Lecture 12: Metals and Alloys

Ferrous Metals

Iron ores

Pig iron

Cast iron

Wrought iron

Steel

Non-ferrous Metals

Testing of Metal Materials

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FERROUS METALS:

Iron is the most widely used engineering material in the world. In Latin iron is ferrum with chemical designation 'Fe'. Ferrous metals contain iron as their main constituent.

Iron ores: are compounds of iron with non-metallic elements as impurities such as carbon, manganese, phosphorous, silicon and sulphur. These are taken out or extracted from earth by mining operations. Important commercial varieties are,

- Hematite: red oxide of iron, Fe_2O_3, rich iron core containing 65-70 percent iron, sp.gr. 4.5-5.3, iron black or steel grey color, found in India and Europe
- Limonite: brown hematite, Fe_2O_3, $3H_2O$, containing 60 percent of iron, sp. gr. 3.6-4.0, color is brown, yellowish brown, available in India, England, Spain
- Magnetite: black oxide of iron, Fe_2O_4, richest ore containing 70-73 percent of iron, sp.gr. 4.9-5.2, black color, found in India, Sweden, Russia, Canada, USA
- Pyrite: sulphide of iron, FeS_2, iron content 45-47 percent, sp.gr. 4.8-5.1, color bronze yellow, found in almost all countries of the World, iron becomes brittle for sulphur
- Siderite: carbonate of iron, $FeCO_3$, also known as spathic iron ore, containing 40 percent of iron, sp.gr. 3.5-4.5, color pale yellow, found in India, England, Russia

Pig Iron:

It is the crude impure iron extracted from iron ores and is known as the basic material for cast iron, wrought iron and steel. Three distinct operations in the manufacture of pig iron are,

- Dressing: crushing ores into pieces
- Calcinations and roasting: heating ores in the presence of air and are oxidized, water and CO_2 are removed, roasting consists of making ores hot and very dry
- Smelting: separates metal from ore, calcined ore mixed with limestone (as flux) and charcoal (as fuel) and fired in blast furnace. Lime (CaO) at about 2000oF becomes chemically active with silica and alumina of iron ore and forms silicates and aluminates of calcium known as slag, separated from heavier liquid which after solidification is pig iron. Slag is used to make cement, railway blast, CA for roads and fertilizer.

Properties of Pig iron:

- It can be hardened but not tempered
- It cannot be magnetized
- It cannot be welded or riveted
- It does not rust
- It is difficult to bend
- It is hard and brittle
- It is neither ductile nor malleable
- It melts easily and fusion temp. is 1200^{o}C.
- It has high comp. strength but weak in tension and shear

Types of Pig iron:

- Bessemer pig: obtained from hematite ore, used in the manufacture of steel by Bessemer or acid open-hearth process
- Grey pig: also called foundry pig, soft variety and is used for cast iron castings
- White pig: also called forge pig, inferior quality, hard and strong, used for wrought iron
- Mottled pig: lies between grey and white pig, stronger, used for heavy foundry castings

Cast Iron: The product of blast furnace i.e. pig iron if contains high percentage of impurities (foundry pig) is further refined by remelting with coke and limestone in a cupola furnace. The refined product is termed as cast iron.

Types, properties and uses of cast iron:

- Grey cast iron: prepared from grey pig, color grey, weaker in strength, excellent machinability, good antifriction, vibration-damping and stress relieving properties, widely used for making castings
- White cast iron: silvery white in color, hard, brittle, cannot be machined, high resistance to wear, cannot be used for delicate casting, mostly used for parts subjected to excessive wear
- Mottled cast iron: intermediate between grey and white cast iron, hard and brittle, used for manhole covers and pipes
- Chilled cast iron: exterior hard and interior soft makes this variety, used to provide wearing surfaces to the castings
- Malleable cast iron: obtained by giving a long time annealing to cast iron, soft, tough and easily machined. Used in differential and steering gear trousing, brake pedals, tractor springs, hangers and washing machine parts
- Alloy cast iron: cast iron obtained by alloying with other metals to improve properties

Wrought Iron: wrought iron is virtually pure iron with low percentage of carbon (up to 0.15%), contains minute thread of slag parallel to each other, process of manufacture from pig iron is laborious and tedious involving the operations of,

¤ refining, ¤ pudding ¤ shingling ¤ rolling

Aston process invented by James Aston (USA) in 1925 is used to manufacture wrought quickly and economically.

