Module-09

Applications and Processing of Metals and Alloys

Contents

Materials – Classification

- Materials are classified into three basic groups based on their mechanical and physical nature as – metals, ceramics and polymers.
- For an engineer, especially, metals are more important owing to ability to carry loads and ease of manufacturing.
- Metallic materials are again classified for ease of selection and/or based on their tonnage of usage broadly into two classes – ferrous and non-ferrous.
- Ferrous materials – chief constituent is iron (*Fe*). E.g.: steel, cast iron.
- Metallic materials those are not ferrous are termed as non-ferrous materials. E.g.: Brass, Silver, Aluminium, Titanium.

Ferrous materials - Introduction

- In engineering applications, lion share is served by ferrous materials.

- Factors account for it are:
  - availability of abundant raw materials combined with economical extraction
  - ease of forming
  - their versatile mechanical and physical properties.

- There are some drawbacks about ferrous materials:
  - poor corrosion resistance
  - high density i.e. low specific strength
  - low thermal and electrical conductivities

Ferrous materials - Classification

- There are two classes – *steels* and *cast irons* – categorized based on carbon content.
- Steels: %C is up to 2.14%
  Cast irons: %C is above 2.14%
- Cast irons are called so because they are usually manufactured through casting technique owing to their brittle nature due to presence of iron carbide.
- Steels are serving major part of present engineering applications.
- However, cast irons mostly serve as structural components. E.g.: automobile motor casings, lathe bed, sliding guides in machinery.

Steels

- In steels, C atoms occupies interstitial sites of Fe.
- Steels are classified based on their C content/alloying additions which in turn dictates their applications: plain carbon steels and alloying steels.
- *Low-carbon steels*: % wt of C < 0.3

  Medium carbon steels: 0.3 <% wt of C < 0.6

  High-carbon steels: % wt of C > 0.6

- Low carbon steels:

  \- Carbon present is not enough to strengthen them by heat treatment, hence are strengthened by cold work.

  \- They are easily weldable and machinable.

  \- Typical applications: tin cans, automotive body components, structural shapes, etc.

Steels (contd….)

- Medium carbon steels:

  - They are less ductile and stronger than low carbon steels.
  - Heat treatable (austenitizing, quenching and tempering).
  - Hardenability is increased by adding Ni, Cr, Mo.
  - Used in various tempered conditions.
  - Typical applications: gears, railway tracks, machine parts.

- High carbon steels:

  - They are strongest and hardest of carbon steels.
  - Heat treatable. Used in tempered or hardened conditions.
  - Alloying additions – Cr, V, W, Mo
  - Typical applications: Knives, razors, hacksaw blades, etc where high wear resistance is the prime requirement.

HSLA and Stainless Steels

- HSLA (hish strength low alloy) steels:
  - They can be strengthened by heat treatment.
  - Ductile and formable.
  - Alloying addition – Cu, V, W, Ni, Cr, Mo, etc.
  - Typical applications: support columns, pressure vessels, bridge beams.

- Stainless steels:
  - They typical consists min.12% Cr along with other alloying elements, thus highly corrosion resistant owing to presence of chromium oxide.
  - Three kinds - ferritic & hardenable Cr steels, austenitic and precipitation hardenable (martensitic, semi-austenitic) – based on presence of prominent microstructural constituent.

Stainless Steels (contd….)

- Stainless steels:

  - Typical applications – cutlery, surgical knives, storage tanks, domestic items

  - *Ferritic steels* are principally Fe-Cr-C alloys with 12-14% Cr. And small additions of Mo, V, Nb, Ni.

  - *Austenitic steels* contain 18% Cr and 8% Ni plus minor alloying elements. Ni stabilizes the austenitic phase assisted by C and N.

  - For, *martensitic steels* ***Ms*** is made to be above the room temperature. These alloys are heat treatable. Major alloying elements are: Cr, Mn and Mo.

  - Ferritic and austenitic steels are hardened and strengthened by cold work because they are not heat treatable.

  - Austenitic steels are non-magnetic as against ferritic and martensitic steels, which are magnetic.

