**Hot Working**

Hot working is the *plastic deformation* of metals above their *recrystallization temperature*.

Hot working occurs under conditions of temperature and strain rate such that recrystallization occurs simultaneously with deformation.

- **Plastic deformation** is a *permanent deformation*, and obtained by applying forces great enough to exceed the elastic limit of the material.

- **Recrystallization temperature** is the temperature at which new, unstrained crystals from the original distorted grains are formed after being plastically deformed.
# Recrystallization Temperature

<table>
<thead>
<tr>
<th>Metal</th>
<th>Temperature [°C (°F)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>150 (300)</td>
</tr>
<tr>
<td>Copper</td>
<td>200 (390)</td>
</tr>
<tr>
<td>Gold</td>
<td>200 (390)</td>
</tr>
<tr>
<td>Iron</td>
<td>450 (840)</td>
</tr>
<tr>
<td>Lead</td>
<td>Below room temperature</td>
</tr>
<tr>
<td>Magnesium</td>
<td>150 (300)</td>
</tr>
<tr>
<td>Nickel</td>
<td>590 (1100)</td>
</tr>
<tr>
<td>Silver</td>
<td>200 (390)</td>
</tr>
<tr>
<td>Tin</td>
<td>Below room temperature</td>
</tr>
<tr>
<td>Zinc</td>
<td>Room temperature</td>
</tr>
</tbody>
</table>
Advantages of Hot Working

1. The *yield strength of metals decreases as temperature increases*, and the *ductility increases*. Thus it becomes possible to alter the shape of metals drastically by hot working
   - without causing them to fracture and
   - without the necessity for using excessively large forces.

2. Hot working *does not produce strain hardening*. Therefore, it *does not cause any increase in yield strength or hardness*, or corresponding decrease in ductility.
Advantages of Hot Working

3. The elevated temperatures promote diffusion that can remove chemical inhomogenities, pores can be welded, shut or reduced in size during deformation and the metallurgical structure can be altered to improve the final properties.

4. Undesirable coarse or columnar grains may be eliminated and a fine, randomly oriented grain structure may be obtained. Metals with fine grain structures have superior strength, ductility and toughness.

5. Impurities which are located around grain boundaries are often reoriented into a "crack-arrestor" configuration, perpendicular to crack propagation.
Disadvantages of Hot Working

1. The high temperatures may promote undesirable reactions between the metal and surroundings,
2. Tolerances are poorer due to thermal contractions and possible non-uniform cooling,
3. Metallurgical structure may also be non-uniform.
Cold Working

Cold working is the plastic deformation of metals below their recrystallization temperature. It is generally performed at room temperature.
Advantages of Cold Working

1. No heating is required.
2. Better surface finish is obtained.
3. Superior dimension control.
4. Better **reproducibility and interchangeability** of parts.
5. Improved strength properties.
6. Directional properties can be imparted.
7. Contamination problems are minimized.
Disadvantages of Cold Working

1. Higher forces are required for deformation.
2. Heavier and more powerful equipment is required.
3. Less ductility is available.
4. Metal surfaces must be clean and scale-free.
5. Strain hardening occur.
6. Imparted directional properties may be detrimental.
7. May produce undesirable residual stresses.
HOT WORKING PROCESSES
Rolling

Rolling usually is the first step in converting cast material (ingot) into finished wrought products. Hot rolled products, such as sheets, plates, bars, and strips, serve as input material for further processes, such as cold forming or machining.

Basically hot rolling consists of passing heated metal between two rolls that revolve in opposite directions, the size of the gap between the rolls being somewhat less than the thickness of the entering metal.
FROM STEEL INGOTS TO FINISHED PRODUCTS

Selected Examples
Rolling

Starting structure (hot metal)

Deformed grains

Recrystallized grain structure

Start of recrystallization

Upper roll

Steel

Lower roll

2 – High nonreversing

Steel returned

Backing rolls

3 – High

4 – High

Cluster
Rolling of Structural Shapes
Characteristics, Quality, and Tolerances of Hot Rolled Products

1. Because they are rolled and finished above the recrystallization temperature, hot rolled products have minimum directional properties and are relatively free of residual stresses.

2. Generally free of voids, cracks or laminations,

3. Surfaces are slightly rough and covered with high temperature oxide known as mill scale,

4. Dimensional tolerances vary with the kind of metal and the size of the product. For most products the tolerance is from 2 to 5 % of the size (height or width).
***VIDEO***
***SSAB_TheHotRollingStripMill_in_Borlange.wmv***
***rollingmill.mpeg***
Forging is the plastic working of metal by means of localized compressive forces exerted by manual or power hammers, presses, or special forging machines. It may be done either hot or cold.

