Metal Forming Processes

Dr. Pulak M. Pandey

http://paniit.iitd.ac.in/~pmpandey
Introduction

- Practically all metals, which are not used in cast form are reduced to some standard shapes for subsequent processing.
- Manufacturing companies producing metals supply metals in form of ingots which are obtained by casting liquid metal into a square cross section.
  - Slab (500-1800 mm wide and 50-300 mm thick)
  - Billets (40 to 150 sq mm)
  - Blooms (150 to 400 sq mm)
- Sometimes continuous casting methods are also used to cast the liquid metal into slabs, billets or blooms.
- These shapes are further processed through hot rolling, forging or extrusion, to produce materials in standard form such as plates, sheets, rods, tubes and structural sections.
Sequence of operations for obtaining different shapes

1. Slab → Hot rolling → Plates Sheets
2. Ingot → Hot rolling → Billet
3. Bloom → Hot rolling → Structural sections
4. Billet → Hot rolling → Bars Rods
5. Cold rolling → Plates Sheets
6. Bars Wires → Drawing

Sequence:
1. Slab → Hot rolling → Plates Sheets
2. Ingot → Hot rolling → Billet
3. Bloom → Hot rolling → Structural sections
4. Billet → Hot rolling → Bars Rods
5. Cold rolling → Plates Sheets
6. Bars Wires → Drawing
Primary Metal Forming Processes

- Rolling
- Forging
- Extrusion
- Tube and wire drawing
- and Deep drawing

Although Punching and Blanking operations are not metal forming processes however these will be covered due to similarity with deep drawing process.
Rolling
Change in grains structure in rolling

(a) Ingot with nonuniform grains
(b) Wrought product with large grains

Deformed elongated grains
New grains forming
Recrystallization complete

Hot rolling
New grains growing
Wrought product with small, uniform grains
Salient points about rolling

- Rolling is the most extensively used metal forming process and its share is roughly 90%.
- The material to be rolled is drawn by means of friction into the two revolving roll gap.
- The compressive forces applied by the rolls reduce the thickness of the material or changes its cross sectional area.
- The geometry of the product depend on the contour of the roll gap.
- Roll materials are cast iron, cast steel and forged steel because of high strength and wear resistance requirements.
- Hot rolls are generally rough so that they can bite the work, and cold rolls are ground and polished for good finish.
In rolling the crystals get elongated in the rolling direction. In cold rolling crystal more or less retain the elongated shape but in hot rolling they start reforming after coming out from the deformation zone.

The peripheral velocity of rolls at entry exceeds that of the strip, which is dragged in if the interface friction is high enough.

In the deformation zone the thickness of the strip gets reduced and it elongates. This increases the linear speed of the at the exit.

Thus there exist a neutral point where roll speed and strip speeds are equal. At this point the direction of the friction reverses.

When the angle of contact $\alpha$ exceeds the friction angle $\lambda$ the rolls cannot draw fresh strip.

Roll torque, power etc. increase with increase in roll work contact length or roll radius.
Pressure during rolling

Typical pressure variation along the contact length in flat rolling. The peak pressure is located at the neutral point. The area beneath the curve, represents roll force.

Friction in rolling: It depends on lubrication, work material and also on the temperature. In cold rolling the value of coefficient of friction is around 0.1 and in warm working it is around 0.2. In hot rolling it is around 0.4. In hot rolling sticking friction condition is also seen and then friction coefficient is observed up to 0.7. In sticking the hot wok surface adheres to roll and thus the central part of the strip undergoes with a severe deformation.
Roll passes to get a 12 mm rod from 100 x 100 mm billet
Roll configurations in rolling mills

- Two-high and three-high mills are generally used for initial and intermediate passes during hot rolling, while four-high and cluster mills are used for final passes.

- Last two arrangements are preferred for cold rolling because roll in these configurations are supported by back-up rolls which minimize the deflections and produce better tolerances.
Various Roll Configurations (a) Two-high (b) Three-high (c) Four-high (d) Cluster mill (e) Tandem mill
Other deformation processes related to rolling
Forging

- Forging is perhaps oldest metal working process and was known even during prehistoric days when metallic tools were made by heating and hammering.
- Forging is basically involves plastic deformation of material between two dies to achieve desired configuration. Depending upon complexity of the part forging is carried out as open die forging and closed die forging.
- In open die forging, the metal is compressed by repeated blows by a mechanical hammer and shape is manipulated manually.
- In closed die forging, the desired configuration is obtained by squeezing the workpiece between two shaped and closed dies.
On squeezing the die cavity gets completely filled and excess material comes out around the periphery of the die as flash which is later trimmed.

