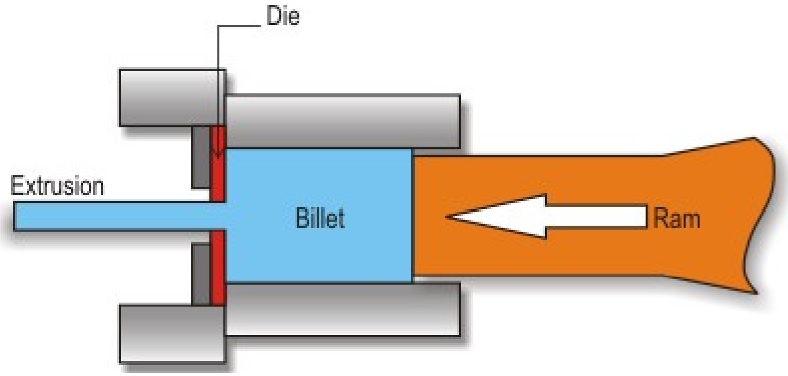
Extrusion

Course Content

- Classification of extrusion processes
  - Direct and
  - Indirect extrusion,
  - Impact extrusion
  - Hydrostatic extrusion
- Extrusion equipment
- Extrusion ratio
- Process variables
- Lubrication & defects in extrusion
- Derivation of extrusion pressure
- Extrusion of tubing
- Production of seamless pipe and tubing.

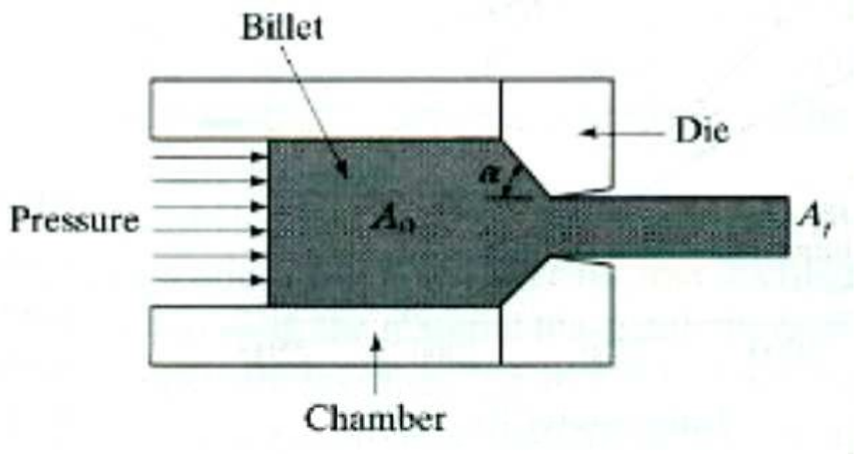
Extrusion is the process by which a block/billet of metal is reduced in cross section by forcing it to flow through a die orifice under high pressure

- In general, extrusion is used to produce cylindrical bars or hollow tubes.
- Most metals are hot extruded due to large amount of forces required in extrusion. Complex shape can be extruded from the more readily extrudable metals such as aluminium.



Note: The products obtained are also called extrusion.

- The reaction of the extrusion billet with the container and die results in high compressive stresses which are effective in reducing cracking of materials during primary breakdown from the ingot.



- This helps to increase the utilisation of extrusion in the working of metals that are difficult to form like stainless steels, nickel-based alloys, and other high-temperature materials.
- Similar to forging, lower ram force and a fine grained recrystallised structure are possible in hot extrusion.
- However, better surface finish and higher strengths (strain hardening of metals) are provided by cold extrusion.

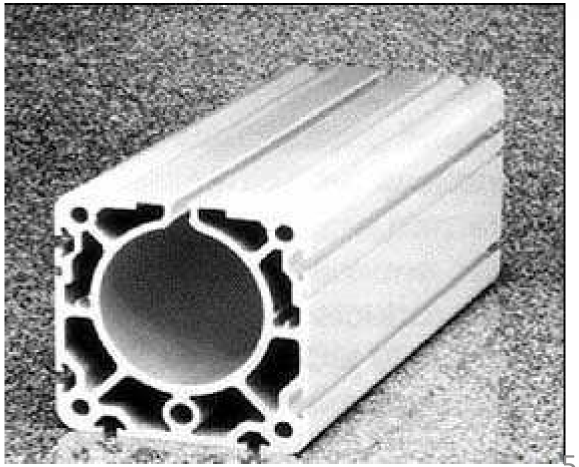
Extrusion Products

Typical parts produced by extrusion are trim parts used in automotive and construction applications, window frame members, railings, aircraft structural parts.

Example: Aluminium extrusions are used in commercial and domestic buildings for window and door frame systems, prefabricated houses/building structures, roofing and exterior cladding, curtain walling, shop fronts, etc. Furthermore, extrusions are also used in transport for airframes, road and rail vehicles and in marine applications.