In forging, three types of deformations are observed.

1. **Draw out**, in which **length is increased and cross section is decreased**,

2. **Upset**, in which **cross section is increased and length is decreased**,

3. **Squeeze**, in which **multidirectional flow is produced in closed impression dies**.
1. **Open Die Hammer or Smith Forging**

The same type of forging done by the blacksmith of old, but now massive mechanical equipment is used to impart the repeated blows.

The impact is then delivered by some type of mechanical hammer, the simplest type being the gravity drop or board hammer.

Open-die forging does not confine the flow of metal, the hammer and anvil often being completely flat.

The operator obtains the desired shape by manipulating the workpiece between blows.
Forging Machines (Hammers)

Figure 16-9 (Left) Double-frame drop hammer. (Courtesy of Erie Press Systems, Erie, PA.) (Right) Schematic diagram of a forging hammer.
Open Die Hammer or Smith Forging

1. Preform mounted on saddle/mandrel.
2. Metal displacement—reduce preform wall thickness to increase diameter.
3. Progressive reduction of wall thickness to produce ring dimensions.
4. Machining to near-net shape.
2. Impression-Die Drop or Closed-Die Forging

The open-die hammer or smith forging is a simple flexible process, but it is not practical for large-scale production because it is slow and the resulting size and shape of the workpiece are dependent on the skill of the operator.

Impression-die or closed-die forging overcomes these difficulties by using shaped dies to control the flow of metal.

Board hammers, steam hammers, and air hammers are all used in impression die drop forging.
Impression-Die Drop (Closed-Die) Forging
Counterblow or impact forging is an alternative to the hammer and anvil arrangement.

Counterblow (impact) machines have two horizontal hammers that move together simultaneously and forge the workpiece between them.

By using these machines, necessity for a heavy base is eliminated, and the machine operates more quietly and with less vibration.
3. **Press Forging**

When the forging of large sections is required, press forging, rather than hammer or impact forging, should be employed.

Here the slow squeezing action penetrates throughout the metal and produces a more uniform metal flow.

To prevent cooling due to long time of contact, heated dies are often used.
4. **Upset Forging**

Upset forging involves increasing the diameter of the end or central portion of a bar by compressing its length.

In this type of forging, split dies having several positions or cavities are commonly used.
Upset Forging
5. Roll Forging

Round or flat bar stock is reduced in thickness and increased in length.

Done on machines that have two semi-cylindrical rolls, containing shaped grooves that are slightly eccentric with the axis of rotation.

As rolls turn one half revolution, the bar is progressively squeezed and rolled out toward the operator.

The operator then inserts the forging between another set of smaller grooves and the process is repeated until the desired size and shape are obtained.

Components such as axles, tapered levers, and leaf springs are produced.
Roll Forging
*** FORMING/forging (SME/Wiley’s video)***
Extrusion

In the extrusion process, metal is compressively forced to flow through a suitably shaped die to form a product with reduced cross section.
Extrusion
Although extrusion may be performed either hot or cold, hot extrusion is employed for many metals to reduce the forces required, eliminate cold-working effects, and reduce directional properties.

Lead, copper, aluminum, magnesium, and alloys of these metals are commonly extruded, taking advantage of the relatively low yield strengths and extrusion temperatures.

Steel is more difficult to extrude. With the development and use of phosphate-based and molten glass lubricants, substantial quantities of hot steel extrusions are now produced. These lubricants adhere to the billet and prevent metal-to-metal contact throughout the process.
Almost any cross-sectional shape can be extruded.
The amount of reduction in a single step is limited only by the capacity of the equipment.
Extrusion dies are relatively inexpensive.
Product changes require only a die change, so small quantities of a desired shape can often be produced economically by extrusion.
The major limitation of the process is the requirement that the cross section must be the same for the length of the product being extruded.
The dimensional tolerances of extrusions are very good. For most shapes ± 0.003 mm/mm or a minimum of ± 0.07 mm is easily attainable.
Extrusion Methods

1. Direct extrusion (hot),
2. Indirect extrusion (hot),
3. Impact extrusion (usually cold).

- Although the indirect extrusion configuration reduces friction between the billet and chamber wall, added equipment complexity and restricted length of product favors the direct method.
Extrusion

Direct extrusion

Indirect extrusion

Diagram showing the process of extrusion with labels for components such as ram, die, work billet, and others.
Extrusion of Hollow Shapes

1. For tubular products, the stationary or moving mandrel processes are often employed.

2. For more complex internal cavities, a spider mandrel (torpedo die) is used.
Extrusion of Tubes

(a) First step

Mandrel
Billet
Plug
Die
Ram

Second step

Tube
Plug

(b) First step

Die
Billet
Ram and mandrel

Second step

Tube
Spider Mandrel (Torpedo Die)
*** (video) ***
COLD WORKING PROCESSES
Cold Working Processes

In cold working, after completing the deformation and releasing the force, the workpiece tries to return back to its original shape, and some amount of strain on the workpiece is recovered, i.e. the strain decreases.

