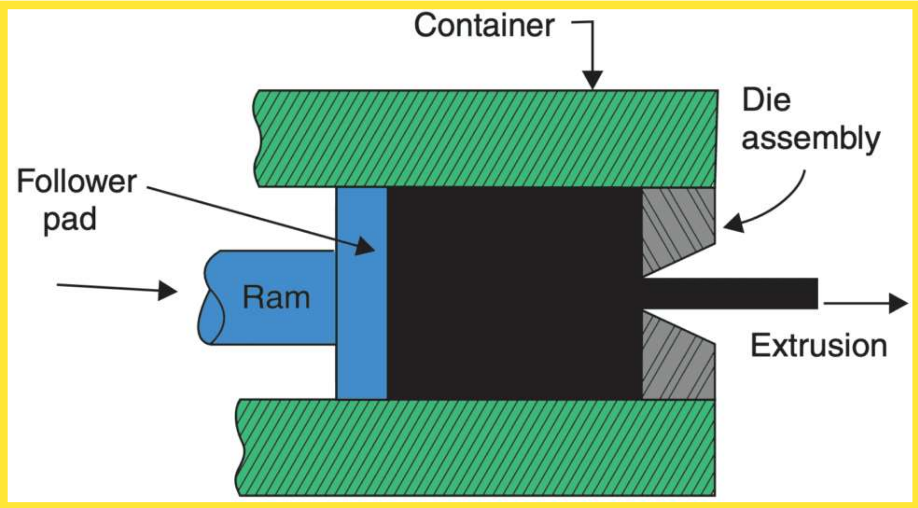
Module II

BULK FORMING OF METALS

EXTRUSION PROCESS

EXTRUSION PROCESS

- Extrusion is a compression process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape
- In the process, the metal assumes the opening provided in the die and comes out as a long strip with the same cross-section as the die-opening.
- Incidentally, the metal strip produced will have a longitudinal grain flow.



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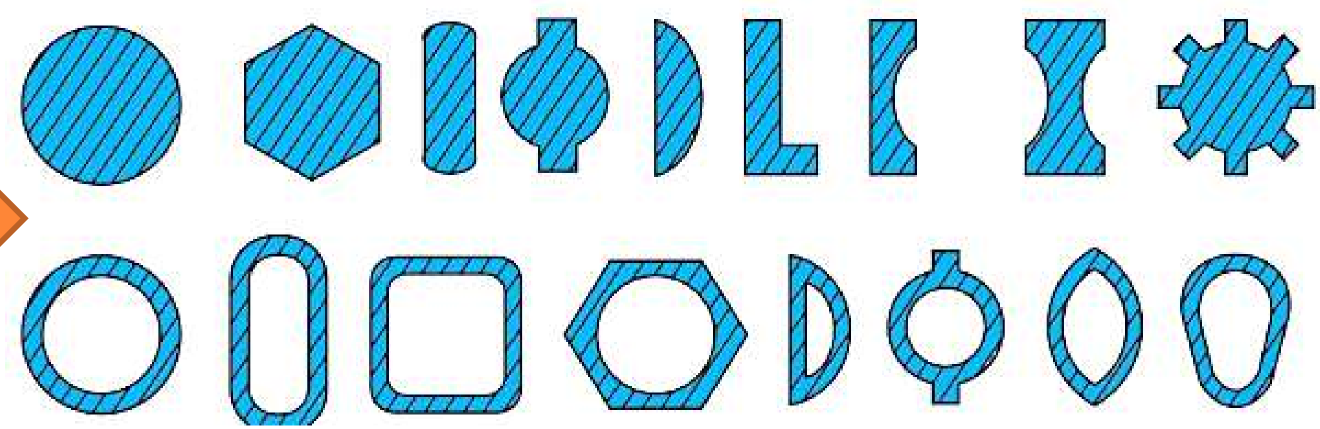
Extrusion Process

- Extrusion may be done hot or cold.
- The pressure required for extrusion depends upon the strength of the material and the extrusion temperature.
- Lesser pressure needed, if the material is hot.
- It will also depend upon the reduction in cross-section required and the speed of extrusion.

Types of extrusion sections



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EXTRUSION PROCESS

- There is a limit to the extrusion speed. If the extrusion is done **at a high speed, the metal may crack**.
- The reduction of cross-sectional area required is also called the **"extrusion ratio"**. There is a limit to this also.
- For **steel extruded hot**, this ratio should not exceed **40: 1**, but for **aluminum extruded hot** it can be as high as **400: 1**.