Aluminium

Brass

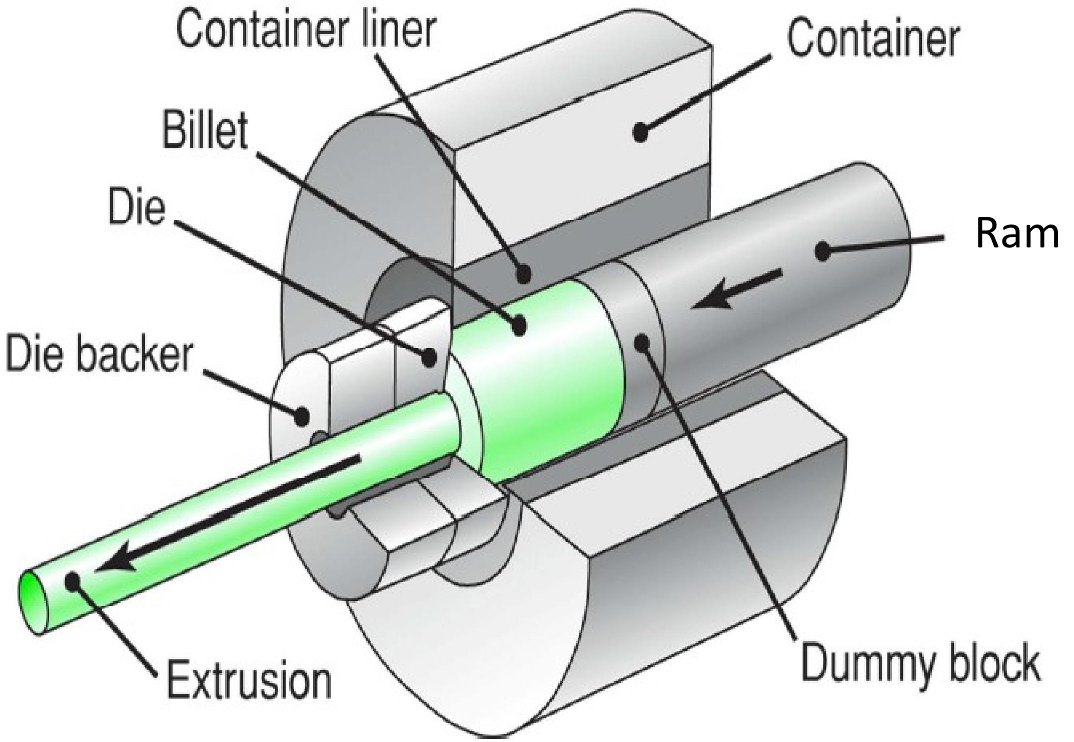


Classification of extrusion processes

- By direction
  - Direct or forward extrusion
  - Indirect or backward extrusion
- By operating temperature
  - Hot extrusion
  - Cold extrusion
- By equipment
  - Horizontal extrusion
  - Vertical extrusion

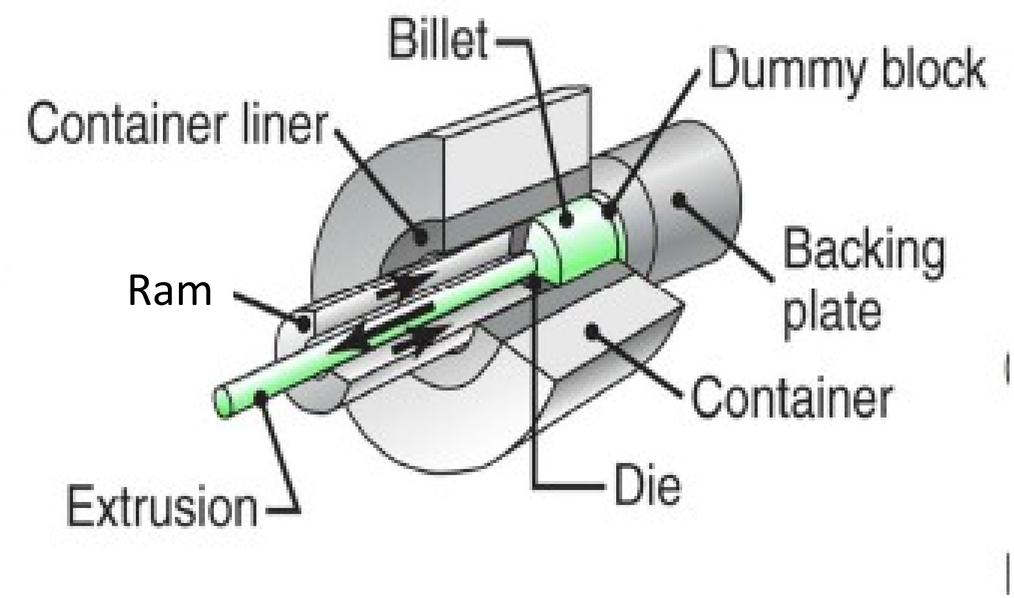
Direct Extrusion

- The metal billet is placed in a container and driven through the die by the ram.
- The dummy block or pressure plate, is placed at the end of the ram in contact with the billet.
- Friction is at the die and container wall requires higher pressure than indirect extrusion.

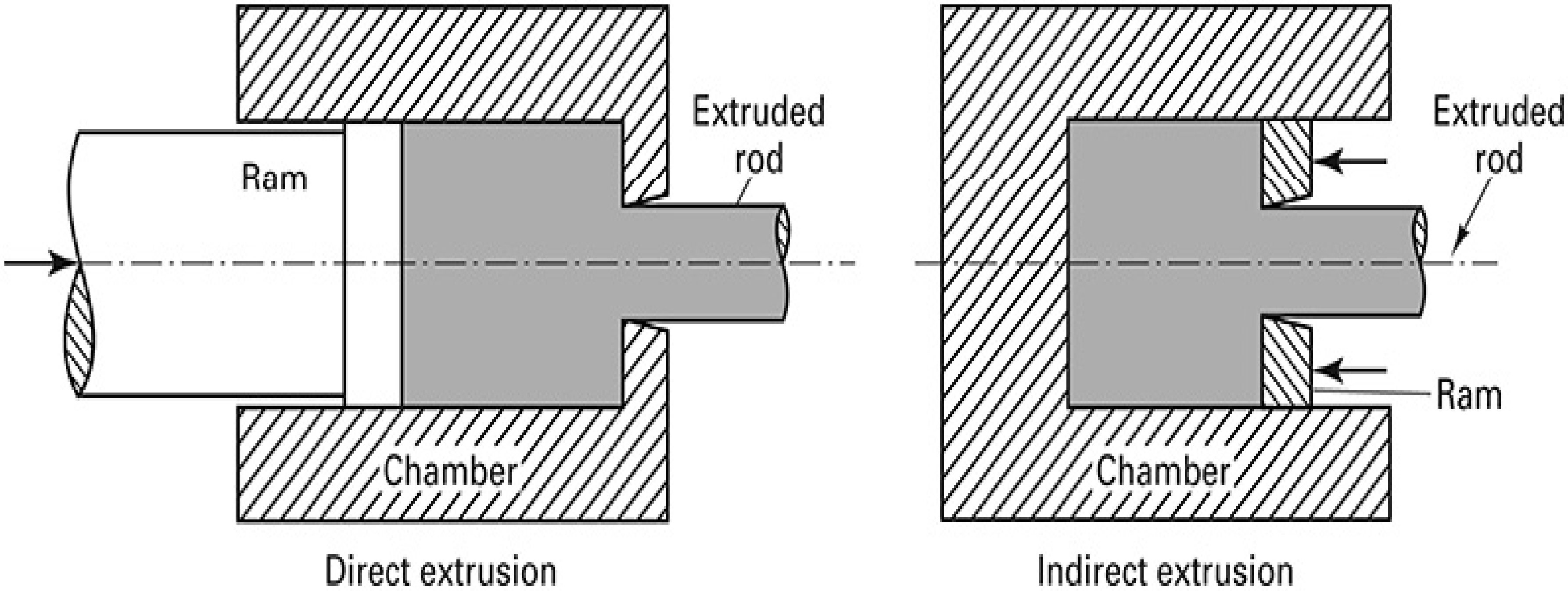


Indirect Extrusion

- The hollow ram containing the die is kept stationary and the container with the billet is caused to move.
- Friction at the die only (no relative movement at the container wall) requires roughly constant pressure.
- Hollow ram limits the applied load.



