ME 4563

Introduction to Manufacturing Processes

College of Engineering
Arkansas State University

Bulk Deformation

Extrusion

Extrusion

As a Process …

- Production of long lengths of solid or hollow products with constant cross-section
- Usually performed at elevated temperatures
- Product can be cut to desired lengths
- Can be competitive to roll forming
- Cold extrusion has similarities to forging and is used to make discrete parts
- Moderate to high equipment and die costs
- Low to moderate labor costs
- Low to moderate operator skills

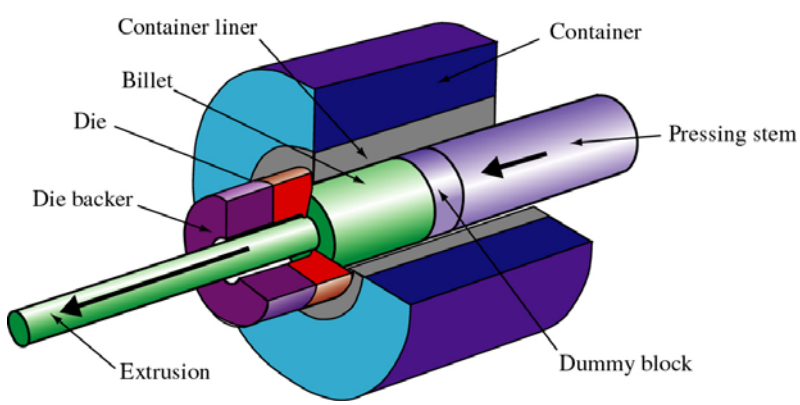
Extrusion

The Process …

- Extrusion is a process that forces metal to flow through a shape-forming die
- The metal is plastically deformed under compression in the die cavity
- Compression is achieved mechanically or hydraulically
- Extrusion processes can be carried on hot or cold
- Extrusion differs from drawing in that the metal is pushed, rather than pulled under tension
- The cross-sections that can be produced vary from solid round, rectangular, to L shapes, T shapes. Tubes and many other different types.

Extrusion

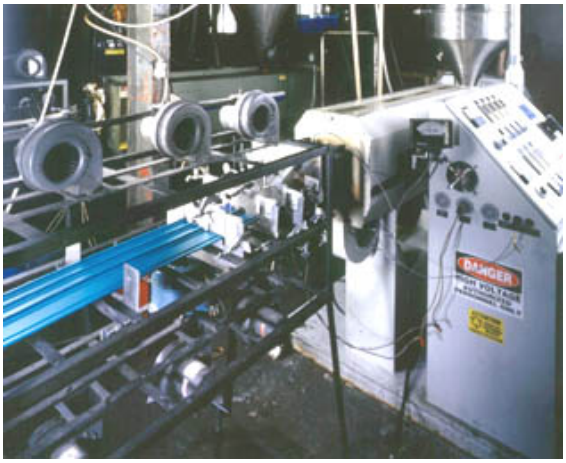
Schematic illustration of the direct extrusion process.



Extrusion

- Extrusion produces compressive and shear forces in the stock
- No tensile force is produced; this makes high deformation possible without tearing the metal
- The cavity in which the raw material is contained is lined with a wear resistant material
- This can withstand the high radial loads that are created when the material is pushed the die
- Extrusions, often minimize the need for secondary machining, but are not of the same dimensional accuracy or surface finish as machined parts

Extrusion



Jet Plastics, Los Angeles, CA

Extrusion

Advantages

- The tooling cost is low, as well as the loss due to material waste (it has high material utilization)
- Intricate cross sectional shapes, hollows and with undercuts can be produced
- The hardness and the yield strength of the material are increased
- In most applications, no further machining is necessary

Extrusion

Disadvantages

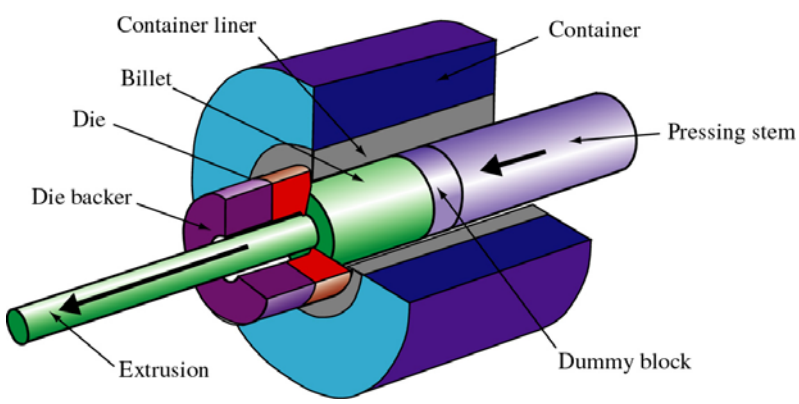
- High tolerances are difficult to achieve.
- The process is limited to ductile materials.
- Extruded products might suffer from surface cracking. It might occur when the surface temperature rise significantly due to high extrusion temperature, friction, or extrusion speed.
- Surface cracking might also occur at low speeds due to periodic sticking of the extruded product along the die land.
- Internal cracking might also occur. These cracks are attributed to a state of secondary tensile stresses at the centerline of the deformation zone in the die.

Types of Extrusion Process

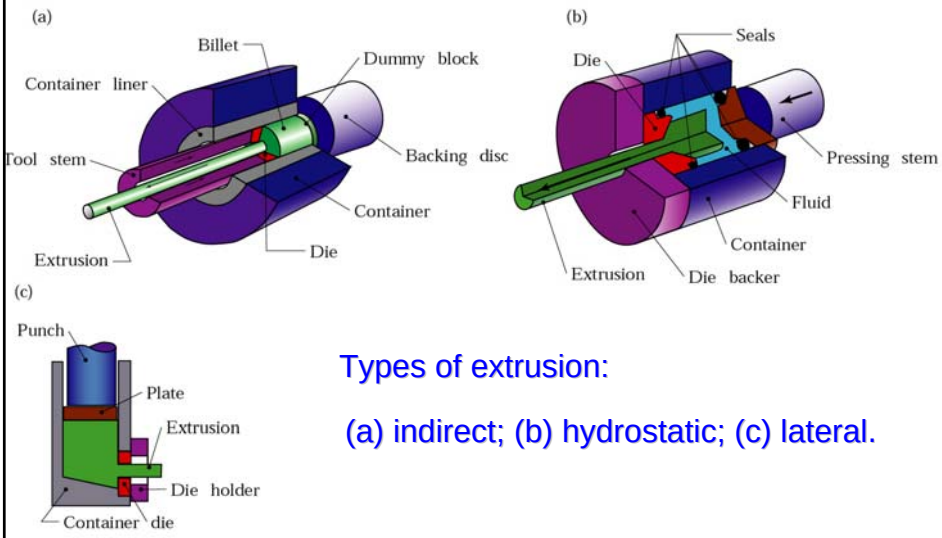
There are four basic types of extrusion as follows:

- Forward or Direct Extrusion
- Reverse or Indirect Extrusion
  (or inverted or backward)
- Hydrostatic Extrusion
- Impact Extrusion

Direct or Forward Extrusion Process



Extrusion



Types of extrusion:

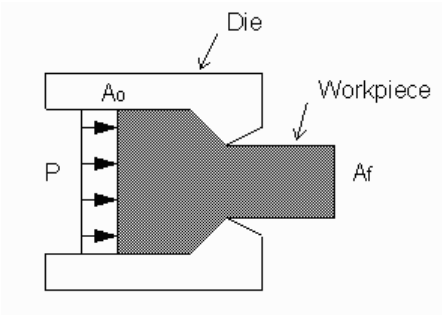
(a) indirect; (b) hydrostatic; (c) lateral.

Direct or Forward Extrusion Process

- Forward extrusion is also known as Direct Extrusion (sometimes known as the Hooker process)
- In this process the confined metal is forced to flow in the direction of the punch travel
- The process is generally used to produce thin-walled tubular parts with heavy flanges, straight tubular shapes, and extrusion of stepped; multiple diameters. Production of rods and other solids shapes, for example
- Best applied to parts having an outer diameter of 25.4 mm (1 in) or more.

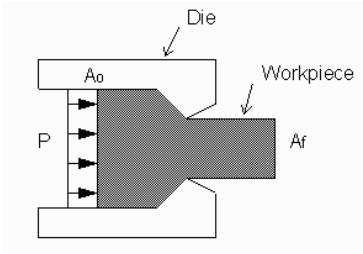
Forward Extrusion Process

- In practice, the work piece is placed in a close-fitting die.
- The punch is forced downward, displacing the metal through a restricted opening in the bottom of the die
- The metal is forced to flow considerable distance beyond the end of the punch
- Cupped or tubular parts of the punch extension serve as a mandrel. This controls the wall thickness and inner contour of the extruded parts.