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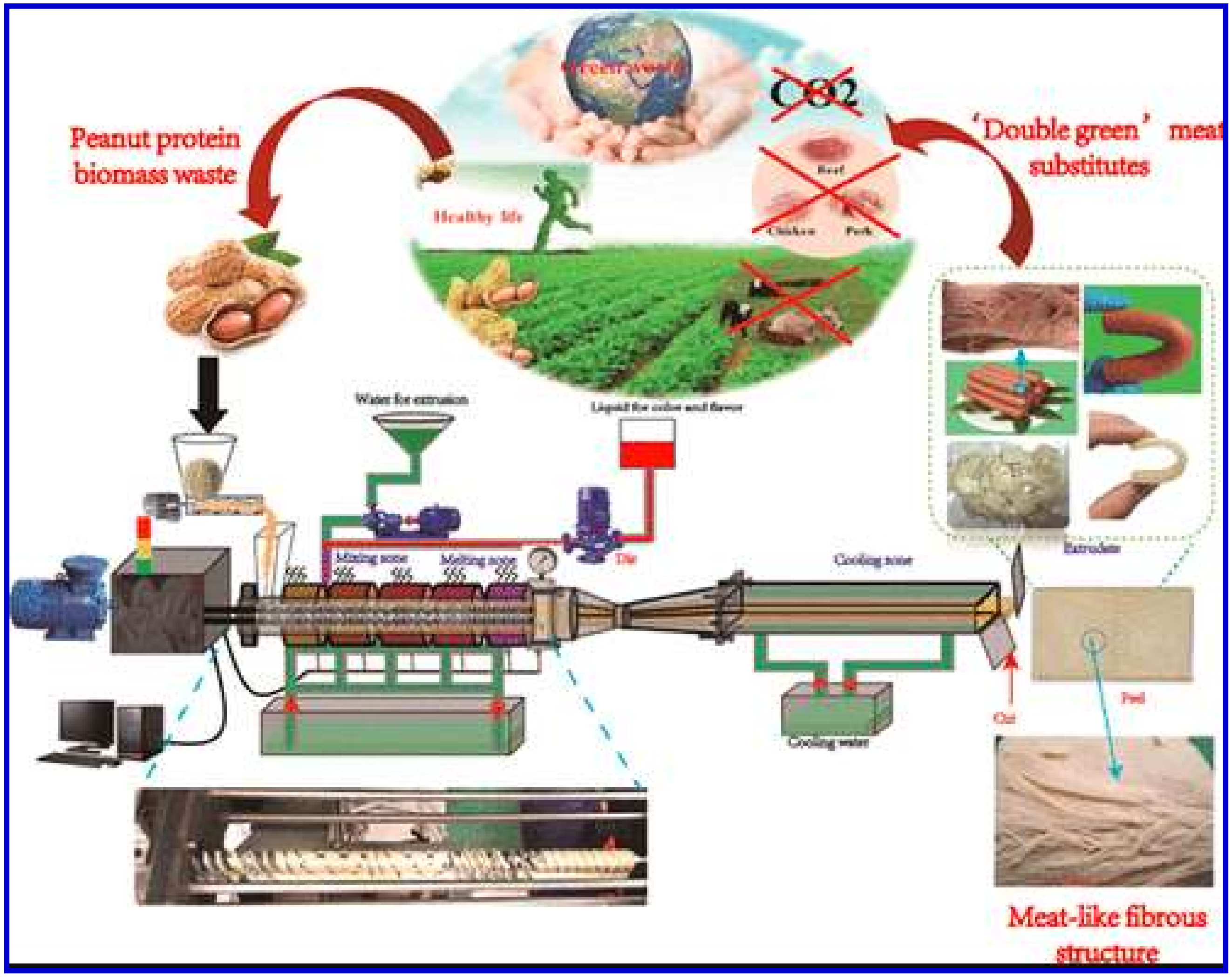
Extrusion in food industry



Zhang et al
(2019)

Converting Peanut Protein Biomass Waste into "Double Green" Meat Substitutes Using a High-Moisture Extrusion Process: A Multiscale Method to Explore a Process for Forming a Meat-Like Fibrous Structure

ADVANTAGES OF EXTRUSION OVER OTHER PROCESSES

- The complexity and range of parts that can be produced by the extrusion process are very large. Dies are relatively simple and easy to make.
- The extrusion process is complete in one pass only.
- This is not so in the case of rolling, the amount of reduction in extrusion is very large indeed.
- The extrusion process can be easily automated.
- Large diameter, hollow products, thin-walled tubes etc. are easily produced by the extrusion process.

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ADVANTAGES OF EXTRUSION OVER OTHER PROCESSES

- Good surface finish and excellent dimensional and geometrical accuracy is the hallmark of extruded products.
- This Extrusion process advantages cannot be matched by rolling.

However, a limitation is that the cross section of the extruded part must be uniform throughout its length.

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CLASSIFICATION OF EXTRUSION PROCESS

Hot Extrusion Processes

reduction of ram force, increased ram speed, and reduction of grain flow characteristics in the final product

