Forming processes are those in which the shape of a metal piece is changed by plastic deformation. Forming processes are commonly classified into hot-working and cold-working operations.

Typical forming processes are:

- Rolling
- Extrusion
- Forging
- Drawing
Rolling is a process of reduction of the cross-sectional area or shaping a metal piece through the deformation caused by a pair of rotating in opposite directions metal rolls. The gap between the rotating rolls is less than the thickness of the entering bar therefore a friction force is necessary in order to bite the bar and to pull it through the rolls.

A metal bar passing through the rotating rolls is squeezed, and it elongates while its cross section area decreases.
A machine used for rolling metal is called rolling mill.

A typical rolling mill consists of a pair of rolls driven by an electric motor transmitting a torque through a gear and pair of cardans. The rolls are equipped with bearings and mounted in a stand with a screw-down mechanism.

Rotating rolls perform two main functions:

- Pull the work into the gap between them by friction between workpart and rolls
- Simultaneously squeeze the work to reduce its cross section
**Equipment – Picture 1**

Adjusting Screw

Rolls

Rolls Housing/ Stand

**Equipment – Picture 2**

Adjusting screw
Equipment – Picture 3

Pictures showing the rolling process:

Types of Rolling

- Based on workpiece geometry:
  - Flat rolling - used to reduce thickness of a rectangular cross section
  - Shape rolling - square cross section is formed into a shape.

- Based on work temperature:
  - Hot Rolling – most common due to the large amount of deformation required
  - Cold rolling – produces finished sheet and plate stock
**Types of Rolling**

*Hot rolling* is a rolling operation carried out at a temperature just below the metal melting point, permitting large amount of deformation.

*Cold rolling* is a rolling operation carried out at room temperature. Cold rolling is commonly conducted after hot rolling when good surface quality and low thickness tolerance are needed. Cold rolling causes material strengthening.

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**Rolled Products Made of Steel**

Some of the steel products made in a rolling mill.
Side view of flat rolling, indicating before and after thicknesses, work velocities, angle of contact with rolls, and other features.

**Diagram of Flat Rolling**

**Flat Rolling Terminology**

*Draft* = amount of thickness reduction

\[ d = t_o - t_f \]

Where, \( d \) = draft;

- \( t_o \) = starting thickness;
- \( t_f \) = final thickness
Flat Rolling Terminology

Reduction = draft expressed as a fraction of starting stock thickness:

\[ r = \frac{d}{t_0} \]

where \( r \) = reduction

Shape Rolling

- **Accomplished** by passing work through rolls that have the reverse of desired shape

- **Products include:**
  - Construction shapes such as I-beams, L-beams, and U-channels
  - Rails for railroad tracks
  - Round and square bars and rods
Rolling Mills

- Equipment is massive and expensive

- Rolling mill configurations:
  - Two-high: two opposing rolls
  - Three-high: work passes through rolls in both directions
  - Four-high: backing rolls support smaller work rolls
  - Cluster mill: multiple backing rolls on smaller rolls
  - Tandem rolling mill: sequence of two-high mills

Two-High Rolling Mill

Various configurations of rolling mills: (a) 2-high rolling mill.
Various configurations of rolling mills: (b) 3-high rolling mill.

Various configurations of rolling mills: (c) four-high rolling mill.
**Cluster Mill**

Multiple backing rolls allow even smaller roll diameters

Various configurations of rolling mills: (d) cluster mill

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**Tandem Rolling Mill**

Rolling mills have several stages, where the each stage successively reduces the thickness of the stock until the desired cross section is achieved.

Various configurations of rolling mills: (e) tandem rolling mill.
Thread Rolling - Definition

Deformation process used to form threads on cylindrical parts by rolling them between two dies

- Important commercial process for mass producing bolts and screws
- Performed by cold working in thread rolling machines

Thread rolling with flat dies: (1) start of cycle, and (2) end of cycle.
Thread Rolling

**Advantages** over thread cutting (machining):

- Higher production rates
- Better material utilization
- Stronger threads and better fatigue resistance due to work hardening
**Ring Rolling - Definition**

Deformation process in which a thick-walled ring of smaller diameter is rolled into a thin-walled ring of larger diameter

- Applications: ball and roller bearing races, steel tires for railroad wheels, and rings for pipes, pressure vessels, and rotating machinery

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**Ring Rolling**

As thick-walled ring is compressed, deformed metal elongates, causing diameter of ring to be enlarged

Hot working process for large rings and cold working process for smaller rings

Ring rolling used to reduce the wall thickness and increase the diameter of a ring:
- (1) start, and (2) completion of process.
Extrusion is a metal forming process involving shaping a metal billet (hot or cold) by forcing it through a die with an opening.