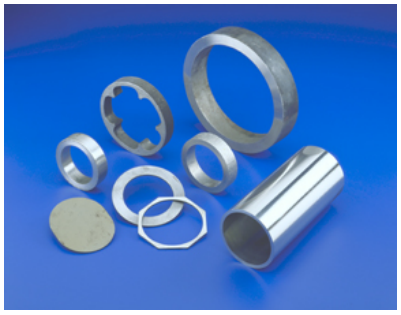


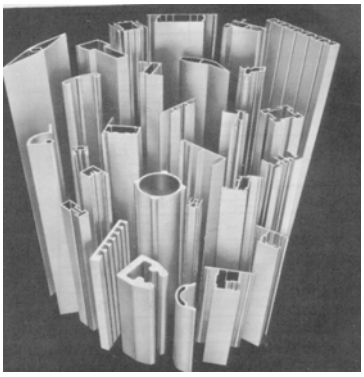
Forward Extrusion Process

- Advantages
  - high dimensional accuracy
  - complex shapes (from poor ductile materials)
- Disadvantages
  - low productivity
  - short tool life
  - expensive tooling



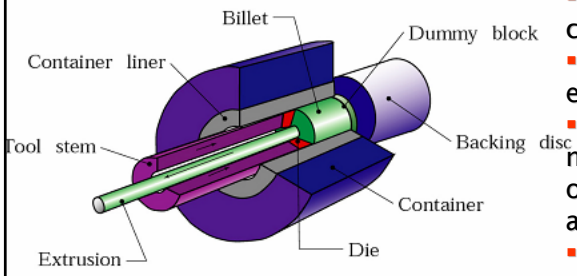
Forward Extrusion Process





Backward or Indirect Extrusion Process

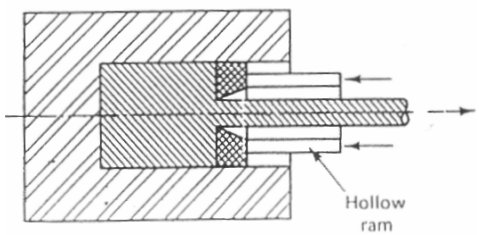
- Backward extrusion is a process that forces the metal confined in the cavity to flow in a direction opposite to that of the punch travel.



- The slug (work piece) is contained in a closed die.
- The descending punch enters the slug.
- The pressure displaces the metal upward through the opening between the punch and die.
- This is generally used for extruding symmetrically shaped parts having a closed end.

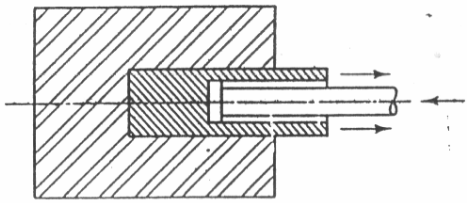
Backward Extrusion Process

- The frictional forces are lower and the power required for extrusion is less than for direct extrusion.
- In practice, a hollow ram carries a die, while the other end of the container is closed with a plate.
- Frequently, for indirect extrusion, the ram containing the die is kept stationary, and the container with the billet is made to move.



Backward Extrusion Process

- Extrusion pressure
  - 30% lower than direct method
- Waste
  - only 5%
- Tooling
  - expensive
  - complex



Combination Extrusion Process

- Combined extrusion uses a combination of forward extrusion and backward extrusion.
- The metal is confined inside a matrix between the lower and upper punches.
- This forces the metal to flow both up and down.
- The extruded part is lifted from the die on the upward stroke of the slide by a lift out on the bed of the press.

Combination Extrusion Process

Some aspects of combined extrusion are:

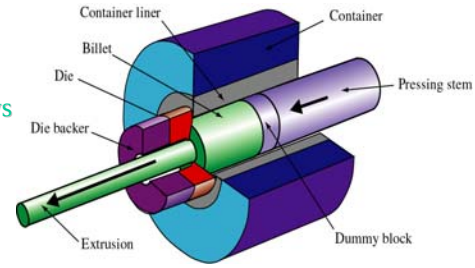
- it is fast
- it can complete parts in few steps
- it can produce large quantities with low unit costs
- it wastes little material
- it can make parts with small radii
- it requires mirror tooling

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 (5076 - 101,525 psi).
- 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.
- Typical parts produced by extrusions are trim parts used in automotive and construction applications, window frame members, railings, aircraft structural parts

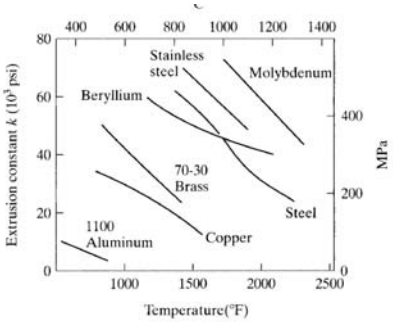
Hot Extrusion

- At elevated temperatures
  - For metals and alloys that don't have sufficient ductility
  - Lower force required
- Problems
  - Cooling: unacceptable metal flows
  - Oxide film formed: abrasive
  - Not good surface quality
- Dummy block
  - Forms Skull of oxide layer



Hot Extrusion

- Advantages
  - Lower stresses
  - Sometimes the only way to extrude certain metals
    - e.g. Titanium, refractory alloys, high strength alloys
- Disadvantages
  - Higher die wear
  - Oxide film buildup results in non-uniform flow, inclusions and poor surface finish
  - Cooling of billet in container results in non-uniform flow
  - Distorted parts



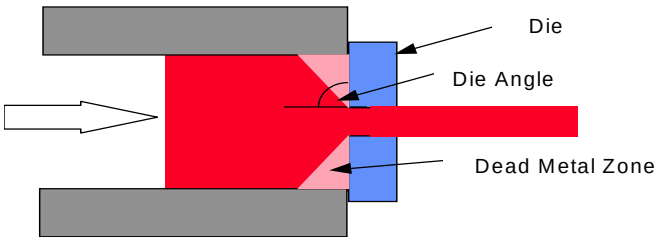
Hot Extrusion

Process temperature ranges

Material	Temp Range (°C)
Lead	200-250
Aluminum and alloys	375-475
Copper and alloys	650-975
Steels	875-1300
Refractory alloys	975-2200

Hot Extrusion – Die Design

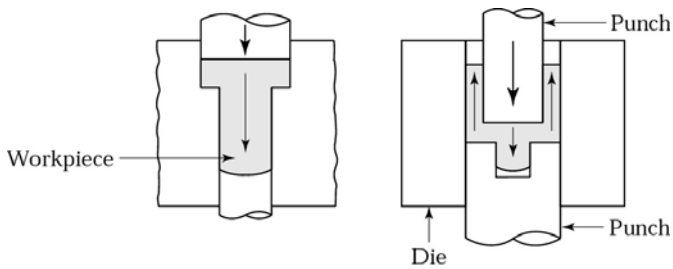
- Difficult and requires a lot of experience
- Square dies (die angle = 90º) give rise to dead metal zones around the die
- Dead metal zones give bright finishes to aluminum alloys (no surface exposed to air)
- Spider dies produce hollow shapes



Cold Extrusion

- Comparatively recent development (1940's)
- 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 of the metals that can be extruded: lead, tin, aluminum alloys, copper, titanium, molybdenum, vanadium, steel
- Examples of parts that are cold extruded: collapsible tubes, aluminum cans, gear blanks

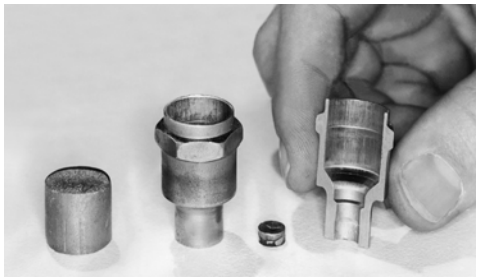
Cold Extrusion

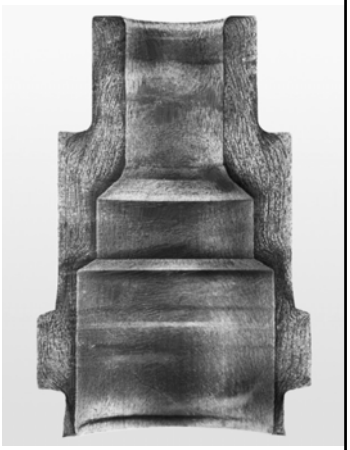


Two examples of cold extrusion. Thin arrows indicate the direction of metal flow during extrusion.

Cold Extrusion

Production steps for a cold extruded spark plug. *Source*: National Machinery Company.





A cross-section of the metal part from figure above, showing the grain flow pattern. *Source*: National Machinery Company.

Cold Extrusion

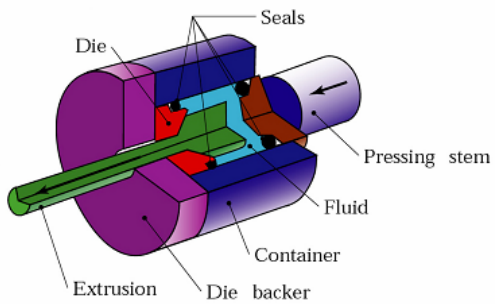
- Advantages
  - Improved mechanical properties
  - Work hardening
  - Good control of tolerances
  - Improved surface finish (with use of lubricant)
  - Elimination of heating costs
  - High production rates
- Disadvantages
  - Higher stresses require more expensive tooling and die material
  - Difficult die design essential to success
  - Lubrication critical

Cold Extrusion

- Comparison to Hot Extrusion
  - Improved mechanical properties
  - Good dimensional tolerance
  - Elimination of billet heating
  - Production rates and costs competetive
    - 2000 parts/hour
  - However, High stresses involved
- Tool and die materials crucial
  - Sufficient strength
  - Sufficient toughness
  - Good Wear and fatigue resistance

Hydrostatic Extrusion

- Developed 1950s
- The chamber is filled with a fluid that transmits the pressure to the billet, which is then extruded through the die.
- NO friction along the walls of the container.



