SME 2713
Manufacturing Process

METAL FORMING – 1
(Introduction)

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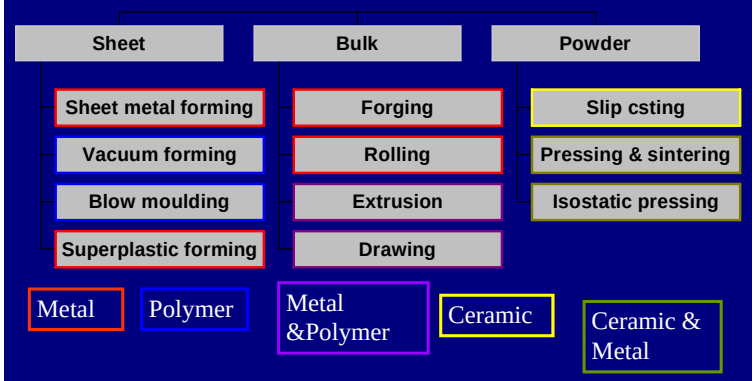
4.1 Introduction

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

Forming Processes



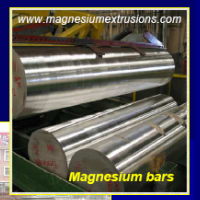
- The products resulting from the working of metals are called ***Wrought Products,*** such as sheet, plate, bar, forging.
- ***Plastic working processes*** can also divided into:

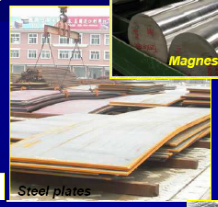
Primary mechanical working process

Designed to reduce an ingot or billet to a standard mill product of simple shape, i.e., sheet, plate, bar.

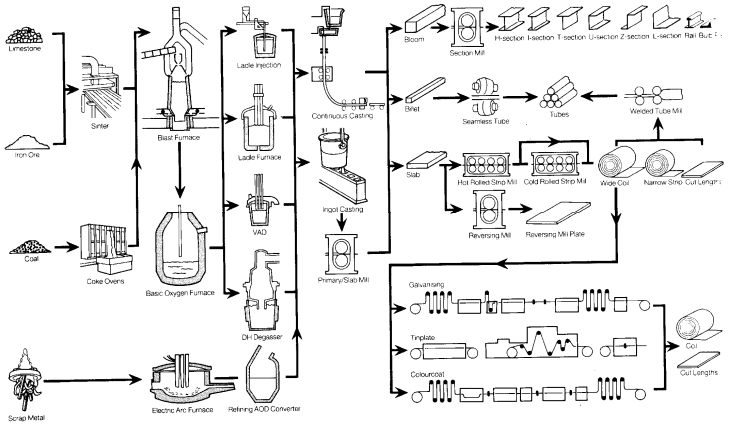
Secondary mechanical working process

Primary sheets, plates or bars are formed into final finished shapes, i.e., wire & tube drawing, sheet metal forming operation.