The amount of decrease in the strain is called springback. Cold working tools (e.g. dies) should be designed by considering the springback effects.
FIG. 15. Spring back in bending operations.
Major Cold Working Processes

1. Squeezing
2. Bending
3. Shearing
4. Drawing
Most of the cold working squeezing processes have identical hot working counterparts or are extension of them. The primary reasons for deforming cold rather than hot are to obtain better dimensional accuracy and surface finish. In many cases the equipment is basically the same, except that it must be more powerful.
Cold Rolling

Sheets, strips, bars and rods are cold rolled to obtain products that have smooth surfaces and dimensions.
Cold Forging

The metal is squeezed into a die cavity that imparts the desired shape.

It is known as **cold heading** if used for making enlarged sections on the ends of a piece of rod or wire, such as the heads on bolts, nails, rivets, and other fasteners.

**Upsetting is done in one or more strokes of the heading punches.**

Enlarged sections at locations other than the ends of rods can also be made.
Cold Forging - Cold Heading
Cold Forging - Cold Heading

CUTTING (74% WASTE)  COLD FORMING (6% WASTE)
Parts Made by Cold Forging
Squeezing Processes

Extrusion

Products like collapsible tubes for toothpaste, medications, and so forth; small cans such as are used for shielding in electronics and electrical apparatus; and larger cans for food and beverages are made by using the process which is often called as impact extrusion.

There are forward and backward types which may use open or closed dies.
Cold - Impact Extrusion

- Backward extrusion open die
- Backward extrusion closed die
- Forward extrusion open die
- Forward extrusion closed die
Squeezing Processes

Coining

It is used to produce **coins, medals and other products** where **exact size** and **fine detail** are required.

Metal is confined within a set of dies by means of the positive displacement of the punch, and **very high pressure** is required.
Peening

Peening involves striking the surface by repeated blows by impelled shot (shot peening) or a round nose tool. The highly localized blows deform and tend to stretch metal surface. Because the surface deformation is resisted by the metal underneath, the result is a surface layer under residual compressive stresses. This provides resistance against cracking under fatigue conditions.
Bending Processes

Bending is the plastic deformation of metals about a linear axis with little or no change in the area.

When two or more bends are made simultaneously with the use of a die, the process is sometimes called forming.

If the axes about which deformation occurs are not linear or not independent, it is known as drawing, it is not bending.

In bending, two axes involved in forming may be at an angle to each other, but each axis must be linear and independent of the other.
Angle Bending

Angle bends up to 150° in sheet metal under about 1.5 mm in thickness may be made in a bar folder. These machines are manually operated.
Angle Bending

V Bending

Air Bending

Rotary Bending
Angle Bending

Bends in heavier sheet metal and more complex bends in thinner sheets are made in a press brake which is mechanically or hydraulically driven. The metal is bent between interchangeable dies that are attached to the bed and the ram.
Angle Bending
Press Brake Dies
**Bending Processes**

**Tube Bending**

Mostly done by using machines.
Roll Bending

Plates, heavy sheets and rolled shapes can be bent to a desired curvature on forming rolls. These usually have three rolls in the form of a pyramid, with the two lower rolls being driven and the upper roll adjustable to control the degree of curvature.
Roll Bending

**FIGURE 15-28** Cold-roll bending of structural shapes. (Courtesy Buffalo Forge Company.)
Cold Roll-Forming

Involves the **progressive bending** of metal strip as it passes through a **series of forming rolls**.

By changing the rolls, a single machine can be adapted to the production of many different shapes.
Figure 4.69
Examples of roll forming passes for a) the double channel, b) round tube.
Seaming

Seaming is used to join ends of sheet metal to form containers such as cans, drums etc. by a series of small rollers on seaming machines.

**FIGURE 15-32** Various types of seams used on sheet metal.
Shearing Processes

Shearing is the mechanical cutting of materials in sheet or plate form without the formation of chips or use of burning or melting. When the two cutting blades are straight, the process is called shearing.