Hydrostatic Extrusion

- Because of the pressurized fluid, lubrication is very effective, and the extruded product has good surface finish and dimensional accuracy.
- Since friction is nearly absent, it is possible to use dies with very low semi-cone angle which greatly minimizes the redundant deformation.
- The only limitation with this process is the practical limit of fluid pressure that may be used because of the constraint involving the strength of the container and the requirement that the fluid not solidify at high pressure

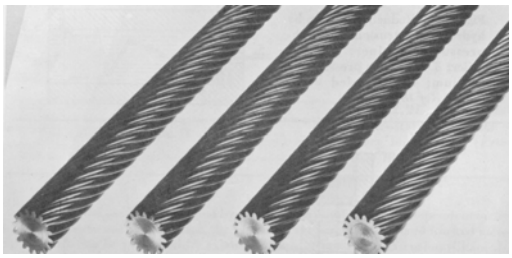
Hydrostatic Extrusion

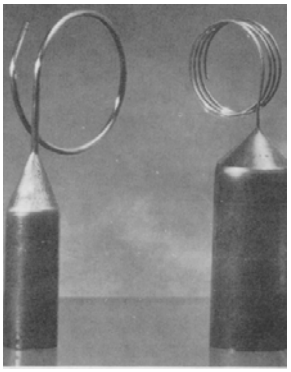
- Suitable for extruding metals of average ductility at high extension ratios.
- Products
  - helical gears
  - copper wire
- Improved process control
  - augmented hydrostatic extrusion
- Materials
  - brittle materials
  - cast iron

Hydrostatic Extrusion

- Advantages
  - No friction at walls
  - Can successful extrude brittle materials
  - Yield stress reduced by hydrostatic pressure
  - Room temperature operation
- Disadvantages
  - Limited industrial applications
  - Complex tooling
  - ?

Hydrostatic Extrusion



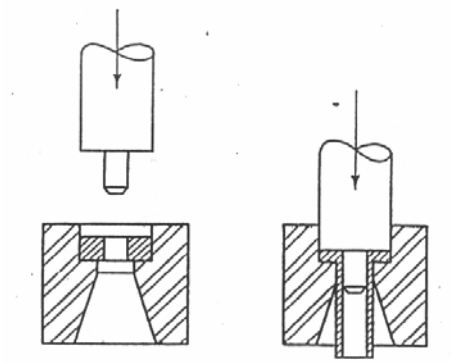


Impact Extrusion

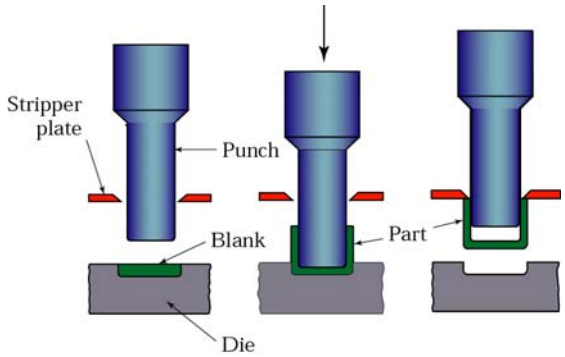
- Form of indirect extrusion
- Particularly suitable for hollow shapes.
- Usually performed on high-speed mechanical press.
  - The punch descends at a high speed and strikes the blank, extruding it upwards.
  - The thickness of the extruded tubular section is a function of the clearance between the punch and the die cavity.
- Although performed cold, considerable heating results from the high-speed deformation.
- Restricted to softer metals: lead, tin, Al & Cu

Impact Extrusion - Forward

- Cold slug held in a die cavity
  - usually aluminum
- Hit by a rapidly moving punch
- Metal flows
  - around the punch
  - Into the die opening



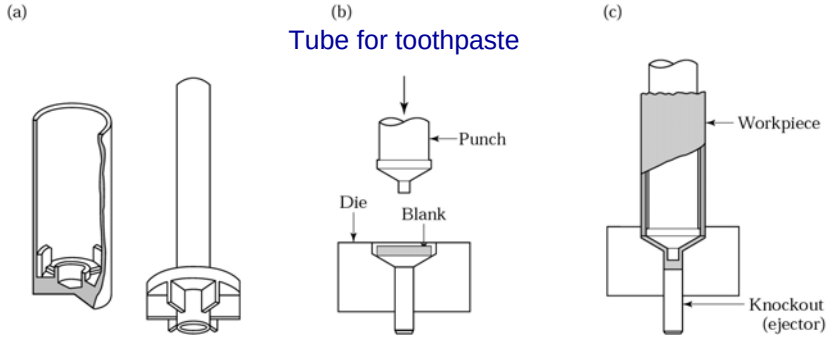
Impact Extrusion - Backward



Schematic illustration of the impact-extrusion process. The extruded parts are stripped by the use of a stripper plate, because they tend to stick to the punch.

Impact Extrusion - Examples

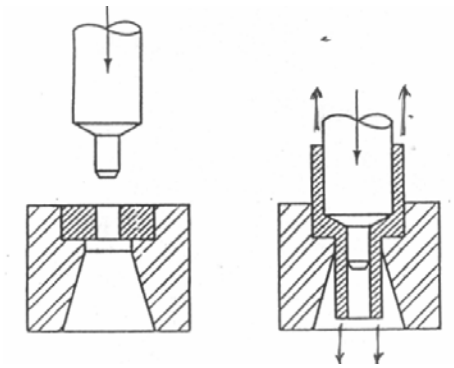
Tube for toothpaste



(a) Two examples of products made by impact extrusion. These parts may also be made by casting, by forging, or by machining; the choice of process depends on the dimensions and the materials involved and on the properties desired. Economic considerations are also important in final process selection. (b) and (c) Impact extrusion of a collapsible tube

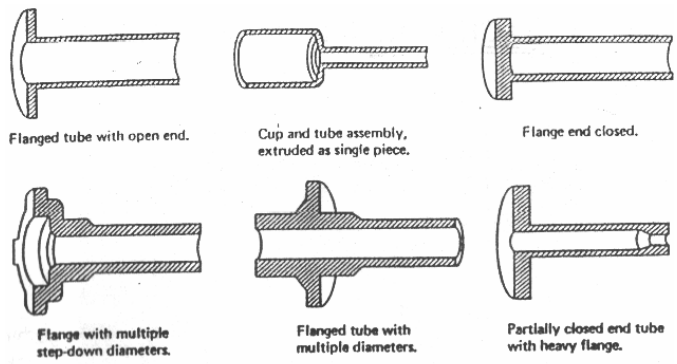
Impact Extrusion - Combination

Forward and Backward in one shot !

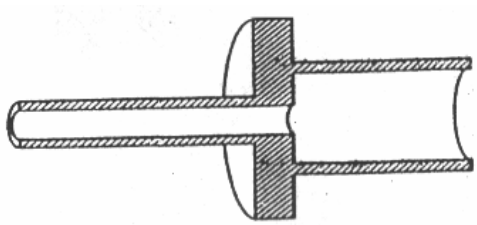


Impact Extrusion - Examples

Commonly used to make collapsible tubes such as toothpaste tubes, cans usually using soft materials such as aluminum, lead, tin

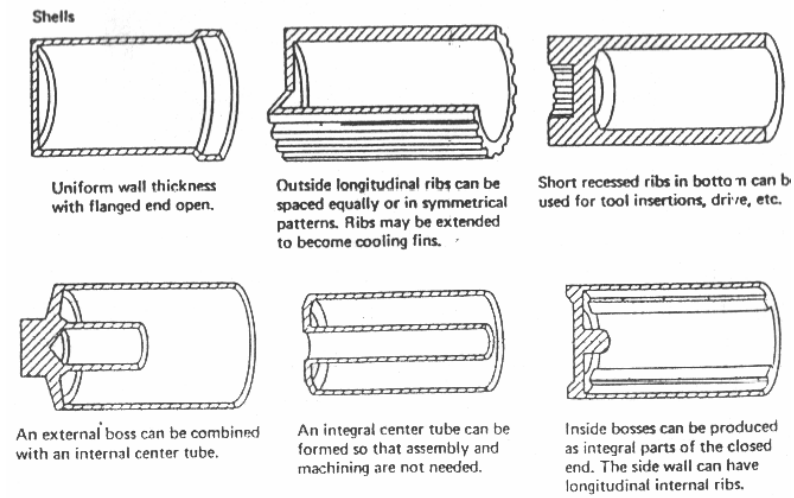


Impact Extrusion - Examples



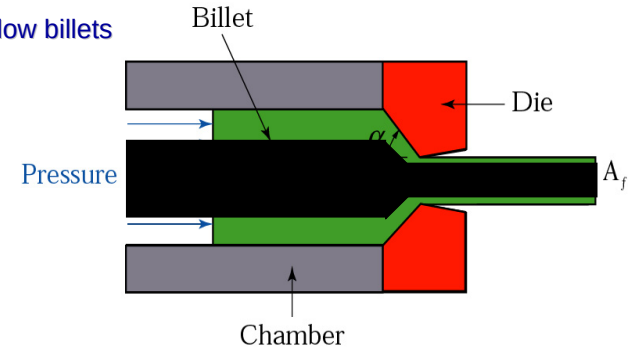
Combination impact with the flange at the midpoint. Such an impact also serves as a transition from one diameter to another. Wall thicknesses can also be varied.