Direct and Indirect Extrusion



Cold extrusion

Cold extrusion is the process done at room temperature or slightly elevated temperatures.

This process can be used for most materials-subject to designing robust enough tooling that can withstand the stresses created by extrusion.

Examples: Pb, Sn, Al, Cu and low alloy steel

Examples of parts that are cold extruded are collapsible tubes, aluminium cans, cylinders, gear blanks.

Advantages:

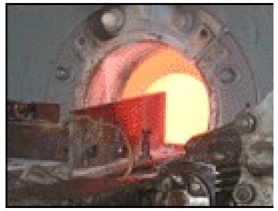
- No oxidation takes place.
- Good mechanical properties due to severe cold working as long as the temperatures created are below the recrystallization temperature.
- Good surface finish with the use of proper lubricants.

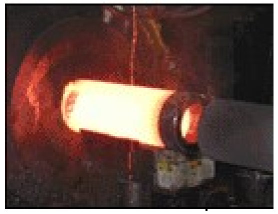
Hot Extrusion

• Hot extrusion is done at fairly high temperatures, approximately 50 to 75 % of the melting point of the metal. The pressures can range from 35-700 MPa.

• The most commonly used extrusion process is the hot direct process. The cross-sectional shape of the extrusion is defined by the shape of the die.

• Due to the high temperatures and pressures and its detrimental effect on the die life as well as other components, good lubrication is necessary. Oil and graphite work at lower temperatures, whereas at higher temperatures glass powder is used.

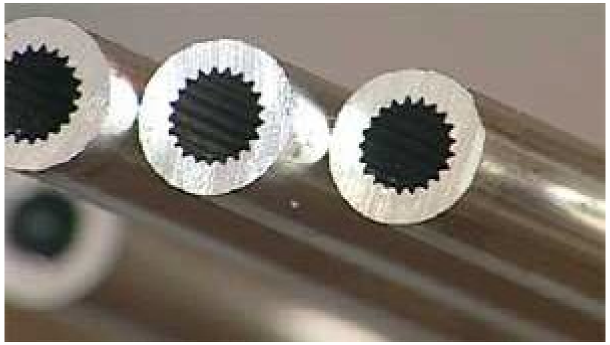


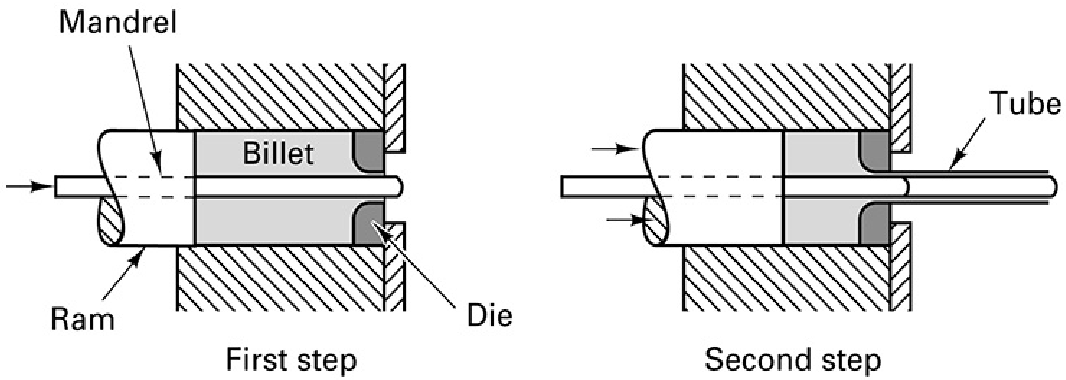


Tube extrusion

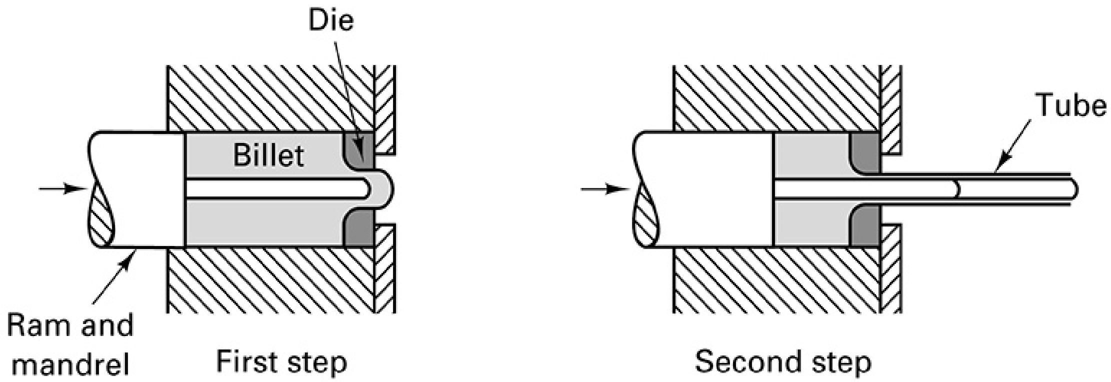
Tubes can be produced by extrusion by attaching a mandrel to the end of the ram. The clearance between the mandrel and the die wall determines the wall thickness of the tube.

Tubes are produced either by starting with a hollow billet or by a two step extrusion in which a solid billet is first pierced and then extruded.





(a)



(b)

Impact extrusion

• Produce short lengths of hollow shapes, such as collapsible toothpaste tubes or spray cans.

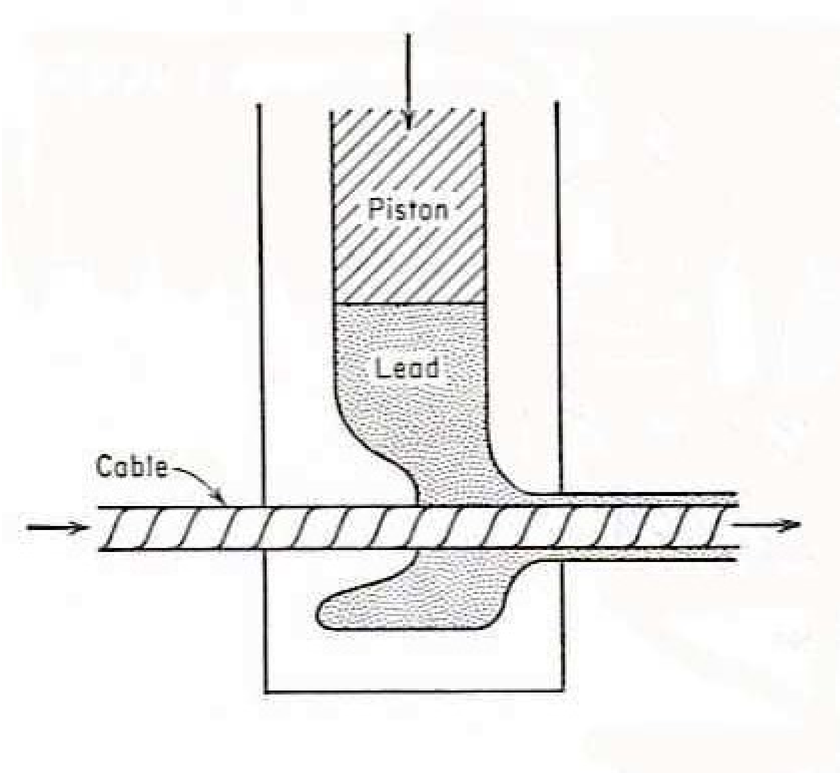
• Requires soft materials such as aluminium, lead, copper or tin are normally used in the impact extrusion

