important.

Tubing is extruded from a solid or hollow billet, as shown in the above figure. For solid billets, the ram is fitted with a mandrel that pierces a hole into the billet. Billets with a previously pierced hole also may be extruded in this manner. Because of friction and the severity of deformation, thin-walled extrusions are more difficult to produce than those with thick walls.

Hollow cross sections are extruded by welding-chamber methods and using dies known as a porthole die, spider die, and bridge die. During extrusion, the metal divides and flows around the supports for the internal mandrel into strands. The strands are rewelded under high pressure in the welding chamber before they exit through the die. The rewelded surfaces have good strength because they have not been exposed to the environment (so, not oxidized).

(would have inhibited good welding)



(a) (b) Porthole die (c) Spider die (d) Bridge die

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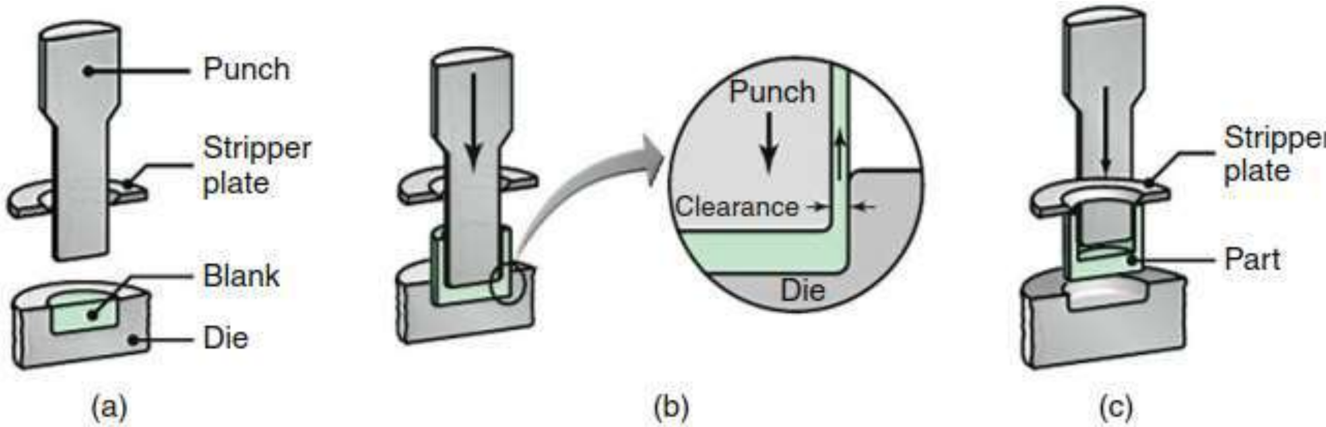
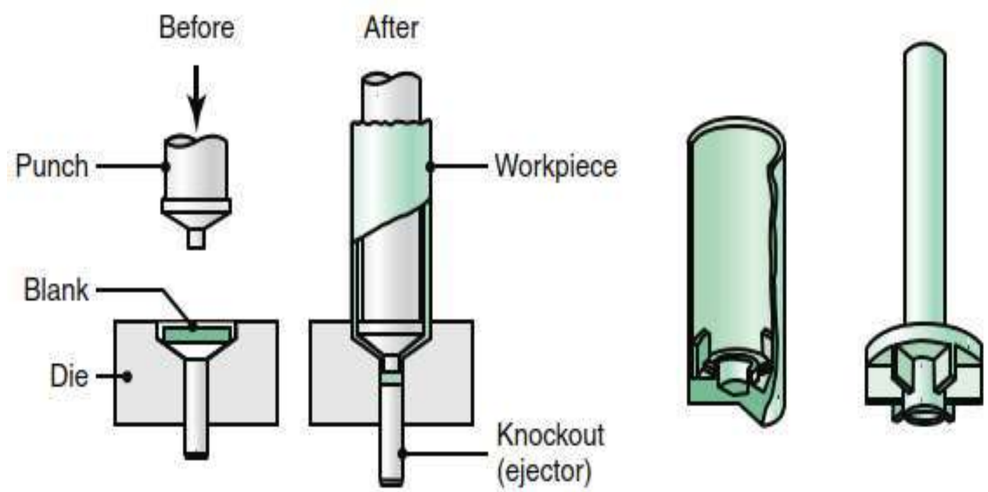
(type of cold extrusion)

Impact Extrusion



Impact extrusion is similar to indirect extrusion in which, the punch descends rapidly on the blank (slug), which is extruded backwards. Because of volume constancy, the thickness of the tubular extruded section is a function of the clearance between the punch and the die cavity.