Press forging and drop forging are two popular methods in closed die forging.

In press forging the metal is squeezed slowly by a hydraulic or mechanical press and component is produced in a single closing of die, hence the dimensional accuracy is much better than drop forging.

Both open and closed die forging processes are carried out in hot as well as in cold state.

In forging favorable grain orientation of metal is obtained
Open and closed die forging
Grain orientation in forging

Forging       Machining
Barreling in forging

Flash less forging or precision forging
Self reading in forging

- Fullering
- Edging
- Cogging
- Upsetting
- Heading
- Swaging
- Radial forging etc.

Go through any book on Manufacturing processes by Kalpakjian, Groover or Degarmo
Extrusion

- It is a relatively new process and its commercial exploitation started early in the nineteenth century with the extrusion of lead pipes. Extrusion of steels became possible only after 1930 when extrusion chambers could be designed to withstand high temperature and pressure.

- In extrusion, the material is compressed in a chamber and the deformed material is forced to flow through the die. The die opening corresponds to the cross section of the required product.

- It is basically a hot working process, however, for softer materials cold extrusion is also performed.
Direct and Indirect Extrusion

- In direct extrusion metal flows in the same direction as that of the ram. Because of the relative motion between the heated billet and the chamber walls, friction is severe and is reduced by using molten glass as a lubricant in case of steels at higher temperatures. At lower temperatures, oils with graphite powder is used for lubrication.

- In indirect extrusion process metal flows in the opposite direction of the ram. It is more efficient since it reduces friction losses considerably. The process, however, is not used extensively because it restricts the length of the extruded component.
Impact Extrusion

It is similar to indirect extrusion. Here the punch descends rapidly on to the blank which gets indirectly extruded on to the punch and to give a tubular section. The length of the tube formed is controlled by the amount of metal in the slug or by the blank thickness. Collapsible tubes for pastes are extruded by this method.
Hydrostatic Extrusion

In this process the friction between container wall and billet is eliminated, however, this process has got limited applications in industry due to specialized equipment & tooling and low production rate due to high set up time.
Large quantities of wires, rods, tubes and other sections are produced by the drawing process which is basically a cold working process. In this process the material is pulled through a die in order to reduce it to the desired shape and size.

In a typical wire drawing operation, once end of the wire is reduced and passed through the opening of the die, gripped and pulled to reduce its diameter.
- By successive drawing operation through dies of reducing diameter the wire can be reduced to a very small diameter.
- Annealing before each drawing operation permits large area reduction.
- Tungsten Carbide dies are used for drawing hard wires, and diamond dies is the choice for fine wires.
Tube drawing

• Tube drawing is also similar to wire drawing, except that a mandrel of appropriate diameter is required to form the internal hole.

• Here two arrangements are shown in figure (a) with a floating plug and (b) with a moving mandrel.

• The process reduces the diameter and thickness of the tube.
Deep Drawing

- This operation is extensively used to make cylindrical shaped parts such as cups, shells, etc from sheet metal.

- As the blank is drawn into the die cavity, compressive stress is set up around the flange and it tends to wrinkle or buckle the flange.
Deformation of workpiece during punch travel
Defects in drawing

(a) Wrinkling in the flange or (b) in the wall (c) tearing, (d) earing, (e) surface scratches
The effect of wrinkling and buckling can be seen from the way a trapezoid on the outer surface of the blank is stretched in one direction and compressed in another direction to become a rectangle on the cup drawn.
Wrinkling and buckling is avoided by applying a blank holder force through a blank holder. Blank holder force increases friction and hence the required punch load. Therefore, blank holder force should be just enough to prevent wrinkling of the flange.

The edges of the punch and die are rounded for the easy and smooth flow of metal.

Sufficient clearance is also provided so that sheet metal could be easily accommodated. In sufficient or large clearance may result into shearing and tearing of sheet.

A drawn cup can be redrawn into a smaller cup but it must be annealed to prevent failure.
Punching and Blanking

- Punching and blanking operations are not metal forming operations but are discussed together with metal forming because of their similarity with deep drawing operation.

