CHAPTER FOUR
Forming Processes

Forming, shown in Fig. 4.1, is the process of changing the shape of the product without chip formation. The volume of the metal of the product remains constant before and after forming process.

Fig. 4.1: Forming Process

4.1 Principles of Metal Forming:

Deformation is a change in the shape or size of an object due to an applied force or a change in temperature. The first case can be a result of tensile (pulling) forces, compressive (pushing) forces, shear, bending or torsion (twisting) shown in Fig. 4.2. In the second case, the most significant factor, which is determined by the temperature, is the mobility of the structural defects such as grain boundaries. The movement or displacement of such mobile defects is thermally activated, and thus limited by the rate of atomic diffusion.
As deformation occurs, internal inter-molecular forces arise that oppose the applied force. If the applied force is not too large these forces may be sufficient to completely resist the applied force, allowing the object to assume a new equilibrium state and to return to its original state when the load is removed.

Depending on the type of material, size and geometry of the object, and the forces applied, various types of deformation may result. The image to the right shows the engineering stress vs. strain diagram for a typical ductile material such as steel. Different deformation modes may occur under different conditions, as can be depicted using a deformation mechanism map. Two types of deformations are existed; elastic and plastic deformation.
Elastic deformation is reversible. Once the forces are no longer applied, the object returns to its original shape.

Plastic deformation is irreversible. However, an object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape.

Factors affecting Formability

1. The nature of the metal

(1) the chemical composition of different chemical composition of the metal, the plastic is different forming properties are also different. For example, the increase of carbon steel with carbon content, increase the stress as shown in Fig. 4.3 while the formability is decreased.

![Fig. 4.3: Effect of Carbon Content](image-url)
(2) The resistance affected by the original grain structure and grain boundaries as shown in Fig. 4.4.

![Fig. 4.4: Effect of grain Boundaries](image)

(3) Coarse-grained cast structure and poor organization because of its plasticity, it is better organization and forging roll forming fine grain structure and good performance. The deformation resistance increases with the increase of difference between the original atom size with impurities atom size shown in Fig. 4.5.

![Fig. 4.5: Effect of Impurities](image)
2. Deformation of metals

(1) deformation temperature as the temperature rises, increasing the kinetic energy of metal atoms, are prone to slip deformation, and plastic deformation resistance decreased as the distance between atom is increases as shown in Fig. 4.6. Meanwhile, most of the steel under high temperature for the single solid solution (austenite) organization, and recrystallization of deformed very rapidly at the same time, all of which are conducive to improving the performance of metal rollforming. Therefore, the production of heat is very important forging deformation conditions.

![Fig. 4.6: Effect of working temperature](image)

(2) strain rate deformation per unit of time. The impact of its malleability is contradictory, on the one hand with the deformation rate increases, the recovery and recrystallization can not be strengthened in time to overcome the phenomenon of cold deformation, the metal showed a decline in the plastic deformation resistance increases malleable, and worse.
Forming processes may be classified as follows

- Bulk forming processes.
- Sheet Metal Processes.

### 4.2 Bulk Forming processes

Bulk Forming processes includes: forging, rolling, extrusion and wire drawing.

#### 4.2.1 Forging

The forging is the process by which the metal is shaped by applying compressive force using various dies and tools. The forging is a metal forming process, because the volume of the metal remains constant during the deformation process. Forging refines the grain structure and improve physical properties.

**Forging Classification**

Forging process may be classified according to various aspects, as one of the forming processes, forging may be classified into hot and cold. According to the type of die used, forging may classified into free and die forging as shown in Fig. 4.7. Fig. 4.8 shows the basic operations in free forging process while Fig. 4.9 shows the smith forging tools. The steps of die forging process is shown in Fig. 4.10.
A forged metal can result in the following:

- Increase length, decrease cross section, called drawing out.
- Decrease length, increase cross section, called upsetting.
- Change length, change cross section, by squeezing in closed impression. This results a strong part.
Swaging  
Upsetting  
Fullering  
Necking  

Fig. 4.8: Free forging operations

Hardie  
Forging Core  

Fig. 4.9: Smith forging tools
Coining is the squeezing of metal while it is confined in a closed set of dies. As shown in Fig. 4.11, it is a closed die forging process typically used in minting coins and jewelry. The pressure required can be high as five or six times the strength of material in order to produce fine details.

Coining is a form of precision stamping in which a workpiece is subjected to a sufficiently high stress to induce plastic flow on the surface of the material. A beneficial feature is that in some metals, the plastic flow reduces surface grain size, and work hardens the surface, while the material deeper in the part retains its toughness and ductility.
Coining is used to manufacture parts for all industries and is commonly used when high relief or very fine features are required. For example, it is used to produce coins, medals, badges, buttons, precision-energy springs and precision parts with small or polished surface features.

