4.1 Introduction

1. Classification of metal forming processes
2. Definition
3. Plastic deformation
4. Competitive characteristics
5. Hot and cold working
6. Recrystallization
7. Strain hardening
8. Process variables
2. Metal Forming Definition

- A group of manufacturing processes in which the material is shaped to a certain geometry by applying external forces large enough to cause a permanent deformation. The deformed material experienced plastic deformation, i.e. it will not return to its original shape after the forces are released.
- The external forces can be in the form of compression, tension, torsion, shearing, bending, drawing or a combination of the various forces.
Various types and combination of forces

Stresses in the form of compression, tension, shear and others

- **Direct-compression type processes:**
  - the applied force is normal to the direction of the metal flow in compression, i.e., forging and rolling processes.

- **Indirect-compression type processes:**
  - the primary forces are frequently tensile, with indirect compressive forces developed by the reaction of the work piece. The metal flow is therefore under the combined stress state, i.e., extrusion, wire-drawing, tube drawing.

3. Plastic Deformation

- **Elastic Deformation** - If a metal deformed by a force return to its original dimensions when the force is removed; the metal undergo elastic deformation.

- **Plastic deformation (metals)**
  - Permanent deformation of metals due to the movement of dislocations on slip system.
1. Initial
2. Small load
3. Unload

Elastic means reversible!

Plastic means permanent!

4. Competitive Characteristics

- Mass conservation—material formed into different shapes without changing its volume, or minimum volume changes, thereby little waste or scrap.
- Better material properties—grain structure or fibre
- Very fast production
Manufacture of a spark plug body: (left) by machining from hexagonal bar stock; (right) by cold forming. Note the reduction in waste.

Comparison of microstructure:

- CASTING: Poor microstructure with high porosity
- MACHINING: Grain structure being cut through giving good mechanical properties
- FORMING: Fibrous grain structure improving mechanical properties

Grain structure or fiber of machined vs rolled component:

Parts produced within seconds.
What about Disadvantages?

• Please state a few disadvantages as compared with other manufacturing processes.

5. Hot and Cold Working

- The methods used to mechanically shape metals into other product forms are called Working Processes.

<table>
<thead>
<tr>
<th>Working processes</th>
<th>Hot working</th>
<th>Cold working</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T = 0.6 - 0.8 T_m$</td>
<td>$T &lt; 0.3 T_m$</td>
<td></td>
</tr>
</tbody>
</table>

Hot working ($0.6 - 0.8 T_m$)

Definition: deformation under conditions of temperature and strain rate such that recrystallisation process take place simultaneously with the deformation.

Examples: rolling, forging, extrusion

Cold working ($< 0.3 T_m$)

Definition: deformation carried out under conditions where recovery processes are not effective.

Examples: rolling, forging, extrusion, wire/tube drawing, swaging, coining

Hot Working

- Hot working involves deformation at temperatures where recrystallisation can occur ($0.6 - 0.8 T_m$).

Examples of hot working temperatures for each metal:

<table>
<thead>
<tr>
<th>Metal</th>
<th>Melting point (°C)</th>
<th>Recrystallisation temperature (°C)</th>
<th>Hot working range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>1535</td>
<td>450</td>
<td>900-1200</td>
</tr>
<tr>
<td>Copper</td>
<td>1083</td>
<td>200</td>
<td>650-900</td>
</tr>
<tr>
<td>Aluminium (alloys)</td>
<td>660</td>
<td>150</td>
<td>350-500</td>
</tr>
<tr>
<td>Zinc</td>
<td>420</td>
<td>20</td>
<td>110-170</td>
</tr>
</tbody>
</table>
Cold Working

- Normally performed at room temperature but *in general < 0.3T_m*, where recovery is limited and recrystallisation does not occur.
- *Work hardening occurs* (strength and hardness increase but ductility decreases).
- The extent of deformation is rather limited if cracks are to be avoid, therefore intermediate anneals that enable recrystallisation are frequently used afterwards.
- The materials suitable for cold working should have a relatively low *yield stress* and a relatively high *work hardening rate* (determined primarily by its tensile properties).

Temperature in Metalworking

- Hot working - Deformation at temperature above recrystallisation temperature typically between 0.5T_m to 0.75T_m
  - Pros
    - larger deformation possible
    - lower forces and power
    - forming of room temperature low ductility material is possible
    - isotropic properties resulted from process
    - no work hardening
  - Pros against cold working
    - Lower forces and power
    - more intricate work geometries possible
    - need for annealing may be reduced/eliminated.
Temperature in Metalworking

- **Cold working**
  - Pros
    - better dimensional control and accuracy
    - Fine grain - better surface finish
    - strain hardening increases strength and hardness
    - grain flow during deformation provides directional properties
    - no heating is needed, easier handling (low operating temperature)
  - Cons
    - higher forces and power are required, therefore bigger capacity machines
    - ductility and strain-hardening limits the extent of forming

- **Isothermal Forming**
  - preheating the tools to the same temperature as the work metal. This eliminates the surface cooling and the resulting thermal gradient in the workpart.
  - Normally applies to highly alloyed steels, titanium alloys and high-temperature nickel alloys.

6. **Recrystallization**

The process in which, at a certain temperature range, new strain-free grains are formed, replacing the older grains.

*FIGURE 10.6*

Changes in the grain structure of cast or large-grain wrought metals during hot rolling. Hot rolling is an effective way to reduce grain size in metals for improved strength and ductility. Cast structures of ingots or continuous castings are converted to a wrought structure by hot working.

- The minimum temperature at which reformation of the crystals occurs is called **recrystallization temperature**.
- Above the recrystallization temperature the kinetic energy of atoms increases and therefore they are able to attach themselves to the newly formed nuclei which in turn begin to grow into crystals. This process continues until all the distorted crystals have been transformed.
- Hot working results in **grain refinement**.
Properties of steels (C10) after hot and cold working

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>Hot rolled</th>
<th>Cold rolled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength, $\sigma_{TS}$ (MPa)</td>
<td>427</td>
<td>558</td>
</tr>
<tr>
<td>Yield stress, $\sigma_{Y}$ (MPa)</td>
<td>220</td>
<td>345</td>
</tr>
<tr>
<td>Brinell hardness (HB)</td>
<td>94</td>
<td>174</td>
</tr>
</tbody>
</table>

7. Strain Hardening

- Berlaku apabila logam dikerjakan dalam keadaan sejuk, di mana kekuatan logam bertambah dan pada masa yang sama kekerasan meningkat.
- Juga dinamakan pengerasan kerja
- Kesan langsung
  Kekerasan dan kekuatan meningkat
  Wujud tegasan tinggal/baki
  Kemuluran berkurang

8. Process Variables - independent

- Starting material - types
- Starting work piece geometry
- Tool and die geometry
- Lubrication
- Starting temperature
- Speed of operation
- Amount of deformation
• **Dependent Variables**
  – Force or power required
  – Nature of material flow
  – Material properties
  – Exit temperature
  – Surface finish

• **Outcome**
  – Experience
  – Experiments
  – Theory