The two possible schemes of extrusion are presented in the picture:

- **Direct Extrusion**

  The metal billet is placed to the container of the extrusion press. The die with an opening is mounted at the end of the container. When the hydraulically driven ram presses the billet, the metal starts to flow through the opening forming the extruded product of the required cross section. In the direct extrusion the extruded metal flows in the direction of the ram motion.
Forming Processes - Indirect Extrusion -

In the indirect extrusion the metal flows in the direction opposite to the ram motion.

Indirect extrusion requires a lower force than direct process as there is no friction between the billet and inside walls of the container.

Forming Processes - Extrusion -

In the hot extrusion process the metal billet is preheated to the required temperature: (450°C - 500°C) for aluminum alloys and (700°C - 800°C) for Copper alloys.

The dies are manufactured from hard alloyed steels.

Extrusion is used for manufacturing round and hexagonal rods, tubes, various profiles (mainly aluminium) and other shapes. Typical examples of parts made by extrusion are the aluminium door- and window-frames.
(a) Direct extrusion to produce a hollow or semi-hollow cross sections; (b) hollow (c) semi-hollow cross sections.

**Extrusion Ratio**

Also called the *reduction ratio*, it is defined as

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

- where,
  - \( r_x \) = extrusion ratio;
  - \( A_o \) = cross-sectional area of the starting billet;
  - \( A_f \) = final cross-sectional area of the extruded section

- Applies to both direct and indirect extrusion
Extrusion Die Features

(a) Definition of die angle;
(b) Effect of die angle on ram force.

For forging, is a compressive metal forming process, involving shaping a metal piece by hammer or press.

The figure shows an open-die forging process. Note the red hot bar stock in place.
Classification of Forging Operations

- **Cold vs. hot forging:**
  - Hot or warm forging – most common, due to the significant deformation and the need to reduce strength and increase ductility of work metal.
  - Cold forging – advantage: increased strength that results from strain hardening.

- **Impact vs. press forging:**
  - Forge hammer - applies an impact load.
  - Forge press - applies gradual pressure.

Types of Forging Dies - Open-die

- Open-die forging - work is compressed between two flat dies, allowing metal to flow laterally with minimum constraint.

![Diagram of open-die forging](image)
**Types of Forging Dies - Impression-die**

- Impression-die forging - die contains cavity or impression that is imparted to workpart. Metal flow is constrained so that flash is created.

![Diagram of Impression-die Forging](image)

**Types of Forging Dies - Flashless**

- Flashless forging - workpart is completely constrained in die. No excess flash is created.

![Diagram of Flashless Forging](image)
Quality of forged parts

Usually forged parts are much stronger/tougher than cast or machined parts made from the same material. This is because the hammering process arranges the microstructure of the metal so that the crystal grains get aligned along the part profile. This leads to an increase in strength. It is therefore common to use forging to make parts that will carry very high stresses during their use, rather than casting.

Forming Processes - Drawing -

Drawing is a metal forming process involving pulling a workpiece (cold or hot) through a die providing reduction of the cross section of the workpiece.
Forming Processes - Drawing -

Drawing is the process most commonly used to make wires from round bars; this process is very similar to extrusion, except that instead of pressure from the back end, in drawing, the wire is pulled from the side where it emerges from the circular die.

Dies are made of specially hardened tool steels, or tungsten carbide. Diamond dies are used for drawing very fine wires. Drawing may be hot (the stock is heated to a high temperature for processing), or cold (the stock is not heated).

Wire and Bar Drawing

Drawing of bar, rod, or wire.
Area Reduction in Drawing

Change in size of work is usually given by area reduction:

\[ r = \frac{A_o - A_f}{A_o} \]

where,
\[ r = \text{area reduction in drawing}; \]
\[ A_o = \text{original area of work}; \]
\[ A_f = \text{area of final work}; \]