- Forward or Direct extrusion
- Backward or Indirect extrusion

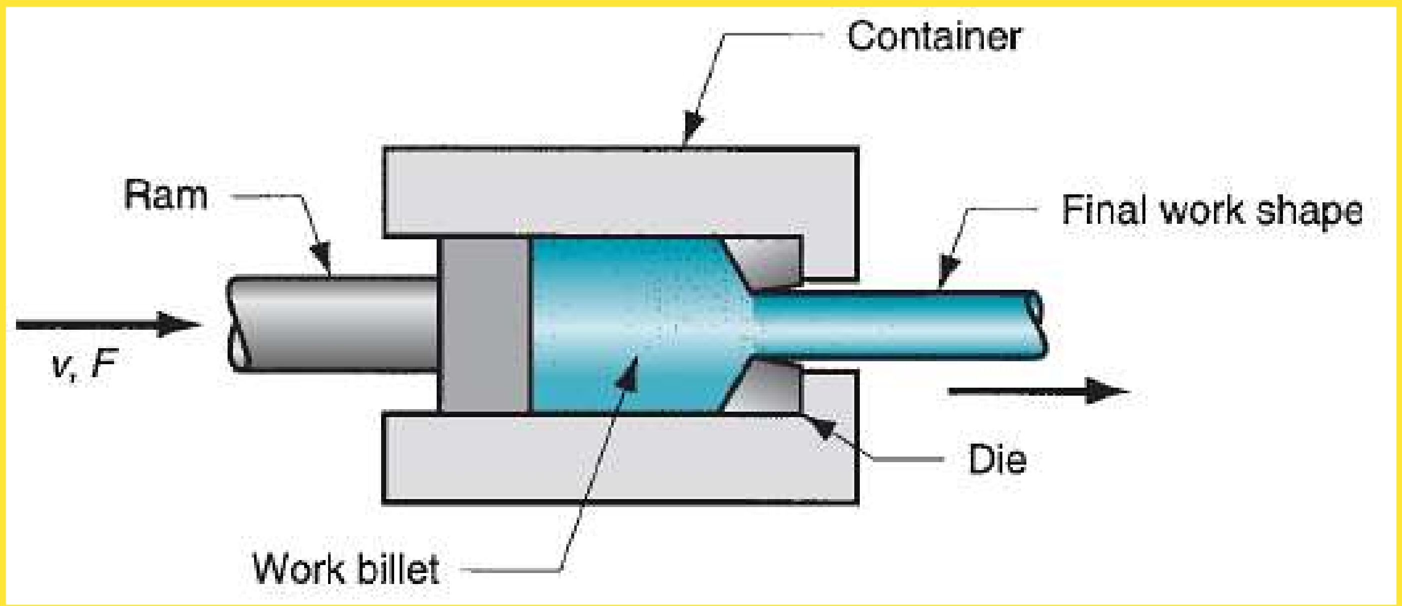
Cold extrusion process

increased strength due to strain hardening, close tolerances, improved surface finish, absence of oxide layers, and high production rates

- Hooker extrusion
- Hydrostatic extrusion
- Impact extrusion
- Cold extrusion forging

Hot extrusion – Forward Extrusion

- In this process, the material to be extruded is in the form of a block. It is heated to the requisite temperature and then it is transferred inside a chamber as shown in the below figure.



Hot extrusion – Forward Extrusion

- In the front portion of the chamber, a die with an opening in the shape of the cross-section of the extruded product is fitted.
- The block of material is pressed from behind by means of a ram and a follower pad.
- Since the chamber is closed on all sides, the heated material is forced to squeeze through the die opening in the form of a long strip of the required cross-section.

Hot extrusion – Forward Extrusion

- The process looks simple but the friction between the material and the chamber walls must be overcome by suitable lubrication.
- When extruding steel products, the high temperature at which the steel has to be heated makes it difficult to find a suitable lubricant.
- The problem is solved by using molten glass as a lubricant. **In addition to reducing friction**, it also provides effective thermal insulation between the billet and the extrusion container.

Hot extrusion – Forward Extrusion

- When lower temperatures are used, a mixture of oil and graphite is used as a lubricant.
- At the end of the extrusion process, a small piece of metal is left behind in the chamber which cannot be extruded.
- This piece is called butt end scrap and is thrown away.
- In hot extrusion, the friction problem is aggravated by the presence of an oxide layer on the surface of the billet. This oxide layer can cause defects in the extruded product.