• A small shot of solid material is placed in the die and is impacted by a ram, which causes cold flow in the material. It may be either direct or indirect extrusion and it is usually performed on a high speed mechanical press.

• Although the process is generally performed cold, considerable heating results from the high speed deformation.

Small objects, soft metal, large numbers, good tolerances

Extrusion was originally applied to the making of lead pipe and later to the lead sheathing on electrical cable.



Extrusion equipment (Presses, dies and tools)

Extrusion equipment mainly includes presses, dies and tooling.

1)Presses

- Most extrusions are made with hydraulic presses.
- These can be classified based on the direction of travel of the ram.
  1) Horizontal presses
  2) Vertical presses

2) Extrusion dies: Die design, Die materials

3) Tools: Typical arrangement of extrusion tools.

Vertical extrusion presses (3- 20 MN capacity)

Chiefly used in the production of thin-wall tubing.

Advantages:

- Easier alignment between the press ram and tools.
- Higher rate of production.
- Require less floor space than horizontal presses.
- uniform deformation, due to uniform cooling of the billet in the container.

Requirements:

- Need considerable headroom to make extrusions of appreciable length.
- A floor pit is necessary.

Horizontal extrusion presses

(15- 50 MN capacity or upto 140 MN)

• Used for most commercial extrusion of bars and shapes.

Disadvantages:

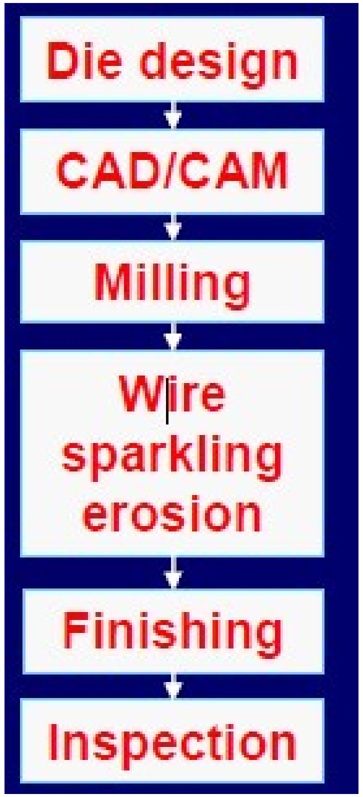
• deformation is non-uniform due to different temperatures between top and bottom parts of the billet.

Ram Speed

- Require high ram speeds in high-temperature extrusion due to heat transfer problem from billet to tools.
- Ram speeds of 0.4-0.6 ms^{-1} for refractory metals requires a hydraulic accumulator with the press.
- Ram speeds of a few mms^{-1} for aluminium and copper due to hot shortness requires direct-drive pumping systems to maintain a uniform finishing temperature.

Die design

- Die design is at the heart of efficient extrusion production.
- Dies must withstand considerable amount of high stresses, thermal shock and oxidation.



Die design consideration

- Wall thickness: different wall thicknesses in one section should be avoided.
- Simple shapes: the more simple shape the more cost effective.
- Symmetrical: more accurate.
- Sharp or rounded corners: sharp corners should be avoided.
- Size to weight ratio:
- Tolerances: Tolerances are added to allow some distortions (industrial standards).

Die materials

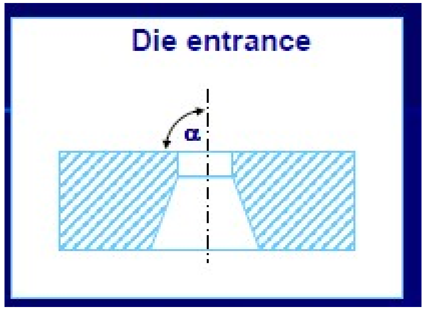
- Dies are made from highly alloy tools steels or ceramics (zirconia, Si_3N_4).
(for cold extrusion offering longer tool life and reduced lubricant used, good wear resistance).
- Wall thickness as small as 0.5 mm (on flat dies) or 0.7 mm (on hollow dies) can be made for aluminium extrusion.
- Heat treatments such as nitriding are required (several times) to increase hardness (1000-1100 Hv or 65-70 HRC). This improves die life. avoiding unscheduled press shutdown.

There are two general types of extrusion dies:

1) Flat-faced dies
2) Dies with conical entrance angle.

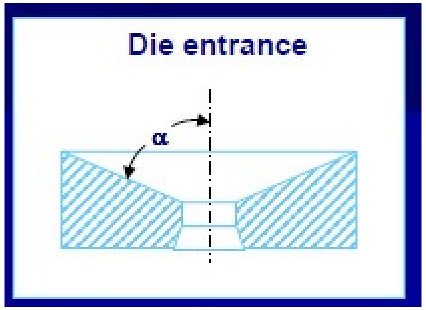



Flat-faced dies



- Metal entering the die will form a dead zone and shears internally to form its own die angle.
- A parallel land on the exit side of the die helps strengthen the die and allow for reworking of the flat face on the entrance side of the die without increasing the exit diameter.