Fig. 4.12 shows a comparison between embossing and coining operations.

![Comparison between embossing and coining](image-url)
4.2.2 Rolling

Rolling, shown in Fig 4.13, is the process of reducing the thickness or changing the cross section of a long workpiece by compressive forces applied through a set of rolls. Rolling may be classified as shown in Fig. 4.14 into

1. flat rolling - reduces the thickness of a sheet of material.

![Fig. 4.13: Rolling Process](image-url)
2. shape rolling - produces new parts with a complex cross section.

![Flat Rolling](image1.png) ![Section Rolling](image2.png)

**Fig. 4.14: Types of rolling**

Plates with thickness greater than 6 mm which can be used in structure applications such as ship hulls boiler, brides and machine structure are made by rolling. Sheets, less than 6 mm thickness, which used for automobile bodies, containers for food and beverage are also made by rolling.

Aluminum beverage cans are now made from sheet 0.28 mm thickness which made by rolling. Straight and long structural shapes, such as solid bars with various cross sections, channels, I beams and railroad rails, shown in Fig. 4.15, are rolled using section rolling.
The primary objectives of the flat rolling process are to reduce the cross-section of the incoming material while improving its properties and to obtain the desired section at the exit from the rolls. The process can be carried out hot, warm, or cold, depending on the application and the material involved.

Basically flat rolling consists of passing metal between two rolls that revolve in opposite directions, the space between the rolls being somewhat less than the thickness of the entering metal. Different types of rolling mills are shown in Fig. 4.16.

Two High Mills
Four High Mills

Cluster mills

Fig. 4.16: Types of rolling mills

Because the rolls rotate with a surface velocity exceeding the speed of the incoming metal, friction along the contact interface acts to propel the metal forward. The metal is squeezed and elongated and usually changed in cross section. The amount of deformation that can be achieved in a single pass between a given pair of rolls depend on the friction conditions along the interface. If too much is demanded, the rolls will simply skid over stationary metal. Too little deformation per pass results in excessive cost.

The rolled products are flat plates and sheets. Rolling of blooms, slabs, billets, plates is usually done at temperatures above the recrystallization temperature (hot rolling). Sheet and strip often are rolled cold in order to maintain close thickness tolerances. Fig. 4.17 shows examples of products extracted using section rolling.
Rolling involves high complexity of metal flow during the process and can be divided into the following categories:

- **Uniform reduction in thickness with no change in width:** Here, the deformation is in plane strain, that is, in the directions of rolling and sheet thickness. This type occurs in rolling of strip, sheet, or foil.

- **Uniform reduction in thickness with an increase in width:** Here, the material is elongated in the rolling direction, is spread in the width direction, and is compressed uniformly in the thickness direction. This type occurs in the rolling of blooms, slabs, and thick plates.

- **Moderately non uniform reduction in cross section:** Here, the metal is elongated in the rolling direction, is spread in the width direction, and is reduced non uniformly in the thickness direction.

- **Highly non uniform reduction in cross section:** Here, the reduction in the thickness direction is highly non uniform. A portion of the rolled section is reduced in thickness while other portions may be extruded or increased in thickness. As a result, in the width direction metal flow may be toward the center.
4.2.3 Extrusion

Extrusion, shown in Fig. 4.18, is the process in which the material is forced through a die having the shape of the final product.

![Extrusion diagram](image)

Fig. 4.18: Extrusion process

Long straight metal parts, tubes and many other different types can be produced by extrusion. The extruded product have a constant cross section. Typical products are made by extrusion are doors and windows frames, tubing having various cross sections and structural and architectural shapes. The production of Hollow products is shown in Fig. 4.19

Depending on the ductility of the material, extrusion may be carried out at room temperature or elevated temperature. Extrusions often minimize the need for secondary machining.
According to the direction of material flow, the extrusion process may be classified as shown in Fig. 4.20 into direct and indirect one.

**Fig. 4.19: Extrusion of hollow Parts**

**Direct extrusion**  
**Indirect Extrusion**

**Fig. 4.20: Types extrusion**
4.2.3.1 Direct Extrusion

Direct extrusion is also called forward extrusion and it is the most general extrusion process. Its work operation includes the placement of the billet in a container as shown in Fig. 4.21, which is heavily walled. Ram or screw is used to push the billet through the die. In between the billet and ram, there is a dummy block, which is reusable and is used for keeping them separated.