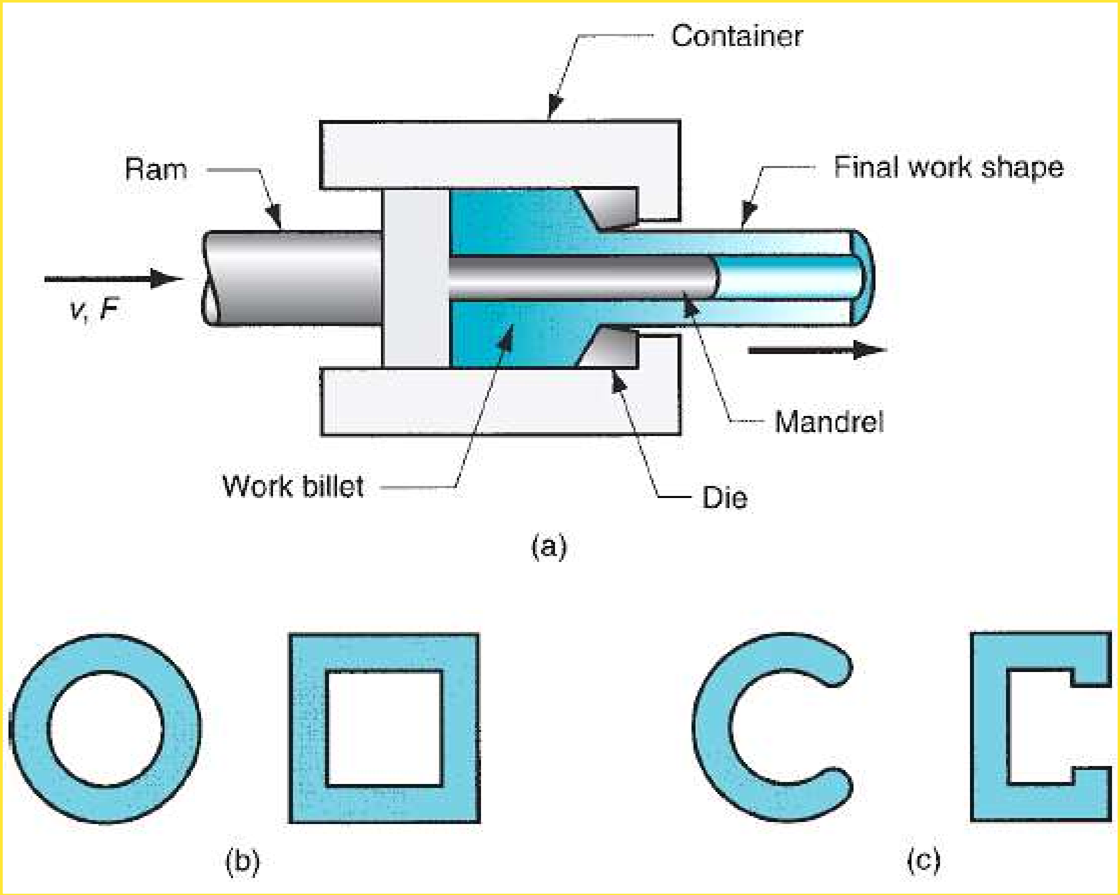
HOT EXTRUSION – FORWARD EXTRUSION

- To address these problems, a dummy block is often used between the ram and the work billet.
- The diameter of the dummy block is slightly smaller than the billet diameter, so that a narrow ring of work metal (mostly the oxide layer) is left in the container, leaving the final product free of oxides.

Hot extrusion – Forward Extrusion

- Hollow sections (e.g., tubes) are possible in direct extrusion by the process setup given below

(a) Direct extrusion to produce a hollow or semi-hollow cross section;
(b) hollow and
(c) semi-hollow cross sections.

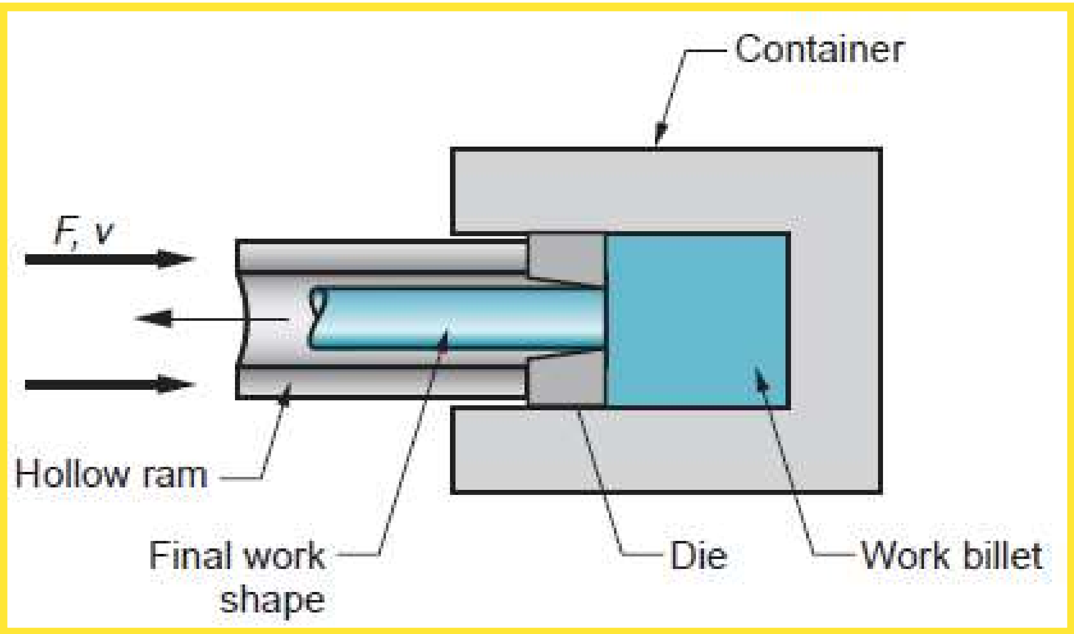


Hot extrusion – Forward Extrusion

- The starting billet is prepared with a hole parallel to its axis. This allows passage of a mandrel that is attached to the dummy block.
- As the billet is compressed, the material is forced to flow through the clearance between the mandrel and the die opening.
- The resulting cross section is **tubular**. **Semi-hollow cross-sectional shapes** are usually extruded in the same way.

Hot extrusion – indirect Extrusion

- In indirect extrusion, also called **backward extrusion and reverse extrusion** as shown in below Figure
- The die is mounted to the ram rather than at the opposite end of the container.