Dies with conical entrance angle

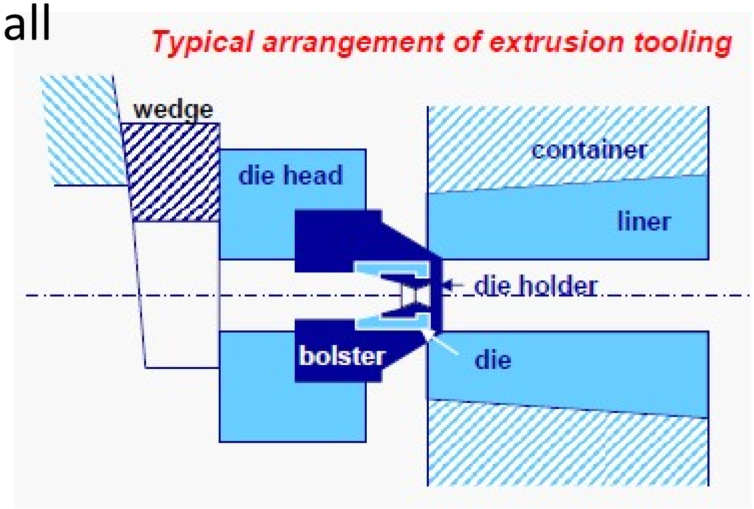


- requires good lubricants.
- decreasing die angle → increasing homogeneity, lower extrusion pressure (but beyond a point the friction in the die surfaces becomes too great.
- for most operation,

  $45^o < \alpha < 60^o$

Typical arrangement of extrusion tooling

- The die stack consists of the die, which is supported by a die holder and a bolster, all of which are held in a die head.
- The assembly is designed for easy replacement of
  - damaged parts
  - reworking
  - reuse of components
- The entire assembly is sealed against the container on a conical seating surface by pressure applied by a wedge.
- The follower pad / dummy block is placed between the hot billet and the ram for protection purpose. Dummy block are therefore replaced periodically since they are subject to many cycles of thermal shock.



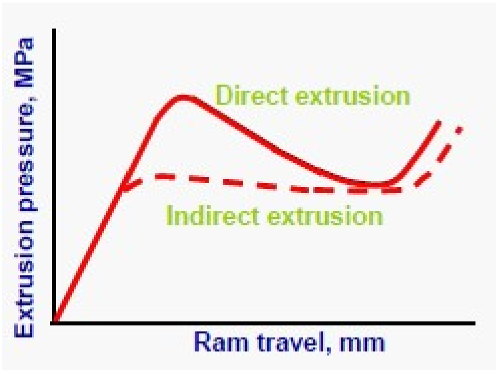
Process Variables

The principal variables influencing the force required to cause extrusion;

1) Extrusion pressure
2) Extrusion ratio
3) Working temperature
4) Deformation
5) Frictional conditions at the die and the container wall.

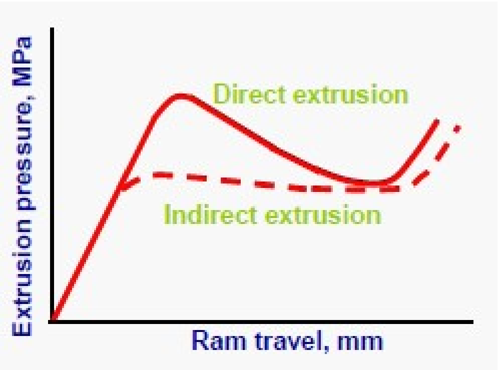
1. Extrusion pressure

$$Extrusion\_pressure = \frac{extrusion\_force}{cross\_sectional\_area}$$



The rapid rise in pressure during initial ram travel is due to the initial compression of the billet to fill the extrusion container.

- For direct extrusion, the metal begins to flow through the die at the maximum pressure, the breakthrough pressure.
- As the billet extrudes through the die the pressure required to maintain flow progressively decreases with decreasing length of the billet in the container.
- At the end of the stroke, the pressure rises up rapidly and it is usual to stop the ram travel so as to leave a small discard in the container.



For indirect extrusion, extrusion pressure is ~ constant with increasing ram travel and represent the stress required to deform the metal through the die.

- Since hollow ram is used in indirect extrusion, size of the extrusions and extrusion pressure are limited.

2. Extrusion Ratio

Extrusion ratio, R, is the ratio of the initial cross-sectional area , Ao, of the billet to the final cross-sectional area , A_f , after extrusion.

$$R = \frac{A_o}{A_f}$$

R~ 40:1 for hot extrusion of steels

R ~ 400:1 for aluminium

Note: R is more descriptive at large deformations !

$$r = 1 - \frac{A_f}{A_o}$$

For reduction in cross section 'r'

Ex: R=20:1 and 50:1→r=0.95 and 0.98 respectively

$$R = \frac{1}{1-r}$$

Extrusion ratio (R) of steel could be 40:1

whereas R for aluminium can reach 400:1

The velocity of the extruded product is given by,

Velocity of the extruded product = ram velocity X R

Extrusion force expressed as, $P = kA_o \ln \frac{A_o}{A_f}$

k-extrusion constant which take care of flow stress, friction, and inhomogeneous deformation

3. Effects of temperature on hot extrusion

- Decreased flow stress or deformation resistance due to increasing extrusion temperature.
- Use minimum temperature to provide metal with suitable plasticity.
- The top working temperature should be safely below the melting point or hot-shortness range.
- Oxidation of billet and extrusion tools.
- Softening of dies and tools.
- Difficult to provide adequate lubrication.

Note: Working temperature in extrusion is normally higher than forging and rolling due to relatively large compressive stresses in minimising cracking.

The temperature of the workpiece in metal working depends on;

1) The initial temperature of the tools and the materials
2) Heat generated due to plastic deformation
3) Heat generated by friction at the die/material interface (highest)
4) Heat transfer between the deforming material and the dies and surrounding environment.

- Usually the temperature is highest at the material/tool interface due to friction.
- If we neglect the temperature gradients and the deforming material is considered as a thin plate, the average instantaneous temperature of the deforming material at the interface is given by

$$T = T_1 + (T_0 - T_1)\exp\left(\frac{-ht}{\rho c \delta}\right)$$

Where To= temperature at the workpiece

T_1=temperature at the die

h =heat transfer coefficient between the material and the dies

δ - materials thickness between the dies

If the temperature increase due to deformation and friction is included, the final average material temperature T_m at a time t is

$$T_m = T_d + T_f + T$$

T_d-Temp. for frictionless deformation process

T_f – Temp. increase due to friction

Ram speed, extrusion ratio and temperature:

- A tenfold increase in the ram speed results in about a 50% increase in the extrusion pressure.
- Low extrusion speeds lead to greater cooling of the billet.
- The higher the temperature of the billet, the higher the extrusion speed to avoid cooling of the billet.
- Therefore, high extrusion speeds are required with high-strength alloys that need high extrusion temperature.
- The selection of the proper extrusion speed and temperature is best determined by trial and error for each alloy and billet size.

Relationships between extrusion ratio, temperature and Pressure

- For a given extrusion pressure, extrusion ratio R increases with increasing Extrusion temperature.
- For a given extrusion temperature, a larger extrusion ratio R can be obtained with a higher extrusion pressure.

