ALLOYS

An alloy is a homogenius mixture of two or more elements with metallic properties or a metal and a non-metal possessing metallic properties. Chemically, alloys are solid solutions and are harder, more malleable & have lower melting points than the component elements. The properties of a metal can be modified by alloying it with some other element. Important elements that form alloys are - Copper, zinc, lead, tin, nickel, aluminium Chromium and Tungsten.

① Purpose of Making Alloys :-

A pure metal may not have all the properties required for the desired end use. These properties like - strength, malleability, ductility and electrical conduction can be improved by alloying it with other metals or non-metals. The main purpose of alloying are given below -

i) To increase the hardness of metal →

Pure metal may not be very hard, their hardness can be improved by alloying them with some other metal or non-metal. For example, Pure gold is very soft & can't be used for making ornaments. If it is alloyed with Copper, it's hardness is improved and it becomes suitable for making ornaments. Similarly, Pure iron is soft & it's hardness can be improved by alloying it with carbon to form steel. The iron-carbon alloy, known as steel has a greater hardness than their corresponding constituent components.

ii) To lower the melting point →

Adding impurity to a pure metal reduces its melting point. Hence the melting point of an alloy is much lower than its constituent elements. Alloying makes the metal easily fusible. Wood metal, an alloy of Pb, Bi, Sn and Cd melts at 60.5°C which is far below the melting point of any individual elements.

iii) To improve corrosion resistance →

Pure metals have a tendency to get corroded by reacting with moisture or environmental gases. Alloying imparts resistance to corrosion to the metal. Pure iron gets corroded easily (rusting), but stainless steel, an alloy of iron with carbon & Chromium resists corrosion.

iv) To modify chemical reactivity →

Chemical reactivity of a metal can be modified by alloying it with a suitable element. The chemical activity of Na reduces on alloying with Mercury (Na-Amalgam).

v) To modify colour ↦

The colour of a metal can be modified by alloying it with suitable metal or non-metal. For example, brass, an alloy of copper (reddish brown) and zinc (silver-white) is yellow in it's colour. The colour of gold may be modified by alloying:-

Sl.no	Name	Composition
1	Red gold	75% gold + 25% Copper
2	Rose gold	75% gold + 22.25% Copper + 2.75% Silver
3	Pink gold	75% gold + 20% Copper + 5% Silver
4	White gold	90% gold + 10% nickel
5	Green gold	75% gold + 25% Silver

(2) Classification of Alloys :-

i) Based on the base metal in the alloy ↦

On the basis of principal metal in the alloy, alloys can be classified as- aluminium alloys, ferrous alloys, magnesium alloys, Copper alloys, lead alloys, tin alloys etc.

ii) Based on the application →

Alloys can be classified on the basis of their applications. For example, alloy used for soldering are called 'Solder alloy' alloy used for typing are called 'type metal' etc.

Ferrous alloys :-

These alloys contain iron as one of the major component. Common ferrous alloys are- steel and cast iron. These are alloys of iron with Carbon and other elements like - Mn, P, S, Cr, Si etc. These alloys differ in carbon-content

Non-Ferrous alloys :-

These alloys do not contain iron as one of main components. Copper, Aluminium, Lead, Nickel, Tin, Zinc, Cobalt, Magnesium etc. are the main components of non-ferrous alloys.

STEEL

Plain carbon-steel is an alloy of iron and carbon with the percentage of carbon ranging between 0.5% - 1.5%. It is malleable and the hardness of steel depends upon the amount of carbon present in it. Steel containing low percentage of carbon (0.05 - 0.30%) is called 'mild steel'. It is used for making steel wires, sheets, rivets, screws, pipes, nails, chains etc. For 'medium carbon steel', the percentage of carbon varies from 0.3 to 0.7%. It is used to make things like- railway coach axles, crank pins on heavy machines etc. If the percentage of carbon is 0.7 to 1.5%, it is called 'high carbon steel'. It is very hard & also is known as- 'hard steels'. It is used to make- rock-drills, railway rails, metal cutting tools, paper knives etc. Steel is considered to be 'alloy steel' when it contains small quantities of elements such as Al, B, Cr, Co, Mn, Ni, Ti, W, V or any other element, added to it to obtain the desired properties.