Properties of Wrought Iron:

- It becomes soft at white heat and can easily be forged and welded
- It cannot be adopted for making castings
- It is ductile, malleable, tough, moderately elastic and unaffected by saline water
- It resists corrosion, melts at $1500^{o}C$, and has a sp. Gr. Of 7.8
- Its ultimate comp. and tensile strengths are 200 and 400 N/mm^2

Uses of wrought iron: it is an important material for engineering construction are used for

- Standard pipes, bars, rods and wires
- Making nails, bolts and nuts, chains and strings etc
- Making plates, sheets, grills, fences and electro magnets

STEEL:

The present age is of steel and practically it replaced cast iron and wrought iron for use in building construction. Steel is manufactured mostly by removing a portion of carbon from cast iron and refining it or by adding the required amount of carbon to wrought iron. Depending upon the percentages of carbon four grades of steel are,

- Soft, mild or low carbon steel containing from 0.05 to 0.15 percent carbon
- Medium hard steel containing .015 to 0.30 percent carbon
- Medium high carbon steel containing 0.30 to 0.60 percent carbon
- High carbon steel or hard steel containing 0.6 to 1.5 percent carbon

Steel is manufactured from pig iron by different processes as shown below along with products.

Manufac. process	Typical products
Basic Bessemer	Pipes, tubes, wires, sheets etc.
Acid Bessemer	Structural shapes, plates, sheets, wires, rails castings etc.
Basic open-hearth	Structural shapes, plates, sheets, wires, tubes etc.
Acid open hearth	Large castings and forgings, armour plates, high strength wires etc.
Acid electric	Special alloy steel, small castings of carbon and alloy steel
Basic electric	Tool steels, high speed steel, high grade carbon steel etc.

The physical properties of steel such as ductility, elasticity, strength etc. are greatly influenced by three factors

- Carbon content
- Presence of impurities, and
- Heat treatment process

Types of steel:

Mild Steel: Composition: Carbon 0.23-0.25 percent, sulphur 0.055% and phosphorous 0.055%

Properties:

- Fibrous structure, bluish color, malleable and ductile
- More tough and elastic than cast iron and wrought iron
- Can be magnetized permanently, easily be welded, riveted and forged
- Equally strong in tension, compression and in shear
- Difficult to harden and temper, sp. Gr. Is 7.8

Uses:

- As rolled structural sections like I, T, channel section, plates, round and square rods etc.
- As mild steel round bars as reinforcements in RCC
- Mild steel tubes
- Plain and corrugated sheets
- For the manufacture of various tools, equipment, machine parts etc.

Other types of steel:

High Carbon Steel: more tough, elastic, stronger than mild steel, can withstand shocks and vibrations, more difficult to forge and weld. Used for making tools, drills, files, machine parts.

High Tensile Steel: low carbon content of 0.8%, contains 0.6% manganese, silicon 0.2%, sulphur 0.05%, and phosphorous 0.05%. used in pre-stressed concrete

Galvanized Iron and Steel; ordinary cast iron ordinary steel are coated with a layer of zinc formed by dipping in molten zinc, makes more resistant to corrosion, used in manufacturing G.I wires, G.I plain and corrugated sheets, G.I pipes etc.

Alloy Steel: To get certain special properties like elasticity, hardness, toughness, tensile strength, corrosion and fatigue resistance, some elements such as nickel, chromium, manganese, vanadium, tungsten etc. are added to carbon steels. These steels are called alloy steels. Alloy steels are as follows:

- Manganese steel: very hard, durable, ductile, used for railway points, crossings, rock cutters, dredger buckets, rollers, heavy load bearing rails etc.
- Chrome steel: chromium increases hardness, strength, heat resistance, used for manufacture of stainless steel, blades, chisels, bearing balls, crushing machines etc.
- Nickel steel: very hard, strong and durable, used for armour vehicles, naval purposes, guns, shafts, axles, boiler plates, automobiles, aircraft industries etc.
- Silicon steel: contains more than 5% silicon, imparts harness to steel, used for the pole pieces of dynamos and transformer cores
- Copper steel: 0.15 to 0.25 percent copper increases resistance to atmospheric corrosion, used for culverts
- Tungsten steel: 3 to 6 percent tungsten improves cutting hardness and abrasion resistance, used for cutting tools, magnets, lathe tools, springs etc.
- Molybdenum steel: 0.2 to 0.3 percent molybdenum increases hardness and tensile strength at high temperature, used in automobile and aircraft industry, axles, springs
- Vanadium steel: 0.1% vanadium imparts strength, toughness and hardness, used for engine frames, crank shafts, springs, axles
- Besides the above ternary alloy steels there are quarternary alloy steels like chrome-nickel, chrome vanadium, chrome-molybdenum manganese-silicon and nickel-molybdenum steels. Other special alloy steels are nickel-chromium-molybdenum steel, high – nickel, chromium, manganese steels

Stainless Steel:

Stainless steel is produced by adding over 12% chromium to low carbon steel. It has corrosion resisting property and can be hardened by heat treatment. When it contains 18 pc chromium and 8 pc nickel, it can be used for cutlery and surgical instruments as unaffected by acids, salts and alkalies.

NON-FERROUS METALS

Aluminium: in the form of Al_2O_3 is the most common metallic element in the earth's crust, commercially extracted from bauxite $Al_2O_3.2H_2O$.
Properties: important properties of aluminium are

- It is of a silvery white color with a bright luster, more resistant to atmospheric corrosion
- It is very light in weight, a good conductor of heat and electricity
- It is very soft and easy to work upon, highly ductile and malleable

Uses of aluminium: has wide range of uses, as window frames, glazing bars, corrugated roofing sheets, structural members, wires, bars, rods, posts, panels, foils etc.