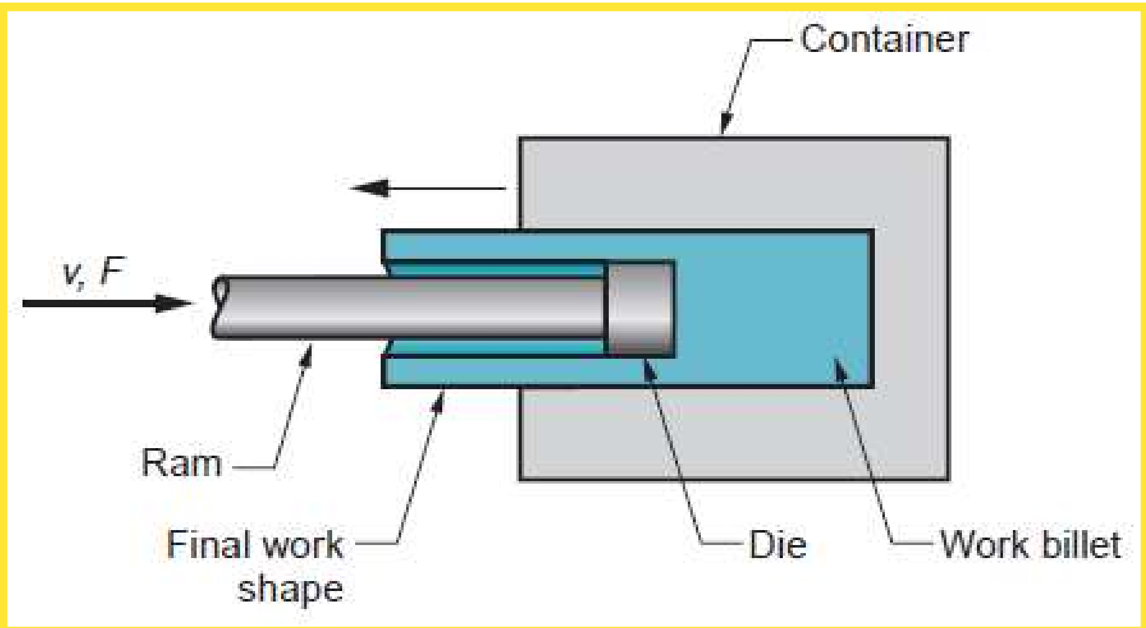


Hot extrusion – Indirect Extrusion

- As the ram penetrates into the work, the metal is forced to flow through the clearance in a direction opposite to the motion of the ram.
- Since the billet is not forced to move relative to the container, there is no friction at the container walls, and the ram force is therefore lower than in direct extrusion.
- **Limitations** of indirect extrusion are imposed by the lower rigidity of the hollow ram and the difficulty in supporting the extruded product as it exits the die.

Hot extrusion – indirect extrusion

- Indirect extrusion can produce hollow(tubular) cross sections, as in Figure
- In this method, the ram is pressed into the billet, forcing the material to flow around the ram and take a cup shape.



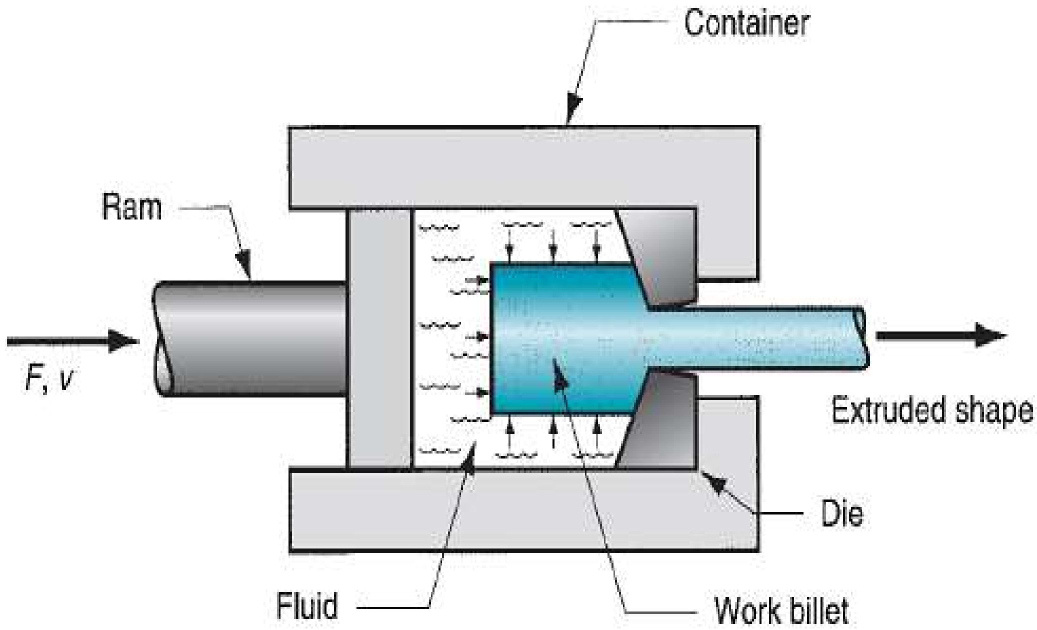
Hot extrusion – indirect Extrusion

- There are practical limitations on the length of the extruded part that can be made by this method.
- **Support of the ram becomes a problem as work length increases.**

Forward or direct extrusion	Backward or indirect extrusion
Simple, but the material must slide along the chamber wall.	In this case, the material does not move but the die moves.
High friction forces must be overcome.	Low friction forces are generated as the mass of material does not move.
High extrusion forces are required but mechanically simple and uncomplicated.	25-30% less extruding force is required as compared to direct extrusion. But hollow ram required limited application.
High scrap or material waste 18-20% on an average.	Low scrap or material waste is only 5-6% of billet weight.
Aluminum, copper, magnesium, zinc, tin, and their alloys	Low carbon steels and stainless steel

HYDROSTATIC EXTRUSION

- One of the problems in direct extrusion is friction along the billet–container interface.