⊙ Purpose of making 'alloy steel' ⇨

The main purpose of alloying steel are to improve -

① Hardness and strength
② Corrosion resistance
③ Ductility and toughness
④ Elasticity and tensile strength
⑤ Cutting ability
⑥ Ability to undergo milling operations like rolling, pressing, etc
⑦ Ability to retain physical properties at high temperatures

⊙ Special effects of alloying elements ⇨

i) Carbon → The carbon content in steel affets its hardness, tensile strength, melting point and ability to undergo machining operation

ii) Nickel → It increases toughness, resistance to impact, strengthens steels, lessens distortion in quenching and improves elasticity, ductility as well as corrosion-resistance.

iii) Chromium → It improves toughness & hardness simultaneously. Cr combines with carbon to form Chromium carbide which improves resistance to abrasion & wear.

iv) Silicon → It improves oxidation resistance & strengthens low alloy steels.

v) Titanium → It prevents localised depletion of Cr in stainless steel during long heating

vi) Molybdenum → It imparts hardness, improves resistance to abrasion & increases tensile strength.

vii) Vanadium → It imparts strength and toughness to heat-treated steel, enhances tensile strength, ductility & shock-resistance.

viii) Tungsten → It increases hardness, toughness, shock and abrasion resistance.

ix) Manganese → Increases strength, toughness, counteracts brittleness from Sulphur.

x) Copper → Increases resistance to atmospheric corrosion and act as strengthening agent

xi) Cobalt → Improves mechanical properties e.g. tensile strength, fatigue strength, hardness, heat resistance

PRODUCTION OF STEEL

All steel production processes consist of some general steps-

i) Removal of carbon, sulphur, phosphorous, silicon from molten 'pig iron' by oxidation (Usually by O_2).

- Carbon gets oxidized to CO_2, and then escapes as gas. This is called - decarbonization.

$$C + O_2 \rightarrow CO_2 \uparrow$$

- Sulphur gets oxidized to SO_2 and escapes as gas. This is known as - desulphurization

$$S + O_2 \rightarrow SO_2 \uparrow$$

Some sulphur is also eliminated through slag formation

When is treated with lime (CaO).

- Silicon gets oxidised to SiO_2 and this oxide combines with lime to from slag and subsequently is removed. This process is used to remove silicon.

$$SiO_2 + CaO \longrightarrow CaSiO_3$$

- Phosphorous also gets oxidized to P_4O_{10} and this oxide combines with lime to from slag and subsequently gets removed. This is known as- 'dephosphorisation'.

$$4P + 5O_2 \longrightarrow P_4O_{10}$$

$$P_4O_{10} + 6CaO \longrightarrow 2Ca_3(PO_4)_2$$

- Manganese forms oxide on oxidation and this MnO gets combined with SiO_2 to form slag and gets removed. This is called- 'demanganization'.

$$MnO + SiO_2 \longrightarrow MnSiO_3$$

ii) Separation of slag followed by addition of requisite quantities of de-oxidizers & other alloying elements. Reducing agents like- Petrolium coke together with ferro-silicon & ferro-manganese are used as deoxidizers. These deoxidisers reduce any FeO left in the mixture.

Manufacture of Steel :-

There are mostly four processes for manufacturing of steels.

① Bessemer Process ↦

In this process, molten pig iron, taken directly from blast furnace is run into Bessemer converter, which is a pear-shaped furnace about 6 metres high and 3 metres in diameter. It is made of steel plates & is lined inside with heat-resisting fire-clay bricks At the base, there are a number of holes, called- tuyeres, through which air can be admitted. The converter can be rotated on a horizontal central axis.