Disadvantages of Direct Extrusion

One of the major disadvantages of the direct extrusion process is that the force needed for the extrusion of billet is more than what is required in the indirect extrusion process. This is because of the introduction of frictional forces due to the requirement for the billet to move the container's entire length. Hence, greatest force is required at the start of the process, which decreases slowly with the use up of billet. At the billet's end, the force is largely increased as the billet is thin and the material has to flow radially for existing the die. For this reason, the butt end of the billet is not used.
4.2.3.2. Indirect Extrusion

Indirect extrusion is also called backwards extrusion and in this process, the die is constant whereas the billet & container move together shown in Fig. 4.22.

![Fig. 4.22: Indirect extrusion](image)

The final and maximum extrusion length is decided by the stem's column strength. As the billet movement is along with the container, all the frictional forces are easily eliminated.

Advantages:
- 25 to 30% reduction of friction, allowing extrusion of larger billets, enhanced speed, and an increased ability to extrude smaller cross-sections
- Container liner lasts longer, due to less wear
- More uniform use of billet ensures that extrusion defects & coarse grained peripherals zones are less likely

Disadvantages of Indirect Extrusion

It is not as versatile as the process of direct extrusions, as the cross-sectional area is confined by the stem's maximum size. The defects and impurities on the billet's surface affect the extrusion's surface.
4.2.3.3 Impact extrusion:

Impact extrusion is one of the indirect extrusion process. The extruded part is very thin used in tooth tube. Fig. 4.23 shows the principles information of impact extrusion process while the steps of the process is shown in Fig. 4.24.

Fig. 4.23: Impact extrusion

Fig. 4.24: Impact extrusion steps
4.2.4 Wire Drawing

Wire drawing, shown in Fig. 4.25, is the process in which the cross section of a solid rod is reduced or changed in shape by pulling it through a die. Drawing is similar to extrusion, however, in drawing the material is subjected to a tensile force, whereas in extrusion the billet is under compression. Fig. 4.26 shows the reduction in wire diameter due to wire drawing process while Fig. 4.27 shows a wire drawing machine.

![Fig. 4.25: Wire Drawing](image)

![Fig. 4.26: Enlarging view of wire diameter reduction](image)
Rod is different than wire. Rod is relatively larger in cross section than that of wire. In industry, wire is generally defined as a rod that has been drawn through a die at least once. Fig. 4.28 shows examples of wire and tube drawing products.
4.3 Sheet Metal Work

In sheet metal work, the thickness of the sheet usually remains unchanged. The operations that carried out on sheet metals are; shearing, bending, drawing, press forming, spinning and explosive forming.

4.3.1 Shearing

Before a sheet metal part is made, a blank of suitable dimensions if first removed from a large sheet by shearing. That is, the sheet is cut by subjecting it to shear stresses typically between a punch and a die as shown in Fig. 4.29 while the process steps are illustrated in Fig. 4.30.

![Fig. 4.29: Shearing process](image)

![Fig. 4.30: Shearing process steps](image)
Comparison Between Drawing, shearing (blanking and piercing)

<table>
<thead>
<tr>
<th>Drawing</th>
<th>Shearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch diameter less than that of die</td>
<td>Punch diameter equal to that of die</td>
</tr>
<tr>
<td>Punch edge is round</td>
<td>Punch edge is sharp</td>
</tr>
<tr>
<td></td>
<td>Blanking</td>
</tr>
<tr>
<td>Blank is the final product</td>
<td>Strip is the final product</td>
</tr>
<tr>
<td>The strip is trash</td>
<td>The blank is trash</td>
</tr>
</tbody>
</table>

![Diagram showing blanking and piercing processes](image-url)
Piercing is the shearing process used to produce a hole by means of a press tool. The punch is sharp and made equal to that of the die. The punch edge is sharp. The hole size is important. A shearing operation that creates an open hole in sheet metal by separating an interior section. The removed metal section is discarded scrap. For piercing holes in stock, the size of the pierce punch governs the size of the hole and clearance is applied to the die.

Blanking is the shearing process used to cut a shape from a strip by means of a press tool. The punch is sharp and made equal to that of the die. The punch edge is sharp. The blank size is important. A shearing operation that creates a hole in sheet metal by separating an interior section. The removed piece of metal is the desired part. For blanking the die size governs the size of the blanked component and clearance is applied to the punch.

Drawing is a bending process used to produce a bent shape by means of a press tool. The punch is sharp and made less than that of the die. The punch edge is round. Figure 4.31 shows examples of shearing products.

