Unit 6: EXTRUSION

Introduction:

Extrusion is a metal working process in which cross section of metal is reduced by forcing the metal through a die orifice under high pressure. It is used to produce cylindrical bars, tubes and sections of any regular or irregular types. Forces required to extrude a metal are quite high and hence hot extrusion is most widely done as deformation resistance of metal is low at high temperature. However, cold extrusion is also performed for soft metals like Aluminum, lead etc.

Difficult to form metals like stainless steels, nickel based alloys and high temperature metals can also be extruded.

History; Originally the principle of extrusion was applied to make lead pipe and lead sheathing of electrical cables.

Types of Extrusion

1) Direct Extrusion

   In this process, the metal billet is placed in a container and compressed and extruded through the die by a ram.

   ![Diagram of Direct Extrusion]

Some features of direct extrusion:

- Both the ram and extrusion move in the same direction.
- A dummy block or pressure plate is in contact with the billet and ram.
• The relative motion between billet and container wall develops high friction. Hence power required is relatively high.

• Brittle metals like Tungsten, Titanium alloys are difficult to extrude because they fracture during the process. Fractures occur because of rapid growth of micro cracks due to tensile stresses.

2) Indirect Extrusion

A hollow ram compresses metal through a die in a direction opposite to ram motion. Either the ram is moved against a stationary billet or the billet (hence container) is made to move against stationary ram.

Some features of indirect extrusion:

• There is no relative motion between the billet and the wall of the container.

• Hence friction is lower and power required is relatively less.

• Limitation; Due to hollow ram, the load that can be applied is limited and only small sections can be extruded.

3) Tube extrusion

A mandrel is attached to the end of the ram as shown, which produces a hollow tube. The clearance between the mandrel and die wall determines the thickness of the tube.
To begin with, either a hollow billet is taken or a solid billet is first pierced through and then extruded.

4) Impact Extrusion

In this process a punch moves into the die and squeezes metal around the die cavity. It may have either direct or indirect extrusion arrangement.

It is useful to produce short lengths of hollow shapes like collapsible tooth paste tubes and thin walled cans.

It is usually a cold working process, but the high speed of deformation develops heating. The process is limited to soft metals like lead, tin, aluminum, copper.
5) Hydrostatic Extrusion

In this process the space between the ram plate and billet is filled with water. Hence billet is subjected to uniform hydrostatic pressure.

![Diagram of Hydrostatic Extrusion](image)

Fig. Hydrostatic Extrusion

Also, there is no direct contact between wall of container and work piece. Hence there is no container-billet friction. As a result, the curve of extrusion pressure v/s ram travel is nearly flat. Therefore, large length to diameter ratios are possible. eg coils of wire.

Advantages:

i) Lubrication is very effective.

ii) Extruded product has good surface finish and dimensional accuracy.

iii) It is possible to use dies with very low semi cone angle (about 20 degrees) because friction is less.

iv) This reduces extrusion pressure and improves homogeneity of deformation.

v) Redundant deformation is minimized.

Limitations:

i) Hot working is not possible.

ii) Leakages of liquid are frequent due to high pressures involved (upto 1.7GPa)

iii) Liquid used should not solidify at high pressure.

iv) Extrusion ratios possible; 20:1 for mild steel, 200:1 for aluminum.
Extrusion Equipment

I) Hydraulic Press

Types based on direction of ram travel:

i) Vertical Press and ii) Horizontal Press

i) Vertical Press (3 MN to 20 MN)

The ram acts vertically on the billet and squeezes it through the die.

Advantages:

i) Easier alignment between the press ram and tools.

ii) Hence closer control on tolerances is possible.

iii) High rates of production.

iv) Requires less floor space.

v) Produces uniform cooling of billet in container. Hence symmetrically uniform deformation of metal occurs.

Limitations:

i) This requires more head room to accommodate vertical motion of ram

ii) Floor pits are needed to accommodate long extrusions.

Applications: Thin walled tubing where uniform wall thickness and concentricity are required.
II) **Horizontal Press (15 MN to 50 MN)**

Ram moves horizontally and extrudes metal.

![Diagram of Horizontal Press](image)

**Advantages:**

i) The head room required is less compared to vertical press.

**Limitations:**

i) Alignment between press ram and tools is difficult.

ii) The bottom of the billet is more in contact with the container wall and hence it is cooled faster compared to the top of the billet. Therefore deformation is non-uniform.

iii) To overcome above difficulty, the container walls are internally heated to avoid differential cooling of the billet.

**Ram speed:**

Higher ram speeds are required for high temperature extrusion to prevent heat loss to container walls.

Ram speeds of 0.4m/s to 0.6m/s are used to extrude refractory metals.