To start with, the converter is turned into the horizontal position and molten pig iron is introduced in it. A blast of hot air is admitted through the tuyeres. The converter is then rotated so as to bring its mouth vertically upwards. The blowing of air is continued. As the air passes upwards through the molten metal,

it oxidises the impurities (Mn, Si, C, P, S etc) present in the pig iron. During the first 5-10 mins. oxidation of only Mn and Si takes place. This MnO and SiO_2 thus combines to form the $MnSiO_3$ slag. Later on, carbon is oxidised to CO, which burns at the mouth of converter with a blue flame. When the whole of carbon is oxidized, the blue flame suddenly dies out

Then the requistie amount of carbon is added (to convert iron to steel) usually in the form of an alloy of Fe, Mn and C, called Spiegeleisen. The blast is continued just for a moment to ensure complete mixing. The resulting product is stainless steel which is much harder & has greater tensile strength than ordinary steel.

Sometimes, a little Al or Si-Fe alloy is also added to molten steel. This takes up any dissolved CO or N_2 from the molten metal. At the end, the converter is tilted to pour out the molten steel.

② Basic Oxygen process →

The basic oxygen process is a development of the old Bessemer process.

This process uses pure oxygen (99%) as the oxidizer, which is blown onto the surface of molten pig iron at great speed through water-cooled pipes. The hot molten pig iron is taken in a converter lined with dolomite and magnesium oxide.

The Oxygen penetrates into the molten pig iron & creates large turbulance and oxidises the impurities. The exothermic reaction keeps the contents molten. The slag is separated by tilting the converter & a rapid analytical check is carried out to bring the metal to it's desired composition and if required, the necessary addition of C, Mn etc. impurities are made.

(In kaldo process, the converter is rotated to ensure thorough mixing)

Q "During oxidation of impurities present in molten pig iron, the melting point of molten mixture gradually rises, due to removal of impurities, yet the mixture remain in molten state without extra external heating" - explain.

- By S.M. Sir

• Notes →

i) The basic oxygen process is much faster than the Open-hearth process or the older Bessemer process.

ii) The use of air in the Bessemer process introduces N_2 into the molten metal. In concentration $< 0.01\%$, N_2 makes steel brittle. Also, formation of surface nitride renders welding of the metal difficult.

iii) If O_2 was blown through the bottom of the converter (as in Bessemer process), the bottom would get excessively heated & then it would melt down.

③ Open hearth process →

In this process, a mixture of cast iron, scrap iron, iron ore (ie. haematite) & lime is melted in an Open hearth furnace. The hearth is lined with silica (SiO_2) or calcinated dolomite ($CaO.MgO$) depending upon the nature of impurities present on cast iron. Silica lining is used if the impurities are Mn, Si etc. and calcinated dolomite lining is used if much of P is present. Heating to about 1500°C is done by producer gas-burning. A regenerative system of heat economy is employed to save the fuel.

Heating is continued for about 8 to 10 hr. During this period the impurities (C, Si, S, P) get oxidised by haematite. Carbon is removed as CO_2, sulphur is eliminated as SO_2, Silicon & Phosphorous are oxidised to SiO_2 & P_4O_{10}; respectively. These react with lime to form slag.

Samples are withdrawn from the hearth time to time & analyzed. The carbon-content is adjusted to proper value. Requisite quantities of other metals may also be added if special steels are to be obtained. After setting up desired composition, the finalised batch of molten steel is removed from the furnace by tilting the hearth.

④ The Electric Arc process →

This process involves the setting up of a carbon arc. The electrodes are held vertically & the mixture consisting of cast iron, scrap iron and iron ore (haematite) mixed with requisite of lime, is held in between.

The furnace is usually lined with dolomite. The chemical reactions start almost instantaneously. Silicon is oxidised to SiO_2. This helps in forming silicate slags of Ca and Mn.

The excessive carbon in the iron ore is oxidised off as CO while phosphorous is oxidised as P_2O_5; which as in the Bessemer process, combines with lime forming calcium phosphate; and passes into slag. The furnace is then tilted carefully so as to pour off the phosphate & other slags.

After this, a mixture containing coke, lime & sand is added. The iron sulphide, still present as impurity, reacts with lime and produces CaS and FeO. CaS passes into slag while, FeO is reduced by coke to metallic Fe. As, sulphur & phosphorous are almost completely removed, the steel obtained by this process is very much superior.