- This problem can be addressed by surrounding the billet with fluid inside the container and pressurizing the fluid by the forward motion of the ram, as in Figure

Hydrostatic extrusion

- This way, there is no friction inside the container, and friction at the die opening is reduced.
- Consequently, ram force is significantly lower than in direct extrusion.
- The fluid pressure acting on all surfaces of the billet gives the process its name. It can be carried out at room temperature or at elevated temperatures.

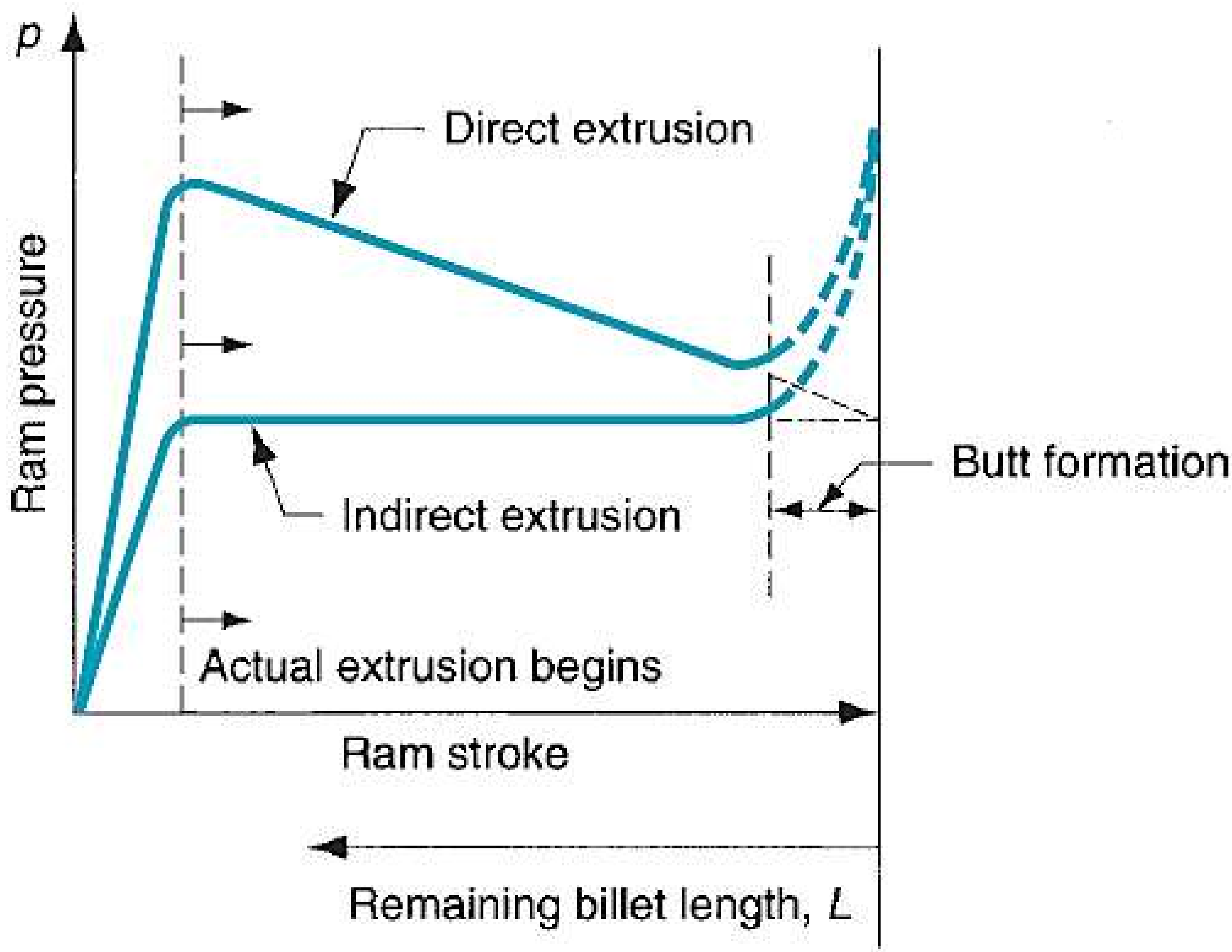
HYDROSTATIC EXTRUSION

- Special fluids and procedures must be used at elevated temperatures. Hydrostatic extrusion is an adaptation of direct extrusion
- Accordingly, <u>this process can be used on metals that would be too brittle for conventional extrusion operations</u>.
- Ductile metals can also be hydrostatically extruded, and high reduction ratios are possible on these materials.

Hydrostatic extrusion

- One of the **disadvantages** of the process is the **required preparation of the starting work billet**.
- The billet must be formed with a taper at one end to fit snugly into the die entry angle.
- This **establishes a seal to prevent fluid from squirting out the die hole when the container is initially pressurized**.