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Hydrostatic Extrusion

→ chamber requires Pressure which is generated via a piston through an incompressible fluid medium surrounding the billet.

→ friction is significantly reduced. fluids like vegetable oils, castor oils, etc. are used.

→ BRITTLE materials can be succesfully extruded using this method, because hydrostatic pressure, low friction, small die angles and high extrusion ratios increases ductility.

Extrusion Defects

→ surface cracking
→ pipe
→ internal cracking

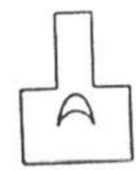
Three types: (a) surface defects, (b) internal fracture, (c) piping defect near the end of direct extrusion

(a) SURFACE CRACKING DEFECTS

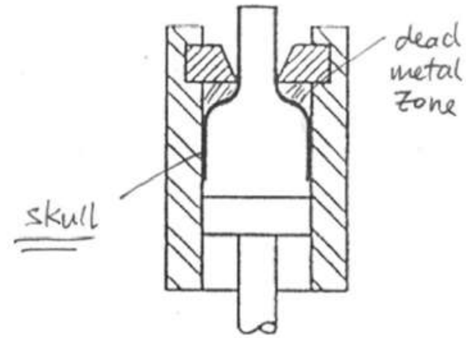
Surface defects occur due to: (a) high temperature, (b) high speed, (c) high friction

.

Piping defects happen due to surface oxides and defects being piped to the middle by the flow pattern.

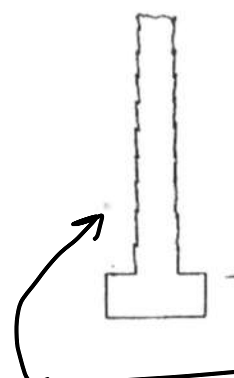


Central bursting

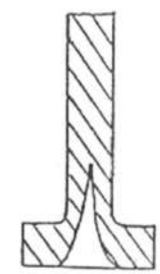


Skin inclusion

not so ductile materials



Fir-tree defect



Piping defect

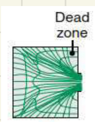
Extrusion Defects

① SURFACE CRACKING

- Caused due to:
  - high extrusion temp.
  - high friction
  - high ram speed.
- these cause surface tearing / cracking which are intergranular in nature and caused by HOT SHORTNESS.
- They occur in Al, Mg, Zn, etc.
- Avoid by lowering billet temp. & extrusion speed.

② PIPING DEFECTS

- Metal flow pattern like the one shown tends to draw surface oxides and impurities towards the center of the billet. This is known as PIPE DEFECT / fishtailing.



- As much as 1/3 of the length of the pipe may contain this type of defect and has to be cut off scrap.
- Avoided by modifying the flow pattern to be more uniform by controlling friction and reducing temp. gradient. May also be minimized by removing scales and impurities prior to extrusion or by chemical etching.

③ INTERNAL CRACKING

→ center of extruded product may develop cracks called center cracking, center-burst, arrowhead fracture, chevron cracking.

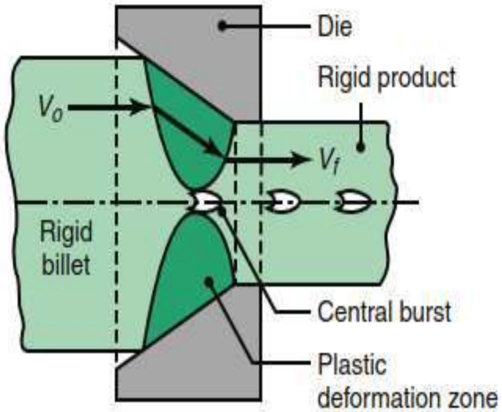
→ These cracks are attributed to a state of hydrostatic tensile stress @ centerline in the deformation zone of the die. They are also observed in tube spinning and tube extrusion.