Cast irons

- Grey cast iron

  - Cementite decomposes during solidification to form carbon flakes. Thus they are brittle.

  - Fractured surface looks grey because of presence of graphite, hence the name.

  - Possess good damping properties.

  - Typical applications – base structures, machine beds

- White cast iron

  - Cooled fast so that cementite does not decompose.

  - Fractures surface looks whitish because of cementite, hence the name.

  - They are brittle and extremely difficult to machine.

  - Used as source materials for producing malleable iron.

Cast irons (contd….)

- Nodular cast iron

  - Alloying addition of Mg/Ce to grey cast iron melt results in graphite to form as modules.

  - They are stronger and ductile than grey cast iron.

  - Typical applications – pump bodies, crank shafts, automotive components, etc.

- Malleable cast iron

  - Formed by heat treating white cast iron. Heat treatment involves heating to 800-900C, keep it there for long hours, then cooling to room temperature.

  - Cementite decomposes to form graphite and ferrite.

  - Typical applications – railroad, connecting rods, marine and other heavy-duty services.

Non-Ferrous materials

- Typical advantages of non-ferrous materials over ferrous materials:
  - high specific strength.
  - low density.
  - high electrical and thermal conductivities.
  - distinct properties thus used for specific purposes.
  - can be formed with ease.

E.g.: Al-alloys
Cu-alloys (brass, bronze)
Mg-alloys
Ti-alloys
Noble metals (E.g.: Ag, Au, Pt, Pa)
Refractory metals (E.g.: Nb, Mo, W and Ta)

Fabrication of metals and alloys

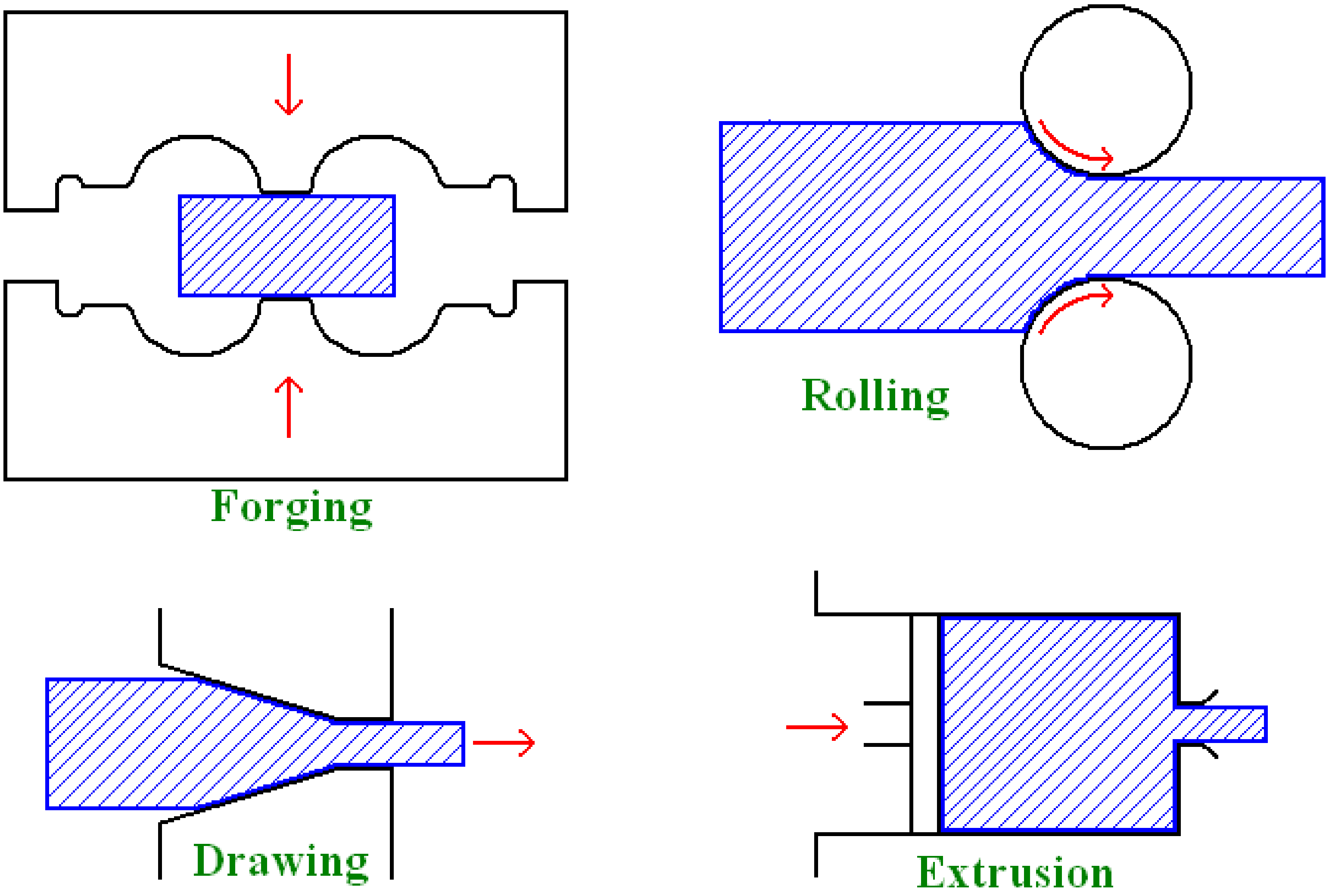
- Four basic manufacturing processes:
- Casting – to give a shape by pouring in liquid metal into a mold that holds the required shape, and letting harden the metal without external pressure.
- Forming – to give shape in solid state by applying pressure.
- Machining – in which material is removed in order to give it the required shape.
- Joining – where different parts are joined by various means.
- Other important technique is powder metallurgy.

