MECHANICAL ENGINEERING SCIENCE

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Unit 2: Engineering Materials, Stress Analysis, and Power Transmission

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INTRODUCTION TO ENGINEERING MATERIALS

Engineering materials are defined as substances which are manufactured and used for various engineering applications.

Why do we study materials?

- An applied scientist or engineer, whether mechanical, civil, chemical, or electrical, will at one time or another be exposed to a design problem involving materials. Examples might include a transmission gear, the superstructure for a building, an oil refinery component, or an integrated circuit chip.

- Often a materials problem is really one of selecting the material that has the right combination of characteristics for a specific application. The selection will be usually based on ***in – service conditions, any deterioration of material properties that may occur during service operation, consideration of cost etc.***

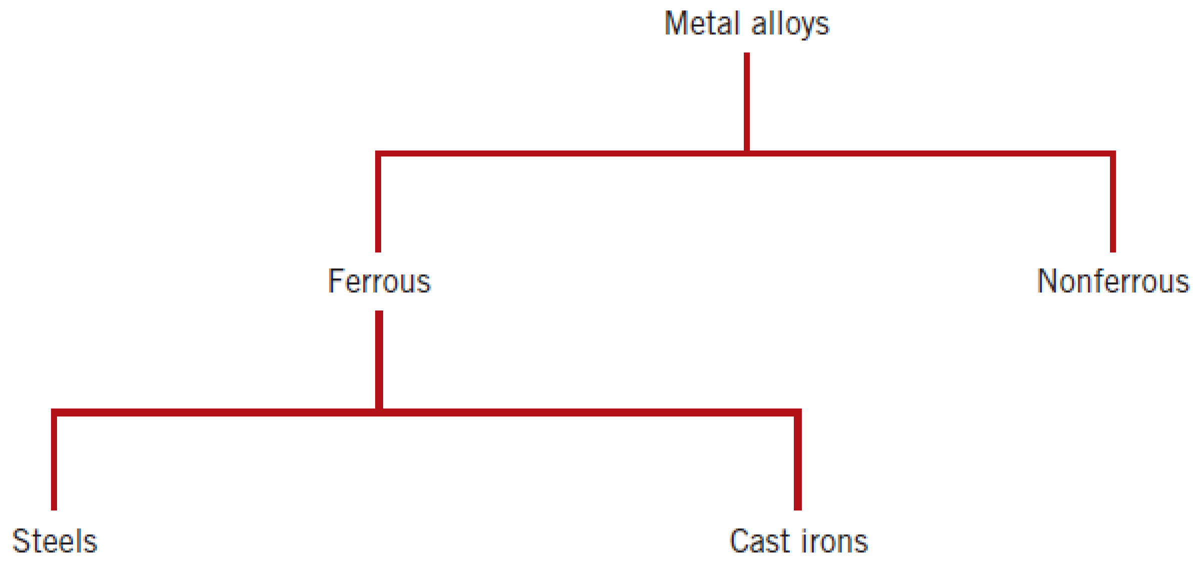
- The more familiar an engineer or scientist is with the various characteristics and structure–property relationships, as well as processing techniques of materials, the more proficient and confident he or she will be to make judicious materials choices based on these criteria.

CLASSIFICATION OF MATERIALS

- Solid materials have been conveniently grouped into three basic classifications: ***metals, ceramics, polymers and composite.***
- This scheme is based primarily on chemical makeup and atomic structure, and most materials fall into one distinct grouping or another, although there are some intermediates.
- In addition, there are the ***composites***, combinations of two or more of the above three basic material classes.
- Another classification is advanced materials—those used in high-technology applications—viz. ***semiconductors, biomaterials, smart materials, and nano engineered materials***.

METAL ALLOYS

- Metal alloys, by virtue of composition, are often grouped into two classes—***ferrous and nonferrous***.
- Ferrous alloys, those in which iron is the principal constituent, include ***steels and cast irons***.
- The nonferrous ones—all alloys that are not iron based.