→ Tendency is
(a) increased by increasing die angle.
(b) increased by increasing amount of impurities.
(c) decreases with increasing extrusion ratio & friction.

Extrusion Defects

The center of the extruded product can develop cracks, which are referred to as center cracking, center-burst, arrowhead fracture, or chevron cracking.

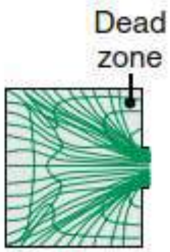
These cracks are attributed to a state of hydrostatic tensile stress at the centerline in the deformation zone in the die.



The tendency for center cracking (a) increases with increasing die angle, (b) increases with increasing amount of impurities, and (c) decreases with increasing extrusion ratio and friction.

Inappropriate metal-flow pattern tends to draw surface oxides and impurities toward the center of the billet like a funnel resulting in pipe defect (referred to as tailpipe / fishtailing).

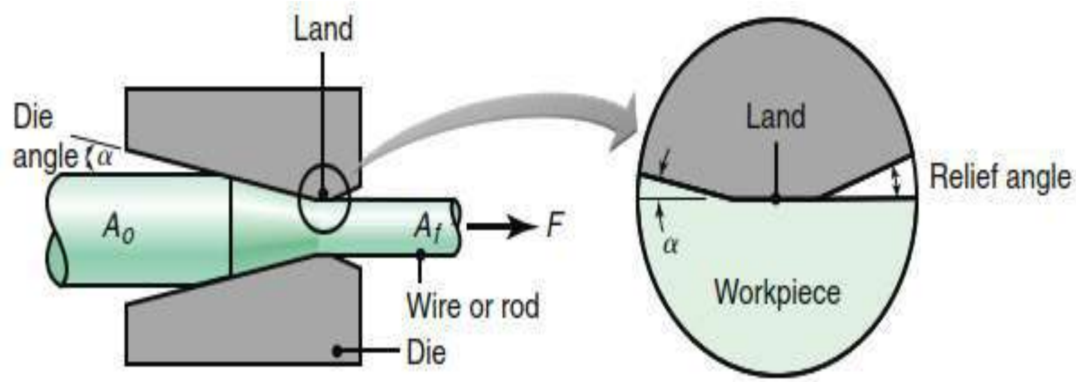
Almost one-third of the length of the extruded part may contain such a defect. Piping can be minimized by promoting more uniform flow pattern, controlling friction and reducing temperature gradients. Billet's surface is often machined prior to extrusion to remove scale and surface impurities..



Drawing

Drawing involves reducing the cross - section of a long rod or wire by pulling it through a die called a draw die.

Thus, the difference between drawing and extrusion is that the material is pushed through a die in extrusion, but the material is pulled through dies in drawing.



Drawing produces – (a) rod and wire products; (b) shafts for power transmission, machine and structural components, (c) blanks for bolts and rivets, (d) electrical wiring, cables, and (e) tension-loaded structural members, welding electrodes, springs, paper clips, spokes for bicycle wheels, and (f) stringed musical instruments..

Drawing Variables: (Area Ratio, die angle, friction, drawing speed)

The drawing force F (under ideal and frictionless condition) can be written as: $\boxed{F = Y_{avg} A_f \ln\left(\frac{A_o}{A_f}\right),}$

where, Y_{avg} is the average true stress of the material in the die gap, and, A_0 and A_f are the cross-sectional areas of the original and the drawn part, respectively.

Drawing Force → (a) increases with increasing friction
(b) Redundant work of Deformation : because of non-uniform deformations in the die zone.

$$\boxed{F = Y_{avg} A_f \left[\left(1 + \frac{\mu}{\alpha}\right) \ln(A_0/A_f) + \frac{2}{3}\alpha \right]}$$

(Maximum Reduction Ratio ~ 63% before yield)