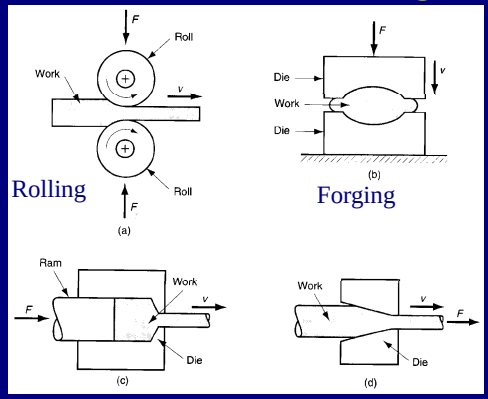




Primary working

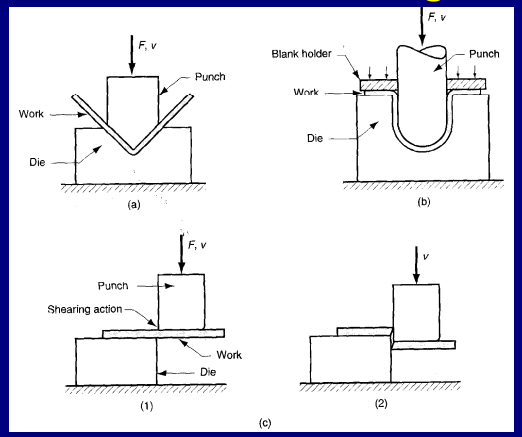


Bulk Metal Forming



Extrusion Drawing

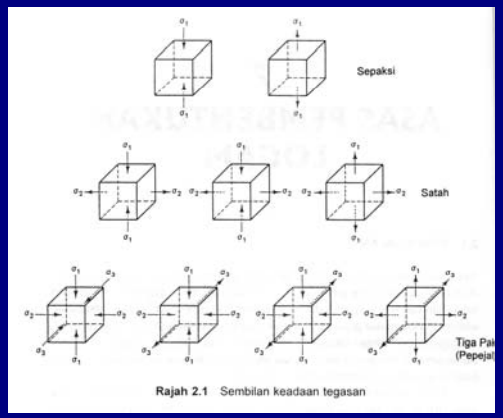
Sheet Metalworking



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

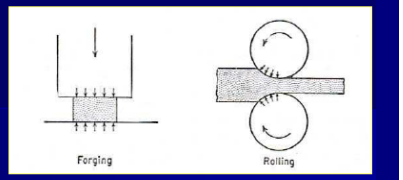


Rajah 2.1 Sembilan keadaan tegasan

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

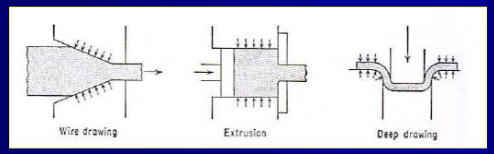
- **Direct-compression type processes**:

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



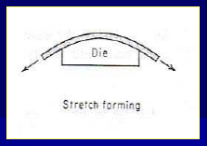
- **Indirect-compression type processes**:

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, wiredrawing, tube drawing.



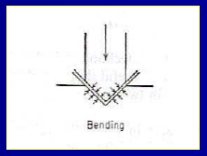
- **Tension type processes**:

the applied force is tensile, i.e., stretching forming.



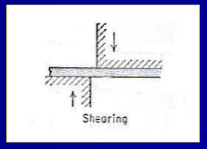
- **Bending processes**:

the applied force involves the application of bending moments to the sheet.



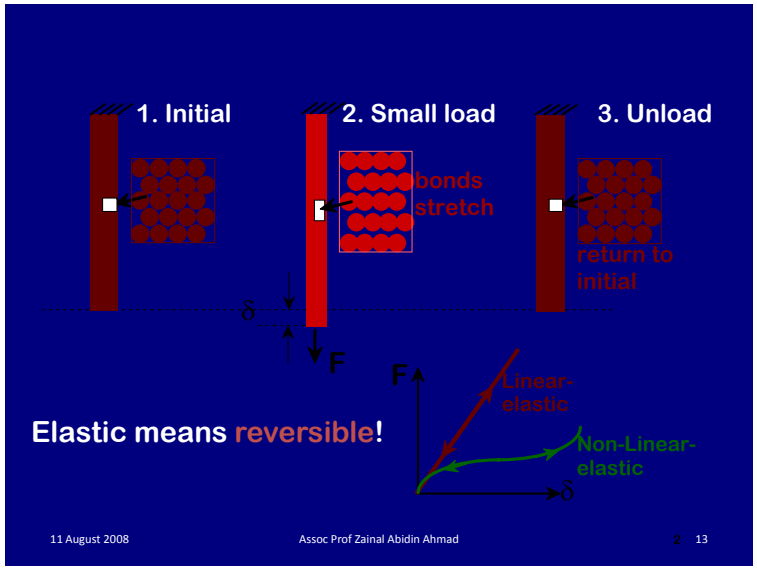
- **Shearing processes**:

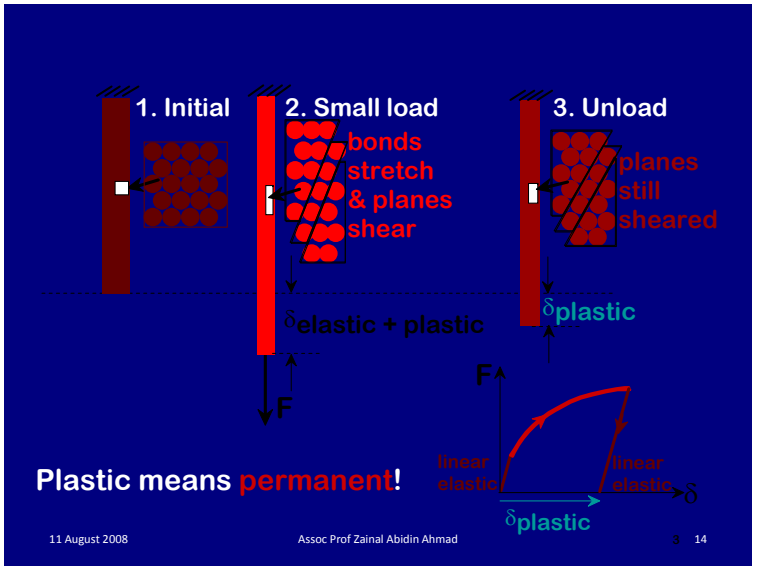
the applied force involves the application of shearing forces of sufficient magnitude to rupture the metal in the plane of shear.