Comparison of Direct vs indirect extrusion processes



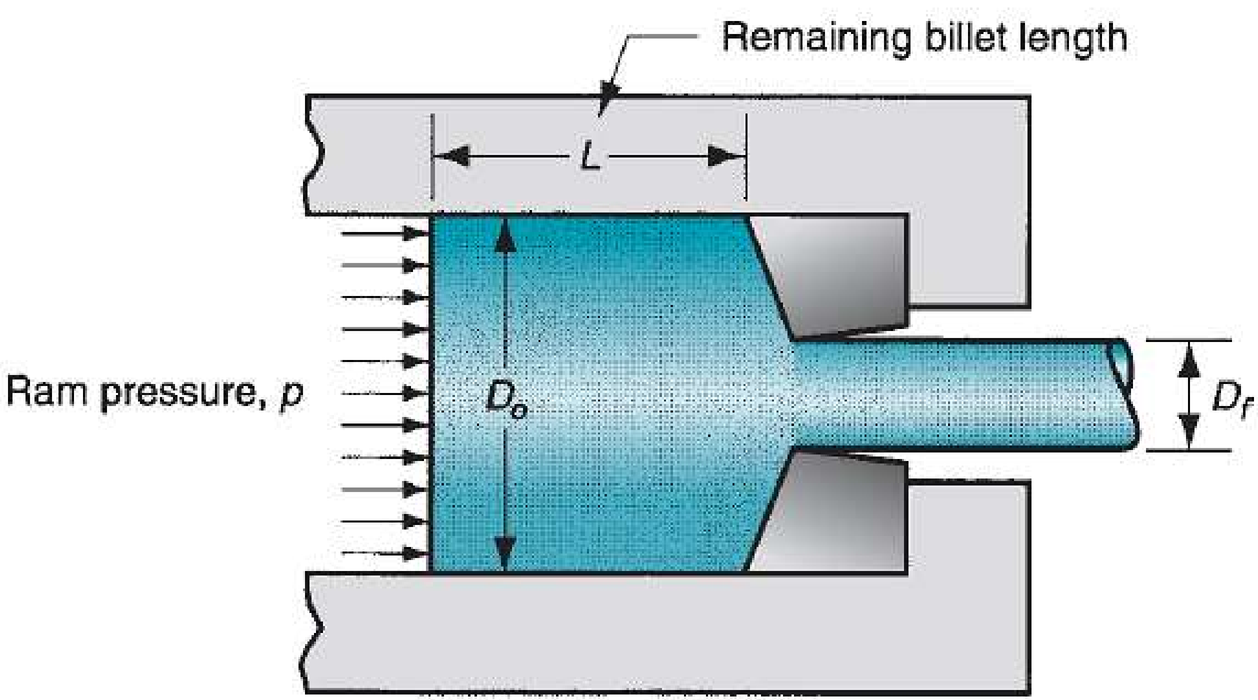
ANALYSIS ON EXTRUSION PROCESS

$$Extrusion\ ratio(r_x) = \frac{A_0}{A_f}$$

A_0-cross-sectional area of the starting billet,mm^2 (in^2); and A_f - final cross-sectional area of the extruded section,mm^2 (in^2)

The ratio applies for both direct and indirect extrusion

$$True\ strain\ (\epsilon) = ln\frac{A_0}{A_f}$$



Analysis on extrusion process

Various methods have been suggested to calculate the actual true strain and associated ram pressure in extrusion. The following empirical equation proposed by Johnson for estimating extrusion strain has gained considerable recognition

$$\epsilon_x = a + b \ln r_x$$

a = 0.8 and b = 1.2 to 1.5. Values of a and b tend to increase with increasing die angle.

The pressure applied by the ram to compress the billet through the die opening depicted in our figure can be computed as follows:

ANALYSIS ON EXTRUSION PROCESS

$$Ram\ pressure\ for\ indirect\ extrusion\ (P_{direct}) = \widehat{Y_f}\, ln r_x$$

$$\widehat{Y_f} = \frac{K \in^n}{1+n}$$

$$Ram\ pressure\ for\ direct\ extrusion (Pdirect) = \widehat{Y_f}\left(\in_x + \frac{2L}{D_0}\right)$$

$$\frac{2L}{D_0}\ accounts\ for\ additional\ pressure\ due\ to\ friction$$

$$at\ the\ container\ billet\ interface$$

With good lubrication, ram pressures would be lower than values calculated by this equation.

$$Ram\ force\ for\ direct\ or\ indirect\ extrusion (F) = PA_0$$

F = ram force in extrusion, N (lb), A_0 – billet area

$$Power = Fv \qquad where\ 'v' is\ ram\ velocity\ in\ m/s$$

SAMPLE PROBLEM

A billet 75mm long and 25 mm in diameter is to be extruded in a direct extrusion operation with extrusion ratio 4.0. The extrudate has a round cross section. The die angle (half angle) 90°. The work metal has a strength coefficient 415 MPa, and strain-hardening exponent 0.18. Use the Johnson formula with a = 0.8 and b = 1.5 to estimate extrusion strain. Determine the pressure applied to the end of the billet as the ram moves forward.