Impact Extrusion - Examples



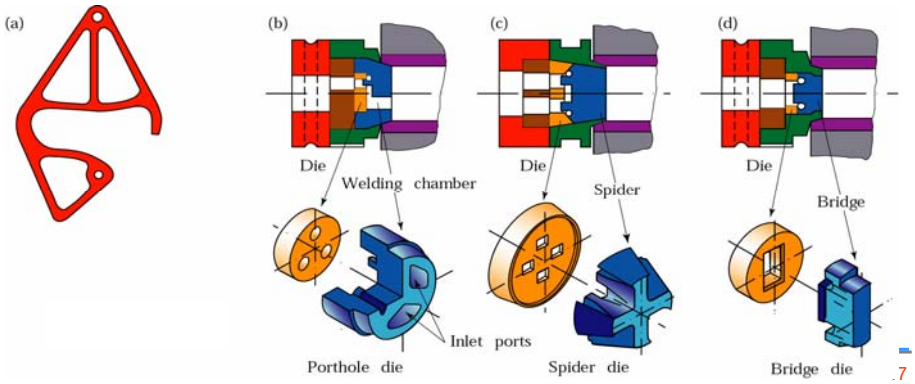
Extrusion of Tubing

- Tubing extrusion
  - Forward extrusion process
  - Use of a Mandrel to pierce a hole in billets
  - Use of hollow billets



Extrusion of Hollow Shapes

- Welding-chamber method
  - Metal divides and flows around
  - Then rewelded under high pressure in welding chamber
- Aluminum and its alloys
- No lubrication used



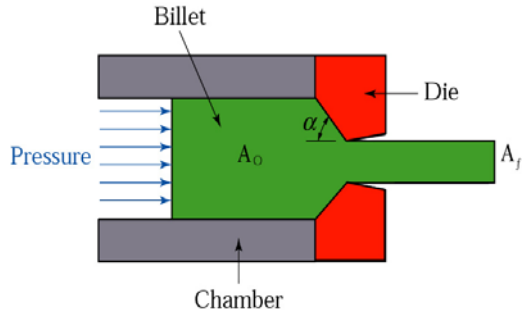
Materials used in Extrusion

(just a list …)

- Metals and alloys:
  Brass, copper, lead, aluminum, steel, magnesium, tin, titanium, and zinc

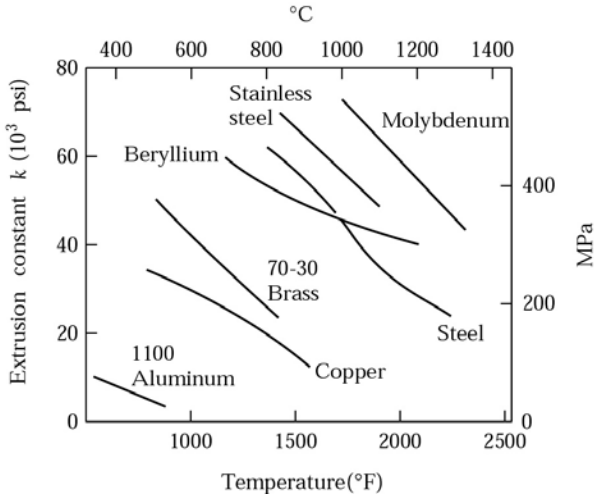
- Thermoplastics:
  ABS, Acrylic, Butyrate, Flexible Vinyl, PETG Co-Polyester, Polycarbonate, Polyethylene-High & Low Densities, Polypropylene, Polystyrene, Polyurethane, Rigid Vinyl, Thermoplastic Elastomers, etc.

Extrusion Force



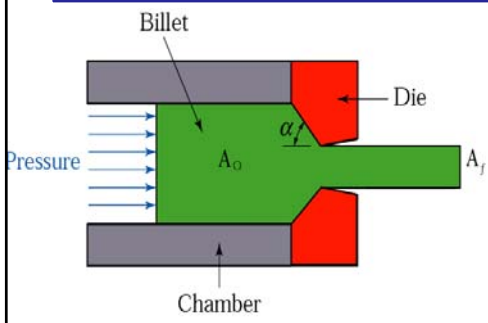
- $F = A_0 \, k \ln (A_0/A_f)$
  - k: Extrusion constant, a billet material related properties
    - gives good estimation of force
    - important in analysis

Extrusion Constant '*k*' for various metals



Extrusion constant *k* for various metals at different temperatures. *Source*: P. Loewenstein

Process Variables in Direct Extrusion



Process variables in direct extrusion:

die angle, reduction in cross-section, extrusion speed, billet temperature, and lubrication

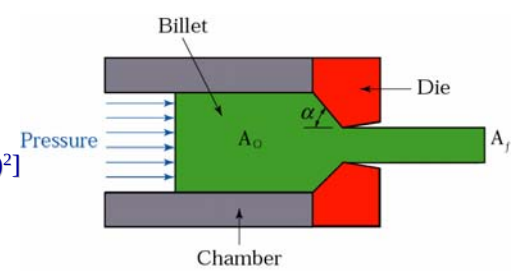
all affect the extrusion process.

Extrusion variables

- Geometry Variables
  - Die angle α
  - Extrusion ratio (E.R.)
- Process Variables
  - Extrusion speed, v, (power = Force x velocity)
    - Lower for Al, Mg, Cu
    - Higher for steels, Ti, Be
  - Temperature
  - Lubrication, μ
- Material variables
  - Extrusion Constant, k

Extrusion Ratio

- Extrusion Ratio, $ER = A_0 / A_f$
  - A_0: Original Area
  - A_f: Final Area
- E.R. varies typically from 10 to 100
- Must be atleast 4.0 to deform the material (as high as 400)
- E.R. is a function of the material ductility
- Example
  - d_0 = 100 mm,
  - d_f = 20 mm,
  - ER = ?
    - $ER = [\pi.(100/2)^2] / [\pi.(20/2)^2]$
    - ER = 25



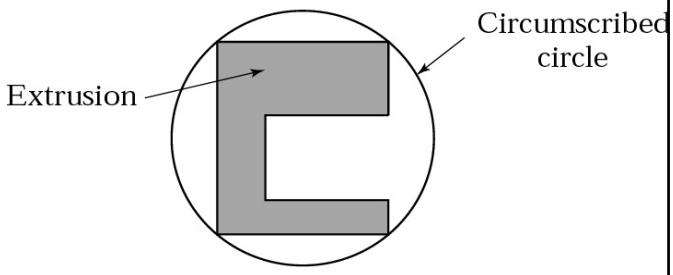
Circumscribing Circle Diameter

- CCD = Circumscribing Circle Diameter
- Diameter of the smallest circle into which an extruded cross-section will fit

– Typically 6 mm to 250 mm

– Can be as high as 1000 mm

– Steel usually restricted to <150 mm

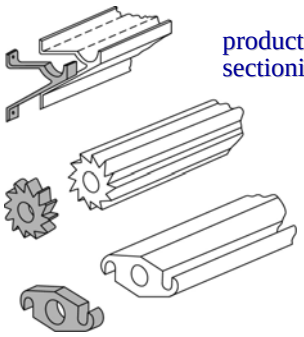


Method of determining the circumscribing-circle diameter (CCD) of an extruded cross-section.

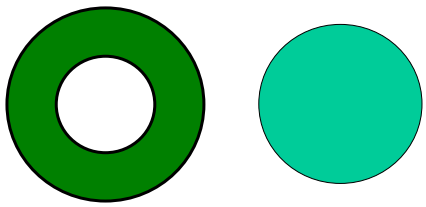
Extrusion – Shape factor

- Shape Factor = Perimeter / Cross Section Area
  - Perimeter: including inner geometry and outside geometry

Important because it relates to the complexity (i.e. cost) of the product



products made by sectioning off extrusions



Extrusion Practice

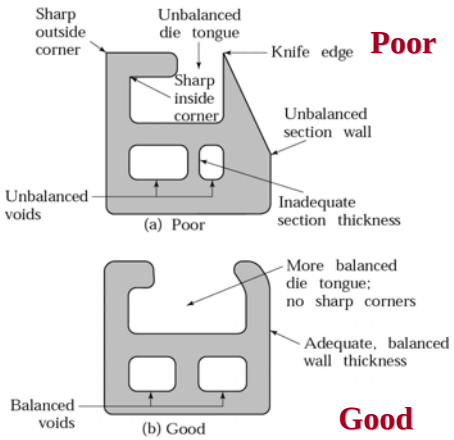
- Ram speeds
  - Up to 0.5 m/s
  - Slower for aluminum, magnesium and copper
  - Higher for steels, titanium and refractory alloys
- Length
  - Typically less than 7.5 m (heat treat ovens limiting)
- Straightening by stretching or rolling (simple cross-sections)
- Coaxial extrusion
  - Two metals with similar properties can be co-extruded
- Stepped extrusion
  - Start with small die
  - Switch to larger X-section die
  - Use in Aerospace industry to minimize machining scrap

Extrusion – Cross Section Design

Poor and good examples of cross-sections to be extruded.