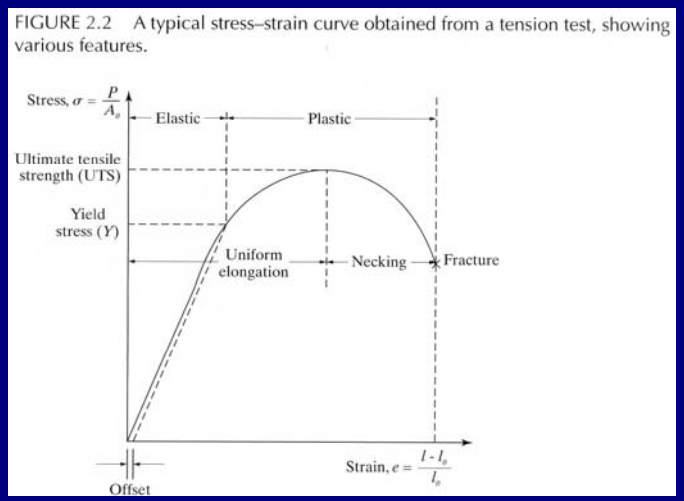


3. Plastic Deformation

- 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.**





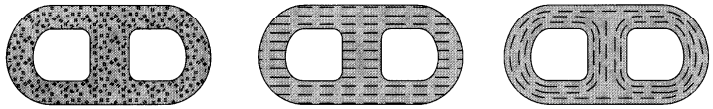


4. Competitive Characteristics

- 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



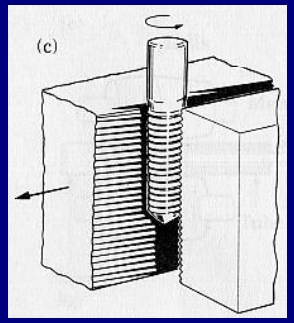
CASTING
Poor microstructure with high porosity

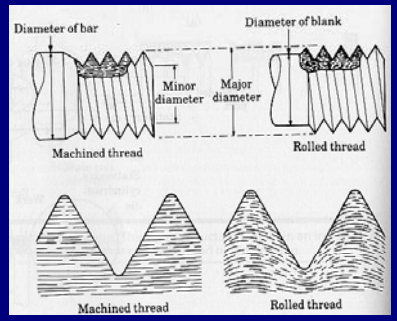
MACHINING
Grain structure being cut through

FORMING
Fibrous grain structure giving good mechanical properties

Mechanical properties improving

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***.

Working processes

- **Hot working** — $T \sim 0.6–0.8T_m$
- **Cold working** — $T \leq 0.3T_m$

Hot working ($0.6\text{-}0.8T_m$)

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 ($< 0.3T_m$)

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

Metal	Melting point (°C)	Recrystallisation temperature (°C)	Hot working range (°C)
Iron	1535	450	900-1200
Copper	1083	200	650-900
Aluminium (alloys)	660	150	350-500
Zinc	420	20	110-170

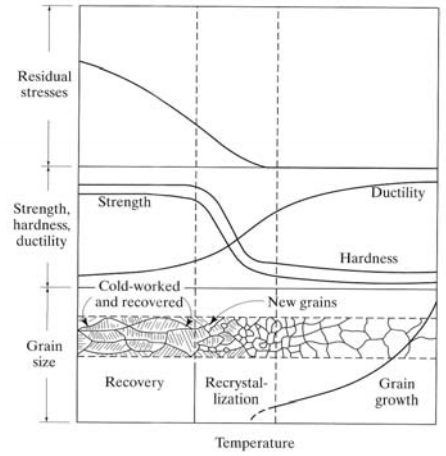
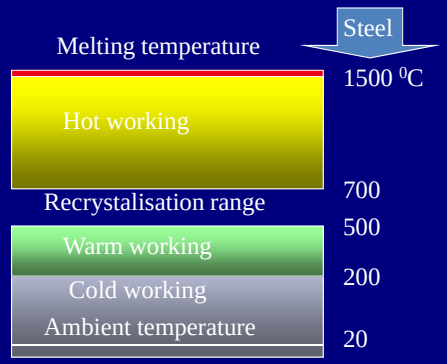