![Fig. 4.31: Shearing products examples](image-url)
PROPER CLEARANCE SELECTION BETWEEN PUNCH & DIE

- Determine the Stock Group by tensile strength of the part material.
- Select the Clearance expressed as % of stock thickness [T] for maximum productivity. Clearance values are per side.
- If your material is in the high range of tensile, use the higher clearance; if in the low range, use the lower clearance.
- If burnish length is the main criterion, select the clearance that produces burnish needed.
- If the burnish length with Jektole Clearance does not meet your needs, choose Regular Clearance.
- Reducing the clearance increases the burnish length and wear on the punch.
4.3.2 Bending

Bending, shown in Fig. 4.32, is one of the most common forming operations. Bending is used not only to form parts such as flanges and seams but also to impart stiffness to the part by increasing its moments of inertia.

In bending, the outer fibers of the material are in tension and the inner fiber are in compression.

Fig. 32: Bending

Tubes and other hollow sections can also be formed by bending operations. However these products require special tooling to avoid bucking and folding. The simplest method is to pack the inside with loose particles, commonly sand, and bend the part in a suitable fixture.
4.3.3 Deep drawing

In deep drawing, shown in Fig. 4.33, a round sheet metal blank is placed over a circular die opening and is held in place with blank holder. The punch travels downward and forces the blank into the die cavity, forming a cup. Some shells and container are too difficult to be drawn in one operation. It may be produced in several stages called redraw.

![Deep drawing process](image)

**Fig. 4.33: Deep drawing process**

Commonly the process as shown in Fig. 4.34 is,

1. A blank is clamped over a die so that it is not free to move.
2. A punch is advanced into the material, forcing it into the die and permanently deforming it.
3. The punch is removed, the part removed from the die, and the excess blank is trimmed off.
It is used to make deep parts both cylindrical and box shape; such as pots, pans, kitchen sinks and container for beverage. It is also used to make parts that are shallow or have moderate depth. Fig. 4.35 shows the general process steps while Fig.4.36 shows some products examples produced using this process.
Fig. 4.36: Deep drawing product examples

Usually, the deformation required in a certain products divided into several steps as shown in the following product example. The detailed process steps are shown in 4.36 for the drinking can.

Fig. 4.37: steps of drawing drinking cans
4.3.4 Press Forming

Press forming is the shaping of components from sheet metal between a punch and a die. Components made in this way have consistently accurate dimensions. The process is also very fast and produces very little waste. Most sheet metals are suited to this process, but mild steel is the most widely used. Fig. 4.38 shows the press forming process while Fig. 4.39 shows example of press forming products.

![Press forming](image)

**Fig. 4.38: Press forming**

![Press forming products example](image)

**Fig. 4.39: Press forming products example**

Motor car panels are amongst the numerous components which are press formed.
4.3.5 Spinning

Spinning, shown in Fig. 4.40, is an old process and involve the forming of axisymmetric parts over a mandrel with tool or rollers. Fig. 4.41 shows the spinning steps for two products as examples.

![Fig. 4.40: Spinning](image)

![Fig. 4.41: steps of product Spinning](image)
A circular blank is held against a mandrel and rotated while a rigid tool deforms and shapes the material over the mandrel. The tools used are very simple and are made of wood or metal.

The process steps are Basically as follows,

1. A mandrel (or die for internal pieces) is placed on a rotating axis (like a turning center).
2. A blank or tube is held to the face of the mandrel.
3. A roller is pushed against the material near the center of rotation, and slowly moved outwards, pushing the blank against the mandrel.
4. The part conforms to the shape of the mandrel (with some springback).
5. The process is stopped, and the part is removed and trimmed.

### 4.3.6 Embossing

Embossing, shown in Fig. 4.42, is one of the stretch forming operations. The sheet is completely clamped on its circumference and the shape is developed entirely at the expense of sheet thickness.

![Fig. 4.42: Embossing](image-url)
4.3.7 Explosive Forming

In this process, shown in Fig. 4.43, the sheet metal blank is clamped over a die and the entire assembly is lowered into a tank filled with water. While explosives are used as a source of energy to form a sheet metal.

![Fig. 4.43: Explosive forming](image)

The air in the die cavity is evacuated, an explosive charge is placed at a certain height, and the charge is detonated. The rapid conversion of the explosive charge into gas generates a shock wave. The pressure of this wave is sufficient to form sheet metals. A variety of shapes can be formed, provided that the material is ductile.

The process has no limitation to the size of the workpiece. It is suitable for low quantity production runs of large parts, as in aerospace applications. The mechanical properties of parts made by this process are basically the same as those made by conventional forming processes.