Note the importance of eliminating sharp corners and of keeping section thicknesses uniform.

Source: J. G. Bralla (ed.); *Handbook of Product Design for Manufacturing*. New York: McGraw-Hill Publishing Company, 1986. Used with permission.

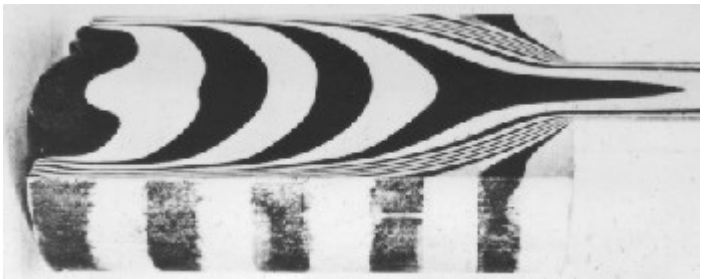


Material Flow

- Easy to extrude metals and alloys
  - Aluminum
  - Copper
  - Magnesium
  - Steels
  - Stainless steels
- Difficult to extrude metals and alloys
  - Titanium
  - Refractory metals

Extrusion

Flow of metal during the process of extrusion



Flow of metal in an Al extrusion process

The core flows more rapidly then the periphery

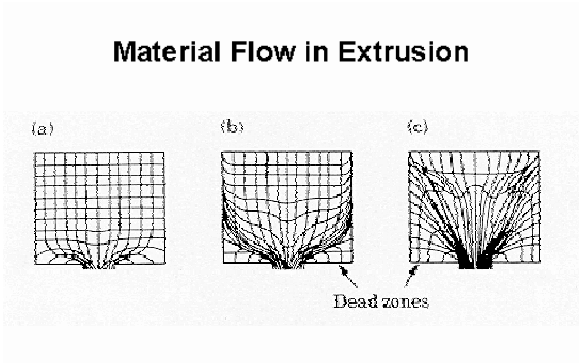
The periphery left behind as a residue is recycled

Extrusion

Flow of metal during the process of extrusion

- Because the billet is forced through a die, with a substantial reduction in its cross-sectional area, the metal flow pattern in extrusion is important.
- Typically, three different metal flow patterns have been observed during the process of extrusion depending upon the prevailing conditions.
- The conditions under which the different flow patterns are obtained are as follows

Flow of metal during the process of extrusion with square dies



Types of 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 type of pattern, observed in metals whose strength increases rapidly with decreasing temperature, leads to a defect known as pipe, or extrusion defect.

Extrusion

Flow of metal during the process of extrusion

(a) The most homogeneous flow pattern is obtained when there is little or no friction at the billet-container-die interfaces. This type of flow occurs when the lubricant is very effective or with indirect extrusion

(b) When friction along all interfaces is high, a dead-metal zone develops. As a result a high-shear area appears as the material flows into the die exit, somewhat like a funnel. This configuration may indicate that the billet surfaces could enter the high shear zone and be extruded, causing defects in the extruded product

Extrusion

Flow of metal during the process of extrusion

(c) The high shear zone extends further back. This extension can result from high container wall friction, which retards the flow of the billet or materials in which the flow stress drops rapidly with increasing temperature.

In hot working, the material near the container walls cools rapidly & hence increases the strength. Thus, the material in the central regions flows toward the die more easily than that at the outer regions.

As a result, a large *dead metal zone* forms and the flow is inhomogeneous. This flow pattern leads to a defect known as a pipe or extrusion defect

Extrusion

Extrusion Temperature Ranges for Various Metals

	°C
Lead	200–250
Aluminum and its alloys	375–475
Copper and its alloys	650–975
Steels	875–1300
Refractory alloys	975–2200

Properties of extruded materials

- Deformation is greater in the outer zones of a bar than it is at the center, particularly when the extrusion ratio is low.
- The center receives only light deformation.
- The improvement in tensile strength of Al 1100 resulting from extrusion with 3:1 ratio is 5000 psi (before extrusion) to 19000 psi (after extrusion). In general, the yield strength is increased about four times the initial strength.
- In general, the inside surfaces of backward extruded parts are 5 to 25 Rockwell-B Hardness harder than the outside surfaces.
- The hardness of material alloys which undergo this backward extrusion process is decreased by 20 to 10 Rockwell-B Hardness. However in forward extrusion the outer surfaces are harder than the inner surfaces.

Extrusion

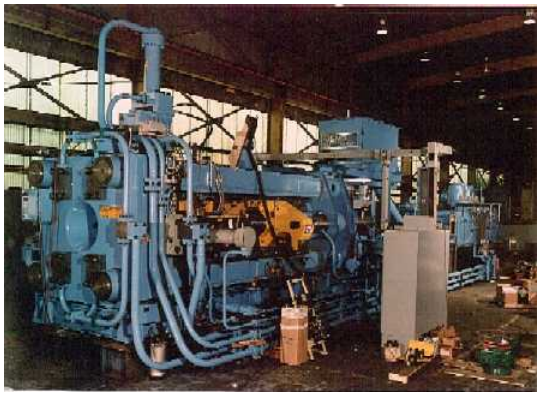
Lubrication
Important in Hot Extrusion

- Important to extrusion
  - harder materials
- Reducing friction
  - Reducing extrusion forces
  - Reduces sticking to walls
  - increased tool life
  - reduced power
  - Prevents contamination
- Choices
  - soaps
  - lubricating oils
  - graphite
- Steel & Hi Temp Materials
  - Glass
- Billet also enclosed in a jacket of softer material such as Cu (when metal sticks to wall) – jacketing or canning

Extrusion Machines

Extrusion - Machines

Most extrusions are made with hydraulic presses. Hydraulic extrusion presses are classified into horizontal and vertical presses, depending upon the direction of travel of the ram



Extrusion - Machines

Vertical extrusion presses

- generally built with capacities of 300 to 2000 tons force
- advantage of easier alignment between the press ram and the tools
- higher rate of production
- the need of less floor space than horizontal presses

- However, they need considerable headroom, and to make extrusions of appreciable length, a floor pit is frequently necessary.

Extrusion - Machines

Vertical extrusion presses

- Vertical presses produce uniform cooling of the billet in the container, and thus symmetrically uniform deformation will result
- In commercial operations the chief use of vertical presses is in the production of thin-wall tubing, where uniform wall thickness and concentricity are most important

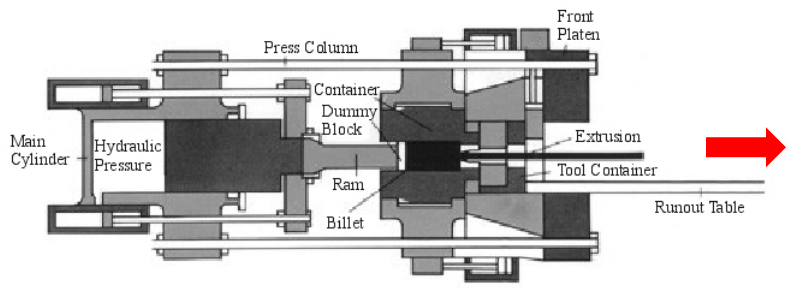
Extrusion - Machines

Horizontal extrusion presses

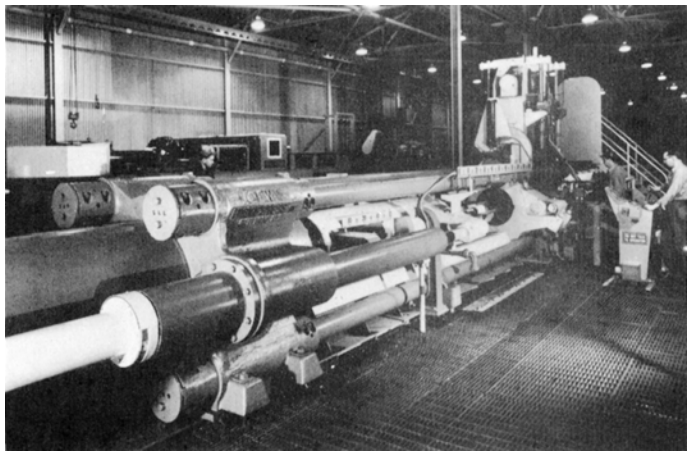
- Used for most commercial extrusion of bars and shapes
- Presses with a capacity of 1500 to 5000 tons are in regular operation, while a few presses of 14000 tons capacity have been constructed
- The bottom of the billet which lies in contact with the container will cool more rapidly than the top of the surface, unless the extrusion container is internally heated, and therefore the deformation will be non-uniform
- Warping of bars will result, and non-uniform wall thickness will occur in tubes