EXTRUSION – SAMPLE PROBLEM SOLUTION

$$\in = 1.3863$$

$$\in_x = 2.8795$$

$$\bar{Y}_f = 373\ MPa$$

Let us examine the ram pressure at billet lengths of L=75mm(starting value), L = 50 mm, L=25 mm, and L=0.

$$l = 75\ mm \qquad p = 373\left(2.8795 + 2\frac{75}{25}\right) = 3312\ MPa$$

$$l = 50\ mm \qquad p = 373\left(2.8795 + 2\frac{50}{25}\right) = 2566\ MPa$$

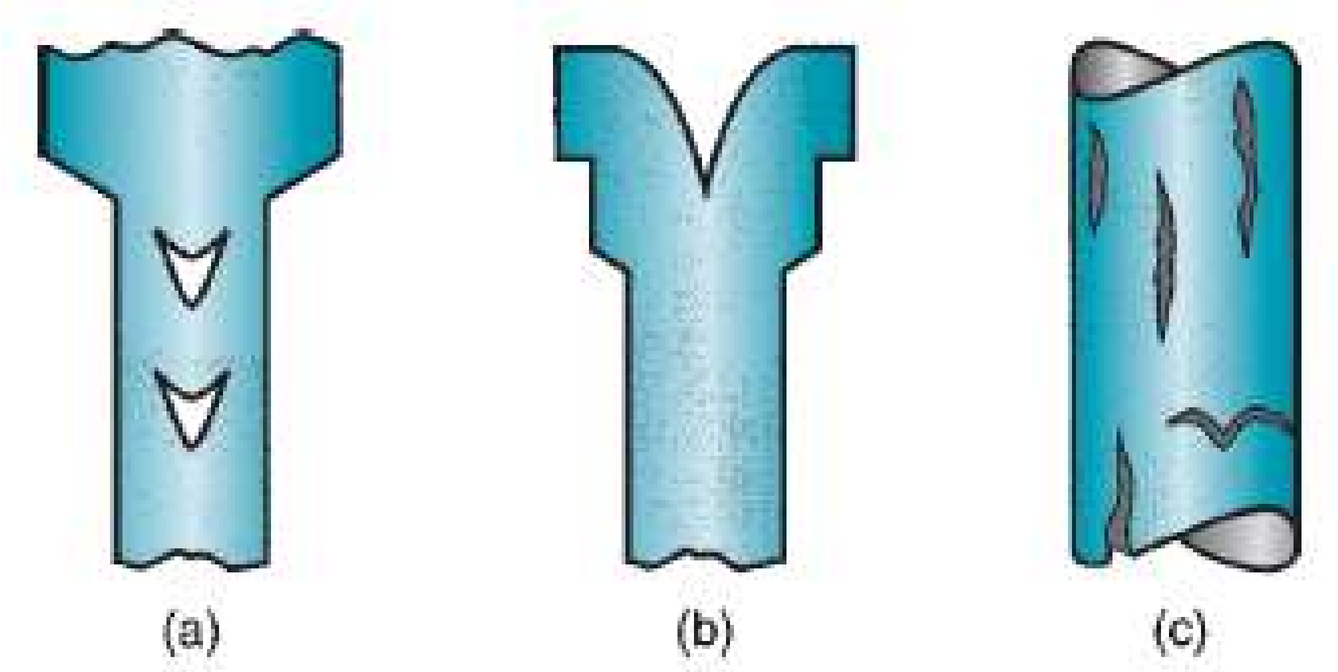
$$l = 25\ mm \qquad p = 373\left(2.8795 + 2\frac{25}{25}\right) = 1820\ MPa$$

$$l = 0\ mm \qquad p = 373\left(2.8795 + 2\frac{0}{25}\right) = 1074\ MPa$$

EXTRUSION – SAMPLE PROBLEM SOLUTION

- Zero length is a hypothetical value in direct extrusion In reality, it is impossible to squeeze all of the metal through the die opening.
- Instead, a portion of the billet (the "butt") remains un extruded and the pressure begins to increase rapidly as L approaches zero.
- This increase in pressure at the end of the stroke is seen in the plot of ram pressure versus ram stroke

DEFECTS IN EXTRUSION



Some common defects in extrusion: (a) center burst, (b) piping, and (c) surface cracking

DEFECTS IN EXTRUSION – CENTER BURST

- This defect is an internal crack that develops as a result of tensile stresses along the centerline of the work part during extrusion
- The significant material movement in these outer regions stretches the material along the center of the work. If stresses are great enough, bursting occurs.
- Tend to occur under conditions that cause large deformation in the regions of the work away from the central axis.

DEFECTS IN EXTRUSION – CENTER BURST

- Conditions that promote center burst are high die angles, low extrusion ratios, and impurities in the work metal that serve as starting points for crack defects.
- The difficult aspect of center burst is its detection. It is an internal defect that is usually not noticeable by visual observation.
- Other names sometimes used for this defect include **arrowhead fracture, center cracking, and chevron cracking**.

DEFECTS IN EXTRUSION – PIPING

- Piping is a defect associated with direct extrusion.
- It is the formation of a sink hole in the end of the billet.
- The use of a dummy block whose diameter is slightly less than that of the billet helps to avoid piping.
- Other names given to this defect include **tailpipe** and **fishtailing**.

DEFECTS IN EXTRUSION – SURFACE CRACKING

- This defect results from high work part temperatures that cause cracks to develop at the surface.
- They often occur when extrusion speed is too high, leading to high strain rates and associated heat generation.
- Other factors contributing to surface cracking are high friction and surface chilling of high temperature billets in hot extrusion

REFERENCES

- Serope Kalpakjian; Steven R. Schmid (2020), Manufacturing Engineering and Technology, Prentice Hall, ISBN 0-13-312874
- M P Groover (2020) Fundamentals of Modern Manufacturing Materials, Processes and Systems
- www.google.com; extrudesign.com