Extrusion temperature ↑ Extrusion ratio (R) ↑

Extrusion pressure ↑

Relationships between extrusion speed and heat dissipation

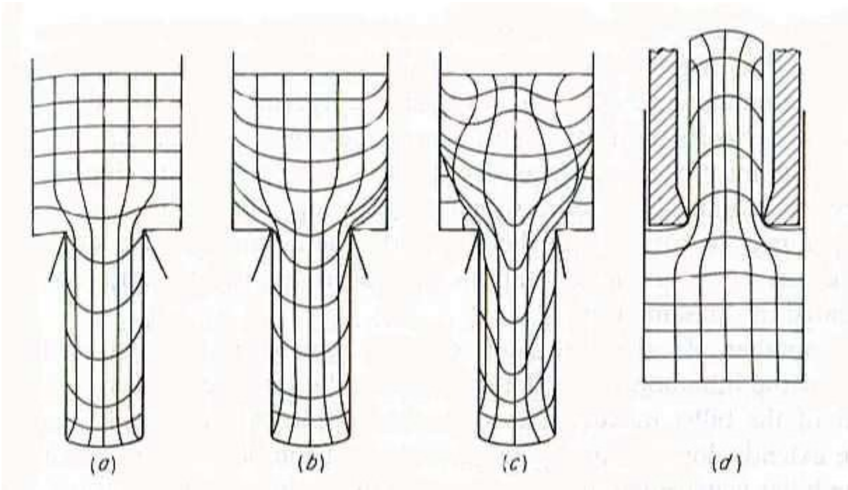
- Extrusion speeds ↑ heat dissipation ↓
- Extrusion speeds ↓ heat dissipation ↑ allowable extrusion ratio ↓

Deformation in extrusion, lubrication and defects

a) Low container friction and a well-lubricated billet – nearly homogeneous deformation.

b) Increased container wall friction, producing a dead zone of stagnant metal at corners which undergoes little deformation.

Essentially pure elongation in the centre and extensive shear along the sides of the billet. The latter leads to redundant work.



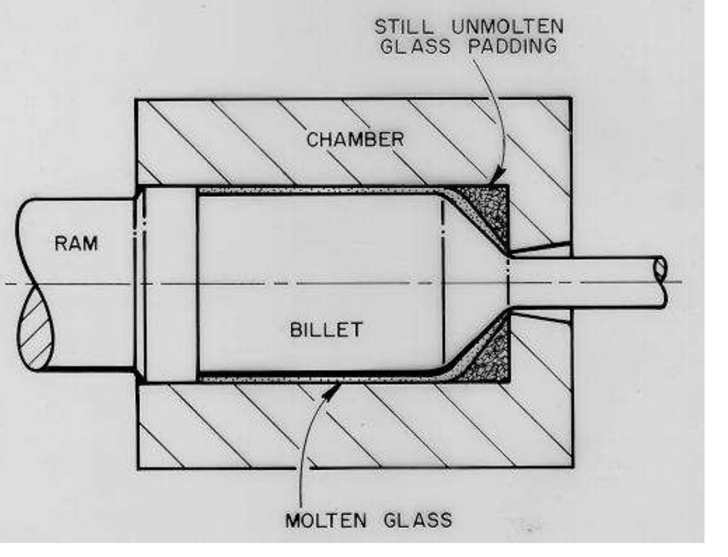
c) For high friction at the container-billet interface, metal flow is concentrated toward the centre and an internal shear plane develops – due to cold container. In the sticky friction, the metal will separate internally along the shear zone. A thin skin will be left in a container and a new metal surface is obtained.

d) Low container friction and a well lubricated billet in indirect extrusion.

Hot extrusion lubricants

- Low shear strength.
- Stable enough to prevent lubricant breakdown at high temperature.
- Molten glass is the most common lubricant for steel and nickel based alloys (high temp extrusion).

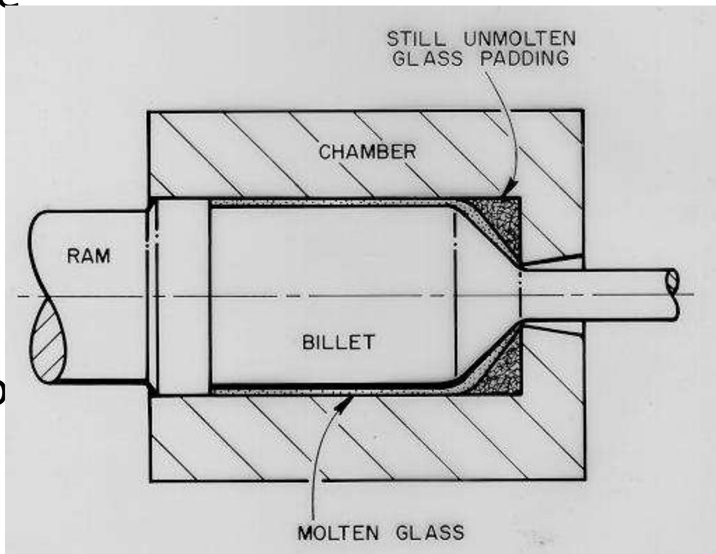
Ugine-Sejournet process



- Graphite-based lubricants are also be used at high extrusion temperature.

Ugine-Sejournet process

- The billet is heated in an inert atmosphere and coated with glass powder before being pressed. The glass pad placed between the die and the billet provide the main source of lubricant.
- This glass coating is soften during extrusion to provide a lubricant film (~25 μm thick), which serves not only as a lubricant but also a thermal insulator to reduce heat loss to the tools.
- The coating thickness depends on a complex interaction between the optimum lubricant, the temperature and the ram speed.
- Lubricant film must be complete and continuous to successful, otherwise defects such as surface crack results.



too low ram speed → thick lubricant coatings with low initial extrusion pressure → limit the length of extrusions

Too high ram speed →dangerously thin coatings

Extrusion Defects

- Inhomogeneous deformation in direct extrusion provide the dead zone along the outer surface of the billet due to the movement of the metal in the centre being higher than the periphery.
- After 2/3 of the billet is extruded, the outer surface of the billet (normally with oxidised skin) moves toward the centre and extrudes to the through the die, resulting in internal oxide stringers. - transverse section can be seen as an annular ring of oxide.

Container wall friction ↑ extrusion defects ↑

Container wall temp. ↓ Extrusion defects ↑

- If lubricant film is carried into the interior of the extrusion along the shear bands, this will show as longitudinal laminations in a similar way as oxide.