Metal Casting – Metal Forming

- Four important casting techniques are:
- Sand casting
- Die casting
- Investment casting
- Continuous casting

- Four important forming techniques are:
- Forging
- Rolling
- Extrusion
- Drawing

Metal Forming techniques



Thermal processing

- Two main kinds of metal processing methods – mechanical and thermal.
- Thermal processing is also known as heat treatment.
- Purpose of heat treatment:
  - improvement in ductility
  - relieving internal stresses
  - grain size refinement
  - increase of strength
  - improvement in machinability and toughness
- Thermal processing factors – temperature up to which material is heated, length of time that the material is held at the elevated temperature, rate of cooling, and the surrounding atmosphere under the thermal treatment.

Thermal processing methods

- Two kinds heat treating methods are – *annealing* and *quenching & tempering*.
- These differ in the way material is cooled from an elevated temperature.
- Annealing involves cooling the material slowly, allowing phase changes.
- Quenching (also known as *hardening*) means cooling the material at a rapid rate to arrest the equilibrium phase transformations.
- During annealing, material is cooled in air and/or heating furnace itself.
- For quenching, material is immersed in water / oil quench bath.

Annealing techniques

- Process annealing – applied to cold worked materials to negate effects of cold work. Commonly sandwiched between two cold work operations. Improves ductility.
- Stress relief – purpose of it is to remove stresses. Temperatures are low such that cold work effects are not affected.
- Full annealing – used for products that are to be machined later-on. Cooling is done in furnace itself. Hardness and strength are restored by additional heat treatments after machining.
- Normalizing – used to refine the grains and produce a more uniform and desirable size distribution. It involves heating the component to attain single phase (e.g.: austenite in steels), then cooling in open air atmosphere.

Quenching & Tempering

- Quenching operation is usually followed by tempering.
- Tempering involves heating martensitic steel at a temperature below the eutectoid transformation temperature to make it softer and more ductile. Here Martensite transforms to ferrite embedded with carbide particles.

- *Martempering* is used to minimize distortion and cracking. It involves cooling the austenized steel to temperature just above *Ms* temperature, holding it there until temperature is uniform, followed by cooling at a moderate rate to room temperature before austenite-to-bainite transformation begins. The final structure of martempered steel is tempered Martensite.
- *Austempering* involves austenite-to-bainite transformation. Thus, the final structure of austempered steel is bainite.