FIGURE 1.14 Schematic illustration of the effects of recovery, recrystallization, and grain growth on mechanical properties and on the shape and size of grains. Note the formation of small new grains during recrystallization. *Source*: G. Sachs.

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 effect on Metal Working



Temperature in Metalworking

- Hot working - Deformation at temperature above recrystallization 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

Temperature in Metalworking

- Warm working - temperature between room temperature and recrystallization temperature, roughly about 0.3 T_m
  - 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

Temperature in Metalworking

- 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.

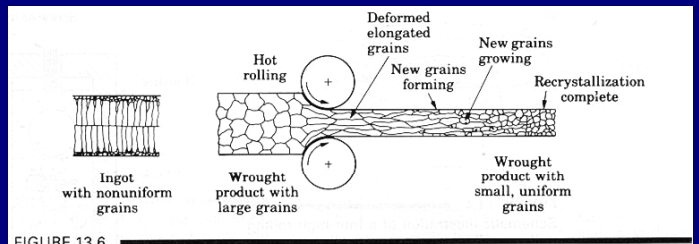
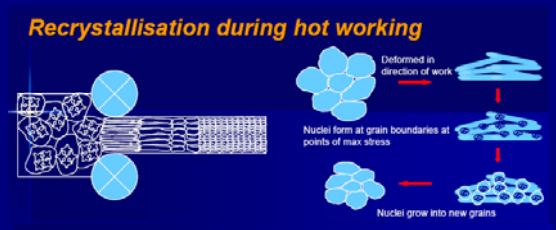


FIGURE 13.6
Changes in the grain structure of cast or large-grain wrought metals during hot rolling. Hot rolling is an effective way to reduce grain size in metals for improved strength and ductility. Cast structures of ingots or continuous castings are converted to a wrought structure by hot working.

6. Recrystallization



- The minimum temperature at which reformation of the crystals occurs is called ***Recrystallisation Temperature***.
- Above the recrystallisation 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 refining***.

Properties of steels (C10) after hot and cold working

Mechanical properties	Hot rolled	Cold rolled
Ultimate tensile strength, σ_{TS} (MPa)	427	558
Yield stress, σ_y (MPa)	220	345
Brinell hardness (HB)	94	174

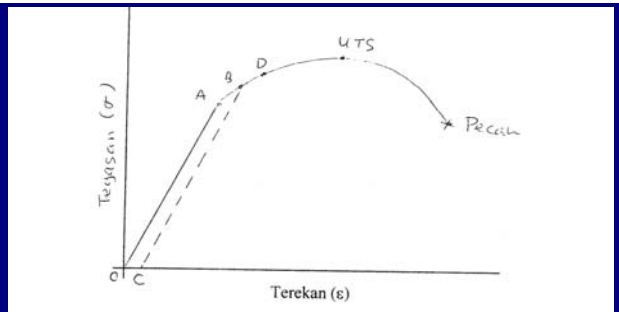
7. Strain Hardening

- 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



Spesimen yang diubah bentuk di dalam zon elestik, iaitu belum melepasi titik alah A, sekiranya beban dilepaskan, ia akan kembali ke bentuknya yang asal (OA). Untuk memperolehi ubah bentuk kekal, tegasan mestilah melebihi titik alah A. Sekiranya bahan ditegangkan sehingga mencapai titik B dan kemudiannya dilepaskan, ia akan cuba kembali kebentuknya yang asal, lelalui BC. Di sini telah wujud ubah bentuk kekal iaitu OC. Sekiranya bahan ini perlu diubah bentuk semula hingga ke titik D, ia akan melalui CBD, dengan titik B sebagai titik alah yang baru. Titik B lebih besar tegasannya berbanding dengan titik A. Ini menunjukkan bahan ini telah bertambah kekuatannya, atau lebih sukar dibentuk selepas mengalami ubah bentuk pertama.

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