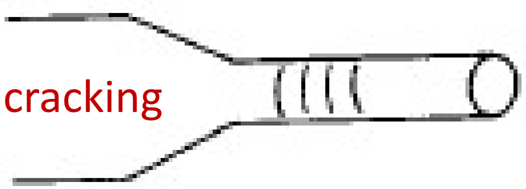
Solutions:

- discard the remainder of the billet (~30%) where the surface oxide begins to enter the die not economical.
- use a follower block with a smaller diameter of the die to scalps the billet and the oxidised layer remains in the container (in brass extrusion).

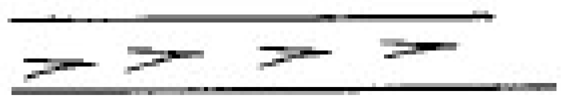
2) Surface cracking, ranging from a badly roughened surface to repetitive transverse cracking called fir-tree cracking, see Figure. This is due to longitudinal tensile stresses generated as the extrusion passes through the die.

- In hot extrusion, this form of cracking usually is intergranular and is associated with hot shortness.
- The most common case is too high ram speed for the extrusion temperature.
- At lower temperature, sticking in the die land and the sudden building up of pressure and then breakaway will cause transverse cracking.

3) Centre bust or Chevron cracking occur due to low extrusion ratios.



Fir-tree cracking



Chevron cracking

Cold extrusion and cold forming

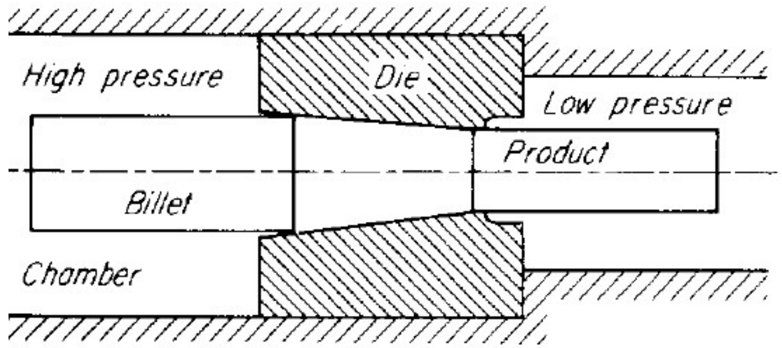
- Cold extrusion is concerned with the cold forming from rod and bar stock of small machine parts, such as spark plug bodies, shafts, pins and hollow cylinders or cans.
- Cold forming also includes other processes such as upsetting, expanding and coining.
- Precision cold-forming can result in high production of parts with good dimensional control and good surface finish.

- Because of extensive strain hardening, it is often possible to use cheaper materials with lower alloy content.
- The materials should have high resistance to ductile fracture and the design of the tooling to minimise tensile-stress concentrations.

Hydrostatic Extrusion

- Hydrostatic gives uniform pressure around the billet.
- Using hydrostatic extrusion, large length to diameter ration or irregular cross section extrusion can be done. Due to
  - No container billet friction
  - The curve extrusion pressure vs. ram travel is nearly flat like indirect extrusion
- Good surface finish and dimensional accuracy doe to pressurized fluid and effective lubrication

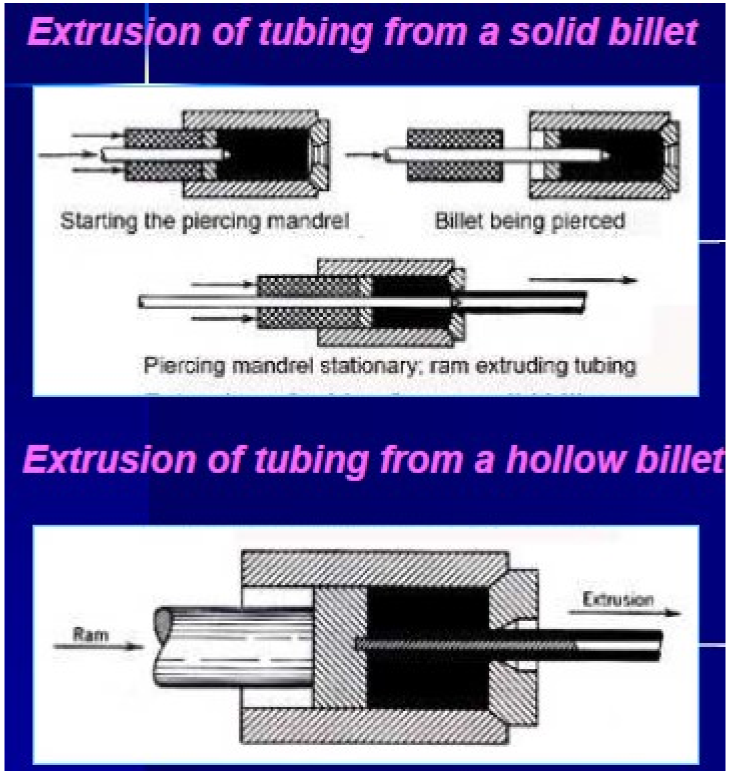
- Pressure limit 1.7GPa due to strength of the container and fluid short not solidify



Hydrostatic Extrusion

- Extrusion ratio 20:1 for mild steel and 200:1 for Al
- Fluid pressure is less than the value required to cause extrusion and axial force is used in the other direction to balance hydrostatic extrusion.
- For brittle materials, Bi or cast iron is extrude by this process to avoid cracking.

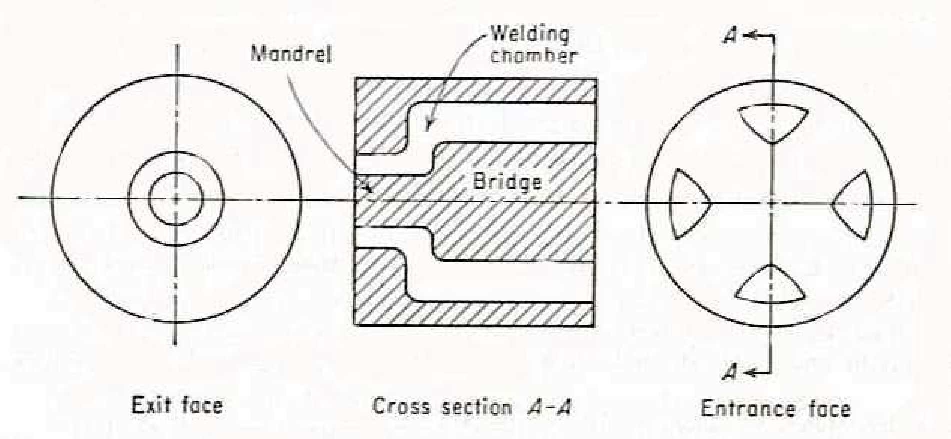
Extrusion of tubing



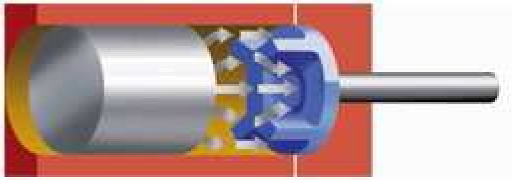
- To produce tubing by extrusion from a solid billet, the ram may also be fitted with a piercing mandrel. As the ram moves forward, the metal is forced over the mandrel and through the hole in the die, causing a long hollow tube. Just like toothpaste, only hollow.