This method is also used in making high quality alloy steels, which are obtained by incorporating Cr, Mn, Ni, W, Mo etc.

The arc furnaces can be divided by two types, such as-

① Direct arc:- Direct arc electric furnaces are usually fitted with three electrodes which penetrate into the furnace crucible & strike short circuited arcs between their lower extremeties & the molten reaction mixture (charge)

② Indirect arc :- In case of indirect arc furnaces, the arc is struck between two large carbon electrodes. Radiation from the arc heats the charge (molten reaction mixture)

* Induction furnaces :- The melting & alloying of steels are carried out conveniently in the induction furnaces. This contains a vertical basin around which an induction coil is wound. The charge in these furnaces forms the short-circuited secondary windings of a transformer. This transformer converts the electrical energy into heat energy and this heat energy would be withdrawn in a normal transformer.

-by S.M. Sir

HEAT TREATMENT OF STEEL

Heat treatment is a process involving a sequence of heating and cooling operations in steel (or any other metal alloy) to obtain a desired combination of properties.

Heat treatment produces the following effects in the properties of metals -

- Relieves the metal of internal stress.
- Refines grain size & makes the metal structure homogeneous.
- Improves machinability
- Improves ductility, toughness, resistance of material to heat, shock & corrosion.
- Improves thermal, magnetic & electrical properties of metal.

Heat treatment alters the physical properties of the metal alloys without affecting chemical properties. Some common heat treatment process employed for steel are:

① Annealing , ② Normalising , ③ Hardening , ④ Tempering

- Heat treatment process :-

First, the steel is heated to a high temperature so that it is converted to austenite phase. It is then kept at this temp. for some time to permit homogenisation of the material. After the formation of homogeneous austenite, the alloy is cooled. If needed, the steel can be reheated & cooled again.

① Annealing →

Annealing is the process of heating steel to a high temp. & then cooling it carefully under controlled condition. Annealing makes the following physical changes in steel:

- The internal stress caused due to uneven contraction during casting are relieved.
- It reduces hardness.
- It improves machinability
- Refines the grain structure
- Helps in removal of the trapped gases.

There are two types of annealing. They are-

i) Process annealing / Low temperature annealing

ii) Full annealing / High temperature annealing

i) Process annealing :-

It is low-temperature annealing in which steel is heated to a temp. below it's critical point & then cooled slowly. Process annealing helps to remove the internal stress in steel. It is generally applied to hypoutectoid steel and is carried out at a temp. below the eutectic point (550-650°C). As there is no phase change during annealing ferrite & cementrite (Fe_3C) are present in microstructure throughout the process.

ii) Full annealing :-

In full annealing, steel is heated to a temp. of about 30-50°C above the upper critical temp. at held at this temp. for a sufficiently long time. It is then gradually cooled to room temp. simply by switching off the furnace. The annealing temp. of mild steel, medium carbon steel & high-carbon steel are 840°-870°C, 780°-840°C & 760°-780°C respectively. After full annealing, the microstructure of ~~hypoutect~~ hypoutectoid steels consists of proeutectoid ferrite & pearlite.

Full annealing helps to refine grains, remove strains from forgings and casting, induces softness, improves machinability, formability & also improves electrical & magnetic properties of steel.

② Normalising ➡

It is also known as 'air quenching'. In this process, steel is heated to 40°-50°C above its upper critical temp., held at this temp. for short time & then cooled in still air at room temp. Air cooling is faster than the furnace-cooling, hence the cooling time is much lower than that for annealing.

Like annealing, normalising also results in formation of ferrite, cementite, and lamellar pearlite, but the micro structure of pearlite is finer than in the fully annealed state resulting in the formation of slightly harder and stronger materials. The purpose of this normalising are:

- To produce a uniform structure.
- Refine grain size of steel.
- Reduce internal stress.
- Produce harder & stronger steel than full annealing
- Improve the engineering properties of steel.