- Objective of punching and blanking is to remove material from the sheet metal by causing rupture, the punch and die corners are not provided with any radius.

- Tool steel is the most common material for tool and die. Carbides are also used when high production is needed.
## Comparison of metal forming processes

<table>
<thead>
<tr>
<th>Metal Forming Process</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-die forging</td>
<td>• Inexpensive tooling and equipment. • Simple to operate. • Wide range of workpiece sizes can be used. • Suitable for low production volume.</td>
<td>• Can be used for simple shapes only. • Fairly skilled operators are required. • Production rate is low. • Dimensional accuracy and surface finish achieved are poorer. • Finishing required for achieving final shape.</td>
</tr>
<tr>
<td>Closed-die forging</td>
<td>• Suitable for high production rate. • Can be used for production of complex shapes. • Good dimensional accuracy and reproducibility</td>
<td>• High equipment and tooling cost. • Appropriate die set for production of each component. • More than one step required for each forging. • Finishing required for achieving final shape.</td>
</tr>
<tr>
<td>Hot rolling</td>
<td>• High production rate. • Suitable for large reduction. • Wide range of shapes (Billets, blooms, slabs, sheets, bars, tubes, structural sections, etc.) can be produced</td>
<td>• High equipment cost • Suitable for production of large sections. • Poor dimensional accuracy and finish.</td>
</tr>
<tr>
<td>Metal Forming Process</td>
<td>Advantages</td>
<td>Limitations</td>
</tr>
<tr>
<td>-----------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
</tbody>
</table>
| Cold rolling          | • High production rate.  
                       • Suitable for production of plates, sheets, foils, etc.  
                       • Good dimensional accuracy and finish.                  | • High equipment cost.  
                       • Deformation limited to small reductions.            |
| Hot extrusion         | • Moderate cost of equipment and toolings.  
                       • Suitable for large reduction.  
                       • Complex sections and long products can be produced. | • Only constant cross-section can be produced.  
                       • Components with thin walls are difficult to produce.  
                       • Lubrication is necessary.  
                       • Dimensional accuracy and finish achieved are not good. |
| Impact extrusion      | • High production rate.  
                       • Good finish and dimensional accuracy.  
                       • Generally no finishing is required.  
                       • Suitable for production of thin sections.       | • Suitable for production of light components from softer materials.  
                       • Deformation limited to small reductions.          |
<table>
<thead>
<tr>
<th>Metal Forming Process</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing</td>
<td>• Low equipment and tooling cost.</td>
<td>• Deformation limited to small reductions.</td>
</tr>
<tr>
<td></td>
<td>• Good surface finish and dimensional accuracy.</td>
<td>• Production of constant cross-sections only.</td>
</tr>
<tr>
<td></td>
<td>• High production rate.</td>
<td>• Lubrication is necessary.</td>
</tr>
<tr>
<td></td>
<td>• Long lengths of rounds, tubings, square, angles, etc. can be produced.</td>
<td></td>
</tr>
<tr>
<td>Deep drawing</td>
<td>• High production rate.</td>
<td>• Limited to forming of thin sheets.</td>
</tr>
<tr>
<td></td>
<td>• Moderate equipment and tooling cost.</td>
<td>• Forming of shallow or deep parts of simple</td>
</tr>
<tr>
<td></td>
<td>• Good surface finish.</td>
<td>shapes only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Finishing required.</td>
</tr>
<tr>
<td>Punching and blanking</td>
<td>• High production rate.</td>
<td>• Limited to thin sheet applications.</td>
</tr>
<tr>
<td></td>
<td>• Low cost of labour.</td>
<td>• Cost of tooling can be high.</td>
</tr>
<tr>
<td></td>
<td>• Almost any shape can be obtained.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Moderate equipment cost.</td>
<td></td>
</tr>
</tbody>
</table>
Self reading for your interest

Defects in metal forming processes and their remedies. (use Kalpakjian’s book)
Defects in Rolling

Schematic illustration of typical defects in flat rolling: (a) wavy edges; (b) zipper cracks in the center of the strip; (c) edge cracks; and (d) alligating.
Examples of defects in forged parts. (a) Laps formed by web buckling during forging; web thickness should be increased to avoid this problem. (b) Internal defects caused by oversized billet; die cavities are filled prematurely, and the material at the center flows past the filled regions as the dies close.
Defects in extrusion

- Surface cracking
- Piping
- Internal cracking