Copper: it is found in the metallic state, occurs naturally in the form of ores containing copper, iron and sulphur, purest metal is produced by electrolytic process, important properties are,

- It is crystalline in structure with reddish brown color, highly ductile and malleable
- It is resistant to corrosion, soft, highly flexible and can be welded only at red heat
- It has a very high electrical and thermal conductivity, melting point of 1083oC
- It can be forged, rolled or otherwise worked hot or cold drawn into wires

Copper is mainly used for

- Electric wires, cables, tubing for hot and cold water supply, gas and sanitation services
- Sheets for D.P.C roofing, cladding, lightening protective devices
- As a constituent of brass and other alloys, a protective coating for other metals

Lead: occurs naturally in the form of lead suphide, important properties are,

- It is bluish grey metal with a high metallic luster, softest and heaviest of all the metals
- highly resistant to atmospheric corrosion and is a good conductor of heat and electricity
- it is least tenacious and very malleable, marks on paper, sp.gr. is 11.35

Lead is mainly used for,

- chemical laboratory and plant drains, water service pipes, gutters, flashings and cisterns
- D.P.C in buildings, lead sheets for roofing, cable coverings, plumbing,

Tin: The chief source of tin is tinstone, SnO2, most commonly used protective metals in construction activities. Important properties are,

- It is a lustrous silvery white metal, highly ductile and malleable, soft and has plasticity
- It is good conductor of heat and electricity, withstands corrosion by acid
- Melts at 232oC, boiling point 765oC, sp.gr. 7.3

Tin is mostly used for,

- Giving protective coatings to iron and steel sheets
- As an alloying element in soft solders and for moisture proof packing

Zinc: common ores are zincite or red zinc ZnO, calamine ZnCO3 etc., important properties are

- Bluish white crystalline metal, brittle at ordinary temperature, resistant to corrosion
- Ductile and malleable between 100 to 150oC, sp.gr. 7.0, melting point 420oC

Zinc is mostly used for galvanizing iron sheets and pipes, for batteries and printing blocks, for preparing paints, and alloys like brass and german silver

Non-Ferrous Alloys:

Brass: Brass is an alloy of copper and zinc and minor percentages of other elements except tin. This is the most widely used copper alloy, stronger than copper and is used in structural applications. It possesses excellent mechanical properties, corrosion resistant and are readily machinable. It can be cast into moulds, drawn into wires, rolled into sheets and turned into tubes. Depending on the composition, common varieties of brasses are: cartridge brass, used for cartridges, tubes, springs; muntze metal, used for architectural work, welding rods, condenser tubes; brazing brass, used for spinning, springs; red brass, used for hardware, radiator cores, plumbing pipes, condenser tubes; high brass, used for stamping, rivets, chains

Bronze: It is an alloy of copper and tin and minor percentages of other elements except zinc. Most useful bronze contain 8-11% of tin and makes gun metal. Common varieties of bronze are, bell metal, used for making bells; gunmetal, for bearings, bolts, nuts; manganese bronze, for ship fittings, shafts, axles; phosphor bronze, for springs, gears, bearings; speculum metal, for making telescopes.

German Silver: An alloy of 20-30% zinc, 45-60% copper, and nickel. It has high tensile strength and is resistant to corrosion, it is used for making utensils, resistance coils, automobile parts, typewriters and musical instruments.

Testing of Metal Materials:

Metal materials are tested for one or more of the following **purposes**,

- To assess numerically the fundamental mechanical properties i.e. ductility, malleability etc.
- To check chemical composition
- To determine suitability of a material for a particular application
- To determine sets of specification
- To determine the surface defects in raw materials or processed parts

Tests on metals may be classified as,

- **Non-destructive tests**: those tests which in a specific context would not damage the material being examined to an extend such that it is rendered useless for future for which it was originally meant. The various methods used for non-destructive testing are as follows,
    - X- ray radiography
    - Gamma radiography
    - Magnetic particle inspection
    - Ultrasonic testing
    - Electrical method and ¤ Damping test

- **Destructive or mechanical tests**: after testing the specimen breaks or remains no longer useful for further use. Important mechanical tests for valuable information about metals and alloys are,

    - Tensile test
    - Impact test
    - Hardness test
    - Fatigue test
    - Creep test

Tensile strength test on a mild steel specimen:

Questions:

- What is the composition of an iron ore? Enumerate different types of iron ores.
- What is pig iron? Name and discuss different varieties of pig iron
- What are the properties and uses of different types of cast iron?
- Compare wrought iron and cast iron. Discuss wrought iron as a material of construction.
- What are the properties and uses of wrought iron?
- What is steel? Classify steel on the basis of carbon content.
- What is mild steel? Briefly state the properties of mild steel.
- What are the properties and uses of aluminium and copper?
- What are the types and uses of alloy steel?