Extrusion - Machines

Horizontal extrusion press



Hydraulic-Extrusion Press



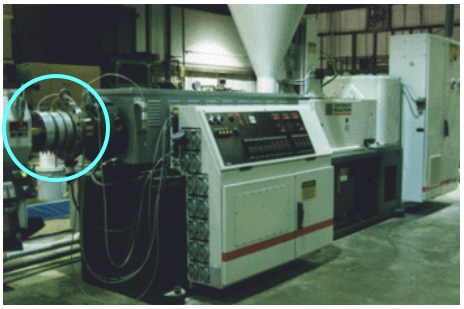
General view of a 1000-ton hydraulic-extrusion press

Extrusion - Machines

Horizontal extrusion press

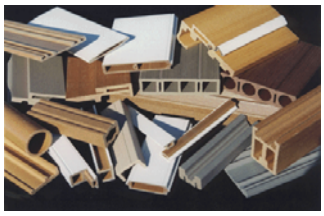

These two pictures show the profile just emerging (left) and production in progress (right)

Extrusion - Machines



"Twin screw" extruders

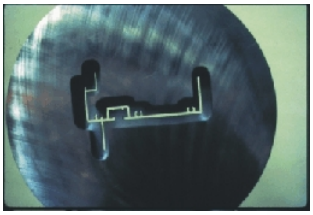
Wood profiles

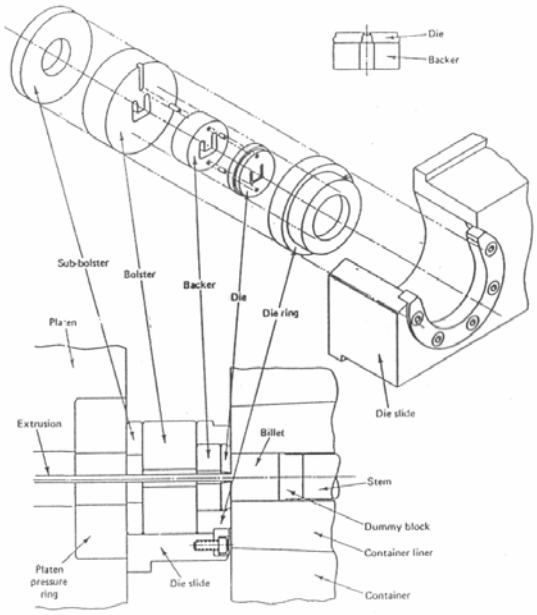


Extrusion Dies

Extrusion

The Die Assembly

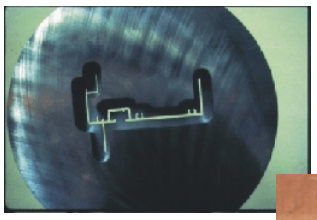




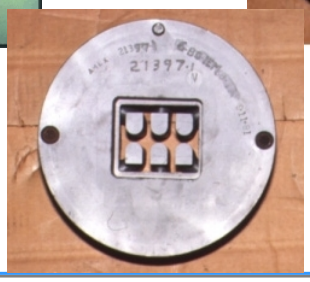
Extrusion

The Die

Solid Die



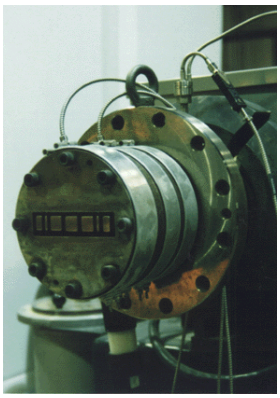
Semi-Hollow Die

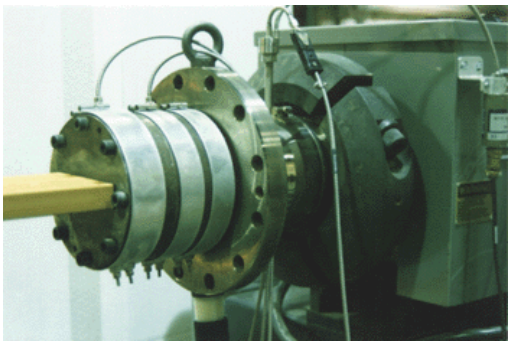


Hollow Die

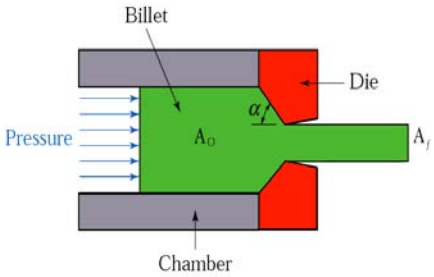
Extrusion

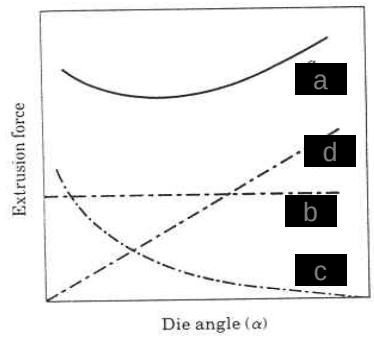
The Die Assembly on the Machine





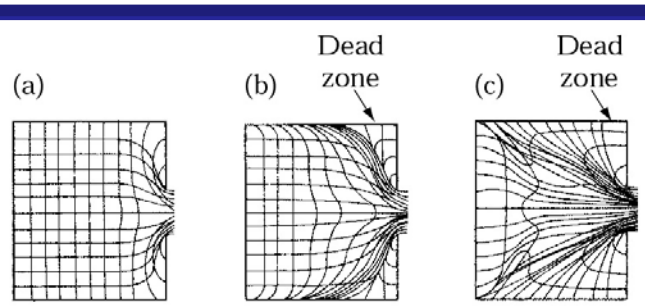
Die angle - effect on extrusion force





- (a) total force
- (b) ideal force
- (c) force required to overcome friction
- (d) force required for redundant work

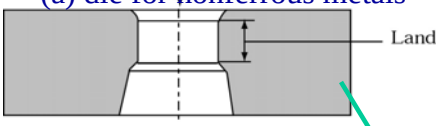
Types of Metal Flow in Extruding With Square Dies



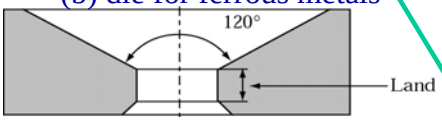
Types of metal flow in extruding with square dies. (a) Flow pattern obtained at low friction, or in indirect extrusion. (b) Pattern obtained with high friction at the billet-chamber interfaces. (c) Pattern obtained at high friction, or with cooling of the outer regions of the billet in the chamber. This type of pattern, observed in metals whose strength increases rapidly with decreasing temperature, leads to a defect known as pipe, or extrusion defect.

Extrusion-Die Configurations

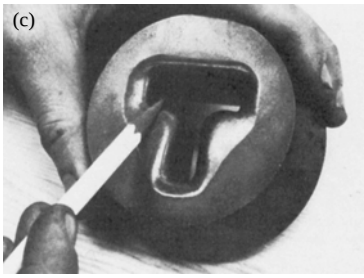
(a) (a) die for nonferrous metals

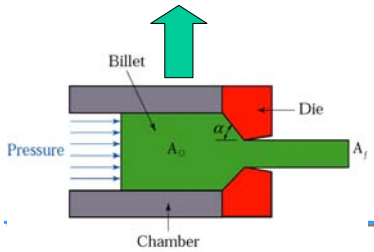


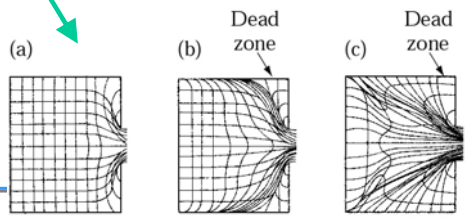
(b) (b) die for ferrous metals



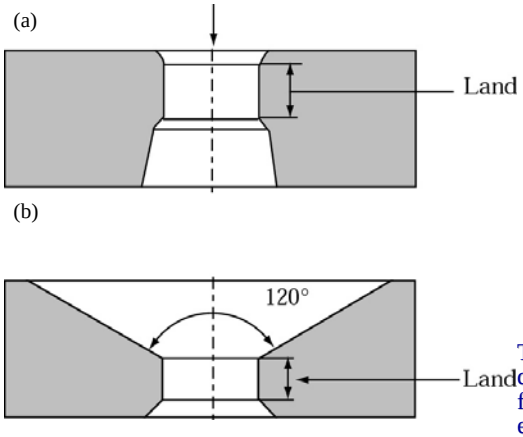
(c) die for T-shaped extrusion, made of hot-work die steel and used with molten glass as a lubricant







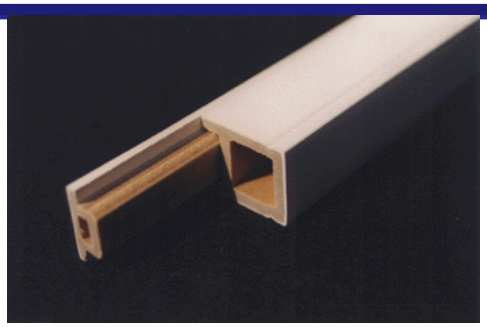
Extrusion-Die Configurations



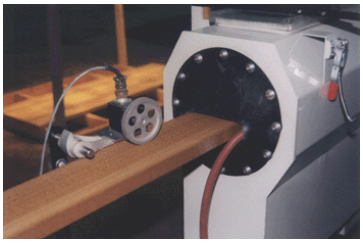
Typical extrusion-die configurations: (a) die for nonferrous metals; (b) die for ferrous metals; (c) die for T-shaped extrusion, made of hot-work die steel and used with molten glass as a lubricant. *Source* for (c): Courtesy of LTV Steel Company.