**Dies and Toolings**

They must withstand high stress and thermal shocks/oxidation. From economics point of view, another important requirement of the dies is that easy replacement of damaged parts and reuse of parts after reworking must be possible.
Typical arrangement of extrusion tooling:

- The die is supported in a die (6) holder(5) and bolster (7).
- The die head (2) all the above parts 5,6 and7.
- The wedge (1) applies pressure and seals the entire assembly.
- The liner(4) is shrunk into container(3) to produce compressive pre stress in the inside surface of liner (Liner needs periodic replacements)

Types of extrusion dies

1) Flat Faced Dies

Some important features:

- It is used when metal entering the die forms a dead zone and shears internally to form its own die angle.
• A parallel land on the exit side of the die strengthens the die.
• It also allows reworking of the flat face on the entrance side without increasing the exit diameter.

2) Conical Dies

![Conical Die](image)

Fig. Conical Die

Some important features:

• The entrance side has conical shape and taper.
• They are used in extrusion with good lubrication.
• Die angle is decreased and this increases homogeneity of deformation and also reduces extrusion pressure.
• If the angle is too small, it leads too high friction in die surface. Hence an optimal angle is necessary.

Other supporting systems required in extrusion equipment:

a) Provision for heating extrusion container
b) Billet heating facilities
c) Automatic transfer equipment for placing the heated billet in the container
d) Hot saw to cut off extrusion product
e) Run out table to catch the extrusion
f) Straightener to correct minor warpage of the extruded product.
Extrusion Variables

They affect the extrusion process considerably. They are:

1) Type of extrusion (direct or indirect)

   In direct extrusion process, metal begins to flow through the die at the maximum value of the pressure called "break through pressure".

   As billet extrudes, the pressure required progressively decreases with decreasing length of the billet in the container (because, the friction between the billet and container decreases).
   
   • In indirect extrusion, there is no relative motion between billet and wall. Therefore extrusion pressure is almost constant with increase in ram travel.
   • It represents the stress required to deform the metal through the die.
   • Limited in application by the need of hollow ram, which limits the size of extrusion & pressure.
   • Hence most of the hot extrusion is done by direct extrusion.
   • At the end of the ram stroke, there is a rapid pressure build up & therefore a small “discard” is left behind in the container, without extruding it.

2. Extrusion Ratio: \( R \)

   \[ R = \frac{\text{Initial cross area of the billet}}{\text{final cross section area after extrusion}} \]

   \[ R = \frac{A_o}{A_f} \]

   Up to = 40 : 1 for hot extrusion of steel

   Up to = 400 : 1 for Aluminium

   ❖ A small change in the fractional reduction results in large increase in extrusion ratio

   Velocity of extruded product = ram velocity \( \times R \)

   Therefore high sliding velocities exist along the die land.

   Extrusion Pr. = \( P = K A_o \ln \left( \frac{A_o}{A_f} \right) \)
K = extrusion constant, which accounts for flow stress, friction, and inhomogeneous deformation.

3. Temperature:

Hot extrusion decreases flow stress of metal, but increases oxidation of billet & extrusion tools. Other features are:

- Softens die & tools
- Difficult to provide lubrication
- Therefore it is advantageous to use the min. temp. which provides required plasticity to metal.

- The upper hot working temp. of metal is the temp. at which “Hot shortness” occurs.
- Higher plastic deformations involved also lead to internal heating of the metal.
- Therefore max. working temp. must be safely below the melting point.
- Typical Values steel billets heated to 1100°C to 1200°C
- Toolings: preheated to 350°C.

4. Extrusion pressures – range: 800 MPa to 1200 MPa

5. Lubrication: (Glass)

- To be maintained at high temperature & under high pressure.
- Low strength alloy (Al) does not require lubrication.
- Metal deformation is non-uniform and therefore wide variation in heat treatment response is observed
- Effect of temperature, pressure & strain rate on the allowable working range or interdependence of extrusion speed & temperature:
- For a given working pressure & temperature there will be a maximum amount of deformation possible on the work piece.
- As pre heat temperature of billet increases, the flow stress falls & therefore amount of possible deformation increases
- As strain rate of deformation increases, more heat is retained in the work & therefore work temperature will have to be reduced so that final temperature is below hot shortness temperature.

6. Ram speed:

Increase in ram speed increases the extrusion pressure.

Whereas, low ram speeds leads to cooling of the billet and because of billet cooling, flow stress is increased.

- The higher the temperature of billet, the greater the effect of low extrusion speed on the cooling of the billet.

- Therefore high extrusion speeds are required with high strength alloys which need high extrusion temperatures.

- At the same time at high extrusion speeds, temperature rise due to deformation is greater.

- The selection of proper extrusion speed & temperature is best determined by trial & error for each alloy and billet size.

- For a given extrusion pressure the extrusion ratio which can be obtained increases with increasing temperature.

- For a given temperature a large extrusion ratio can be obtained with high pressure.

- Maximum billet temperature is determined by the temperature at which melting is about to occur.

- The temperature rise of extrusion is determined by the speed of extrusion & extrusion ratio.