Ferrous Metals

- In ferrous materials the main alloying element is carbon (C).
- Depending on the amount of carbon present, alloys will have different properties, especially when the carbon content is either less/higher than 1.5%.
- The ferrous alloys with less than 1.5% C are termed as steels and the ferrous alloys with higher than 1.5% (2–4%) C are termed as cast irons.
- On the basis of the percentage of carbon and their alloying elements present, these can be classified into the following groups.

i. ***Mild Steels:*** The percentage of carbon in iron ranges from 0.15% to 0.25%. These are moderately strong and have good weldability. The production cost of these materials is also low.

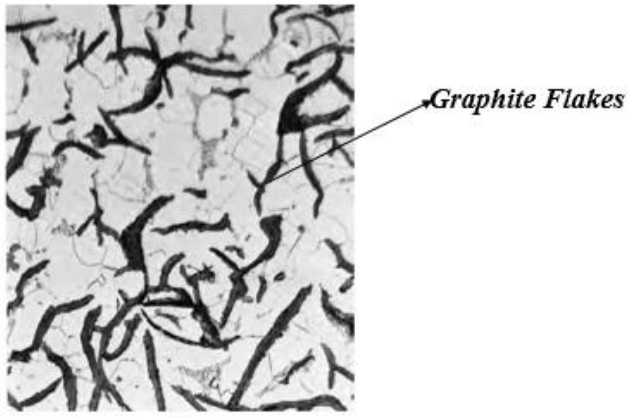
ii. ***Medium Carbon Steels:*** These contain carbon between 0.3% and 0.6%. The strength of these materials is high but their weldability is comparatively less.

iii. ***High Carbon Steels:*** These contain carbon varying from 0.65% to 1.5%. These materials get hard and tough by heat treatment and their weldability is poor. The steel formed in which carbon content is up to 1.5%, silica up to 0.5%, and manganese up to 1.5% along with traces of other elements is called plain carbon steel.

Cast Irons: The carbon content in these substances varies between 2% and 4%. The cost of production of these substances is quite low and these are used as ferrous casting alloys.

Grey Cast Iron:

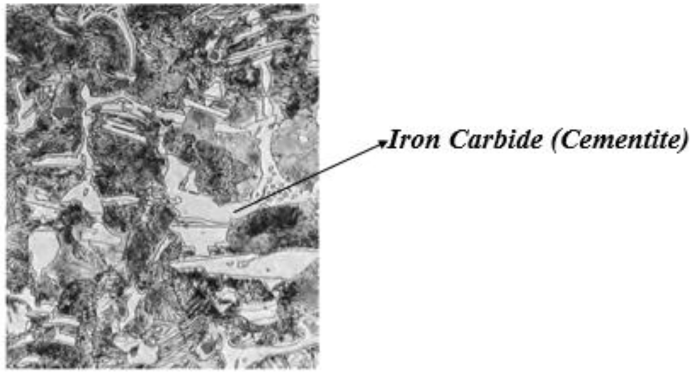
- These alloys consist of carbon in the form of graphite flakes, which are surrounded by either ferrite or pearlite.
- Because of the presence of graphite, fractured surface of these alloys looks greyish, and so is the name for them.
- Due to graphite flakes, grey cast irons are weak and brittle.
- However, they possess good damping properties, and thus typical applications include base structures, bed for heavy machines, etc.; they also show high resistance to wear.



Microstructure

White Cast Iron:

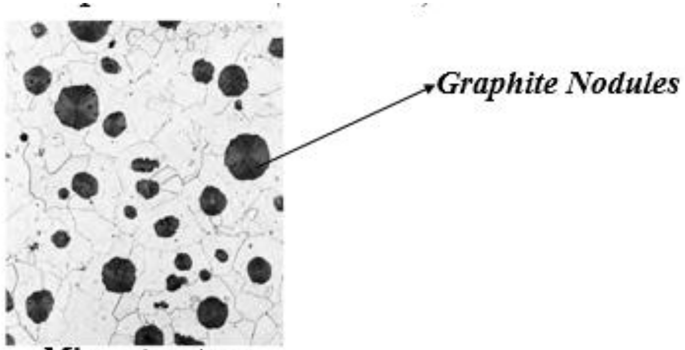
- Because of presence of cementite, fractured surface appears white, hence the name.
- They are very brittle and extremely difficult to machine.
- Hence their use is limited to wear resistant applications such as rollers in rolling mills. Usually, white cast iron is heat treated to produce malleable iron.