Extrusion

The Die



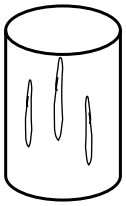
Co-extrusion – two profiles



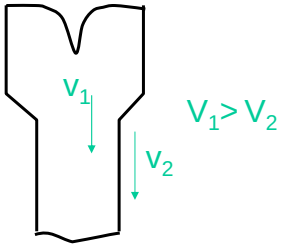
Extrusion Defects

Extrusion - Defects

- Surface appearance/cracking
  - Often along grain boundaries
  - Due to high temperatures, high friction and high velocities
  - Or due to sticking of the product to the die surface
  - Tearing, Fir-tree effect, Bamboo defect

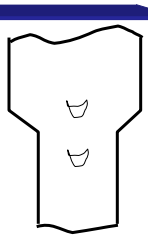


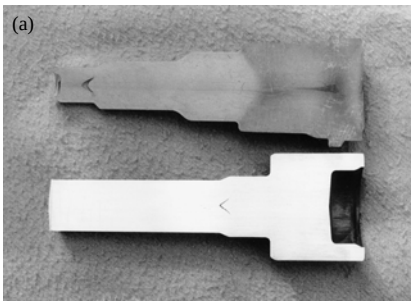
- Piping (tail-piping / fish-pipe)
  - Drawing surface oxides and impurities toward the center of the billets
  - Results in significant length lost
  - Minimized by machining the billets first to make flow more uniform

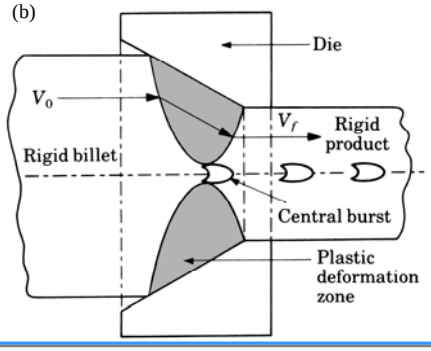


Extrusion - Defects

- Chevron cracking (internal)
  - Increases with increasing impurities, die angle
  - Decrease with increasing E.R. and friction







Extrusion - Defects

- *Surface defect* If the extrusion temperature, friction, or extrusion speeds are too high, surface temperatures rise significantly and can lead to surface cracking and tearing
- These cracks are inter-granular and are a result of hot shortness.
- This can be avoided by using lower temperatures and speeds.
- However, surface cracking may also occur at low temperatures and has been attributed to periodic sticking of the extruded product along the die land. Because of this sticking, the extrusion pressure increases rapidly

Extrusion - Defects

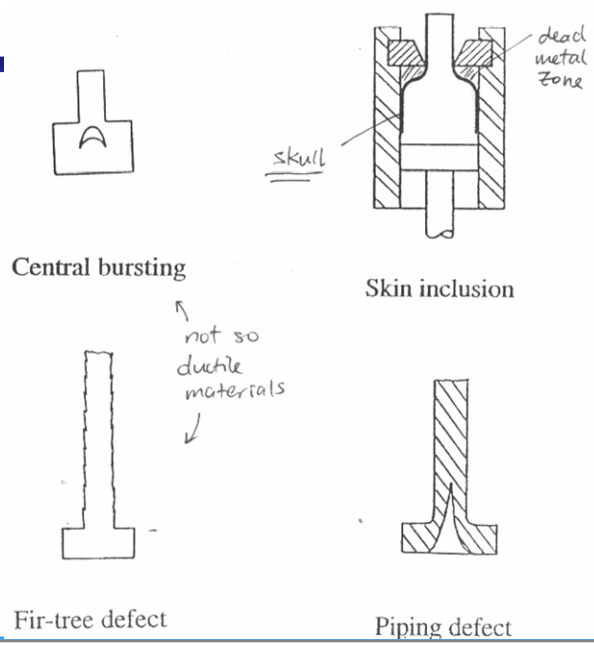
- *Extrusion defect* Some types of metal flow tend to draw surface oxides and impurities toward the center of the billet. This defect is known as *extrusion defect*, *pipe*, *tailpipe* or *fishtailing*.
- A considerable portion of the metal can be rendered useless as an extruded product because of this.
- This defect can be reduced by modifying the flow pattern to a less inhomogeneous one, such as by controlling friction and minimizing temperature gradients.
- Another method is to machine the surface of the billet prior to extrusion to eliminate scale and impurities

Extrusion - Defects

- *Internal cracking* The center of an extruded product can develop cracks (also known as *centerburst*, *center cracking*, *arrowhead fracture* or *chevron cracking*) due to a state of hydrostatic tensile stress at the centerline of the deformation zone in the die.

- This situation is similar to the necked region in an uni-axial tensile test specimen.

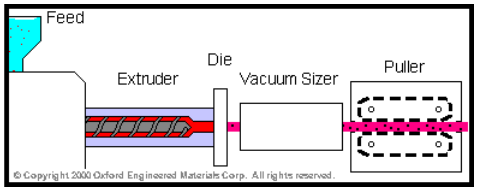
- The major variables influencing this are the die angle, extrusion ratio and friction.



Plastic Extrusion

Plastic Extrusion

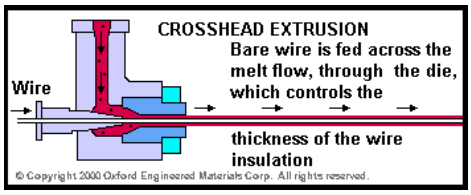
The most common variation on straight extrusion is **dual durometer** extrusion. Here, a "side machine" (about 1/4 or less the size of the main machine) runs in tandem with the primary machine, feeding a different material (flexible vinyl with rigid PVC, for example) to the die, where the the streams merge into one extrusion made of two bonded profiles that are often "two hardnesses", or dual durometers.



Extrusion

Plastic Extrusion

Another common variation is **cross-head extrusion**. In this process the flow of plastic is altered to allow solid material, such as copper wire or fiberglass strands to feed into the melt flow, and become part of the extrusion. Cross head extrusion is used when such reinforcements cannot pass through the machine's screw and barrel.



Extrusion

Plastic Extrusion

Materials:

Most thermoplastics can be extruded, including LDPE, HDPE, ABS, polystyrene, polypropylene, acetates, butyrates, nylons, polyphenylene sulfides, acetals, polycarbonates and thermoplastic rubbers and polyesters, among others

Plastic Extrusion

Secondary Operations

- Include cutting and drilling, mitering of corners (for gaskets or frames), belling (increasing the diameter at the end), taping (typically done during extrusion), and cutting to length.

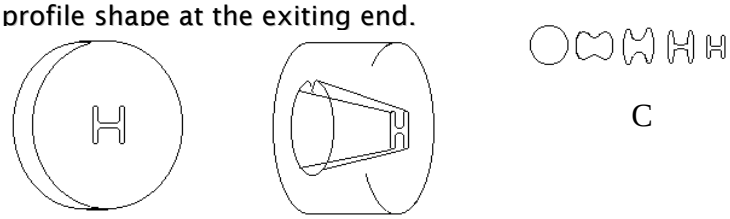
- This can be done during extrusion (on-line), or after extrusion (off-line). Off-line cutting is more laborious and expensive, but can hold tighter tolerances.

- Secondary punching can be done on-line or off-line, but is cheaper on-line. This setup actually has a mini-punch press as part of the extrusion line.

Plastic Extrusion

Tooling

- Basic extrusion tooling typically consists of a ***flat plate die*, (see "A")** or a round steel plate with a cut opening to the profile shape.
- ***Streamlined dies* (see "B"and "C")** are longer, and have a gradual transformation from round (at the machine end) to the profile shape at the exiting end.

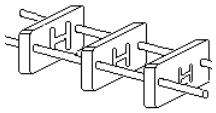


A B C

Extrusion

Plastic Extrusion - Calibrator

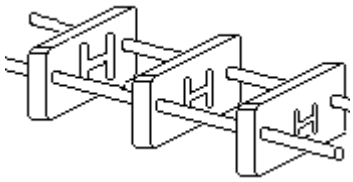
- A ***Calibrator*** is a long assembly, being either a continuous piece, or many pieces, through which the profile passes.
- The openings are cut to the profile shape, graduated from oversized at first to the final profile shape.
- As the profile passes through, any tendency for it to move or sag is counter-acted, and it is pushed back (repeatedly) to it's correct shape.
- While these devices are expensive, (2,000 to $20,000 or more), they help the profile to be run at maximum speed, for the best piece price.
- Give a better defined shape, and thus, a tighter set of tolerances.