Processes in which the shearing blades are in the form of the curved edges of punches and dies, are called by other names, such as blanking, piercing, notching, shaving, trimming, etc.
Squaring shears which are foot or power operated may be used for shearing sheets of metals along straight lines.
Rod Shearing
Shearing Processes

Piercing and Blanking

The shearing blades take the form of closed, curved lines on the edges of a punch and die.

Piercing and blanking are usually done by some type of mechanical press.
Shearing Processes

Piercing and Blanking

In **piercing**, the piece **punched out is the scrap** and the remainder of the strip becomes the desired workpiece.

In **blanking**, the piece **punched out is the desired workpiece** and undesirable features are left on the strip.
Piercing and Blanking Die Sets

The basic components of piercing and blanking die sets are a punch, a die and a stripper plate.

Stripper plate is used to prevent the climbing up of the stock with the punch.

The punch and the die have sharp edges.

Commonly, the clearance between the punch and the die is about 5 to 7% of the stock (sheet metal) thickness.
Piercing and Blanking Die Sets

There are three types of die sets.

1. Simple Die Sets
2. Progressive Die Sets
3. Compound Die Sets

Simple die sets consist of a punch and a die. Can be used for a single process.
Progressive Die Sets

Consist of two or more sets of punches and dies mounted in tandem.

The strip stock is fed into the die and part is completed with successive strokes of the press.
Progressive Die Sets

- Ram
- Blanking punch
- Piercing punch
- Strripper
- Metal strip
- Finished washer
- Scrap
- Die
- Stop
- Metal strip
Compound Die Sets

Piercing and blanking, or other combinations occur simultaneously within a single stroke of the ram while the strip of stock remains in one position.

Dies of this type are more accurate, but they usually are more expensive to construct and are more subject to breakage and locking.
Compound Die Sets

- Strip
- Punch (hole)
- Die (blank)
- Stripper
- Die (hole) & punch (blank)
- Pressure pad
- Complete washer
- Scrap
*** FORMING/sheet metal shearing and bending (SME/Wiley’s video)***

***FORMING/sheet metal stamping die and processing (SME/Wiley’s video)***
Drawing Processes

Cold drawing is a term that can refer to two somewhat different operations.

If the stock is in the form of sheet metal, cold drawing is the forming of three-dimensional parts wherein plastic flow occurs over a curved axis. This type of cold drawing is similar to hot drawing.

On the other hand, if the stock is bar, tube, wire, or rod, cold drawing refers to the process of reducing the cross section and increasing the length of the metal by pulling it through a die.
Bar and Tube Drawing - Bar Drawing

One end of a bar is reduced or pointed, inserted through a die of somewhat smaller cross section than the original bar, grasped by grips and pulled in tension, drawing the remainder of the bar through the die.

Intermediate annealing may be necessary to restore ductility and enable further working.
Bar and Tube Drawing -

**Tube Drawing**

*Tube drawing is used to produce seamless tubing.*

**Mandrels** are used for tubes from about 12.5 mm to 250 mm in diameter.
Tube Drawing

- **Tube Before Drawing**
- **Tube After Drawing**
- **Die**
- **Mandrel**
Bar and Tube Drawing - Tube Drawing

Heavy-walled tubes and those less than 12.5 mm in diameter are often drawn without a mandrel in a process known as tube sinking.
Wire Drawing

Wire drawing is essentially the same as bar drawing except that it involves smaller diameters and is generally done as a continuous process through a succession of drawing dies.

Starting stock in coil form

Lubrication box

Die

Draw block

Direction of travel

Carbide Wire Drawing Die

Steel casing

Back relief

Bell radius

Entrance angle

Approach angle

Land
**Wire Drawing**

Small diameter wires are usually drawn on tandem machines which contain 3 to 12 dies, each held in water-cooled die blocks.
Deep Drawing (Shell Drawing)

Deep drawing is, drawing of closed cylindrical or rectangular containers, or a variation of these shapes, with a depth greater than the narrower dimension of their opening.

Because the process had its earliest uses in manufacturing artillery shells (top mermisi kovanı) and cartridge cases, it is sometimes called shell drawing.

When the depth of the drawn part is less than the diameter, or minimum surface dimension of the blank, the process is considered to be shallow drawing.
Deep Drawing
Deep Drawing

- Scrap Web
- Draw Pad
- Punch
- Blanking Die
- Draw Die

**Force Transmission Zones:**
- Forming zone
- Bending zone
- Draw ring
- Force transmission zone
- Force application zone

$F_p$