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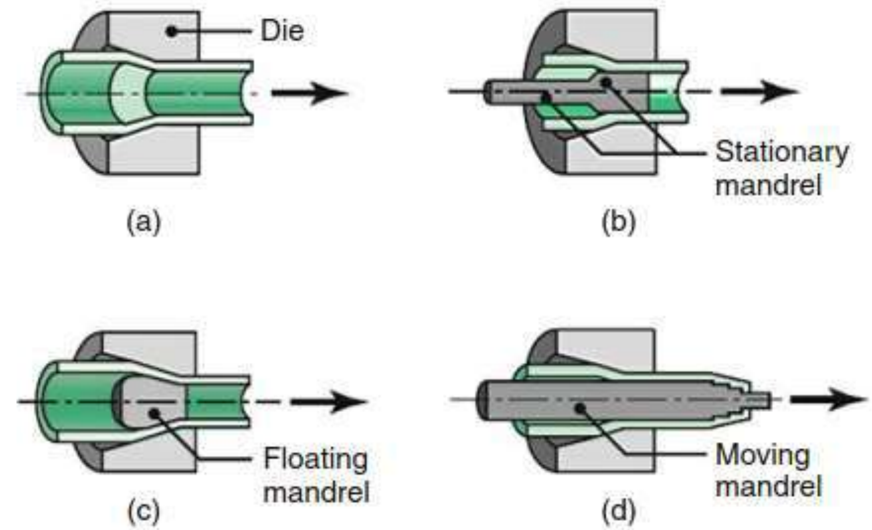
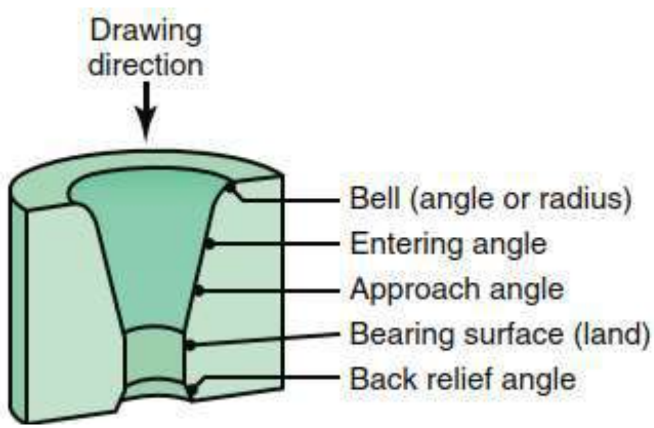
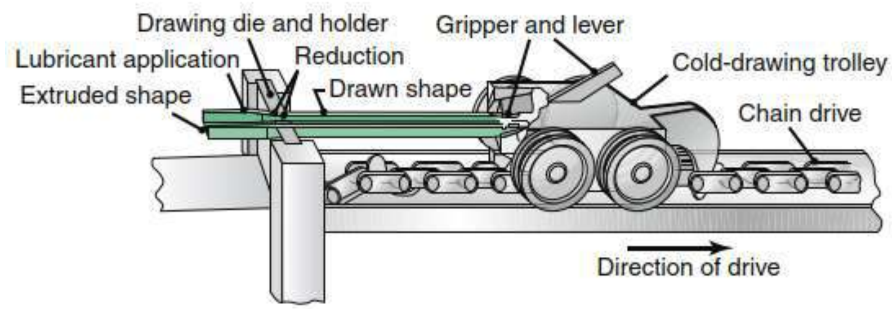
Tube Drawing

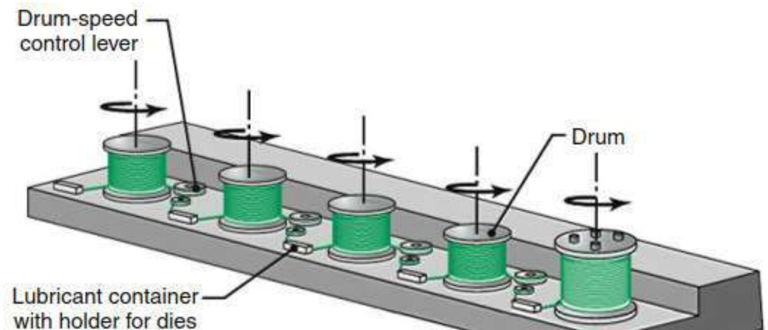
Various solid cross sections can be produced by drawing through dies with different profiles.

Reduction sequence per pass is critical to ensure proper material flow in the die, reduce internal or external defects, and improve surface quality.









(Tandem Drawing)

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