- If the billets are hollow, a rod that matches the diameter of the cast hole in the billet (but slightly smaller than the hole in the die at the opposite end of the chamber) are used.
- Note: the bore of the hole will become oxidized resulting in a tube with an oxidized inside surface.

Extrusion tubing with a porthole die



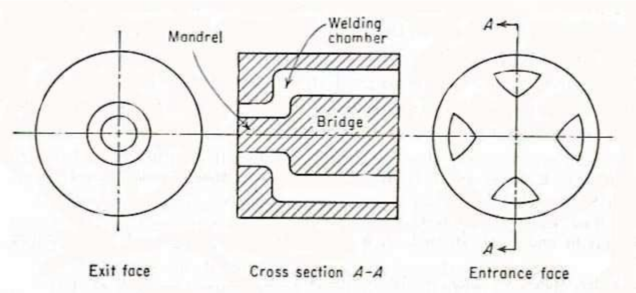
A sketch of a porthole extrusion die



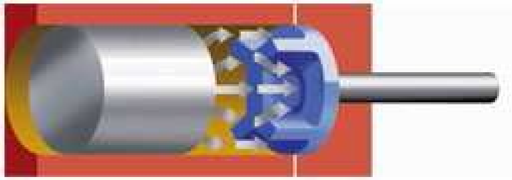
Porthole extrusion

Example: pyramid porthole dies

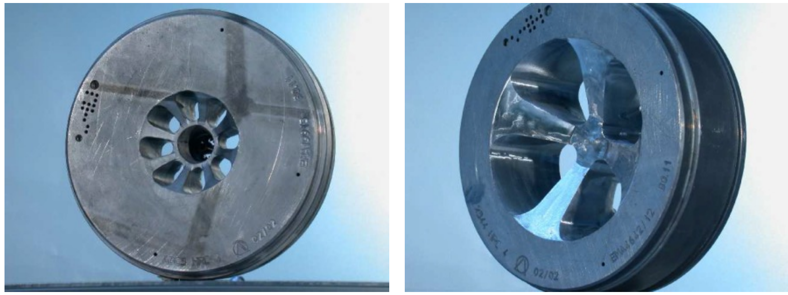
Extrusion tubing with a porthole die



A sketch of a porthole extrusion die



Porthole extrusion



Example: pyramid porthole dies

- The metal is forced to flow into separate streams and around the central bridge, which supports a short mandrel.
- The separate streams of metal which flow through the ports are brought together in a welding chamber surrounding the mandrel, and the metal exits from the die as a tube.
- Since the separate metal streams are jointed within the die, where there is no atmosphere contamination, a perfectly sound weld is obtained.
- Porthole extrusion is used to produce hollow unsymmetrical shapes in aluminium alloys.

Production of seamless pipe and tubing

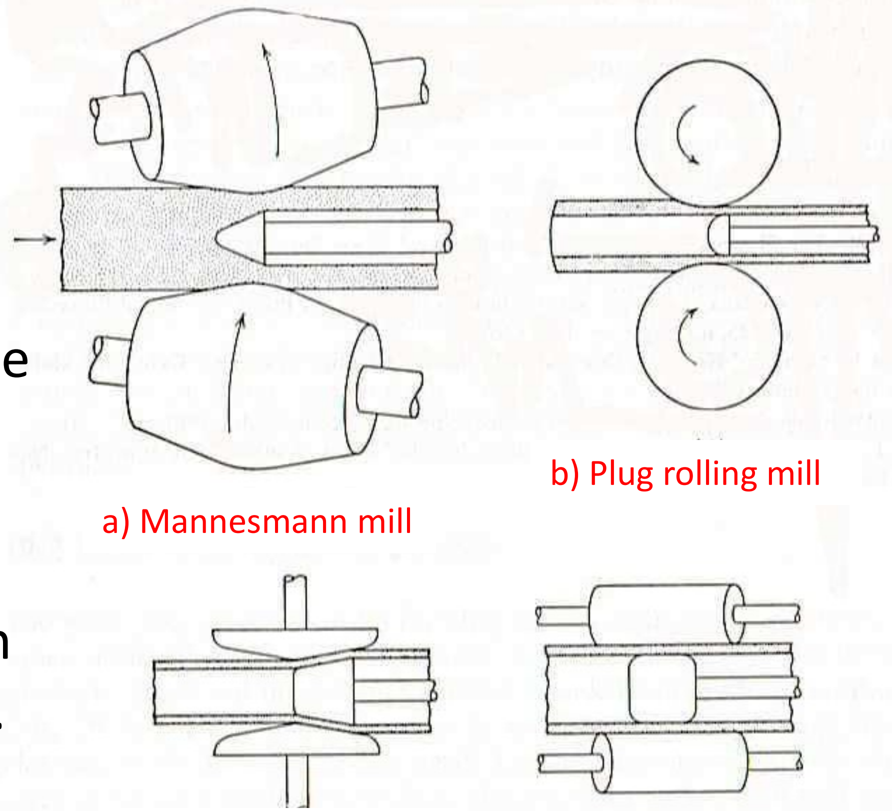
- Extrusion is suited for producing seamless pipe and tubing, especially for metals which are difficult to work.
- The red-hot billet is rotated and drawn by rolls over a piercing rod, or mandrel. The action of the rolls causes the metal to flow over and about the mandrel to create a hollow pipe shell.
- After reheating, the shell is moved forward over a support bar and is hot rolled in several reducing/sizing stands to the desired wall thickness and diameter.

a)The Mannesmann mill is used for the rotary piercing of steel and copper billets using two barrel-shape driven rolls, which are set at an angle to each other. The axial thrust is developed as well as rotation to the billet.

(b)The plug rolling mills drive the tube over a long mandrel containing a plug.

(c) The three-roll piercing machine produces more concentric tubes with smoother inside and outside surface.

(d)The reeling mill burnishes the outside and inside surfaces and removes the slight oval shape, which is usually one of the last steps in the production of pipe or tubing



a) Mannesmann mill

b) Plug rolling mill

c) Three-roll piercing machine

d) Reeling mill

Production of seamless pipe and tubing