③ Hardening →

Hardening is the rapid cooling of steel by immersing it in a liquid bath such as water or air. The process is also known as 'quenching'. It increases the hardness, strength & wear resistance of steel. In this process, steel is heated to 30°-50°c above the upper critical temp., held at this temp. for sometimes & then cooled rapidly or quenched in a suitable medium like water, oil, brine or molten salt bath. Due to rapid cooling, carbon remains in solution & austenite transforms to martensite. The Hardened steel is in a stressed condition & hence it is very brittle. It can't be used for practical purposes, hence hardening is followed by tempering

④ Tempering →

In tempering, the quenched steel is re-heated to a pre-determined temperature (200°c for high-carbon steel & 400-650°c for steel having 0.35 - 3.5% carbon), then it is allowed to cool slowly. This reduces the hardness & brittleness of steel & increases it's toughness and ductility. For better ductility and toughness, the tempering temp. should not exceed 400°c. Tempering reduces the strain and stress that develops due to quenching. It is always applied to cutting tools like blades, cutters, chisels etc.

N.B: The temperature to which steel is heated is judged from the colour of the oxide film formed on the surface.

Temp.	Colour
230°c	Pale yellow
260°c	Brown
280°c	Purple
300°c	Blue

⊛ Case-hardening :-

The process of hardening of surface of wrought iron by the presence of carbon at the surface is called 'case-hardening'. This is produced by heating wrought iron in contact with $K_4[Fe(CN)_6]$ when due to the decomposition of ferrocyanide ultimately into carbon, a surface layer of steel is produced. In other words, a surface-layer of steel is formed on the wrought iron. The inner portions still remains as wrought iron & therefore retain the toughness associated with wrought iron. Case hardened wrought iron is used for making armour plates.

⊛ Nitriding :-

In this process, steel (containing ~1% Al) is heated in an atmosphere of $NH_3(g)$ at 550°–600°C. It is believed that nitrogen formed by dissociation of ammonia reacts with iron & aluminium to form on the surface, iron and aluminium nitrides. These nitrides settle in the interstitial positions of iron crystals. Thus, a steel with a very hard-surface is produced. It is used for cylinders bores.

⊛ Carburizing :-

It is a heat treatment process in which steel absorbs carbon while the metal is heated in presence of charcoal or carbon monoxide. In this process Carbon is diffused to low-carbon steels to increase the carbon-content to sufficient levels so that the surface will respond to heat-treatment & produce a hard layer. There are three types of carburizing

i) Gas carburizing → CH_4 or C_3H_8 (gas) + Carrier gas (N_2, CO, CO_2) are used

ii) Liquid carburizing → Salt bath of cyanide-chloride-carbonate mixture is used

iii) Solid carburizing → Coke + $BaCO_3$ mixture is used

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Alloy steels : Mechanical and other properties of steel are greatly modified by alloying with different transition metals and silicon. Some of these alloy steels are :

Silicon steel	3.5% Si and very little carbon; used in making electromagnets and transformers.
Stainless steel	12-15% Cr; resists corrosion and action of acids. Stainless steel utensils and other articles are made from it.
Manganese steel	12-13% Mn; extremely hard and resistant to wear. Making of grinding machinery, safe, rock drill.
Cobalt steel	up to 35% cobalt; highly magnetic. Making permanent magnets.
Nickel steel	2-4% Ni; high tensile strength—making cables, propeller shafts, gears etc.
Invar	up to 36% Ni : low coefficient of thermal expansion—used in scientific instruments.
Chrome-nickel steel	1-4% Ni; 0.5-2% Cr. High tensile strength, greater corrosion resistance—motor car and bicycle parts.
Platinite	46% Ni; coefficient of thermal expansion same as that of glass. Used in glassmetal seals, electric bulbs etc.
Chrome-vanadium steel	1-10% Cr, 0.14-0.55% V. High tensile strength, resistant to stress and torsion. Making of automobile axles and springs.
Tungsten steel	10-20% W, 3-8% Cr. Very hard, corrosion-resistant and retains temper at high temperature. Used in making high-speed cutting tools.
Molybdenum steel	6-7% Mo; this also retains temper at high temperature and is used in making high-speed cutting tools.
Misch-metal	70% Ce and traces of other rare earth metals. Used to produce spark in gas and cigarette lighters.