Deformation, Lubrication and Defects in Extrusion:

Pressure required in extrusion depends on the way the metal flows in the container & extrusion die. The metal flow is mainly determined by conditions of lubrication.

Deformation in Extrusion Process

The defects in extrusion are related to the way in which metal deforms during extrusion.

(1) Homogeneous Deformation: (with less friction)

Fig a) indicates homogeneous deformation in direct extrusion.
Fig d) shows homogeneous deformation in indirect extrusion.

The following conditions are favorable for homogeneous deformation:

i) Low container friction
ii) Well lubricated billet
iii) Hydrostatic extrusion conditions
iv) Indirect extrusion process.

Characteristics of homogeneous deformation:

The deformation is more uniform until close to the die entrance where metal flow is restricted.

(2) Deformation with more friction between billet and container wall

Fig (b) above indicates increased container wall friction.

- This is indicated by severe distortion of grid pattern at the corners of the die due to a “dead zone.”
• The dead zone consists of stagnant metal which does not undergo any deformation.
• The grid elements at the centre of the billet undergo pure elongation into the extruded rod.
• The grid elements near the sides of the billet undergo shear deformation.
• The shear deformation requires additional energy called “redundant work”. This work is not related to metal working from billet to extruded product.

(3) Deformation with very high friction

Fig (c) above indicates the condition of high friction at the container – billet interface.

• The metal flow is concentrated towards the centre.
• An internal shear plane develops due to high friction.
• This situation also exists when the billet surface is chilled by a cold container. This is because, at low temperature of the billet at the sides, the flow stress increases compared to the flow stress at the central portion of the billet.
• Under such sticking conditions between the billet and container, a shear zone is formed along which the metal separates internally.
• In this condition, extruded product contains clean new metal and outer surface of billet remains in the container.

Lubrication in Extrusion Process

The following are the requirements of a lubricant in hot extrusion:
• It must have a low shear strength
• It must be stable enough without breaking down at high working temperatures.
• The most widely used lubricant for steels and nickel based alloys is “molten glass”.

The process using molten glass as lubricant is called “Ugine-Sejournet Process”.

The steps involved are:
• The billet is heated in inert atmosphere.
• It is coated with glass powder before it enters the extrusion container.
• The glass coating serves as a lubricant and also as a thermal insulator, thereby reducing heat loss from billet to container wall and other tools.
• The thickness of glass film between extrusion and die is about 25 microns.

Interaction between optimal lubricant, temperature and ram speed:

• If ram speed is too low, the lubricant is thick because of low initial extrusion pressure. This exhausts the glass reservoir rapidly. This increases cost of lubricant.
• If the ram speed is too high, the glass film becomes too thin and friction increases.

Important requirements of lubrication:

• The lubricant film must be complete and continuous to be successful.
• Any gaps in film develops shear zones in metal which eventually develop into surface cracks.

Defects in Extrusion

1) **Laminations of glass/ oxide** into the interior of extrusion.
   Cause: Improper lubrication method
   Remedy: To provide optimum lubrication on the outside of billet and to use optimal ram speed.

2) **Extrusion defect:**
   The last 1/3rd of extrusion may have oxides and other impurities in it rendering it unfit for use because of poor mechanical properties. This leads to the formation of “annular ring of oxide” in the extruded product.
Cause: The metal in the middle (2/3rd) is first extruded as it moves faster than the periphery of billet due to friction. This tendency of extrusion defect increases with friction between billet and container wall.

Remedy: The last 1/3rd of billet is left out without extruding it. But this is economically not feasible. Instead a “follower block” is widely used. This block is slightly smaller diameter than the container and it scalps or scrapes the billet, leaving behind the oxide layers in the container.

3) **Axial Hole/ Funnel:**
   It is an axial hole in the back end of extrusion.
   Cause: Rapid radial flow of metal during extrusion of last 1/4th of billet.
   Remedy: Inclining the face of the ram at an angle to the ram axis.

4) **Surface Cracking:**
   It is in the form of rough surface or fir-tree cracking.
   Cause: i) Longitudinal tensile stresses generated as extrusion passes through the die.
       ii) Very high ram speed for the given temperature.
   Remedy: Use of optimal ram speed and billet temperature and heating the container.

5) **Center Burst (or Chevron Cracking):**
   Cause: Low extrusion ratios and low friction in the deformation zone at the die.
   Remedy: Increasing the friction at tool-billet interface to obtain a sound product.

6) **Variation in hot worked structure and properties:**
   This is the non-uniform properties of the extruded product, having variation in properties from front to back end.
Extrusion of Tubes

By piercing and extruding in one step:

This method is better compared to the one using a mandrel.

The piercing mandrel and the ram are operated by two separate hydraulic systems. This requires a double action extrusion press. Steps:

i) First the piercing mandrel is withdrawn and the billet is pressed with the ram.

ii) Next, the billet is pierced with the sharp mandrel, ejecting a metal plug through the die.

iii) Then the ram advances and extrudes the billet over the mandrel to produce the tube.