Microstructure

Nodular (or Ductile) Cast Iron:

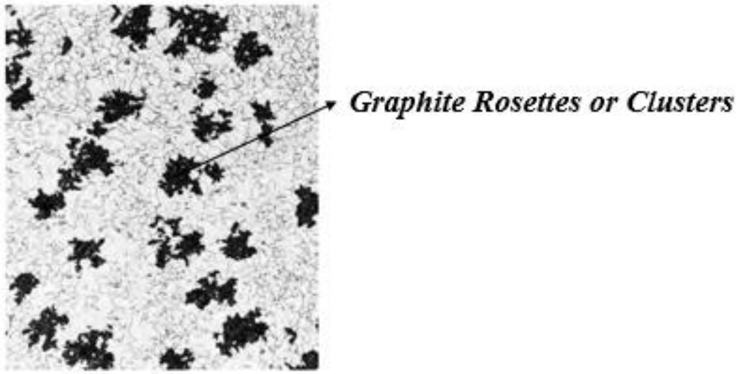
- Small additions of Mg/Cr to the grey cast iron melt before casting can result in graphite to form nodules or sphere-like particles.
- Matrix surrounding these particles can be either ferrite or pearlite depending on the heat treatment.
- These are stronger and ductile than grey cast irons.
- Typical applications include pump bodies, crank shafts, automotive components, etc.



Microstructure

Malleable Cast Iron:

- Malleable Cast Iron is a type of cast iron that has been heat-treated to improve its ductility and toughness, making it less brittle than regular cast iron.
- Heat treatments involve heating the material up to 800–900°C, and keep it for long hours, before cooling it to room temperature.
- High temperature incubation causes cementite to decompose and form ferrite and graphite.
- Thus, these materials are stronger with appreciable amount of ductility.
- Typical applications include railroad, connecting rods, marine, and other heavy-duty services.



Microstructure

Steels:

- **Steel = Iron + Carbon + Alloying Elements**
- Tool steels are **special alloy steels** that are **specifically designed** to make **cutting tools, dies, molds**, and other **high-strength components**.
- They need to **resist wear, retain hardness at high temperatures**, and have **high strength and toughness**.
- The major types of stainless steel are austenitic, ferritic, martensitic, and duplex. These categories are based on their crystal structure and alloying elements, which influence their properties and applications.

Two special categories:

i. Tool Steels ii. **Stainless Steels**

Key Features:

•High hardness and strength
•Wear resistance
•Can be heat treated for desired properties

Main Alloying Elements:

•Carbon – For hardness
•Chromium, Vanadium, Molybdenum, Tungsten – Improve wear resistance, toughness, and hardness at high temps

- **Stainless steels** are a group of corrosion-resistant alloys containing **iron**, **chromium** (at least 10.5%), and varying amounts of other elements such as **nickel**, **molybdenum**, **carbon**, and **manganese**.
- Their standout feature is their **resistance to rust and staining**, which comes primarily from the **chromium** content that forms a **passive oxide layer** on the surface.

Key Characteristics of Stainless Steel:

- Corrosion resistance
- Strength and durability
- Heat resistance
- Aesthetic appeal
- Hygienic properties)
- Recyclability

Common Applications:

- **Architecture:** railings, cladding, roofing
- **Food & Beverage Industry:** processing equipment, sinks, utensils
- **Medical:** surgical tools, implants
- **Automotive:** exhaust systems, trim
- **Energy:** nuclear reactors, pipelines
- **Household:** appliances, cookware

NON FERROUS ALLOYS

- Steel and other ferrous alloys are consumed in exceedingly large quantities because they have such a wide range of mechanical properties, may be fabricated with relative ease, and are economical to produce.

- However, they have some distinct limitations, chiefly:
  (1) a relatively high density,
  (2) a comparatively low electrical conductivity, and
  (3) an inherent susceptibility to corrosion in some common environments.

- Thus, for many applications it is advantageous or even necessary to utilize other alloys having more suitable property combinations.