Extrusion

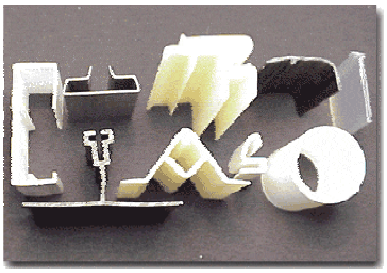
Plastic Extrusion

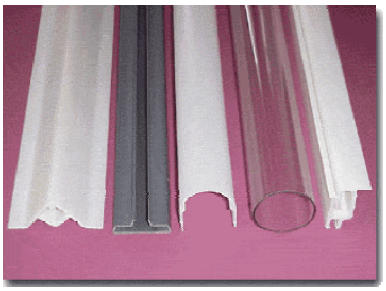
- This simplified underwater CALIBRATOR may consist of 4 to 40 plates, at intervals along a steel rod frame
- More plates at closer intervals mean much tighter tolerances
- Profile opening starts oversized, and reduces to the final shape
- Calibrators maximize running speed and accuracy



Extrusion

Plastic Extrusion

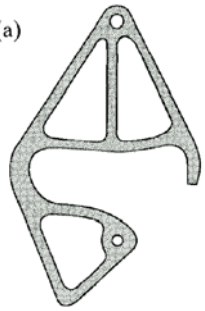




Typical uses of extrusions

- Windows and doors (aluminum)
- Aircraft components
  - stringers, ribs
- Tubing
  - copper and plastic for plumbing,
  - aluminum, steel for lawn furniture
- Discrete parts (sawn off)

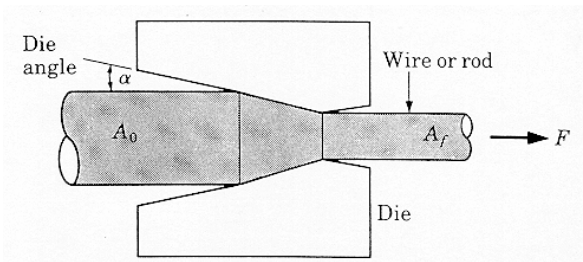
(a)



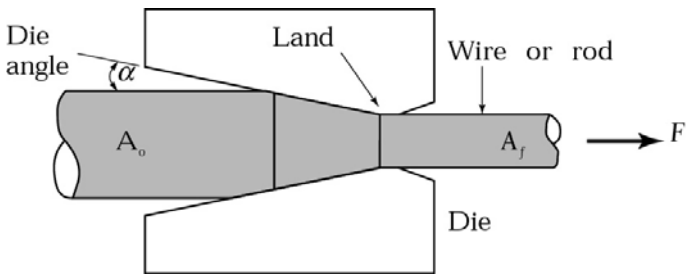
Drawing

Drawing Process

- Like extrusion but material ***pulled*** out the orifice of the required shape instead of being pushed in.
- Resulting shape variety is more limited than extrusion
  - Rod (larger cross sections)
  - Wire (smaller cross sections)



Process Variables in Wire Drawing

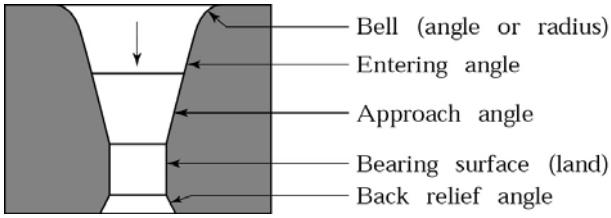


Process variables in wire drawing. The die angle, the reduction in cross-sectional area per pass, the speed of drawing, the temperature, and the lubrication all affect the drawing force, *F*.

Drawing Process

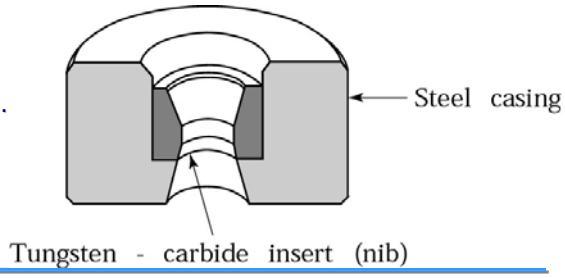
- Advantages
  - Very long product with non-flat cross-section than extrusion - wire, rod (total length can exceed miles)
  - Non circular cross sections can be produced
- Disadvantages
  - Higher forces required
  - If exceed tensile strength further deformation can be non-uniform
  - Limited size reduction per pass (Maximum 63%)
  - Need multiple dies and take up rolls

Die for Round Drawing

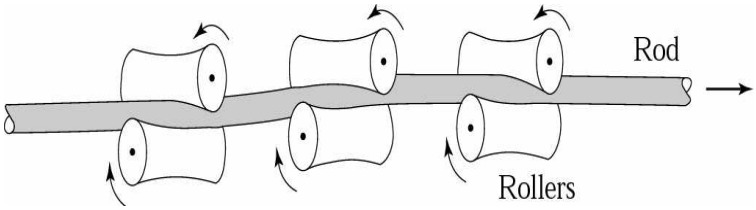


Terminology of a typical die used for drawing round rod or wire.

Tungsten- carbide die insert in a steel casing. Diamond dies, used in drawing thin wire, are encased in a similar manner.

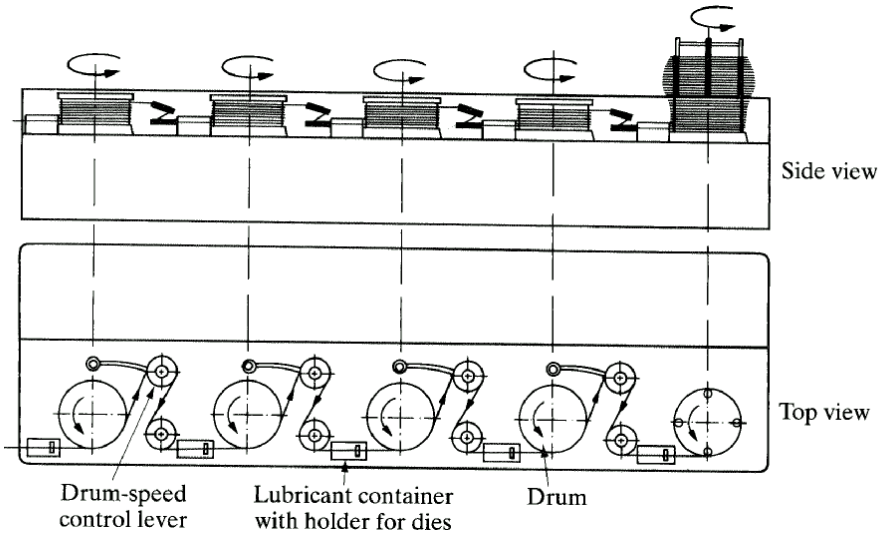


Roll Straightening



Schematic illustration of roll straightening of a drawn round rod

Multistage wire drawing machine



Variations – Drawing of Sheets and Plates

- Drawing is a plastic deformation in which a flat sheet or plate is formed into a recessed, three-dimensional part with a depth several times the thickness of the metal
- As a punch descends into a die or the die moves upward over a punch, the metal assumes the configuration of the mating punch and die tooling
- We distinguish between hot drawing and cold drawing

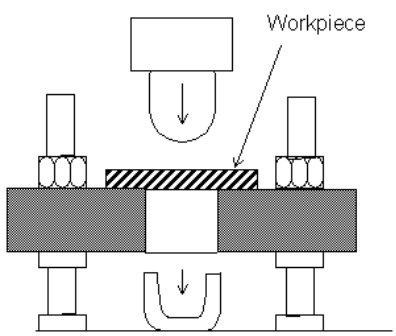
Extrusion

Variations – Drawing of Sheets and Plates

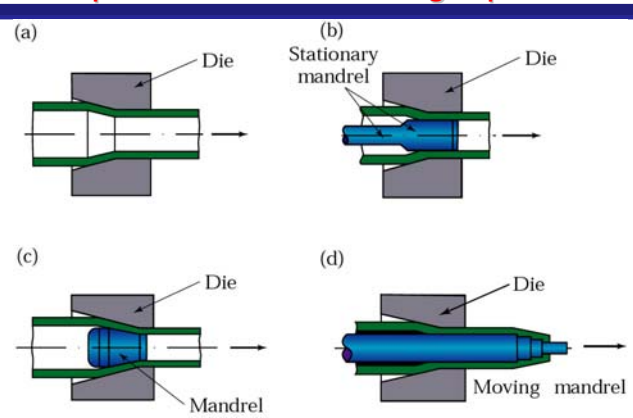
- Hot drawing is used for forming relatively thick-walled parts of simple geometry, usually cylindrical
  - The thickness of the material reduces considerably as it moves through the dies
  - This process is used in forming components such as oxygen tanks and large artillery shells
- Cold drawing uses relatively thin metal, changes the thickness very little or not at all, and produces parts in various shapes

Extrusion

Variations – Drawing of Sheets and Plates



Examples of Tube-Drawing Operations



Examples of tube-drawing operations, with and without an internal mandrel. Note that a variety of diameters and wall thicknesses can be produced from the same initial tube stock (which has been made by other processes).

Summary of Metal Forming Processes

- They rely on plastic flow of the bulk of the material
- Forces causing the plastic flow are the result of different kinds of machines
- Result in products which typically require subsequent processing to make useful products
- Products from these processes are ubiquitous