NON FERROUS ALLOYS

Aluminium Alloys:

- Aluminium alloys have high thermal and electrical conductivities, and good corrosion resistant characteristics.
- As Al has FCC crystal structure, these alloys are ductile even at low temperatures and can be formed easily.
- However, the great limitation of these alloys is their low melting point (660°C), which restricts their use at elevated temperatures.
- Chief alloying elements include Cu, Si, Mn, Mg, Zn.
- Recently, alloys of Al and other low-density metals like Li, Mg, Ti gained much attention as there is much concern about vehicle weight reduction.
- Al–Li alloys draw much more attention of metallurgy especially as they are very useful in aircraft and aerospace industries.
- Common applications of Al alloys include beverage cans, automotive parts, bus bodies, aircraft structures, etc.

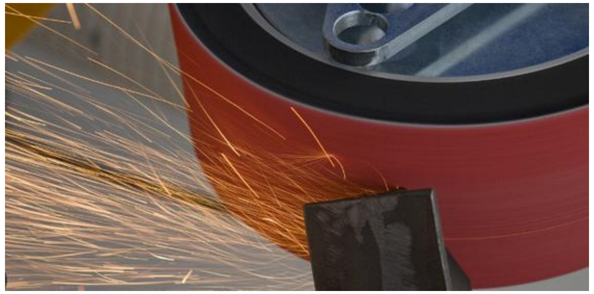
Source:
[Aerospace Materials and Material Technologies](#) Springer Nature

CERAMICS:

- Ceramics can be defined as a compound of metallic and non – metallic elements with predominantly ‘ionic’ interatomic bonding.

- Some of their examples are **Magnesia (MgO), Alumina (Al_2O_3), Zirconia (ZrO_2), Beryllia (BeO), Silicon Carbide (SiC) and Tungsten Carbide (TiC).**

- Typical applications **- ceramic substrates for electronic devices, turbocharger rotors, aerospace turbine blades, nuclear fuel rods, lightweight armour, cutting tools, abrasives, thermal barriers and furnace/kiln furniture.**



PLASTICS:

- ***A plastic can be defined as a solid material consisting of an organic polymer of a long molecular chain and high molecular weight.***
- Plastics are divided into two basic groups depending on their behaviour at elevated temperatures, viz., ***thermoplastics and thermosetting plastics***.
- Typical applications –
  Polyamide (Nylon etc.) – gears, bearing, conveyor rollers, cooling fans
  Polyethylene (Polythene) – gaskets, washers, pipes
  Polytetrafluoroethylene (Teflon) – self lubricating bearing
  Phenolic – clutch and brake linings

Abrasives:

- Abrasives are hard, non-metallic, sharp edged, and irregular shaped materials used to remove small amount of materials by cutting action.
- It is employed in grinding, polishing, super finishing, buffing, and honing operations.

Abrasives are generally classified into two categories:

1. **Natural Abrasives:** Diamond, Aluminum Oxide, Garnet etc
2. **Synthetic Abrasives:** Silicon Carbide (SiC), Aluminum Oxide (Al_2O_3), Cubic Boron Nitride (CBN, Synthetic Diamond etc

- Properties of abrasives include **hardness**, which determines their ability to cut or wear down other materials, and **toughness**, which refers to their resistance to fracturing during use.
- Abrasive materials are widely used across various industries, including metalworking for grinding, cutting, and polishing; construction for cutting stone, concrete, and tiles; electronics for wafer slicing and circuit board shaping; automotive for surface preparation and paint removal.

Glass:

- It is a super cooled amorphous material. It consists of more than 50% silica and other additives such as oxides of aluminium, sodium, calcium, magnesium, titanium, lithium, lead, and potassium.
- The availability of various types of glasses is soda-lime glass, lead-alkali glass, borosilicate glass, etc.

Glass possesses several key properties:

- **Transparent -** allowing light to pass through;
- **Brittle -** it breaks easily under stress
- **Hard -** providing resistance to scratching
- **chemically inert -** making it resistant to many chemicals
- **thermal resistance**

- Glass is used in a wide range of applications, including construction for windows, doors, and facades; automotive for windshields and mirrors; electronics for smartphone screens and optical fibers; laboratories for beakers, test tubes, and slides; and households for cookware, containers etc.

THANK YOU

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